

The Importance of Access to Bilateral Hearing through Cochlear Implants in Children

Karen A. Gordon, Ph.D., C.C.C.-A., Reg. CASLPO,^{1,2,4}
Blake C. Papsin, M.D., FRCSC,^{1,3,4}
Vicky Papaioannou, MCISc, Reg. CASLPO,^{2,3,4} and
Sharon L. Cushing, M.D., FRCSC^{1,3,4}

ABSTRACT

Children with hearing loss require early access to sound in both ears to support their development. In this article, we describe barriers to providing bilateral hearing and developmental consequences of delays during early sensitive periods. Barriers include late identification of hearing loss in one or both ears and delayed access to intervention with hearing devices such as cochlear implants. Effects of delayed bilateral input on the auditory pathways and brain are discussed as well as behavioral effects on speech perception and other developmental outcomes including language and academics. Evidence for these effects has supported an evolution in cochlear implant candidacy in children that was started with unilateral implantation in children with profound deafness bilaterally to bilateral implantation to implantation of children with asymmetric hearing loss including children with single-side deafness. Opportunities to enhance the developmental benefits of bilateral hearing in children with hearing loss are also discussed including efforts to improve binaural/spatial hearing and consideration of concurrent vestibular deficits which are common in children with hearing loss.

KEYWORDS: deafness, bilateral cochlear implants, bimodal hearing, universal hearing screening, sensitive periods, cytomegalovirus, binaural/spatial hearing, aural preference

¹Archie's Cochlear Implant Laboratory, The Hospital for Sick Children, Toronto, Canada; ²Department of Communication Disorders, The Hospital for Sick Children, Toronto, Canada; ³Department of Otolaryngology, The Hospital for Sick Children, Toronto, Canada; ⁴Department of Otolaryngology – Head and Neck Surgery, University of Toronto, Toronto, Canada.

Address for correspondence: Karen A. Gordon, Ph.D., C.C.C.-A., Reg CASLPO, Archie's Cochlear Implant Laboratory, Room 6D08, The Hospital for Sick Children,

555 University Avenue, Toronto, ON M5G 1X8 (e-mail: karen.gordon@utoronto.ca).

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Audiologists provide audibility of sounds, particularly speech, to individuals with hearing loss. In children, this means identifying the presence of a permanent hearing loss, establishing the degree of loss, and then determining whether a hearing device is needed. The timing of each of these stages is essential in children to support language development during early sensitive periods.^{1,2} It has also come to light that providing access to sound in both ears is important in children with hearing loss^{3,4}; there are clear benefits of bilateral hearing and also significant detriments of relying on one ear to hear.^{5,6} Yet, bilateral hearing can be challenging to provide in children. In this article, we aim to identify existing barriers to bilateral hearing in children with hearing loss and to highlight clinical opportunities to reduce these barriers.

BARRIERS DELAY BILATERAL HEARING IN CHILDREN DURING SENSITIVE PERIODS IN DEVELOPMENT

Financial/Economic Barriers

One of the most practical barriers to providing bilateral hearing in children is economic/financial concern. Bilateral hearing devices presently double costs to children's families and to public and private funders of the devices. This economic concern is exacerbated in children with severe to profound hearing loss who need two cochlear implants to access sound in both ears. Increased costs of bilateral cochlear implants may be refused by insurance providers or other funding agencies including governmental health care systems. Indeed, bilateral cochlear implants are not a reality for children in many countries for this reason.⁷ The additional costs of cochlear implantation may also be a limiting factor for securing funding in children who have one deaf ear but who have better residual hearing in the other ear despite evidence of cost-effectiveness in adults.⁸

Although a concern in the short term, the economic implications of providing bilateral hearing must be weighed in context with the developmental requirements of children given the long-term effects of auditory deprivation. The immature brain undergoes rapid changes

throughout the first months and years of life⁹ and is thus vulnerable to abnormal development during this time.¹ Without hearing during early life, the developing brain reorganizes to process remaining sensory input such as vision (cross-modal plasticity), making it difficult to restore functional hearing later.¹⁰⁻¹² Delays in language acquisition are also difficult to reverse.^{2,13} It is true that audibility can be restored to one ear in children to promote auditory development^{14,15} and language,¹⁶ but we know from children with single-side hearing that this hearing is not sufficient to avoid deficits in oral language development and academic outcomes.^{6,17,18} These challenges have their own economic implications¹⁹⁻²¹ and reflect the loss of important listening skills that require hearing in both ears including sound localization²² and detection of one voice among many different sounds/noise.²³

Barriers Result from Delays in Identification

Barriers to providing bilateral hearing in children during early sensitive periods of development^{24,25} are also related to delays in identification of hearing loss. Newborn hearing screening programs have proven to be instrumental in providing early access to sound for children with congenital hearing loss.² However, these programs are not available in all countries and, even in countries where they do exist, they can be inaccessible in some regions. Most recently, some newborn hearing screening programs were halted in the initial response to the COVID-19 pandemic and catch-up screening was not necessarily performed. When in place, newborn hearing screening programs typically assess hearing in each ear which allows bilateral as well as unilateral hearing problems to be identified.^{26,27} It is important that screeners do not dismiss an abnormal finding in one ear as spurious because of a pass result in the other ear. Another concern regarding newborn hearing screening is that many children with initially good access to sound will have progressive deterioration of their hearing.²⁸ One of the leading causes of progressive hearing loss in children is congenital cytomegalovirus (cCMV).²⁹ In our

Canadian province of Ontario, universal screening of cCMV is completed through PCR analyses of bloodspots in all newborns in addition to hearing screening.³⁰ In this program, infants identified with cCMV undergo regular monitoring of their hearing in both ears. This program has been very important in identifying asymmetric progressive hearing loss in children because cCMV is known to be associated with single-side deafness in young children.^{31,32}

Given the importance of hearing development in early life, children with hearing loss must receive hearing devices without delay. Outcomes of early intervention are clear in children who need hearing aids, cochlear implants, or a combination of both.^{2,13,33,34} These studies demonstrate that delays of even months in implantation can lead to gaps in development. Adherence to the early hearing detection and intervention guidelines for hearing screening by 1 month of age, full hearing assessment by 3 months of age, and early intervention by 6 months of age reduces age at cochlear implantation by approximately 15 months which, in turn, improves language skills.² These guidelines have been adopted into the 2019 position statement of the Joint Committee on Infant Hearing.³⁵ Language gaps with delays to device activation are exacerbated with increasing severity of hearing loss.¹³ There is sufficient evidence for candidacy of cochlear implants to infants younger than 12 months³⁴ and for providing cochlear implants to limit asymmetric hearing.^{33,36}

Candidacy for cochlear implantation is typically determined through an evidence-based multidisciplinary process^{37,38} and cochlear implant candidacy has evolved significantly since this device was first provided to children in the mid-1990s. This means that cochlear implants were not provided or were delayed in some children who were not initially cochlear implant candidates. Cochlear implants were initially provided in only one ear to children with profound hearing loss in both ears. Later, hearing aids were used to provide sound to the unimplanted ear with some benefits for speech perception.^{39,40} The success of “bimodal hearing” (a cochlear implant in one ear and acoustic hearing through a hearing aid in the other) lead

to suggestions that bilateral cochlear implants might provide children with better hearing than one cochlear implant. Children who were experienced unilateral cochlear implants received a second device and showed improved abilities to hear speech in noise and some spatial hearing skills.^{5,41,42} Still, many of these children continued to show asymmetric hearing with an “aural preference” for listening with their first cochlear implant.^{3,24,33,43} Changes in the auditory cortex, measured by multichannel electroencephalography, revealed that unilateral cochlear implant use promoted abnormal strengthening from the stimulated ear to both auditory cortices.^{4,24,44,45} Further studies showed that providing bilateral cochlear implants in the same surgery (simultaneously) at young ages was cost-effective^{46,47} and better able to support development of pathways from both ears to auditory cortices^{4,24,48} than providing bilateral implants sequentially with long interimplant delays. The cortical data are supported by findings of remaining asymmetries in hearing in children with interimplant delays exceeding approximately 2-3 years relative to children receiving bilateral implants simultaneously.^{33,43,49}

Barriers Due to Configuration of Hearing Loss

Advantages of bilateral hearing in children with profound bilateral deafness through bimodal hearing and bilateral cochlear implants lead to questions about the use of cochlear implantation in children with asymmetric hearing loss. This latter group of children did not historically meet cochlear implant candidacy because they had good access to sound in one ear through hearing aids or even through one normal hearing ear. However, their deaf ear was deprived of sound and they were at risk of poorer hearing outcomes relative to their peers with hearing loss who received intervention to provide bilateral hearing. Several centers have provided cochlear implants to such children with good outcomes.^{33,36,39,50-53} Cortical reorganization which increases preference for the better hearing ear is more limited when the delay to cochlear implantation is reduced²⁵ and children implanted more quickly also show improved speech perception when using their bimodal

devices compared with either device alone.³³ Outcomes in children with bimodal devices have also revealed that cochlear implants can provide better hearing benefits than hearing aids for children with severe hearing loss.^{36,50} With this evidence, bimodal hearing device users with severe hearing loss are now considered candidates to receive a cochlear implant in the initially better hearing ear.

Successful use of bimodal devices in children with asymmetric hearing loss has also led to the consideration of cochlear implantation in individuals with single-side deafness.^{31,54–57} Developmental effects of unilateral hearing loss in children on language and learning have been reported for many decades^{6,17}; yet, interventions were limited to removing the head shadow effect of the deaf ear by sending sound from that side to the normal hearing ear through CROS hearing aids or bone conduction devices. Bilateral hearing could not be provided through these methods and was thought to remain out of reach for these children because of concerns that a hearing device in the deaf ear might disrupt the hearing in the normal hearing ear. Adults with single-side deafness have shown clear benefits of cochlear implantation^{8,58,59} and studies are presently underway to determine the effectiveness of implantation in children with single-side deafness.^{31,56,57,60} Early findings show that many children with single-side deafness do use their cochlear implants daily.^{55–57,60} Cochlear implants can also restore representation of the deaf ear in the auditory cortex when provided to young children with single-side deafness^{32,61} but cannot protect children with later onset of deafness from deterioration of auditory pathways from the newly deafened ear.⁶¹

OPPORTUNITIES TO IMPROVE BINAURAL HEARING IN CHILDREN

Evidence thus far supports providing bilateral hearing in children with the most appropriate device in each ear without delay.³ This will best support development of hearing in each ear and protect the bilateral auditory pathways from asymmetric function. However, efforts to rapidly provide hearing to each ear in early development will need to be further supported.

Looking ahead, we will need to address the remaining gaps in hearing for children using devices such as hearing aids and cochlear implants. It is clear that children with hearing loss require considerable effort to hear^{18,62–65} and we should expect that this has consequences for their overall development.

Children with bilateral cochlear implants still have poor abilities to locate sounds in space^{5,66–68} and to detect changes in the time differences of one sound reaching the two ears^{69,70} which may result, in part, from the uncoordinated input provided by independent devices used in each ear.^{71,72} Improved outcomes for children with hearing loss will require advances in how hearing devices represent sound such as speech and improvements in how the auditory system processes this input. Advances should also promote binaural hearing by reducing inaccuracies in interaural level and timing differences and mismatched place of stimulation that can occur between devices and ears.^{71,73,74} Furthermore, we should think about additional therapeutic techniques that can help children best use the sound they receive through hearing devices. Currently, therapies are focused appropriately on establishing language in children. Beyond this, novel techniques are needed to help children acquire spatial hearing so they can use this language in more complex listening situations. Additionally, we need to consider the potential impact of concurrent vestibular deficits in children with hearing loss on spatial and cognitive development.^{75,76} As in the past, coordinated research can add essential evidence to shape changes in our clinical management of children with hearing loss.

SUMMARY AND CONCLUSION

Present evidence indicates that barriers which delay intervention in children with hearing loss have significant consequences to auditory development, language acquisition, cognitive function, and academic learning. These barriers include delayed identification of hearing loss which can be avoided in part through universal hearing screening programs and programs that identify infants at high risk for hearing loss such as those with cCMV. Further delays in providing

audible sound to children with permanent hearing loss must also be avoided and efforts are needed to provide hearing in both ears. By reducing these barriers, we expect to improve overall development in children with hearing loss. Coordinated research and innovation aims to further reduce gaps between children with hearing loss and their typically developing peers.

CONFLICTS OF INTEREST

B.C.P. and S.L.C. are on the speaker's bureau for Cochlear Corporation, S.L.C. is on the speaker's bureau for Interacoustics and received royalties as a Plural Publishing editor for Balance Disorders in the Pediatric Population, K. A.G. is an adjunct faculty at Salus University, S. L.C. and B.C.P. hold Patent #: 7041-0: Systems and Methods for Balance Stabilization Sponsored Research Agreement—Cochlear Americas.

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