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Asymmetric and Unilateral Hearing Loss in Children

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Abstract

Asymmetric and unilateral hearing losses in children have traditionally been underappreciated, but health care practitioners are now beginning to understand their effect on development and the underlying pathophysiologic mechanisms. The common wisdom among medical and educational professionals has been that at least one normal hearing or near-normal hearing ear was sufficient for typical speech and language development in children. The objective of this review is to illustrate to the non-otolaryngologist the consequences of asymmetric and unilateral hearing loss in children on developmental and educational outcomes. In the process, etiology, detection, and management are discussed. Lastly, implications for further research are considered.

Keywords

unilateral hearing loss; asymmetric hearing loss; children

INTRODUCTION

Unilateral and asymmetric hearing loss (HL) have historically been underappreciated, but health care practitioners now know that they are more common and have more adverse effects on children than previously believed. The traditional thinking was that only one normal-hearing ear was necessary for normal development of speech and language. However, multiple studies have shown that even a mild degree of unilateral hearing loss (UHL) can have adverse effects on language development (J. E. Lieu, 2004).

Hearing loss can be classified from multiple perspectives, including type, degree, and configuration of loss. *Type* describes which part of the auditory system is compromised, and includes conductive, sensorineural, and mixed losses; *degree* of HL is a measure of how severe the loss; and the *configuration* describes the HL in relation to frequency or pitch, such as a high-frequency vs. a low frequency HL (American Speech-Language-Hearing Association, 2014). For the purposes of this review, we focus on another descriptor: bilateral, unilateral, or asymmetric. Bilateral means a HL in both ears, and unilateral means a HL in one ear. The difference between asymmetric and UHL is subtle. Asymmetric HL (AHL) is simply a difference in loss greater than 15 decibels (dB) between ears at 0.5, 1, and 2 kHz, or greater than 20 dB at 3, 4, and 6 kHz on audiogram (American Academy Otolaryngology-Head Neck Surgery, 1997). If the better-hearing ear is normal, then this is called UHL. If the better-hearing ear is impaired, then this is called AHL. UHL can include

all types, degrees, and configurations of HL, but is limited to one ear. Another term for severe to profound UHL is single-sided deafness.

This review is intended for a broad group of non-otolaryngologist stakeholders involved in the care of children with UHL and AHL, including pediatricians, primary care physicians, speech-language pathologists, audiologists, teachers, deaf educators, and health policymakers. The objective of this review is to illustrate to the non-otolaryngologist the consequences of asymmetric and unilateral hearing loss in children on developmental and educational outcomes. In the process, etiology, detection, and management are discussed. Lastly, implications for further research are considered.

CONSEQUENCES OF UNILATERAL HEARING LOSS IN CHILDREN

Though today we recognize that children with UHL require intervention to prevent impairments in speech and language development, it was previously thought that having one normal-hearing ear was sufficient. Bess and Tharpe (1984) were the first to report a negative consequence of UHL in children, showing that 35% of children with UHL failed at least one grade as compared to 3.5% for the school district overall. Several years later, Oyler et al. (1988) confirmed these findings, showing that 24% of children with UHL in a school district repeated a grade, compared to 2% overall. The evidence for UHL negatively affecting child development continued to mount, as Brookhouser et al. (1991) later reported that 59% of children with UHL had some sort of academic or behavioral problem at school. Borg et al. (2002) reported that preschool children with UHL have impaired language development, leading to a more sophisticated understanding of the specific deficits in children with UHL.

More recently, Lieu et al. (2010) showed that children with UHL were more than four times as likely to have had an individualized education program, and more than twice as likely to have received speech therapy than their normal-hearing peers. Unfortunately, even after focused interventions such as these, children with UHL may continue to have academic difficulties as they grow older (J. E. C. Lieu, Tye-Murray, & Fu, 2012), suggesting that early intervention alone may not result in catching up with their normalhearing peers.

As more evidence about the speech and language deficits in children with UHL continues to emerge, researchers have started to look at the brain itself. From studies in adults, it is known that when the brain is deprived of binaural input and solely receives monaural stimulation, the cortex undergoes reorganization over the following year (Bilecen et al., 2000; Vasama, Makela, Pykko, & Hari, 1995). Schmithorst et al. have suggested that if this scenario occurs in children, the development of spoken language may be impacted permanently (2014). The difference is that in adults, the hearing in one ear is lost after speech and language have already developed, whereas in children, the impaired or absent hearing in one ear may affect the development of vital cortical connections for optimal speech and language.

EPIDEMIOLOGY AND DETECTION OF UNILATERAL HEARING LOSS IN CHILDREN

In the United States, 3 to 6% of schoolchildren have some degree of UHL (Ross, Visser, Holstrum, Qin, & Kenneson, 2010). However, the prevalence of UHL increases with age, and more than one out of ten children initially diagnosed with UHL will progress to bilateral hearing loss (Declau, Boudewyns, Van den Ende, Peeters, & van den Heyning, 2008; Haffey, Fowler, & Anne, 2013; Uwiera et al., 2009). In addition to the increase with age, the baseline prevalence of UHL may be increasing as well. A large population study of adolescents in the US showed that the baseline prevalence of any type of hearing loss increased from 15% in 1988–94 to 20% in 2005–06; when stratified into bilateral and UHL, unilateral was the most common type and increased from 11 to 14% in this time period (Shargorodsky, Curhan, Curhan, & Eavey, 2010). Estimates for the prevalence for AHL have not been calculated separately and are subsumed in estimates of prevalence of bilateral HL. In a typical classroom size of 30 children, this means that up to four children may have UHL, highlighting the need for continued follow-up during school to avoid ignoring the needs of these children during their most crucial years of development.

First implemented in the United States in the 1990s, UNHS has vastly changed how children with UHL are identified. Before UNHS was instituted, children with UHL were typically identified during school screening programs, usually in kindergarten or first grade. The impact of UNHS on the detection of pediatric UHL should be considered a public health success. Prior to UNHS, the percentage of children with sensorineural UHL detected prior before 6 months of age was 3%; this increased to 42% after implementing UNHS in an academic tertiary center in Missouri. The average age at diagnosis also declined from 4.4 to 2.6 years of age in this study (Ghogomu, Umansky, & Lieu, 2014). However, the existence of UNHS alone may not explain this entire effect, as another retrospective review of children with UHL at an academic tertiary center in Ohio showed that only 26% had been identified through UNHS, and the average age at diagnosis was still 5.6 years (Haffey et al., 2013). Regardless, UNHS still plays a substantial role in the detection of congenital UHL, and the earlier detection of UHL mirrors the decreased age of identification of congenital bilateral HL (Wessex Universal Neonatal Hearing Screening Trial Group, 1998).

CAUSES OF UNILATERAL HEARING LOSS

Imaging modalities such as computed tomography (CT) and magnetic resonance imaging (MRI) are important tools in determining the etiology of children with AHL and UHL. In a cohort of 114 children with AHL of unknown etiology, CT and MRI revealed abnormalities in 39% of children (Mafong, Shin, & Lalwani, 2002). Although MRI has the advantage of not exposing the child to ionizing radiation, several studies have concluded that CT is a superior first line diagnostic modality (Bamiou, Savy, O'Mahoney, Phelps, & Sirimanna, 1999; Haffey et al., 2013; Licameli & Kenna, 2010). Obtaining an MRI usually requires sedation in children who cannot sit still due to the long imaging time, whereas CT can be obtained in children as young as 6 or 7 years old without sedation. The benefit of MRI is that some abnormalities such as cochlear nerve aplasia are better visualized, in contrast to CT, where bony abnormalities such as enlarged vestibular aqueduct are more readily

detected. Laboratory or genetic studies, though easy to obtain, have not been as valuable in determining the etiology of UHL in children (Mafong et al., 2002). Although there are reports of familial UHL in the literature (Dikkers, Verheij, & van Mechelen, 2005; Dodson et al., 2012; Dodson, Kamei, Sismanis, & Nance, 2007; Patel & Oghalai, 2006), no genetic mutations associated specifically with UHL have yet been identified with certainty.

Prior to the advent of UNHS, the most common cause and time of onset of childhood sensorineural UHL was unknown. As UNHS now allows for better identification of children with UHL, the most common time of onset is now understood to be congenital, accounting for 45% of infants and children with sensorineural UHL (Ghogomu et al., 2014). Of congenital causes, it appears that cochlear nerve deficiency may be the most common, accounting for up to 50% of children with congenital severe-to-profound UHL (Nakano, Arimoto, & Matsunaga, 2013). For the purposes of prevention, acquired causes of HL including infections such as congenital cytomegalovirus (CMV) (Kumar et al., 1984) and meningitis (Fortnum & Davis, 1993), as well as temporal bone trauma (Morgan, Coker, & Jenkins, 1994) should be recognized (See Table 1). We highlight here a few important etiologies of UHL below.

Cochlear nerve deficiency is an increasingly recognized cause of UHL in children (Buchman et al., 2006), and is specifically responsible for more severe loss. The anatomic features present in cochlear nerve deficiency are stenosis of the bony cochlear nerve canal, narrowing or absence of the internal auditory canal, or both (Laury, Casey, McKay, & Germiller, 2009). The cochlear nerve can be aplastic (completely absent), or hypoplastic (abnormally small). Unfortunately, the etiologic mechanism of cochlear nerve deficiency is not well understood, and it is unknown whether it is due to a failure to develop properly or a degenerative process (Glastonbury et al., 2002). Because cochlear nerve deficiency is seen both bilaterally and unilaterally in children, it may represent a problem with transcription or epigenetic phenomena rather than simply missing a gene. Adding credence to a genetic cause is that other abnormalities are also seen in these children. For example, ophthalmologic abnormalities were seen in 67% of children with unilateral cochlear nerve deficiency, the most common of which were oculomotor disturbances and refractive errors (Clemmens et al., 2013).

The presence of an enlarged vestibular aqueduct (EVA) is well recognized as a potential cause of pediatric UHL. Found in 23% of children with UHL (Clemmens et al., 2013), this is a common abnormality in this population. In a retrospective study of children with severe-to-profound sensorineural UHL referred for bone-anchored hearing aid (BAHA) placement, 41% of children who had imaging were found to have abnormal temporal bone anatomy on CT. The most common finding was an EVA, present in 14% of these children (Friedman et al., 2013). Interestingly, EVA was more commonly bilateral than unilateral in this study, suggesting that these children may progress to bilateral HL. However, children with unilateral EVA commonly progress to bilateral HL, and more than half of the patients in these patients initially presented with UHL in the ear without an EVA (Greinwald et al., 2013), raising into question the specific pathophysiologic mechanism between EVA and hearing loss. It has been suggested that EVA and Pendred syndrome may have a similar etiology, due to the common presence of a mutation in the SLC26A4 gene (Bogazzi et al.,

2004). Pendrin, the protein encoded by this gene, is an anion transporter located in the thyroid, inner ear, and kidney. There is evidence that a malfunction in this transporter causes increased pressure in the endolymphatic duct and results in hair cell damage in mice (Hulander et al., 2003). Whether this is also seen in humans remains to be established.

HL is the most common complication from bacterial meningitis in children (Baraff, Lee, & Schriger, 1993), and there is emerging evidence that infection with *Streptococcus pneumoniae*, specifically, is associated with a much higher risk of HL. Although notorious for causing bilateral profound HL, such in the case of Helen Keller, meningitis more commonly results in UHL or AHL, and can result from a number of different bacteria, including *S. pneumoniae*, *Neisseria meningitidis*, group B *Streptococcus*, and *Hemophilus influenzae*. In a review of 79 children with bacterial meningitis, however, infection with *S. pneumoniae* was found to be a statistically significant predictor of subsequent sensorineural HL (Wellman, Sommer, & McKenna, 2003). This mechanism is presumed to be due to bacterial spread from the subarachnoid space through the cochlear aqueduct to the labyrinth, resulting in toxic labyrinthitis, ischemia, and/or direct nerve damage (Brookhouser, Auslander, & Meskan, 1988; Jiang, Liu, Wu, Zheng, & Liu, 1990). The optimal treatment of bacterial meningitis is in evolution, but a recent systematic review found that corticosteroid therapy in addition to antibiotics was associated with a statistically significant decrease in neurologic sequelae, including HL. Although there was no impact seen on mortality in this study, the authors recommended including corticosteroids in the treatment of bacterial meningitis for this reason (Brouwer, McIntyre, Prasad, & van de Beek, 2013).

Cytomegalovirus (CMV), a DNA virus from the Herpesviridae family, represents an important cause of congenital HL that can be present at birth or develop over time, referred to as delayed onset. CMV infection is one of the few preventable causes of HL in children, and affects 1 out of 100 infants (Hicks et al., 1993; Misono et al., 2011). Even though up to 90% of the infected children will be asymptomatic (that is, not show any clinical signs of CMV infection at birth), 6–23% of asymptomatic (and 22–65% of symptomatic) children will develop some form of HL during childhood (K.B. Fowler & Boppana, 2006). Symptomatic CMV infection causes problems in multiple systems, including jaundice, hepatosplenomegaly, microcephaly, elevated liver enzymes, and hypotonia, and seizures (Boppana, Pass, Britt, Stagno, & Alford, 1992). When children identified with congenital CMV infection are monitored over time, one out of three with symptomatic infection and one out of 10 with asymptomatic infection will develop sensorineural hearing loss (Goderis et al., 2014). Unfortunately, whether the mother has a primary CMV infection or is seroimmune to CMV prior to pregnancy does not appear to influence the rate at which HL occurs in the child (K. B. Fowler, 2013). Treating the child with intravenous antiviral agent ganciclovir carries a significant risk of neutropenia, but does reduce the progression of HL. However, the optimal length of time for treatment is not well established, and is currently under investigation (del Rosal et al., 2012; Shin, Keamy, & Steinberg, 2011). Currently, the standard of care is to treat symptomatic children with oral antiviral agent valgancyclovir for six months, with close monitoring for neutropenia (Kimberlin et al., 2008), and there is new compelling evidence for this practice (Kimberlin et al., 2015). An additional question for further research is *who to treat*, as most children with asymptomatic CMV infection will not

suffer HL, and we are currently unable to predict which children will progress to develop HL. Due to the common toxicity of neutropenia caused by ganciclovir and valganciclovir, routine use of these medications in asymptomatic children cannot be recommended.

Aural atresia, a congenital absence or stenosis of the external auditory canal, is most often unilateral, more commonly on the right side, and more common in males (Klockars & Rautio, 2009). Children with aural atresia receive higher rates of speech therapy and other educational interventions than normal-hearing children (Jensen, Grames, & Lieu, 2013; Kesser, Krook, & Gray, 2013). Management options include canalplasty to recreate the external auditory canal, which has been shown to improve hearing and sound localization (Moon et al., 2014), or amplification using either a middle ear implant or bone conduction device, both of which improve directional hearing (Agterberg et al., 2014).

Ototoxicity resulting in sensorineural HL from medications such as antibiotics and chemotherapy are unfortunate iatrogenic causes of pediatric UHL. Why AHL or UHL would result from ototoxicity is unknown, as one might expect a bilateral symmetric hearing loss from systemic exposure. Regardless, aminoglycoside antibiotics, highly effective against Gram-negative bacteria such as *Hemophilus influenza* and *Neisseria meningitidis*, are also toxic to the hair cells of the cochlea. New investigative efforts have shown that perhaps bacterial endotoxins such as lipopolysaccharide (LPS) may synergistically increase the damaging effect of aminoglycosides on hair cells, by allowing the entry of CC2⁺ monocytes into the cochlea and augmenting the inflammatory response (Hirose, Li, Ohlemiller, & Ransohoff, 2014; Sato, Shick, Ransohoff, & Hirose, 2010). How this will change clinical practice remains to be elucidated. In the case of chemotherapy, as more and more children are surviving childhood malignancies such as hematologic and brain tumors, it is becoming apparent that these children are at a higher risk of HL. Exposure to carboplatin and cisplatin specifically has been shown to result in subsequent HL (Jehanne et al., 2009; Kubota et al., 2004). Promising new investigations have shown that steroid administration may be protective of ototoxicity from platinum-based agents (Marshak, Steiner, Kaminer, Levy, & Shupak, 2014), but these require further study before becoming standard practice. The mechanism of protection from these chemotherapeutic agents remains unclear, but may be due to intracellular transporters (Waissbluth & Daniel, 2013).

ADVANTAGE TO HEARING WITH BOTH EARS

Binaural hearing, or hearing with both ears, presents several important advantages above monaural hearing to the listener. It has been long established that binaural hearing provides improved speech perception, improved localization of sound, increased loudness perception due to binaural summation, and overall improved hearing both in noisy and quiet environments (Cadieux, Firszt, & Reeder, 2013; Ching, van Wanrooy, & Dillon, 2007). Ease of listening has been more recently identified to be a binaural benefit. Understanding the advantages of binaural hearing is crucial to awareness of the handicap a child with AHL or UHL faces. What is unknown, however, is how much providing educational interventions or interventions to improve hearing close the gap between children with UHL and their peers.

In the past, some expressed concerns about the use of conventional hearing aids in children with UHL (Updike, 1994) because they were thought not to have any benefit. However, this practice is rapidly changing, as Briggs et al. (2011) reported that although speech perception was unchanged after using amplification in children with UHL, quality of life increased significantly. Cochlear implantation has also begun to be offered to children with severe to profound UHL. Even though children with single-sided deafness were not initially recommended cochlear implants due to the hearing in the normalhearing ear being “too good,” implantation has been shown to be successful in children with AHL or UHL (Dwyer, Firszt, & Reeder, 2014; Hassepass et al., 2013). In addition, while not yet considered the standard of care, implant centers are beginning to implant children with AHL, and so far are reporting positive results by implanting the poorer-hearing ear (Cadieux et al., 2013). As previously mentioned, however, instituting speech therapy and IEPs for children with UHL does not completely eliminate the risk of future academic difficulties (J. E. C. Lieu et al., 2012). We stand to learn much from providing cochlear implants for this population in the future, as long-term studies are not yet available.

The traditional thinking about why UHL and AHL cause educational problems in children has been that because these children are not hearing well, that they simply are not paying attention or are losing opportunities for incidental learning by not overhearing speech. In a typical classroom, the speech-to-noise ratio may be +3 to +6 dB. Normalhearing children in the sixth grade achieved a greater than 95% speech understanding with a +8.5 dB speech-to-noise ratio; however, children in the first grade required +15.5 dB to achieve the same level of speech understanding (Bradley & Sato, 2008). Children with UHL require significantly higher speech-to-noise ratios to achieve the same amount of understanding, which contributes to their difficulty in the classroom.

Recent investigations attempting to look at the mechanism for how UHL and AHL affect the brain have shown that having auditory input from only one side, as is the case with severe UHL, can cause functional reorganization of the brain (Propst, Greinwald, & Schmithorst, 2010; Schmithorst et al., 2014). On functional magnetic resonance imaging (fMRI), children with UHL show significant differences in how sound is processed in the cortex as compared to normal-hearing children. Because children with UHL activate attention networks less strongly than normal hearing children in response to auditory stimuli, this may explain the memory, learning, and attention deficits seen in this population. Additional changes have been noted in MRI studies that investigated white matter, or the pathways connecting various regions of the brain, using diffusion tensor imaging (Rachakonda, Shimony, Coalson, & Lieu, 2014; Schmithorst et al., 2014). However, interpretations of these data are still speculative, and more research is needed to definitively show that these findings are associated with higher-level cortical function.

Finally, for all the investigative efforts and medical recommendations to schools regarding how to improve education for children with UHL and AHL, it is up to the schools themselves to follow or disregard such recommendations. In the United States, children with hearing loss receive extra attention and resources in schools because it is required by the Individuals with Disabilities Act (IDEA), enacted in 1975. However, the implementation of

this law differs from state to state, and sometimes even across school systems in the same state.

FUTURE DIRECTIONS

This article should allow stakeholders involved with the care of children with UHL to understand areas in need of more evidence for the specific deficits caused by UHL. Speech-language pathologists must describe specifically what kinds of speech deficits are commonly found as well as what treatment is effective; neuroscientists and educators must describe the learning deficits. Once the evidence is in place, policymakers will need to act on this evidence to ensure that school systems dealing with budget constraints are required to help these children, rather than ignoring the issue. For now, we must build on the momentum in recognizing UHL as an important problem in children, and continue to advance the knowledge on the specific deficits and responsible mechanisms in children with UHL.

CONCLUSION

Unilateral and asymmetric hearing loss in children, although traditionally not thought to be problematic, is becoming better recognized as a source of speech language delay educational difficulties. Detection of UHL has been greatly improved with newborn hearing screening, yet it is important to continue screening throughout childhood due to the high rate of progression of hearing loss throughout childhood. There remain multiple causes for acquired UHL which merit investigation to improve prevention, including ototoxicity from medications such as aminoglycoside antibiotics and platinum-based chemotherapeutic agents, and in utero infections such as CMV. In addition, a multidisciplinary approach is needed to better quantify the effects of UHL from an educational perspective, as well as identifying the specific best treatments, from a speech-language pathology and speech therapy perspective. As otologic surgeons are now beginning to place cochlear implants in children with asymmetric and UHL, long-term results to confirm initial findings of success will soon follow.

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TABLE 1

Etiology of unilateral and asymmetric hearing loss in children.

Causes of unilateral hearing loss	Prevalence among all children with unilateral hearing loss (%)	Reference
Unknown/No risk factors	31–54	(Declau et al., 2008; Ghogomu et al., 2014)
Congenital causes	45	(Ghogomu et al., 2014)
Cochlear nerve deficiency	26–50	(Clemmens et al., 2013; Nakano et al., 2013)
Developmental delay	21	(Haffey et al., 2013)
Premature birth	20	(Haffey et al., 2013)
Low birth weight	6–20	(Declau et al., 2008; Haffey et al., 2013)
Hereditary	3–11	(Declau et al., 2008; Ghogomu et al., 2014)
Hyperbilirubinemia	5–11	(Declau et al., 2008; Friedman et al., 2013; Haffey et al., 2013)
In utero infections	3–7	(Declau et al., 2008; Friedman et al., 2013; Ghogomu et al., 2014)
Craniofacial anomalies	5	(Declau et al., 2008)
Deafness syndrome	4	(Declau et al., 2008)
Low APGAR score	2	(Declau et al., 2008)
Acquired causes		
Ototoxic medication/Intravenous antibiotic use	3–21	(Declau et al., 2008; Friedman et al., 2013; Haffey et al., 2013)
Prolonged NICU stay	14–20	(Friedman et al., 2013; Haffey et al., 2013)
Mechanical ventilation	4–17	(Declau et al., 2008; Friedman et al., 2013; Haffey et al., 2013)
Meningitis	3–5	(Ghogomu et al., 2014; Haffey et al., 2013)
Head trauma	3–4	(Ghogomu et al., 2014; Haffey et al., 2013)