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Science Matters: Evaluating Masked Speech Perception in Children: Moving Towards Clinical Tools that Provide Information about Children's Functional Hearing Skills

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Introduction

As researchers who work with children who are hard of hearing, pediatric audiologists often ask us to recommend speech perception tools that assess children's functional hearing. Functional hearing refers to how individuals use their hearing in everyday life, which often involves listening in environments that contain multiple sources of competing sounds. Unfortunately, few such tools are currently available. This is problematic because, while several speech-in-noise tests are available for clinical use with children, scores on conventional speech-in-noise measures do not appear to be closely associated with children's functional hearing.[1]

One reason that conventional clinical tools do not fully capture children's functional hearing abilities is that they involve testing in either quiet, in the presence of broadband noise, or in the presence of speech produced by many talkers (i.e., ? 4 talkers). These sounds are relatively steady-state, similar to noise produced by cafeteria babble or by heating and ventilation systems. Steady-state noise masks target speech by interfering with the peripheral encoding of sound.[2] For example, the noise produced by an air conditioner in the classroom may cause a child to miss an important phoneme in a word produced by their teacher. In the literature this type of interference is referred to as *energetic masking*.

Although noise is prevalent in children's environments, there is a growing awareness that children spend most of their days listening and learning in the presence of competing speech.[3] This is an important consideration for researchers and clinicians because background maskers composed of a small number of talkers tend to produce both energetic and *informational* masking.[4,5] Informational masking occurs when listeners have difficulty separating talkers into different auditory objects and/or allocating attention to one talker while ignoring competing talkers.[6,7] Children are especially vulnerable to the detrimental effects of informational masking.[8,9] While children with normal hearing often require a more advantageous signal-to-noise ratio (SNR) than adults to recognize speech in a noise masker, the performance gap between adults and children is significantly larger in a speech masker composed of a small number of talkers.[8] Moreover, children do not attain adult-like speech recognition performance in the presence of competing speech until adolescence.[9]

Classroom Acoustics

A classroom acoustics standard is in place in the United States, providing recommendations for classroom noise levels.[10] This standard was developed by the Acoustical Society of America and approved in 2002 by the American National Standards Institute as ANSI S12.60. The objective of this standard is to address the negative effects of acoustical variables in classrooms, as well the obstacles that result from impairments affecting a child's access to sound. The American Speech-Language and Hearing Association states that "…through specific design requirements and acoustical performance criteria, the standard tries to create a classroom environment that optimizes speech understanding."[11] No such standard exists in Canada, though Speech-Language & Audiology Canada is aware that noise in Canadian classrooms is an important issue that needs to be addressed.[12]

ANSI S12.60 recommends that *unoccupied* classroom background noise levels should not exceed 35 dBA.[10] Noise sources often found in an unoccupied classroom noise assessment are defined as external or internal. Examples of external sources include outside street traffic and children playing on a playground.[13] Examples of internal sources include those found in adjacent classrooms or hallways, as well as noise produce by sources such as heating and air condition systems or overhead lighting. Unfortunately, even with the standard in place, few classrooms in the United States[14] and Canada[15] have favourable acoustics; most exceed the recommended noise levels.

One limitation of the current noise standard is that measurements are taken in unoccupied classrooms; thus, movement within the classroom is not accounted for. This movement may include chairs scraping on the floor, projection systems, or children and teachers shuffling or fidgeting about the classroom. A second limitation is that the current standard fails to account for an important source of extraneous sound in the classroom – competing speech. Teachers are well aware, and results from recent studies show, that children spend much of their day listening and learning with competing speech in the background.[3] As discussed in the following sections, it turns out that competing speech poses a significant challenge to developing children, particularly children who are hard of hearing.

Children's Speech Recognition in the Presence of Competing Noise, Babble, or Speech

Young children have more difficulty than adults recognizing speech in the presence of almost any competing background sound.[8,9,16] For children with normal hearing, the ability to recognize phonemes, words, or sentences in noise appears to mature by around 10 years of age. In their seminal study, Hall and his colleagues from the University of North Carolina estimated children's and adults' speech recognition thresholds (SRTs) for spondaic words (spondees) in the presence of speech-shaped noise.[8] The children ranged in age from 5 to 10 years. Children required a more advantageous SNR relative to adults to achieve the same level of performance. The average child-adult SRT difference was 3 dB.

Several studies have examined children's speech perception abilities in the presence of speech babble or "cafeteria noise," which is operationally defined here as a mixture of 4 or more talkers. The findings are similar to those observed in studies that have assessed masked speech perception in the presence of Gaussian or speech-shaped noise.[16,17] The explanation for the similar pattern of results observed with competing noise and babble is that the combined acoustic waveforms of multiple talkers fill in the temporal and spectral gaps that would be present in a small number of speech streams, and the babble begins to sound more like noise than like speech.[18]

Consider instead the situation in which a child in the classroom is trying to listen to the teacher while two fellow classmates are having a conversation from behind. In the study by Hall and colleagues mentioned previously,[8] SRTs were also estimated in the presence of a 2-talker masker. In contrast to the 3-dB child-adult difference observed in the noise masker, the average child-adult difference was 7 dB in the speech masker. These findings have been replicated across a number of different laboratories using a variety of speech materials. In addition to the larger performance gap between children and adults in the presence of competing speech, children do not show adult-like performance on speech-in-speech tasks until after 12–13 years of age.[9] This prolonged time course of development indicates that it takes years of experience with sound and/or neural maturation in order to master the perceptual skills required to separate and attend to a target talker when other people are talking in the background.

The Influence of Hearing Loss on Speech Recognition in the Presence of Competing Speech

We are beginning to gain an appreciation for how the variable and/or degraded experience with sound often associated with hearing loss early in life impacts the development of both language[19] and functional hearing.[20] Findings from recent studies conducted in our laboratories at Boys Town National Research Hospital and at the University of North Carolina suggest that the well-known performance gap on measures of masked speech perception between children who are hard of hearing and children with normal hearing is larger in competing speech than in competing noise.[21] We first demonstrated that children with normal hearing had an average SNR advantage of 8.1 dB compared with age-matched children with sensory/neural hearing loss when asked to identify spondees in a 2-talker masker. The children with hearing loss were tested wearing their personal hearing aids. Note that the average advantage was only 3.5 dB in a noise masker. These findings provided initial evidence that hearing loss early in life can interfere with children's perceptual processing abilities.

In a follow-up study, we tested the hypothesis that speech perception in a 2-talker speech masker is more closely associated with the everyday communication challenges experience by children who are hard of hearing than testing in a noise masker.[20] The results indicated that SRTs in a noise masker were uncorrelated with parental reports of their children’s functional auditory skills. In sharp contrast, SRTs in a 2-talker masker were highly correlated with the parental reports. This pattern of results suggest that the assessment of speech perception in the presence of a small number of competing talkers taps into some of the same abilities that children who are hard of hearing rely on to hear and understand speech in natural listening environments. We are actively working on new experiments in the laboratory to confirm this finding, and to evaluate the impact of factors such as degree of hearing loss, age, and amount of hearing aid use on the functional hearing skills of children who are hard of hearing.

Clinical Tools for Assessing Children’s Masked Speech Recognition

Helping children, particularly children who are hard of hearing, overcome the effects of poor classroom acoustics is a challenge for educational audiologists. Certain accommodations are often implemented, including preferential seating and the use of wireless assistive listening devices (e.g., FM systems) at school. To determine if such accommodations are necessary, audiologists often perform an observation that evaluates the classroom and teacher, and may also assess children’s speech perception abilities using one or more masked speech perception tests.

There are a variety of masked speech perception tests available to pediatric audiologists. Most of these tests assess hearing in the presence of noise or babble. The age of the child and specific complaints from child, parent, or teacher can guide the audiologist’s decision on which test or tests to consider in a hearing evaluation. Commonly used tests for evaluating speech recognition in noise or babble include the Bamford-Kowal-Bench Speech in Noise (BKB-SIN) test,[22] the Hearing in Noise Test for Children (HINT-C) test,[23] and the Pediatric AZ Bio test.[24] The BKB-SIN test is an adaptive procedure which measures SNR loss in a multi-talker babble. The HINT-C is also an adaptive procedure, but measures sentence recognition thresholds corresponding to 50% correct in a speech-shaped noise. Finally, the Pediatric AZ Bio test is an open-set sentence recognition task that measures percent keywords correct in quiet or in 10-talker babble. All of these tests are suitable for use with school-aged children, and the combination of sentence target materials with an open-set response format provides an approximation of children’s daily performance in quiet or in presence of relatively steady-state background sounds. Scores on these tests are used to help diagnose hearing loss, evaluate (re)habilitative outcomes, establish hearing aid and cochlear implant candidacy, recommend services or interventions (e.g., FM systems), and set educational goals and expectations.[25]

Missing from the pediatric speech perception testing battery are tools that evaluate not only the peripheral consequences of sensory/neural hearing loss, but also the perceptual and cognitive processes that underlie speech understanding in real-world environments. There is a movement to develop new tools that include testing in the presence of complex and dynamic maskers, such as competing speech. This idea is not new; there has been longstanding support for incorporating speech maskers into clinical speech perception assessments.[26] Nonetheless, it has only been in recent years that clinical interest and evidence-based research have led to in the formation of a new generation of speech-in-speech clinical assessment tools.

A promising new tool is the North American Listening in Spatialized Noise - Sentences (LiSN-S) test.[28] This test evaluates sentence recognition in the presence of competing speech, with normative data collected on children as young as 6 years of age. A unique feature of this test is that the competing speech can be presented via headphones so that it is perceived as arriving from the same or a different location in space as the target sentences. These presentation options provide an opportunity to examine the extent to which children rely on spatial separation to separate competing streams of speech. This is particularly relevant to real-world performance, as different sounds typical arise from different locations in space.

We are part of a multi-center study funded by the National Institutes of Health to develop a new pediatric English/Spanish speech perception test. While a major goal of this test development is to provide equivalent testing options in either English or Spanish, another important goal is to provide clinicians with a test that can be used in quiet, in competing steady-state noise, and in competing two-talker speech.[29] The test includes a closed-set picture pointing paradigm that presents four images on each trial. During each trial, a disyllabic word is presented to the child in the booth through headphones, insert earphones, or a loudspeaker. Children respond by selecting the picture illustrating the word they thought they heard via a touchscreen monitor. Results obtained with the steady-state noise reflect energetic masking, while performance with the competing speech masker provides further information about auditory segregation and informational masking. We are completing the second year of a 5-year grant to refine, validate, and implement this new clinical measure. To date, we have focused on refining the test procedures for efficiency and clinical use. We will soon begin clinical testing at seven clinical sites across the United States, collecting normative data for children with normal hearing and children who are hard of hearing.

Summary

There is a consensus from professional acoustics and audiology organizations that the relatively high levels of background noise present in modern classrooms have a detrimental effect on children’s listening and learning. This knowledge has been translated into the clinic by incorporating measures of speech recognition in noise into the pediatric test battery. These tools play a critical role in assessing and managing hearing loss, informing decisions regarding device candidacy, and implementing classroom accommodations. However, a major limitation of conventional speech-in-noise tests is that sounds other than steady-noise and babble permeate children’s everyday environments. Research has confirmed what teachers, parents, and audiologists have known to be true; children spend the majority of their days listening and learning in the presence of background sounds that are complex and dynamic, such as speech produced by people talking in the background. A new generation of speech-in-speech tools is being developed to address this important gap in clinical practice. Initial research findings indicate that these tools have the potential to capture aspects of children’s functional hearing that conventional speech-in-noise tests do not.

References

1. Hillock-Dunn A, Taylor C, Buss E, and Leibold LJ. Assessing speech perception in children with hearing loss: What conventional clinical tools may miss. Ear Hear 2015;36:e57–e60.
2. Brungart DS. Informational and energetic masking effects in multitalker speech perception. In P. Divenyi (Ed.), Speech Separation by Humans and Machines. New York: Springer; 2005.
3. Ambrose SE, VanDam M, and Moeller MP. Linguistic input, electronic media, and communication outcomes of toddlers with hearing loss. Ear Hear 2014;35:139–47.
4. Carhart R, Tillman TW, and Greetis ES. Perceptual masking in multiple sound backgrounds. J Acoust Soc Am 1969;45:694–703.
5. Freyman RL, Balakrishnan U, and Helfer KS. Effect of number of masking talkers and auditory priming on informational masking in speech recognition. J Acoust Soc Am 2004;115:2246–56.
6. Bregman AS. Auditory Scene Analysis: The perceptual organization of sound. Cambridge, MA: MIT Press; 1990.
7. Bronkhorst AW. The cocktail party phenomenon: A review of research on speech intelligibility in multiple-talker conditions. Acta Acustica United with Acustica 2000;86:117–28.
8. Hall JW III, Grose JH, Buss E, and Dev M. Spondee recognition in a two-talker masker and a speech-shaped noise masker in adults and children. Ear Hear 2002;23:159–65.
9. Corbin NE, Bonino AY, Buss E, and Leibold LJ. Development of open-set word recognition in children: Speech-shaped noise and two-talker speech maskers. Ear Hear 2016;37:55–63.
10. ANSI. ANSI/ASA S12.60-2010 Acoustical Performance Criteria, Design Requirements, and Guidelines for Schools, Part 1: Permanent Schools. American National Standards Institute: New York; 2010.
11. American Speech-Language-Hearing Association. American national standard on classroom acoustics. 2018. Available at: https://www.asha.org/public/hearing/American-National-Standard-on-Classroom-Acoustics/.
12. Concerned About Classrooms Coalition. Concerned About Classrooms Coalition. 2018. 2018. Available at: https://www.sac-oac.ca/sites/default/files/resources/noise%20in%20classroom%20backgrounder.pdf.
13. Crandell C, and Smaldino J. Classroom Acoustics for Children with Normal Hearing and with Hearing Impairment. Lang Speech Hear Serv Schools 2000;31:362–70.
14. Nelson E, Smaldino J, Erler S, and Garstecki D. Background noise levels and reverberation times in old and new elementary school classrooms. J Educ Audiol 2008;14:12–18.
15. Bradley JS. Does the classroom assist or impede the learning process? Canadian Assoc Principals J 2005;13:(1):32–4.
16. Elliott LL, Connors S, Kille E, Levin S, Ball K, and Katz D. Children’s understanding of monosyllabic nouns in quiet and in noise. J Acoust Soc Am 1979;66:12–21.
17. Fallon M, Trehub SE, and Schneider BA. Children’s perception of speech in multitalker babble. J Acoust Soc Am 2000;108:3023–29.
18. Freyman RL, Balakrishnan U, and Helfer KS. Effect of number of masking talkers and auditory priming on informational masking in speech recognition. J Acoust Soc Am 2004;115:2246–56.
19. Moeller MP, and Tomblin JB. An introduction to the outcomes of children with hearing loss study. Ear Hear 2015;36:4S–13S.
20. Hillock-Dunn A, Taylor C, Buss E, and Leibold LJ. Assessing speech perception in children with hearing loss: What conventional clinical tools may miss. Ear Hear 2015;36:e57–e60.

21. Leibold LJ, Hillock-Dunn A, Duncan N, Roush PA, and Buss E. Influence of hearing loss on children's identification of spondee words in a speech-shaped noise or a two-talker masker. Ear Hear 2013; 34: 575-584.
22. Bench J, Kowal A. and Bamford J. The BKB (Bamford-Kowal-Bench) sentence lists for partially-hearing children. Br J Audiol 1979;13:108–112.
23. Nilsson M, Soli SD, and Sullivan JA. Development of the hearing in noise test for the measurement of speech reception thresholds in quiet and in noise. J Acoust Soc Am 1994;95:1085–99.
24. Spahr AJ, Dorman MF, Litvak LM, et al. Development and validation of the Pediatric AzBio sentence lists. Ear Hear 2014;35:418–22.
25. Madell JR. Speech Audiometry in Behavioral evaluation of hearing in infants and young children. Thieme;1998.
26. Carhart R, and Tillman TW.Interaction of competing speech signals with hearing losses. Arch Otolaryngol 1970;91:273–79.
27. Jerger S, Lewis S, Hawkins J, and Jerger J. Pediatric speech intelligibility test. I. Generation of test materials. Int J Ped Otolaryngol 1980;2:217–30.
28. Brown DK, Cameron S, Martin JS, Watson C, and Dillon H. The North American Listening in Spatialized Noise Test (NA LiSN-S): Normative data and test-retest reliability studies for adolescents and young adults. J Am Acad Audiol 2010;21:629–41.