A Critical Review of Remote-Microphone Technology for Children with Normal Hearing and Auditory Differences

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The goal of this review is to provide an overview of published evidence to support the use of remote-microphone, hearing-assistance technology (HAT) in populations of children who have normal pure-tone hearing thresholds but exhibit significantly poorer auditory performance and processing than peers with typical functioning. These populations include children who are diagnosed with Auditory Processing Disorder (APD), Autism Spectrum Disorder (ASD), Attention-Deficit Hyperactivity Disorder (ADHD), Friedreich's Ataxia, Dyslexia, and Language Disorder. Following the review of evidence, an evidence-based protocol will be recommended that may be used to assess and fit HAT to these populations, and a case study will be provided to demonstrate how to implement the recommended assessment and fitting protocols.

Introduction

Published research provides evidence that several populations of children with normal pure-tone hearing thresholds exhibit significantly poorer auditory-processing abilities or speech-recognition performance than peers with typical functioning. These populations include children who are diagnosed with Auditory Processing Disorder (APD), Autism Spectrum Disorder (ASD), Attention-Deficit Hyperactivity Disorder (ADHD), Language Disorder, Friedreich's Ataxia (FRDA), and Dyslexia. The goal of this article is to provide educational audiologists and school personnel research evidence to support the educational hearing needs of these populations. The following sections will (1) provide an overview of the auditory deficits reported for these populations, (2) review published studies that support remote-microphone, hearing-assistance technology (HAT) for these populations (e.g., frequency/digital modulation [FM/DM] systems), and (3) recommend an evidence-based assessment and fitting protocol for HAT on these populations. The fourth and final section of this article will present a case study to demonstrate how the recommended protocols may be used to assess and fit remote-microphone HAT on children with normal hearing and disabilities.

I. Auditory Deficits

There is a large body of evidence to support the presence of auditory deficits in children diagnosed with APD, ASD, ADHD, Language Disorder, FRDA, and Dyslexia relative to peers with typical auditory processing and performance. The goal of this article, however, is to focus on published studies that simulated listening experiences in a noisy classroom, which will provide evidence for educational need for HAT in these populations.

First, given the varied nature of APD, children with this disorder may experience significant difficulties over a wide range of auditory tasks, such as temporal aspects of speech, dichotic listening, and hearing speech in the presence of background noise (Chermak, 2002). More specifically, one study suggested that children with APD showed significantly poorer speech recognition in noise at 0 and +3 signal-to-noise ratios (SNRs) by an average of 10% when compared to a control group without APD (Lagacé, Jutras, Giguére, & Gagné, 2011). Similarly, Muchnik et al. (2004) reported in a study that 12 of the 15 children with APD had speech-in-noise thresholds in at least one ear that were, on average, at least 20% lower and two standard deviations below the age and gender-matched control group. The behavioral deficits reported in the aforementioned studies are well-supported with subjective reports from parents and children regarding their listening and academic difficulties at school relative to peers who reported significantly less difficulty (Johnston, John, Kreisman, Hall, & Crandall, 2009). Additionally, results of this study highlighted the potential for significantly lower psychosocial function (i.e., locus of control, anxiety, depression, attention problems, and interpersonal relationships) in children with APD relative to peers. The underlying mechanisms involved in APD are not well understood. However, some investigators believe APD is associated with abnormalities in the efferent auditory pathway, more specifically, the medial olivocochlear bundle (Mishra, 2014; Muchnik et al., 2004).

Second, children diagnosed with ASD and ADHD also exhibit substantial and similar listening difficulties in background noise (Alcántara, Weisblatt, Moore, & Bolton, 2004; Corbett & Constantine, 2006; Gomez & Condon,1999; Rance, Saunders, Carew, Johansson, & Tan, 2010; Schafer et al., 2013b, 2014b; Tomchek & Dunn, 2007; Updike, 2006). In fact, these two groups are combined or compared in several studies because these children show similar deficits on many tasks including speech recognition in noise, auditory and visual attention, and parent-observed behaivors (Schafer et al., 2013b; Corbett & Constantine, 2006). When examining speech-recognition thresholds at 50% correct levels in children who were high functioning and diagnosed with ASD and/or ADHD as compared to performance of typically-functioning children in a control group, children with the disorders had significantly poorer (higher) thresholds on the order of 2 to 5 dB SNR relative to the control groups (Alcántara et al., 2004; Schafer et al., 2013b). Similarly, in a study specific to children with ADHD and learning disabilities, Gomez and Condon (1999) reported significantly poorer speech recognition in noise composite scores relative to a neurotypical control group of children with ADHD and no learning disabilities. In another study, Rance et al. (2014) reported significantly poorer auditory temporal processing (less sensitive to amplitude variations) and spatial processing (poorer binaural integration) for children with ASD relative to a neurotypical control group. One final study compared performance of children with ASD and ADHD and reported that both groups showed significantly poorer auditory attention in a quiet condition relative to a group of neurotypical children (Corbett & Constantine, 2006).

Behavioral deficits of the children in the ASD and ADHD aforementioned studies are supported by subjective data from the children and parents. First, both children with ASD and ADHD exhibit similar deficits for auditory filtering and sensitivity (Corbett & Constantine, 2006; Gomez & Condon, 1999; Mangeot, Miller, McGrath-Clarke, Simon, & Hagerman, 2001; Tomchek & Dunn, 2007). For example, 58% to 79% of parents reported that their children with ASD were distractible or could not function in noisy environments, were unresponsive to discriminative auditory stimuli, and had difficulty attending to auditory information (Tomchek & Dunn, 2007). Furthermore, another study suggests that the most significant predictor of educational performance is the child's auditory-filtering ability, defined as the ability to hear speech stimuli, complete tasks, and function in the presence of background noise (Ashburner, Rodger, & Ziviani, 2008).

Although the behavioral and observed characteristics of ADHD and ASD are similar, the underlying mechanisms involved in the two disorders are likely different. For example, Brennan and Arnsten (2008) reported structural differences in the prefrontal cortex and its connections to other parts of the brain. The prefrontal cortex is critical to achieving many tasks including sustained attention, behavioral inhibition, divided attention, and allocation of attentional resources; deficits in the prefrontal cortex result in forgetfulness, impulsivity, distractibility, and poor planning. On the other hand, recent research suggests that the multisensory deficits in children with ASD likely result from gene mutations and increased dendritic spine density (i.e., connections between neurons) in the temporal lobe relative to control groups (Tang et al., 2014). The increased number of connections among neurons is predicted to result in increased excitation and overstimulation in children with ASD. Additionally, according to Russo and colleagues, children diagnosed with ASD show abnormal speech-evoked cortical responses in quiet as well as noisy conditions relative to neurotypical peers (Russo, Zecker, Trommer, Chen, & Kraus, 2009).

Third, the presence of language disorders is also of concern because many children diagnosed with APD, ASD, and ADHD exhibit coexisting disabilities with language disorders as one of the most common. In fact, two of the first author's previous studies included several children who were diagnosed with multiple disabilities including ASD, ADHD, and language disorders (Schafer et al. 2013b, 2014b). Given the importance of language processing for completing speech-recognition and comprehension-focused tasks in the classroom, it is critical that HAT be considered for children diagnosed with language disorders, particularly when children are diagnosed with multiple disabilities.

Fourth, FRDA is a rare, neurodegenerative disease that results in steady multisensory decline as well as auditory neuropathy spectrum disorder. In one study highlighting the auditory difficulties in this population, Rance et al. (2014) reported that, on average, children with FRDA had significantly poorer phoneme-recognition scores in noise at a 0-dB SNR by 26% than typically functioning controls. Additionally, the children reported on a subjective questionnaire significantly more difficulty than a control group when communicating as well as in noisy and reverberant environments.

Finally, children diagnosed with Dyslexia often exhibit abnormal phonological processing. In one study, children with dyslexia showed significantly poorer average perception of Vowel-Consonant-Vowel stimuli in noise by 9% correct relative to children of the same chronological age (Ziegler, Pech-Georgel, George, & Lorenzi, 2009). The underlying neurobiological mechanisms associated with Dyslexia are still unknown.

II. Reported Benefits of Remote-Microphone HAT

Table 1 provides an overview of published evidence over the last decade that support the use of FM systems for improving speech recognition in noise and other auditory behaviors in children who are diagnosed with APD, ASD, ADHD, Language Disorder, FRDA, and Dyslexia. In most studies, children used ear-level, open-ear FM system devices designed for children with normal-hearing sensitivity. However, one study utilized body-worn FM systems with earphones. To date, there are not published articles on the digital (i.e., DM) systems for children with normal hearing, which were recently released to the market. Across most of the studies, there is a clear improvement in speech-recognition performance in background noise in conditions with versus without the FM system, with FM gains ranging from 17 to 86% for fixed-intensity stimuli and 6 to 10 dB for adaptive-test stimuli. Several studies also included behavioral tests specific to the population including tests of psychosocial function for children with APD (Johnston et al., 2009), comprehension in noise for children with various disorders (Schafer et al., 2014b), and phonological processing for children with Dyslexia (Hornickel, Zecker, Bradlow, & Kraus, 2012). In addition to behavioral measures, most studies utilized a subjective questionnaire for the child, parent, or teacher. Results of these questionnaires lend strong support for the use of FM systems in order to improve communication, comprehension, attention, and listening abilities, particularly in noisy or reverberant environments. The published evidence provided in the previous two sections may be used as part of the evidence-based assessment described below.

Table 1. Evidence Regarding Benefit of Remote-Microphone Technology in Children with Normal Hearing and Auditory Differences

Disorder; Participants	Authors, Year	Test Measure: Results
APD: • 10 APD • 13 controls	Johnston et al., 2009	1. Sentence recognition in speech-shaped noise at +5 dB SNR: Improved significantly by 10 dB with FM vs. without FM with greater FM benefit for APD vs. control group 2. Parent SIFTER: At baseline, APD significantly worse than controls for 'Academics', but the difference no longer existed for Academics after the FM trial 3. Participant LIFE: Significant benefit of FM over no FM when teacher talking in front of room, teacher talking with back turned, and other students making noise 4. Psychosocial function BASC-2: Improved ratings for locus of control, anxiety, depression, and interpersonal relationships
ASD: • 10 ASD with FM • 10 controls	Rance et al., 2014	1. Word recognition in babble at 0 dB SNR: Average improvement of 17% from no-FM to FM condition for ASD group and 10% improvement for control group 2. Child APHAB: Significantly less difficulty with communication, in noise, and in reverberation 3. Teacher LIFE: Teachers rated FM as "highly beneficial" for each child; FM improved listening/comprehension, classroom behavior, and general attentiveness
ASD/ADHD: • 7 ASD (2 ADHD; 2 APD) • ADHD (2 APD) • 11 controls	Schafer et al., 2013	1. Sentence recognition in babble, decreasing SNRs: Improved significantly by 6 dB over 2 separate test sessions; performance significantly worse than controls with no-FM, but with FM, performance similar to controls 2. Examiner-observed classroom behavior: Significant improvement of on-task behavior with FM vs. no FM 3. Teacher SIFTER: No significant improvements with FM vs. no FM 4. Teacher CHAPS: Significant improvements for noise, quiet, ideal, auditory memory sequencing, and auditory attention span with FM vs. no FM
ASD, ADHD, LD, or SLI • 12 subjects	Schafer et al., 2014	1. Sentence recognition in babble at -5 dB SNR: Right ear FM, left ear FM and bilateral FM significantly better than no-FM condition by an average of 65 to 86% 2. Listening comprehension in classroom noise at -5 dB SNR: Significant improvement with FM vs. no FM on main idea, details, reasoning, vocabulary, and understanding messages subtests 3. Student LIFE-R (n=8) and CHILD (n=7): Significant benefit of FM at school in classroom situations on LIFE; significant benefit of FM at home when in noise and in social situations on the CHILD 4. Parent CHILD: Significant benefit of FM in quiet, in noise, at a distance, in social situations, and for media
ADHD/ADD: • 31 subjects	Updike, 2006	1. Closed-set word recognition in white noise at +4 dB SNR: Average improvement of 34% with FM over no FM 2. Teacher questionnaires: Significant improvement in attention and listening skills
Friedreich Ataxia: • 10 subjects	Rance, 2010	1. Word recognition in babble at 0 dB SNR: Average improvement of 27% from no-FM to FM condition 2. Child APHAB: Significantly less difficulty with communication, in noise, and in reverberation
Dyslexia: • 38 subjects • 19 used FM • 19 controls with Dyslexia	Hornickel et al., 2012	1. Phonological processing and reading: Significant improvements after 1 year trial with FM while controls had no improvements 2. Auditory brainstem response to stop consonants: FM group had significantly improved neural consistency (i.e., repeatability) relative to the control group, particularly in children who showed the greatest gains in phonological awareness

Note. ADHD=Attention-Deficit Hyperactivity Disorder; APD=Auditory Processing Disorder; ASD=Autism Spectrum Disorder; APHAB=Abbreviated Profile of Hearing Aid Benefit; BASC-2=Behavior Assessment System for Children, 2nd edition; CHAPS=Children's Auditory Performance Scale; FM=frequency modulation system; LIFE=Listening Inventory for Education; LD=language disorders; SIFTER=Screening Instrument for Targeting Educational Risk; SLI=Specific Language Impairment; SNR=signal-to-noise ratio.

III. Evidence-Based Assessment and Fitting Protocol for HAT

According to the Individuals with Disabilities Education Act (IDEA, 2004), children with documented disabilities, such as those discussed in this article, may receive special education support when the disability interferes with their education. Additionally, children who are eligible for special education or who qualify under Section 504 services may receive assistive technology, which is defined by IDEA (2004) as any item, piece of equipment or product system, whether acquired commercially off the shelf, modified, or customized, that is used to increase, maintain, or improve the functional capabilities of children with disabilities. Remote-microphone technology, such as FM or digital-transmission (DM) systems, is a form of assistive technology because, as outlined in Table 1, it may be used to increase, maintain, and improve the functional capabilities of children with these disabilities. However, because these are not the typical populations who receive FM/DM systems, such as those with hearing aids or cochlear implants, educational audiologists and other school personnel often must show that the child has “educational need” in order to purchase the assistive technology. According to IDEA (2004), educational need should be determined through a functional evaluation of the child in the child’s customary environment. However, no explanation of the components that should be included in the functional evaluation are provided. As a result, the following section will outline a recommended protocol for determining educational need in children diagnosed with APD, ASD, ADHD, Language Disorder, FRDA, and Dyslexia. This protocol also applies to children with hearing loss, hearing aids, and cochlear implants. The evidence-based protocol was based on methods used successfully in published studies (e.g., Table 1) as well as through clinical and educational audiology experience of the authors. Although, each the following measures has clinical value, the functional evaluation will need to be individualized to meet the needs of each student. The components of the recommended functional evaluation are outlined in Table 2.

When writing a report for a functional evaluation, an audiologist may, first, consider citing peer-reviewed literature related to listening difficulties, poorer speech recognition, and degraded auditory processing in children who are diagnosed with the child’s disorder. Section I and Table 1 in this article may be used to cite degraded performance and to provide evidence that remote-microphone HAT significantly improves behavioral performance and subjective listening abilities of the children in these populations.

Table 2. Recommended Test Measures for a Functional Evaluation for Remote-Microphone Hearing-Assistance Technology (HAT)

Test Measure/Item	Description
1. Cite literature on the population	In report, cite research related to the benefit of HAT in the population under assessment.
2. Cite acoustics research/ measure classroom acoustics	In report, cite research about typical classroom acoustics that do not meet ASHA and ANSI recommendations. Measure classroom acoustics using software apps.
3. Classroom observation and interviews	Observe and document seating location, attention, participation, independence, and on-task/off-task behavior relative to a peer. Interview the child to assess hearing difficulty in class; interview parents to determine concerns.
4. Speech recognition or comprehension in noise	Conduct speech recognition or comprehension measures in soundbooth or child’s classroom with speech and noise loudspeakers spatially separated.
5. Teacher questionnaires	Assess child’s academic performance, communication, and listening behaviors in each academic class with questionnaires.
6. Other evaluations/goals and academic standing	Examine other evaluations and IEP goals to see if HAT could support difficulties found, and examine academic standing.
7. Trial with HAT	Conduct pre/post trial observations, interviews, questionnaires, and speech recognition/comprehension.

Note. ASHA=American Speech-Language-Hearing Association; ANSI=American National Standards Institute; IEP=Individual Education Plan.

Second, the audiologist may consider citing acoustics of typical classrooms (Knecht, Nelson, Whitelaw, & Feth, 2002; Nelson, Smaldino, Erler, & Garstecki, 2007/2008), which do not meet the recommended levels for unoccupied noise or reverberation recommended by the American Speech-Language-Hearing Association (2005; 2010) or the American National Standards Institute (ANSI; 2010). Additionally, Cruckley, Scollie, and Parsa (2011) reported occupied noise levels across different child listening environments including a daycare/toddler room, daycare pre-school, elementary school, and high school where, for 85% of the day, noise levels ranged from approximately 60 to 80 dBA. If the teacher's speech were approximately 64 dBA at a distance of 2 meters (~6.5 feet; Olsen, 1998), the majority of the school day could involve listening at negative SNRs.

Furthermore, because of today's handheld software apps, it is possible to measure classroom acoustics. In an article published in 2012, Ostergren and Smaldino (2012) describe how to measure unoccupied or occupied noise levels as well as reverberation times using one commercially available software app. Screen shots from this software may be saved or emailed in order to incorporate the data into the child's functional evaluation report.

Third, classroom observations may be conducted by the educational audiologist, speech-language pathologist, or special-education personnel to examine the child's seating location, attending behavior, classroom participation, independence on teacher-assigned tasks, and general classroom acoustics. The authors of this article use a form to organize the abovementioned information as well as to record information about the number of teachers and classrooms in which the student is educated, to document use of FM-system technology by other children in the child's school, to chart on-task versus off-task behaviors relative to a typically-functioning peer, and to record information from a student and parent interview regarding hearing abilities and difficulties at school.

Fourth, speech recognition and comprehension in noise measures are particularly useful for identifying hearing difficulties in simulated classroom environments and to examine benefit of remote-microphone HAT by comparing test conditions with and without HAT. To conduct speech recognition measures in the soundbooth or classroom, the examiner will need two loudspeakers (one at 0 degrees and one at 180 degrees azimuth equidistant from child: 3 to 6 feet), a compact disc player, a sound-level meter or acoustics software app to calibrate the signal levels, and a 2-channel speech-in-noise test to allow for spatial separation of speech and noise stimuli and loudspeakers. A critical review of speech-in-noise tests for children may be found in Schafer (2010), but the authors of this article typically utilize the Phrases in Noise Test (PINT) for younger children ages 3 to 5 years and the Bamford-Kowal-Bench Speech-in-Noise (BKB-SIN) test for children ages 6 years and older. The PINT estimates the 50% correct speech-in-noise threshold using 12 closed-set phrases and multi-classroom noise at pre-recorded SNRs (Schafer et al, 2012a, 2012b). The stimuli, recorded on a CD, may be repeated or acted out with a doll and objects (e.g., brush his teeth; comb his hair). The BKB-SIN standard or split-track (i.e., 2 channel) CD consists of open-set sentences in the presence of multi-talker babble presented at pre-recorded SNRs (Etymotic Research, 2005). The authors typically use the split-track CD to allow for testing with the remote-microphone technology, which would require spatial separation of the speech and noise loudspeakers (i.e., 0 and 180 degrees, respectively). Normative data from the PINT and BKB-SIN test manuals may be used to identify when children have significantly poorer performance than typically-functioning peers and to determine any significant improvement in speech recognition when using a FM/DM system relative to the unaided condition.

Recent studies showed that children with normal hearing have significantly poorer auditory comprehension (e.g., answering questions about story content) relative to speech recognition (e.g., repeating sentences) in conditions with the same SNR and level of reverberation (Schafer et al., 2013a; Valente, Plevinsky, Franco, Heinrichs-Graham, & Lewis, 2012). Comprehension, a higher auditory-skill level than recognition, is difficult for children because it requires a combination of recognition, cognition, attention, and working memory. Unfortunately, there are few, if any, recorded comprehension-based measures that are available for use in the clinic or classroom. However, the authors of this study have utilized the Listening Test 2 (Bowers, Huisingh, & LoGiudice, 2006) as well as the Ross Information Processing Assessment – Primary (RIPA-P; Ross-Swain, 1999) to examine the child's ability to comprehend auditory-only information. The Listening Test 2 consists of a series of stories, increasing in length, each of which are followed by questions about the story's main idea, details, vocabulary, reasoning, and understanding of the entire message. In a previous study (Schafer et al., 2013a), the authors of this study recorded the speech stimuli in this test using acoustic software on Channel 1 of a CD, and added classroom noise from the PINT to Channel 2 of the CD. Although this recorded version is not commercially available, audiologist may consider presenting the speech stimuli using live voice. Using the live-voice presentation mode, children could be tested in a quiet versus a fixed-intensity noise condition (e.g., speech-shaped noise from the audiometer or recorded multi-talker babble from the split-track BKB-SIN CD) or noise conditions with and without a FM/DM system. In a current study, the authors of this manuscript are using two sections of the RIPA-P to assess comprehension and auditory memory. The first subtest, Immediate Memory, requires participants to repeat digits, words, and sentences that increase in length and complexity. The second subtest, Recent Recall, requires participants to recall and provide verbal information about their environment and recent activities. Again, the RIPA is not recorded, but may be presented live voice and in the presence of noise.

Fifth, teacher questionnaires may be utilized to document auditory-listening, communication, and academic difficulties in the classroom relative to typically-functioning peers. The American Academy of Audiology (AAA, 2008) has an excellent resource that outlines functional outcome questionnaires for children. In the authors' experience, three questionnaires are particularly helpful for assessing children in the schools and include the Screening Instrument for Targeting Educational Risk (S.I.F.T.E.R.; Anderson, 1989), the Children's Auditory Performance Scale (C.H.A.P.S.; Smoski, Brunt, & Tannahill, 1998), and the Listening Inventory for Education – Revised (L.I.F.E.-R) for the teacher (Anderson, Smaldino, & Spangler, 2012). Each of these questionnaires provides normative data to suggest when a child has educational risk, listening problems, or auditory processing differences when compared to classmates. If the audiologist plans to assess listening difficulties in the home environment, the examiners often use the parent and child versions of the Children's Home Inventory for Listening Difficulty (C.H.I.L.D.; Anderson & Smaldino, 2011)

Sixth, when possible, educational audiologists or other school personnel may examine Individual Education Plan (IEP) goals and objectives as well as reports from other professionals to examine areas of difficulty. For example, many speech-language tests include subtests focusing on listening comprehension (e.g., following multi-step directions), which is often negatively affected in children diagnosed with ASD, language disorders, and sometimes APD. Additionally, the educational psychologist or diagnostician may administer intelligence tests that consist of verbal and non-verbal sections. In a child with a language disorder or listening difficulties, the verbal section likely will be substantially poorer than the non-verbal section.

Finally, when time and equipment permits, the audiologist may consider a four- to six-week trial period with remote-microphone HAT. The trial will also require a HAT fitting (described below) as well as teacher and school personnel training regarding appropriate use of the HAT during teacher-led instruction, group situations with a pass around microphone, and therapy situations. In the authors' opinions, there are some times during a school day where the child may not use HAT, such as on the playground, during P.E., and during lunch. Several of the measures listed in Table 2 can be repeated after the trial period including the classroom observations and interviews, speech recognition/comprehension, and teacher questionnaires. Additionally, the audiologist may want to interview other school personnel, such as the speech-language pathologist, occupational therapist, or teacher's aide, who use the HAT during the trial period.

After completing a previous study on children with ASD (Schafer et al., 2013b), the first author of this article realized the importance of individualizing the HAT fitting to each child, rather than choosing the manufacturer default volume setting, because several children reported that they would prefer a softer or louder signal from the FM system. We attributed these reports, in part, to the 30-dB range of normal hearing (i.e., -5 to 25 dB HL) for many school hearing screenings and the different size of children's ear canals. As a result, a step-by-step fitting protocol was developed and tested in typically-developing children with normal hearing (Schafer et al, 2014a) as well as in children diagnosed with various disorders (Schafer et al., 2014b) using the AAA recommendations (2008) as a guide. The four steps to the recommended fitting using the Audioscan Verifit are outlined in Table 3. Prior to the fitting, the audiologist will need to conduct an otoscopic exam and a behavioral hearing test. Also, the audiologist may consider determining the real-ear-to-coupler difference with foam insert earphone (ER-3A) to account for the difference between the 2-cc coupler and the child's ear, which is likely smaller. Otherwise, estimated age-related RECDs may be selected on the Verifit. In the previous investigations, the authors used estimated RECDs (Schafer et al., 2014a, 2014b) given the expected variability of RECDs with the open fittings.

Table 3. Recommended Real-Ear Measures for fitting Hearing Assistance Technology (HAT) on Children with Normal Hearing

Measurement	Description
1. Meet DSL v5 Target	On Verifit, select 'FM' as instrument and 'On-ear' as mode; present Speech-std[1] passage at 65 dB SPL. Inspect visually, and adjust FM/DM volume or gain to meet DSL target at 1, 2, and 4 kHz.
2. Measure MPO	Use same Verifit settings, but change stimulus to MPO. Inspect visually to ensure estimated uncomfortable loudness level not exceeded.
3. Measure REOR	Change instrument to 'Open' and mute transmitter. Present Speech-std[1] passage at 65 dB SPL.
4. Measure REUR	Remove the FM/DM receiver from ear, but leave probe in ear. Repeat presentation of Speech-std[1] passage at 65 dB SPL. Compare REOR to REUR to determine change in ear canal resonance.

Note. DSL=Desired Sensation Level v5; FM=frequency modulation system; DM=digital modulation system; MPO=maximum power output; REOR=real ear occlusion response; REUR=real ear unaided response; SPL=sound pressure level.

In Measurement 1, the goal is to meet the Desired Sensation Level v5 (Scollie et al., 2005) child prescriptive targets. To do this, the child's hearing thresholds are entered into the Verifit, the active transmitter microphone is placed in the Verifit sound chamber, and the probe microphone is placed in the ear canal along with the open-fit FM/DM receiver. With the Verifit set to 'FM' as the instrument and 'On-ear' as the mode, a 65 dB SPL speech input is then presented to the transmitter microphone. The examiner will, then, inspect the output on the Verifit screen and adjust the volume of the FM/DM receiver (often with the FM/DM transmitter), if necessary, to match the DSL v5 target as closely as possible for 1000, 2000, and 4000 Hz.

The second measurement will ensure that the maximum power output (MPO) does not exceed the estimated uncomfortable loudness level (UCL), which is predicted based on the child's thresholds and plotted on the Verifit screen. The settings for this measurement are the same as those used for Measurement 1, but the stimulus is changed to MPO. The examiner will visually inspect the output of the FM receiver to ensure the estimated UCL is not exceeded.

The third and fourth measurement are conducted to determine any changes in the unaided ear canal resonance from the placement of the receiver in the ear. Prior to this measure, the FM transmitter is turned off or muted, and the Verifit instrument is changed to 'Open'. The stimulus for both measurements is a 65 dB SPL speech input. Measurement 3 determines the Real Ear Occlusion Response (REOR) by leaving the FM/DM receiver on the ear (muted). Measurement 4, however, determines the Real Ear Unaided Response (REUR) by removing the FM/DM receiver with the probe microphone still in the ear. If the dome or method used to couple the FM/DM receiver to the ear causes a large change in the ear canal resonance (i.e., > 5 dB), particularly at 1000, 2000, and 4000 Hz, the audiologist may see other, more open, coupling methods (i.e., smaller dome) for the receiver.

Of course, not every child will participate in the fitting procedures, and in these cases the authors have adopted several procedures. First, if a behavioral hearing test cannot be obtained, we attempt to conduct distortion product otoacoustic emissions (OAE) to confirm normal outer hair cell function. Second, if a child cannot tolerate OAEs, the authors interview the parents regarding hearing responsiveness and previous hearing testing. If hearing thresholds must be estimated for the fitting procedures, the authors recommend very conservative 10 dB HL thresholds. Next, if children will not tolerate the real-ear fitting, the authors estimate the appropriate setting, at least for the Phonak iSense and Focus, at a +6 volume setting, which was the average volume setting necessary to meet DSL v5 targets in the Schafer et al. (2014a, 2014b) studies and in current research with the Focus. Future research will need to be conducted to examine settings for other products. Additionally, future research will need to more closely examine potential benefits of FM/DM classroom soundfield systems (loudspeaker) as well as less expensive, personal, body-worn FM systems coupled to children with earphones and earbuds.

III. Case Study

The following case study demonstrates how the abovementioned evidence-based assessment and fitting protocols may be utilized with a child who has normal hearing but exhibits substantial listening difficulties in noise and in the classroom.

Cheri is a 9-year-old girl who was referred for an assistive-technology evaluation following a request by her mother who was interested in determining the potential benefit of a FM system for use at school and at home. At the time of the evaluation, Cheri was diagnosed with ADHD, ASD, Language Disorder, and Intellectual Disability, and she had normal hearing from 250 to 8000 Hz according to pure-tone audiometry. During a parent interview, her mother reported that Cheri has poor grades as well as a difficult time listening and understanding, conversing with others, following directions at school, and attending at school. She frequently needs re-direction to complete a task. For the assessment, the educational audiologist decided to conduct behavioral testing in her soundbooth and to administer questionnaires before and after a six-week trial period with a bilateral open-fit FM system (Phonak iSense micro; inspiro).

Prior to the trial period, the system was fit using the abovementioned real-ear protocol (Table 3). For real-ear measurements 1 and 2, the audiologist was able to achieve FM output that was within 2 dB SPL of DSL v5 target, and according to the MPO, the estimated UCL was not exceeded for any frequency. Measurements 3 and 4 revealed minimal (3 dB) changes to the REUR when the receiver was in place (REOR) for 1000 through 4000 Hz.

Pre-post speech-recognition performance in noise, using fixed-intensity BKB-SIN at a -5 dB SNR, revealed a substantial increase in performance from 0% key-words correct with no FM to 70% key-words correct with bilateral FM. The Listening Test 2 was attempted, but she was unable to reliably complete the task in the no-FM or FM-system condition. The teacher C.H.A.P.S. reveled an average improvement from the at-risk to the normal range in noise (i.e., average noise score of -2 to 1), and the teacher L.I.F.E.-R indicated an average improvement from 39 (i.e., sometimes experiences listening challenges) with no FM to 59 (i.e., occasional listening challenges) with the FM system. Although the child's responses were somewhat unreliable on the student version of the L.I.F.E., average scores increased from 48 without the FM (i.e., sometimes experiences listening challenges) to 85 with the FM system (i.e., no listening challenges or very rare). Based on FM-system use in the home, the parent rated each situation on the C.H.I.L.D. questionnaire (i.e., quiet, noise, distance, social, and media) as better when Cheri was using the FM system versus when it was not used. Finally, the mother used a journal during the trial period to document situations where the systems was helpful or not helpful. Specific comments from the beginning to the end of the journal and trial period outlined in Table 4.

Using the recommended measures outlined in Table 2, the audiologist wrote a report that (1) cited literature and described the hearing difficulties of children diagnosed with ASD and ADHD; (2) outlined the impact of poor acoustics in typical classrooms; (3) explained the child's listening difficulties, which were described by the mother during the initial interview; (4) described the substantial improvements in speech recognition with the FM system and attempted comprehension testing; (5) reported the positive subjective FM-system ratings on the student, teacher, and parent questionnaires, and (6) provided the student's current academic standing in her courses. The test measures and citations used to assess the hearing needs of this child provide a clear picture of her functional performance in the customary listening environment, which in this case was at school and at home. Incorporation of the pre-post measures and the trial period allowed the audiologist to document and report degraded performance without the FM system at home and at school and substantially improved performance with the FM system in these same environments.

Conclusions

As discussed in Section 1 of this article, there are numerous peer-reviewed publications that reported significantly poorer speech recognition in noise, auditory processing (behavioral and electrophysiological), classroom performance, and overall listening abilities in children diagnosed with APD, ASD, ADHD, Language Disorder, FRDA, and Dyslexia. Educational audiologists have the opportunity to improve auditory performance in these populations by recommending the use of remote-microphone HAT, which is well-supported in the literature (Table 1). However, recommendations for HAT in these populations may be hindered by budgetary constraints or because the audiologist must document educational need for the HAT. As a result, the authors of this article provided recommendations for conducting an evidence-based assessment (Section III; Table 2) for HAT, which is intended to aid audiologists in obtaining the financial support necessary to purchase the equipment. Additionally, a step-by-step HAT fitting protocol was reviewed to standardize remote-microphone fittings these populations with normal hearing (Section III; Table 3). Finally, the case study provides a concrete example of how the recommended assessment and fitting protocols may be used with a child who is being assessed for remote-microphone HAT.

Table 4. Progression of Parent Journaling During a 6-Week FM-System Trial Period

1. She loved it and seemed more confident with it.
2. Her responses were quick without explanations and fewer questions.
3. She asked to wear the system.
4. She wore it in the car today, and her answers were quick; she seems less confused.
5. She wore it while playing with a friend and responded even when involved in play.
6. She wore it in a noisy lobby and answered me from across the room with a big smile. In the car, conversations were direct without confusion.
7. Still seeing a lot of quick and direct responses.
8. She does not like wearing it in the heat.
9. She is hearing and responding great in noisy places, even with kids crying next to her.
10. Wore system at mall; she was very responsive.
11. She had two friends sleep over, and there was a lot of activity and noise from 4 girls. She was hearing and responding to my statements.
12. The teacher told me that she thought the system was helping.
13. I am excited the system is helping my daughter. I would like the microphone to be wireless and for the earpieces to be labeled blue or red.

Note. Some journal entries were paraphrased.

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