A Sound Foundation Through Early Amplification

Proceedings of the 7th International Conference 2016

There's a brain between those cochleae: Real-world speech understanding in children with hearing loss

Dawna Lewis, Ph.D.

Abstract

Children's real-world speech understanding is a complicated process. For children with hearing loss, access to the auditory signal will be impacted by the child's unaided and aided hearing status, the level of the signal reaching the ears, and the acoustic conditions in that environment. As a result of the combined effects of non-optimal acoustical environments, elevated hearing thresholds, and factors related to varying use and/or benefit from amplification, children with hearing loss are likely to experience inconsistent access to auditory information during periods of auditory skill development. Effects of hearing loss on foundational auditory skills can then affect higher perceptual processes, particularly in complex listening environments. In this chapter, we will examine factors that affect real-world speech understanding in children with hearing loss and provide an assessment of those factors.

Introduction

To provide a framework for a discussion of factors that affect real-world speech understanding, let us consider a child with hearing loss who is attempting to listen and learn in a typical elementary school classroom. In such an environment, children are introduced to new and potentially complex information, multiple changing talkers (with concurrent changes in target talker location), and frequently changing background noise levels that have the potential to interfere with acoustic access to target speech. Children must be able to hear the talkers in their environment, identify which of those talkers are important at any given moment, separate target talkers from all other sound sources (including other talkers), and maintain attention to the talker of interest. They must also use speech, language, and cognitive skills to process the information for understanding. This is a developmental process (readers are referred to Werner, Fay, & Popper [2012] for a review of auditory development in humans). For children with hearing loss, the process of understanding speech is impacted by reduced access to the auditory signal.

Figure 1 illustrates a potential seating arrangement in an elementary classroom. Suppose that our child has been given what the school defines as preferential seating. This seating places her in the center grouping of desks closest to the board. At times, this child will be listening to the teacher, who might be near the board or may be moving throughout the classroom. She also might be listening to children in her group of desks or to children who are farther away in one of the other groups, some of whom could be difficult to locate or see. At the same time, the child could be trying to ignore talkers in any of those locations who represent distractions from the talkers she is trying to follow. The audibility of any of these talkers will be impacted by acoustic factors inside and outside the room (e.g., noise, distance, reverberation) and how those factors interact with the child's hearing loss and personal/classroom amplification. The child will also be attempting to interpret the signals that she hears as part of the learning process.

Figure 1. Potential seating arrangement in an elementary classroom.

Auditory access to the incoming signal

Audibility of the acoustic signal is a significant contributor to a child's ability to understand speech. For a child with hearing loss, that access is reduced or eliminated. In natural environments, audibility will be impacted by numerous factors, including the child's unaided and aided hearing status, the level of the signal reaching her ears and the acoustic conditions in that environment. In the next few paragraphs, we will use graphs from the Situational Hearing Aid Response Profile (SHARP) to illustrate how these factors can impact auditory access for a child with hearing loss in our simulated classroom (Stelmachowicz, Lewis, Karasek, & Creutz, 1994; Brennan, McCreery, Lewis, Kopun, & Stelmachowicz, 2013).

The effects of hearing thresholds on audibility of speech are illustrated in Figures 2 and 3. In each graph, softer levels are lower on the y-axis and frequencies increase from left to right across the x-axis. The symbols represent thresholds for the right (O) or left (X) ears. The light shaded areas represent the portion of a given long-term average speech spectrum that is audible to the listener. Portions of the speech spectrum that are not audible are not shaded. Figure 2 illustrates the audibility of average conversational speech presented in quiet at a distance of one meter from a child. For our purposes, we have chosen a child talker to represent another student in the classroom. In Figure 2, the upper left graph shows audibility for a child with mild hearing loss. Here, audibility begins to decline for frequencies above 1000 Hz such that, by 6000 Hz, only the peaks of speech are audible. The upper right graph shows audibility of the same input for a child with a mild-moderate hearing loss. Average levels and above are audible in the low frequencies only. The lower graph shows that none of the signal would be audible for a child with a moderate-severe hearing loss.

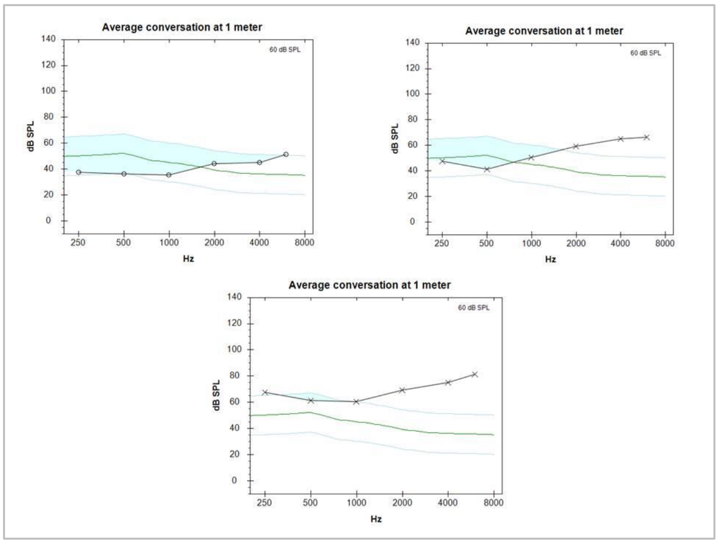

Figure 2. The audibility of average conversational speech presented in quiet at a distance of one meter from a child

Auditory access to the signal will change when the level of the speech input increases. Figure 3 shows the audibility of a classroom teacher's voice at the same one meter distance for the same degrees and configurations of hearing loss. As can be seen in the upper left graph, almost the entire speech spectrum is audible for a child with mild hearing loss. For a child with mild-moderate hearing loss (upper right graph), much of the speech information in the mid to high frequencies remains inaccessible. The increased input level provides very little audibility of any of the speech signal for a child with moderate-severe hearing loss (lower graph). These graphs illustrate the effects of both hearing thresholds and speech levels on access to the speech signal.

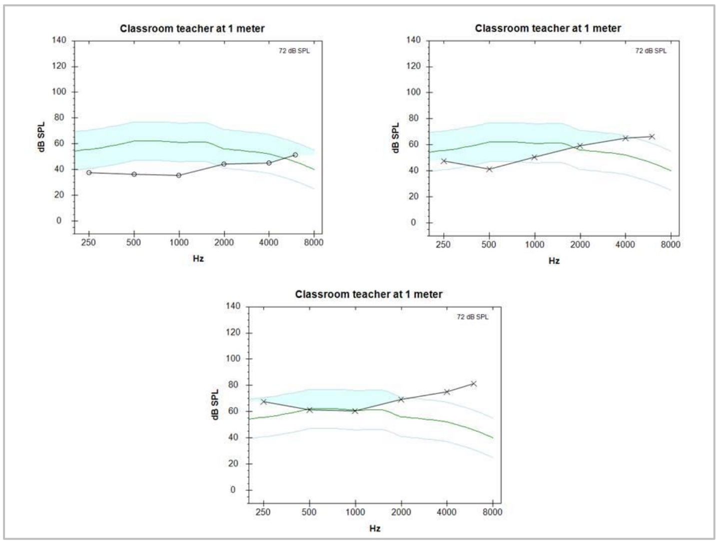

Figure 3. Audibility of a classroom teacher's voice at the same one meter distance for the same degrees and configurations of hearing loss

In Figures 4 and 5, we see the interaction of signal level, distance, and background noise on access to speech for a child with a mild hearing loss. In Figure 4, the upper two panels show the audibility of average conversation from a child talker at one and four meters, respectively. The lower two graphs show the audibility of a classroom teacher at those same distances, respectively. Here, it is clear that distance (left versus right graphs) has a greater negative effect on the audibility of average conversation than on the audibility of the teacher's voice (upper versus lower graphs). Figure 5 shows what happens when noise is added to the mix. Here, a simplified representation of background noise (the darker shaded area) has been added to each graph. As expected, noise has a greater effect on the audibility of average conversation (upper graphs) than a teacher's voice (lower graphs) at either distance. However, as the lower panels illustrate, even the teacher's voice is greatly affected by the background noise as distance between talker and listener increases.

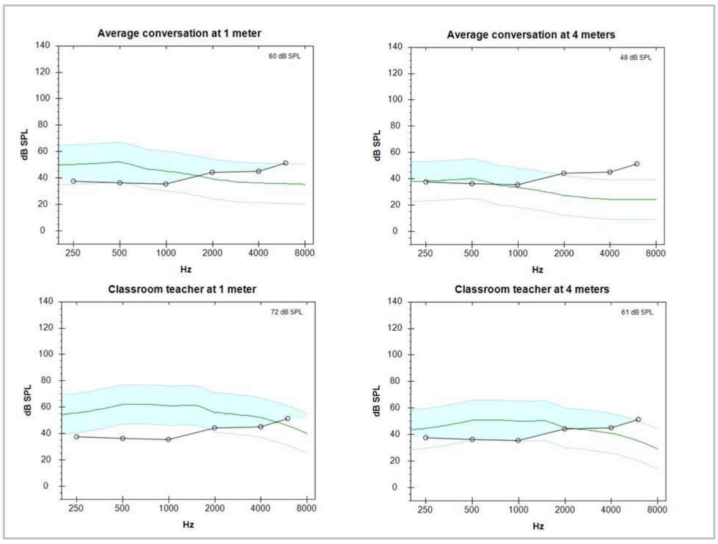

Figure 4. The audibility of average conversation from a child talker and a classroom teacher at one and four meters

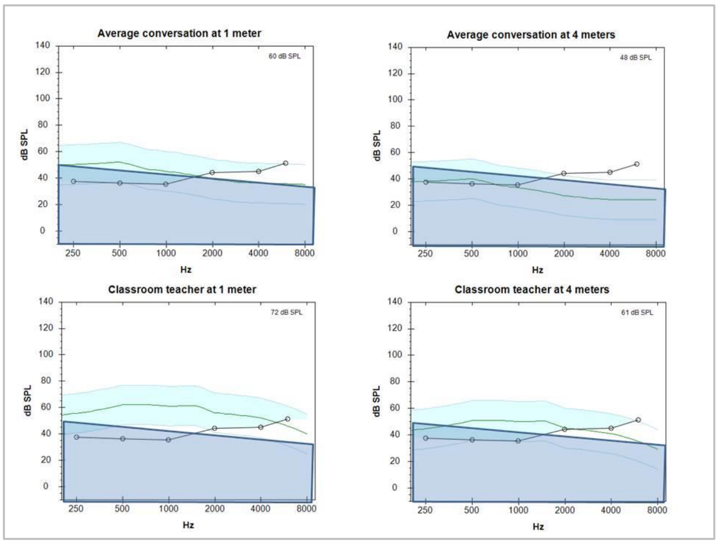

Figure 5. The audibility of average conversation from a child talker and a classroom teacher with background noise at one and four meters

Figures 2-5 provide information regarding audibility of speech based on unaided hearing. However, once a child has been identified with hearing loss, hearing aids are the primary means by which audiologists attempt to improve auditory access. Figure 6 illustrates the impact of amplification and background noise on the audibility of average conversational speech at one meter for a child with mild-moderate hearing loss. As seen in the upper left graph, audibility is limited to the lowest frequencies without amplification. In the upper right graph, we can see that hearing aids improve audibility such that the majority of the speech spectrum is audible. However, background noise was a factor in both conditions. Using our simplified representation, the lower graph shows the effects of noise on both the unamplified and amplified speech signals. Little change is noted in the unaided condition (lower left graph), as little of the speech signal was audible in the beginning. In the aided condition (lower right graph), amplification of the noise signal results in reduced audibility of softer components of speech that would be available in quiet. Together, the examples above demonstrate that audibility is not static. It can vary considerably over time and between conditions, resulting in inconsistent auditory access for a child with hearing loss.

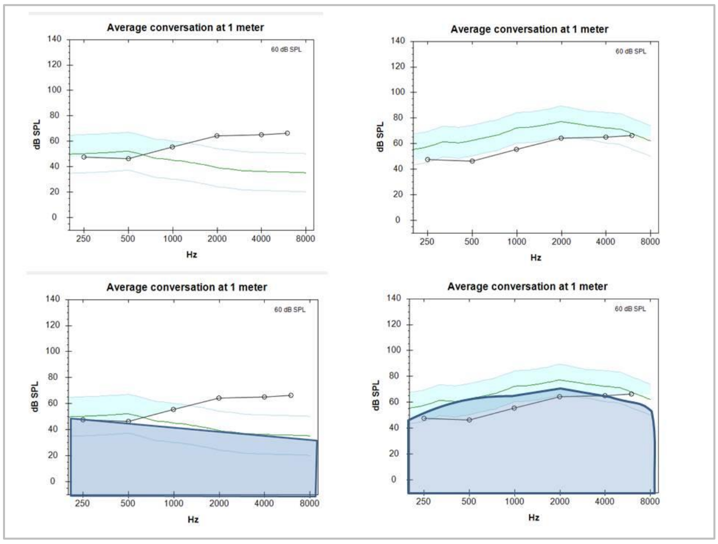

Figure 6. The impact of amplification and background noise on the audibility of average conversational speech at one meter for a child with mild-moderate hearing loss

Auditory experience and outcomes

Although the figures above are helpful in illustrating how hearing loss impacts the availability of the speech signal, they represent only a starting point in our appreciation of its impact on speech understanding. Recall our child in the classroom and the complex process required to understand speech in that environment. Numerous research groups evaluating outcomes in children with hearing loss have shown that auditory experience is an important contributor in areas that include speech perception, speech/language development, academic skills, and psychosocial skills (to be discussed below). The following paragraphs provide a summary of research studies that examined the effects of hearing loss on children's outcomes in areas that are important for learning.

Language outcomes in children with hearing loss

Yoshinaga-Itano and colleagues (Yoshinaga-Itano, Sedey, Coulter & Mehl, 1998) conducted a large-scale study of one to three-year-old children who were deaf or hard-of-hearing and whose age of identification was before or after six months of age. Both groups received amplification and began intervention within a few months of identification. Receptive and expressive language skills were significantly better for the children whose hearing loss was identified before six months.

Outcomes in infants/toddlers with hearing loss

Sininger, Grimes and Christensen (2010) conducted a longitudinal study of children with mild to profound hearing loss who had been fitted with hearing aids. Outcomes measures (beginning at three years of age) included speech perception, articulation, and receptive/expressive language. Findings indicated that:

- The age of hearing-aid fitting impacted all outcomes, with earlier fitting predicting better outcomes.
- Degree of hearing loss was the strongest predictor of performance on measures of speech production and receptive/expressive language.

Outcomes of Children with Hearing Loss
(http://ochlstudy.org/index.html)

The Outcomes of Children with Hearing Loss (OCHL) project is a large-scale multi-state, multi-center study examining outcomes in children with bilateral mild-severe hearing loss from birth through school age. A central hypothesis of this project is that a child's cumulative auditory experience (access to auditory input over time) might impact processes that support learning (Moeller & Tomblin, 2015). Representative recent results of this group's research found that:

- Aided audibility was positively correlated with speech and language skills in the preschool years (Tomblin, Oleson, Ambrose, Walker, & Moeller, 2014).
- Degree of hearing loss was associated with language level. The age at which hearing aids were fitted was associated with language growth over time from 2-6 years of age. Aided audibility above and beyond degree of hearing loss was associated with differential language growth over time from 2-6 year of age (Tomblin et al. 2015).
- Better aided audibility was associated with better outcomes on a range of auditory development and speech recognition measures across age. Better verbal

working memory was associated with better speech recognition in quiet and noise (McCreery et al., 2015).

- The sensation level of speech at 4 kHz predicted relative production accuracy of s-related morphemes in 3-year olds who wore hearing aids (Koehlinger, Van Horne, Oleson, McCreery, & Moeller, 2015).
- Better speech production outcomes were found in 2-year olds who were fitted with hearing aids before 6 months of age and those with milder degrees of hearing loss (Ambrose et al., 2014).
- For children with mild hearing loss, the amount of daily hearing aid use predicted grammar and vocabulary (Walker et al., 2015).

Longitudinal Outcomes of Children with Hearing Impairment (http://outcomes.nal.gov.au/)

The Longitudinal Outcomes of Children with Hearing Impairment project, conducted by the National Acoustics Laboratories, is a population-based study that examines a range of long-term outcomes in children with hearing loss who were identified early or late. The population includes children who wear hearing aids and/or cochlear implants and children with additional disabilities.

- At 3 years of age, scores on standardized measures of expressive/receptive language, speech production, and social and auditory function were, on average, 1 SD below normative values (Ching et al., 2013).
- At 3 years of age, five predictors accounted for 40% of the variance in global outcomes: gender, additional disabilities, severity of hearing loss, maternal education, and age at which the cochlear implant was activated for children that used this device. Age of amplification was not significant (Ching et al., 2013).
- At 5 years of age, better language outcomes were associated with earlier amplification in children who wore hearing aids and with earlier first activation in children with cochlear implants (Ching, 2015).

Erber (1982) proposed a hierarchy of developmental listening levels involved (Figure 7). These levels are important to consider when determining the auditory skills and cognitive processing that would be required for a child to perform a listening task (Thibodeau, 2000).

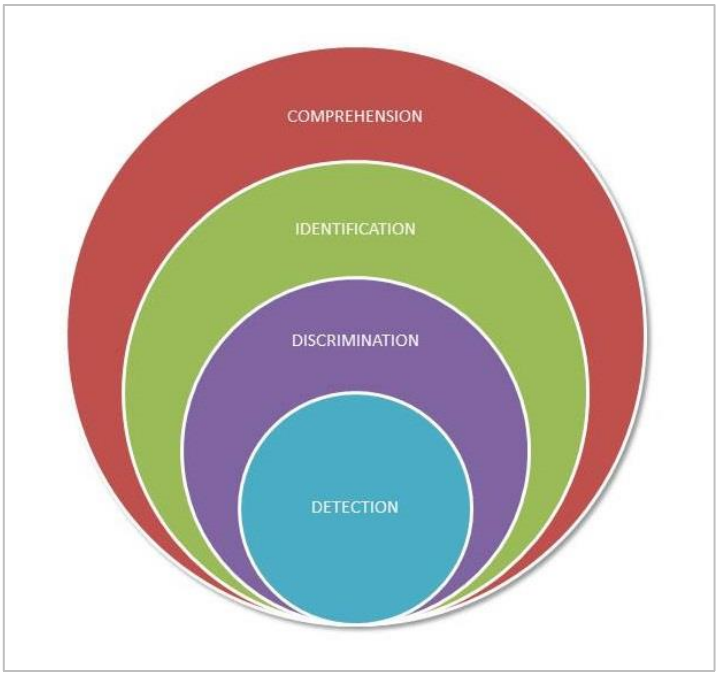

Figure 7. The hierarchy of developmental listening levels

As suggested by Figure 7, processing at each successive level encompasses the ability to perform at each of the lower levels. For our purposes, let us consider these levels in terms of the effort that would be required to access speech for a child with hearing loss in the classroom. At the lowest level (detection), the child only needs to be aware of the presence of speech. Discrimination requires the ability to recognize that there is a change in the signal or that two signals are different. However, the child will not need to be able to attach meaning to those sounds. Identification and comprehension require increasingly greater top-down processing abilities. The cognitive and linguistic effort required simply to know that someone in the class is speaking would be very low compared to that needed to process the speech information for understanding. Consider also the potential impact of cumulative auditory experience at each level of processing. Children with little to no auditory experience are able to detect sounds once they are made audible. However, as the studies reviewed in this chapter suggest, experience and skill development are necessary for children to use what they hear for understanding.

Assessing speech understanding in complex conditions

To evaluate speech perception of children with hearing loss in real-world listening environments such as classrooms, it is important to use tasks that represent the listening situations they will experience. Tasks that that are less complex provide useful baseline information about how the child is processing auditory input but might not assess higher-level cognitive skills necessary for comprehension (Klatte, Hellbruck, Seidel, & Leistner, 2010a; Klatte, Lachmann, & Meis, 2010). For example, it has been suggested that tasks simulating school lessons might be needed to assess effects of the acoustical environment on children's comprehension (Klatte et al., 2010). A variety of cognitively demanding tasks have been used to examine speech understanding and outcomes of children with hearing loss to represent the complexity of understanding speech in the real world. These include:

- Word learning (Stelmachowicz, Pittman, Hoover, & Lewis, 2004; Pittman, Lewis, Hoover & Stelmachowicz, 2005; Pittman & Rash, 2016);
- Dual- task paradigms (Hick & Tharpe, 2002; McFadden & Pittman, 2008);
- Verbal processing time measures (Lewis et al,., 2016);
- Comprehension tasks (Jerger et al., 2006; Lewis, Valente & Spalding, 2015);
- Assessments of Fatigue (Bess et al., 2016; Hick & Tharpe, 2002; Hornsby, Werfel, Camarata, & Bess, 2014).

In the Listening and Learning Laboratory at Boys Town National Research Hospital, we have been using complex tasks to evaluate the influence of dynamic features of multi-source environments that impact speech understanding in isolation and in combination for children with normal hearing (NH) and children with mild bilateral or unilateral hearing loss (MBHL and UHL, respectively). The following paragraphs will describe the results of some of our recent work.

Comprehension and sentence recognition in a simulated classroom environment

We conducted a series of studies to examine the effect of acoustic environment on speech understanding during sentence-recognition and comprehension tasks in a simulated classroom environment. The first study (Valente, Plevinsky, Franco, Heinrichs-Graham & Lewis, 2012) was conducted in an acoustical environment typical of many classrooms (signal-to-noise ratio [SNR] = 10 dB, RT = 0.6 sec). Children (8-12 years) and adults with NH listened to an audiovisual presentation of a teacher and four students reading lines from an age-appropriate play, reproduced over monitors and loudspeakers located around the listener (discussion) or spoken only by the teacher located at 0° azimuth relative to the listener (lecture). A gyroscopic headtracker monitored looking behavior. Comprehension was assessed by asking subjects questions about the story at its completion. Subjects also completed an auditory-only sentence recognition task in both conditions. Children performed poorer than adults in both conditions of the comprehension task and their scores were lower for the discussion condition than for the lecture condition. However, for the sentence-recognition task, both age groups scored above 95% correct. These findings suggest that the age effect (children versus adults) observed for comprehension was not due to differences in speech recognition abilities. Looking behavior revealed that children attempted to look at talkers more than adults, but this increased looking was not sufficient to improve their performance to the same level that was achieved by adults.

In a second experiment in the same study, we also examined how adverse acoustic environments (SNR = 10 dB, RT = 1.5 sec; SNR = 7 dB, RT = 1.5 sec; SNR = 7 dB, RT = 0.6 sec) would affect outcomes. Two age groups of children (8 and 11 years) and adults with normal hearing participated. Although scores on the sentence-recognition task decreased for poorer acoustic environments, all were above 82%. For the comprehension task, performance for all subject groups in the discussion condition decreased to a greater extent than in the lecture condition as the acoustics worsened. In addition, younger children performed more poorly than older children and adults in all conditions and environments.

Using the same paradigm, Lewis et al. (2015) examined performance in the discussion condition for children (8-12 years) with MBHL, UHL, and age-matched peers with NH. No differences were observed between those with UHL and MBHL. Near-ceiling performance was observed on the speech-recognition task for all groups. In contrast, children with hearing loss performed more poorly than those with NH on the comprehension task. Although no significant differences in number of looking attempts were observed between those with and without hearing loss, patterns of looking by children with hearing loss were more similar to younger (8-10 yrs) than to older (11-12 yrs) children with NH. In addition, children with hearing loss and those with NH looked directly at talkers as they spoke less than 50% of the time.

Considered together, these studies demonstrate that differences in performance for children with MBHL and UHL, compared to peers with NH, depend on the specific task. Although no differences in sentence recognition were observed between the groups of children, children with MBHL and UHL were at a significant disadvantage relative to their peers with NH when tested using a comprehension task. Furthermore, although sentences are commonly used to assess children's speech understanding in noise and reverberation, the high scores obtained in these studies suggest that simple speech-recognition tests using a single talker might be limited in their ability to address potential difficulties experienced by children for more cognitively demanding tasks in the acoustic conditions typically found in classrooms.

Conclusion

In children with hearing loss, speech understanding will be impacted by the signal entering the ears and how that signal is processed, interpreted, and understood. Multiple factors play a role in this process, both peripherally and centrally, and are impacted by both present and cumulative experiences. Understanding the roles and interactions of these factors is critical for providing communication access for children with hearing loss.

References

Ambrose, S. E., Unflat Berry, L. M., Walker, E. A., Harrison, M., Oleson, J., & Moeller, M. P. (2014). Speech sound production in 2-year-olds who are hard of hearing. *American Journal of Speech-Language Pathology*, *23*(2), 91–104.

Bess, F. H., Gustafson, S. J., Corbett, B. A., Lambert, E. W., Camarata, S. M., & Hornsby, B. W. Y. (2016). Salivary Cortisol Profiles of Children with Hearing Loss. *Ear and Hearing*, *37*(3), 334–344.

Brennan, M., McCreery, R., Lewis, D., Kopun, J., & Stelmachowicz, P. (2013). Incorporating measures of nonlinear frequency compression into the Situational Hearing Aid Response Profile (SHARP). Presented at the Poster presented at A Sound Foundation Through Early Amplification Conference, Chicago, IL.

Ching, T. Y. C. (2015). Is early intervention effective in improving spoken language outcomes of children with congenital hearing loss? *American Journal of Audiology*, *24*(3), 345–348.

Ching, T. Y. C., Dillon, H., Marnane, V., Hou, S., Day, J., Seeto, M., ... Yeh, A. (2013). Outcomes of early- and late-identified children at 3 years of age: findings from a prospective population-based study. *Ear and Hearing*, *34*(5), 535–552.

Erber, N. (1982). *Auditory Training*. Washington, DC: Alexander Graham Bell Association for the Deaf and Hard-of-Hearing.

Hick, C. B., & Tharpe, A. M. (2002). Listening effort and fatigue in school-age children with and without hearing loss. *Journal of Speech, Language, and Hearing Research: JSLHR*, *45*(3), 573–584.

Hornsby, B. W. Y., Werfel, K., Camarata, S., & Bess, F. H. (2014). Subjective fatigue in children with hearing loss: some preliminary findings. *American Journal of Audiology*, *23*(1), 129–134.

Jerger, S., Damian, M. F., Tye-Murray, N., Dougherty, M., Mehta, J., & Spence, M. (2006). Effects of childhood hearing loss on organization of semantic memory: typicality and relatedness: *Ear and Hearing*, *27*(6), 686–702.

Klatte, M., Hellbruck, J., Seidel, J., & Leistner, P. (2010). Effects of classroom acoustics on performance and well-being in elementary school children: a field study. *Environment and Behavior*, *42*(5), 659–692.

Klatte, M., Lachmann, T., & Meis, M. (2010). Effects of noise and reverberation on speech perception and listening comprehension of children and adults in a classroom-like setting. *Noise & Health*, *12*(49), 270–282.

Koehlinger, K., Van Horne, A. O., Oleson, J., McCreery, R., & Moeller, M. P. (2015). The role of sentence position, allomorph, and morpheme type on accurate use of s-related morphemes by children who are hard of hearing. *Journal of Speech, Language, and Hearing Research: JSLHR*, *58*(2), 396–409.

Lewis, D. E., Valente, D. L., & Spalding, J. L. (2015). Effect of minimal/mild hearing loss on children's speech understanding in a simulated classroom. *Ear and Hearing*, *36*(1), 136–144.

Lewis, D., Schmid, K., O'Leary, S., Spalding, J., Heinrichs-Graham, E., & High, R. (2016). Effects of noise on speech recognition and listening effort in children with normal hearing and children with mild bilateral or unilateral hearing loss. *Journal of Speech, Language, and Hearing Research: JSLHR*, *59*(5), 1218–1232.

McCreery, R. W., Walker, E. A., Spratford, M., Oleson, J., Bentler, R., Holte, L., & Roush, P. (2015). Speech recognition and parent ratings from auditory development questionnaires in children who are hard of hearing. *Ear and Hearing*, *36 Suppl 1*, 60S–75S.

McFadden, B., & Pittman, A. (2008). Effect of minimal hearing loss on children's ability to multitask in quiet and in noise. *Language, Speech, and Hearing Services in Schools*, *39*(3), 342–351.

Moeller, M. P., & Tomblin, J. B. (2015). An introduction to the outcomes of children with hearing loss study. *Ear and Hearing*, *36 Suppl 1*, 4S–13S.

Pittman, A. L., Lewis, D. E., Hoover, B. M., & Stelmachowicz, P. G. (2005). Rapid word-learning in normal-hearing and hearing-impaired children: effects of age, receptive vocabulary, and high-frequency amplification. *Ear and Hearing*, *26*(6), 619–629.

Pittman, A. L., & Rash, M. A. (2016). Auditory lexical decision and repetition in children: effects of acoustic and lexical constraints. *Ear and Hearing*, *37*(2), e119-128.

Sininger, Y. S., Grimes, A., & Christensen, E. (2010). Auditory development in early amplified children: factors influencing auditory-based communication outcomes in children with hearing loss. *Ear and Hearing*, *31*(2), 166–185.

Stelmachowicz, P. G., Pittman, A. L., Hoover, B. M., & Lewis, D. E. (2004). Novel-word learning in children with normal hearing and hearing loss. *Ear and Hearing*, *25*(1), 47–56.

Stelmachowicz, P., Lewis, D., Karasek, A., & Creutz, T. (1994). *Situational hearing aid response profile (SHARP, version 2.0) user's manual.* Omaha, NE: Boys Town National Research Hospital.

Thibodeau, L. (2000). Speech Audiometry. In *R. Roeser, M. Valente & H. Hosford-Dunn (Eds). Audiology Diagnosis* (pp. 281–309). New York: Thieme.

Tomblin, J. B., Harrison, M., Ambrose, S. E., Walker, E. A., Oleson, J. J., & Moeller, M. P. (2015). Language Outcomes in Young Children with Mild to Severe Hearing Loss. *Ear and Hearing*, *36 Suppl 1*, 76S–91S.

Tomblin, J. B., Oleson, J. J., Ambrose, S. E., Walker, E., & Moeller, M. P. (2014). The influence of hearing aids on the speech and language development of children with hearing loss. *JAMA Otolaryngology-- Head & Neck Surgery*, *140*(5), 403–409.

Valente, D. L., Plevinsky, H. M., Franco, J. M., Heinrichs-Graham, E. C., & Lewis, D. E. (2012). Experimental investigation of the effects of the acoustical conditions in a simulated classroom on speech recognition and learning in children. *The Journal of the Acoustical Society of America*, *131*(1), 232–246.

Walker, E. A., Holte, L., McCreery, R. W., Spratford, M., Page, T., & Moeller, M. P. (2015). The influence of hearing aid use on outcomes of children with mild hearing loss. *Journal of Speech, Language, and Hearing Research: JSLHR*, *58*(5), 1611–1625.

Werner, L., Fay, R., & Popper, A. (2012). *Human Auditory Development*. New York: Springer.

Yoshinaga-Itano, C., Sedey, A. L., Coulter, D. K., & Mehl, A. L. (1998). Language of early- and later-identified children with hearing loss. *Pediatrics*, *102*(5), 1161–1171.

Acknowledgements:
Research from the Listening and Learning Lab at BTNRH that is presented in this paper is supported by National Institutes of Health grants R03 DC009675, T32 DC000013, P20 GM109023, and P30 DC004662. The content of this manuscript is the responsibility and opinions of the author and does not necessarily represent the views of the National Institutes of Health. The author is a member of the Phonak Pediatric Research Advisory Board.

Author

Dawna Lewis, Ph.D.
Boys Town National Research Hospital
Omaha, Nebraska, United States
Dawna.lewis@boystown.org

Editors

Anne Marie Tharpe, Ph.D.
Chair, Phonak Research Advisory Board
Professor and Chair
Department of Hearing & Speech Sciences
Vanderbilt University School of Medicine
Nashville, Tennessee, United States

Marlene Bagatto, Ph.D.
Research Associate and Adjunct Research Professor
National Centre for Audiology
Western University
London, Ontario, Canada