Use of Wireless Technology for Children with Auditory Processing Disorders, Attention-Deficit Hyperactivity Disorder, and Language Disorders

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ABSTRACT

There are several populations of children who have normal hearing but exhibit auditory listening difficulties in the classroom. Recent publications will be reviewed to support the use of wireless, remote microphone technology for improving speech-recognition performance in noise and classroom-listening abilities in children diagnosed with auditory processing disorders (APDs), attention-deficit hyperactivity disorder (ADHD), and autism spectrum disorders (ASDs). In addition, a series of case studies on children diagnosed with APDs, ADHD, ASDs, and/or language disorders will be presented to (1) support specific remote microphone-fitting procedures and (2) to report speech-recognition performance in noise; listening comprehension; and participant-, parent-, and teacher-rated listening behaviors following a trial period with the technology. The results of these case studies will validate fitting procedures for these populations with auditory listening difficulties and will provide additional, evidence-based support for the use of remote microphone technology for children diagnosed with APDs, ADHD, ASDs, and/or language disorders.

KEYWORDS: Remote microphone technology, normal hearing, autism, auditory processing, attention deficit

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Learning Outcomes: As a result of this activity, the participant will be able to (1) list three normal hearing populations of children who may benefit from personal wireless, remote microphone technology and (2) describe the steps involved in fitting wireless, remote microphone technology to children diagnosed with auditory processing disorders, attention-deficit hyperactivity disorder, and autism spectrum disorders, and/or language disorders.

The acoustics of typical classrooms do not meet the recommendations from the American Speech-Language-Hearing Association[1] or the American National Standards Institute. Typical classrooms pose significant listening challenges for all children regardless of hearing status.[2–5] Poor classroom acoustics are particularly concerning because numerous studies suggest that speech-recognition performance of children with normal hearing is severely influenced by typical classroom noise and reverberation levels.[6–9] For example, to obtain 95% correct speech-recognition performance, a signal-to-noise ratio (SNR) of +10 to +20 dB was required for children who were 6 to 12 years old and had normal hearing; however, this SNR is inaccessible in typical classrooms, which are reported to have 0- to +5-dB SNRs.[3,7,10] When compared to speech-recognition performance, the presence of noise and reverberation has an even greater effect on children's listening comprehension.[11] More specifically, when 8- and 11-year-old children with normal hearing were tested at a +7-dB SNR with a long reverberation time of 1.5 seconds, the average speech-recognition score was ~95% and the average discussion-based comprehension score was ~15%. Therefore, children's auditory performance is negatively affected by increasing noise and reverberation levels as well as more complex auditory tasks, such as listening comprehension.

Speech recognition and listening comprehension in background noise may be even more affected by the presence of certain disabilities, such as an auditory processing disorder (APD), Friedreich ataxia (FRDA), autism spectrum disorder (ASD), and attention-deficit hyperactivity disorder (ADHD).[12–14] Studies that examined speech-recognition performance in background noise found significantly poorer performance for the children with the aforementioned disabilities as compared to typically functioning peers, despite the fact that both groups had normal pure tone hearing thresholds. For example, Lagacé et al reported that children with APD had significantly poorer speech-recognition scores across −3-, 0-, +3-, and +4-dB SNRs for low-predictability and high-predictability sentences in the presence of background noise.[12] In a pediatric study on children with FRDA, a neurodegenerative disease resulting in multisensory decline, the authors reported average phoneme-recognition scores in noise (0-dB SNR) of 56% for children with FRDA and 82% for typically functioning controls.[13] Finally, in a study including children with ADHD and ASD, the children with the disorders had significantly poorer speech-in-noise thresholds of −5-dB SNR when compared with the −10-dB SNR thresholds of age and gender-matched peers.[14]

Fortunately, use of remote microphone technology, such as frequency-modulated (FM) systems, significantly improves auditory performance of children with these disabilities, often to the level of their typically functioning peers.[13–17] More specifically, two studies on children with APD reported that, relative to a control group and to their own unaided conditions, use of FM systems by children with APD resulted in significantly improved academic performance, sentence recall, psychosocial behavior, phonological awareness, and speech-recognition performance in noise.[15,17] In one study, children's average sentence thresholds in noise improved significantly from +6 dB in the unaided condition to −4 dB in the FM system condition, which suggests that these children could obtain 50% of sentences correct in a negative SNR when using the FM system.[15] Additionally, participants with APD showed significant improvements in academic performance and psychosocial function following the trial with the FM system. In a study on children with FRDA, the authors reported a significant improvement in speech-recognition performance in noise of 25 percentage points with FM systems relative to the unaided condition.[13] Similarly, children with ASD and ADHD significantly improved their average speech-in-noise thresholds from −5-dB SNR in the unaided condition to −11-dB SNR in the FM system condition, which was equivalent to the no-FM system performance of the typically functioning controls.[14] In addition, use of the FM system during a trial period resulted in significantly improved teacher-rated and investigator-observed behavior in the classroom.

The reported benefits of remote microphone technology for children diagnosed with APD, FRDA, ASD, and ADHD are an important milestone for managing the audiological needs of these children. However, questions remain regarding the audiological management of these populations of children. First, how should remote microphone technology be fit and verified on children with normal hearing but with abnormal auditory functioning? Second, how can the potential benefit of remote microphone technology be determined in normal-hearing children with significant cognitive challenges? Finally, can remote microphone technology be beneficial for normal-hearing children with milder disabilities, such as expressive and receptive language impairments? The primary goal of this investigation was to begin to answer these questions through this pilot study on normal-hearing children diagnosed with various disabilities.

METHODS

The fitting, verification, and test procedures in the present study were modeled from a previous study that assessed the validity of the American Academy of Audiology (AAA) guidelines fitting and verifying nonoccluding open-ear FM systems on children with normal hearing.[18,19] In addition, data collected in the present study were compared to a previous study on listening comprehension in noise of children with normal hearing and typical functioning.[20]

Participants

The participants in the study included 12 children, ages 6 to 11 years (mean = 9;5; standard deviation [SD] = 1;5), with normal hearing as determined with pure tone thresholds of less than 20-dB hearing level (HL) from 250 to 6000 Hz. One child could not complete an entire hearing test reliably, but he passed a transient otoacoustic emissions screening. As shown in Table 1, children were identified with various disabilities including the primary disabilities of APD ($n = 2$) or teacher-reported listening problems ($n = 1$), ADHD ($n = 1$), ASD ($n = 4$), or language impairment ($n = 4$). Children's disabilities/diagnoses were reported by the parents on case history forms; all official diagnoses were determined by licensed professionals. According to the case histories, the children had no chronic ear conditions or surgeries. Results of the assessments used by the licensed professionals to determine each child's disability/disabilities were often not accessible to the investigators.

Table 1 Overview of Subject Demographics and FM System Volume

Subject	Age (y; mo)	Disorder	FM Volume: Right	FM Volume: Left
1	8; 10	APD	−2	−2
2	10; 7	APD	8	8
3	8; 0	Teacher-reported listening problems	6	6
4	11; 11	ADHD, LD	6	8
5	9; 6	ASD, SLI	8	8
6	9; 3	ASD, APD, SLI	6	6
7	10; 5	ASD, APD, SLI	8	8
8	9; 5	ASD, ID, ADHD, SLI	2	0
9	8; 11	SLI	0	0
10	6; 4	SLI, APD, ADHD	2	2
11	10; 2	SLI	8	6
12	11; 3	SLI	6	6

Abbreviations: ADHD, attention-deficit hyperactivity disorder; APD, auditory processing disorder; ASD, auditory spectrum disorder; FM, frequency modulation; ID, intellectual disability; LD, language disorder; SLI, specific language impairment.

We attempted to include an additional child, who was lower functioning and had ASD, but he would not tolerate inserts or headphones for the hearing test or otoacoustic emissions or the FM receivers placed on his ear. Therefore, it is important for the reader to note that some children with severe disabilities may not tolerate audiological intervention, making individual FM system assessments critical for determining the appropriateness and potential benefit of the device.

FM Systems and Equipment

All participants were fitted with bilateral Phonak iSense Micro (Phonak, Zurich, Switzerland) FM receivers with Standard xReceivers and small domes, which is a new and smaller (i.e., smaller wire and open dome) option for coupling to the iSense Micro that was not originally released on the market. When in use, the FM receivers were synched to an inspiro transmitter.

Real-ear probe microphone measures were used in the fitting of the FM system (Audioscan, Verifit, Dorchester, Ontario). All behavioral test measures were conducted in a double-walled sound booth, and stimuli were presented with a clinical audiometer (GSI61, Eden Prairie, MN), two compact disc (CD) players (Sony 5-CD Changer; Sony CD-Radio-Cassette-Corder CFD-ZW755; Sony, Minato, Tokyo), and four head-level, single-coned loudspeakers (2 Grason Stadler Standard; 2 Sony CFD-ZW755). The participant was seated in a calibrated location in the sound booth with a signal loudspeaker located at 0 degrees azimuth and three noise loudspeakers located at 90, 180, and 270 degrees azimuth. This test arrangement was intended to simulate listening in a noisy classroom and was used in a previous investigation on peers with typical functioning.[18] The intensities of the test stimuli were determined with a sound-level meter (Larson-Davis 824, Depew, NY).

Test Stimuli and Questionnaires

SPEECH RECOGNITION IN NOISE

The Bamford-Kowal-Bench Speech-in-Noise (BKB-SIN) sentences and multitalker babble on CD were used.[21] The fixed-intensity sentence stimuli were presented at 60 decibels with A-weighting (dBA) and fixed-intensity uncorrelated babble was presented at 65 dBA from the three noise loudspeakers, all measured at the location of the participant's head. These signal levels are not uncommon in typical classrooms with occupied noise levels ranging from 56 to 76 dBA.[22]

LOUDNESS RATINGS

Children were asked to rate the loudness of a randomly selected list of fixed-intensity, BKB-SIN sentences (60 dBA) in the presence of fixed-intensity multitalker babble (55 dBA). Speech stimuli were presented from a loudspeaker located at 0 degrees azimuth while noise was presented from a loudspeaker located at 180 degrees azimuth. During testing, children were given a loudness scale, which was developed in a previous investigation, and were asked to point to the loudness level of the man's speech after listening to four BKB-SIN sentences at a +5 SNR.[18]

LISTENING COMPREHENSION IN NOISE

The children's listening comprehension in noise was determined with an investigator-recorded version of The Listening Comprehension Test 2 (Linguisystems, East Moline, IL) in the presence of continuous four-classroom noise.[8,20,23,24] The speech and noise stimuli were equated for the average RMS. The Listening Comprehension Test 2 stimuli include 25 stories with three to four associated questions per story. The associated questions assess a specific listening behavior or skill within one of five subtests: (1) main idea: identifying the primary topic; (2) details: recalling one or more details; (3) reasoning: inferring answers; (4) vocabulary: defining a specific word; (5) understanding messages: extracting the most important information and answering questions. Speech stimuli were presented at 60 dBA from the signal speaker located at 0 degrees azimuth while the multi-classroom noise was presented at 65 dBA (−5 SNR) from the noise speakers located at 90, 180, and 270 degrees azimuth. Raw scores were calculated for each subtest and compared with the mean and raw scores from the Examiner's

Manual, which also provides additional details about the test.[23]

QUESTIONNAIRES

The parents and participants completed the family member and child versions of the Children's Home Inventory for Listening Difficulty (C.H.I.L.D.).[25] The C.H.I.L.D. included 15 items related to hearing in quiet, media, social situations, noise, and at a distance. A number and modifier was assigned to each item on the scale relating to hearing ability, which ranged from "great" (rating of 8) to "huh?" (rating of 1). In addition, if possible, the participants and teachers completed the Listening Inventory for Education-Revised (L.I.F.E.-R.), which consisted of 15 questions related to hearing and understanding in classroom-based situations along with photos of these situations.[26,27] The modifiers on the L.I.F.E.-R. Student Appraisal of Listening Difficulty questionnaire completed by the child range from "always easy" to "always difficult."[26] The modifiers on the L.I.F.E.-R. Teacher Appraisal of Listening Difficulty questionnaire completed by the teacher range from "no challenge or very rare" to "almost always challenged."[27] Classroom teachers also were asked to complete the Children's Auditory Performance Scale (C.H.A.P.S.), which is a 36-item questionnaire designed to examine the listening difficulties of a child compared with age-matched, typically functioning peers.[28] Rating modifiers range from "less difficulty" (rating of +1) to "cannot function at all" (rating of −5). The six listening conditions on the C.H.A.P.S. include: noise, quiet, ideal, multiple inputs (i.e., auditory, visual, tactile), auditory memory (i.e., recalling spoken information), and auditory attention span.

Procedures

The investigators attempted to utilize the same fitting and test procedures with all participants including the (1) FM system fitting; (2) behavioral test measures; (3) FM system trial period; and (4) pre- and postprocedure child, parent, and teacher questionnaires. Prior to participation, an informed consent form was signed by a parent, and children who were 7 years of age or older completed an assent form. Additionally, parents completed a case history form, and children received a hearing test via traditional pure tone, air-conduction test procedures or otoacoustic emissions. Testing was conducted over two test sessions.

FM SYSTEM FITTING

In the first session, children participated in the real-ear fitting and verification procedures modeled from a previous investigation where the AAA recommendations for fitting FM systems were validated for children with normal hearing.[18] In the present investigation, the investigators aimed to determine if these same procedures are appropriate for children with normal hearing, but with various disabilities (APD, ADHD, ASD, language disorders). The goals of the proposed fitting procedures were for the FM system to (1) meet the Desired Sensation Level (DSL) v5 prescriptive targets and (2) to verify that output from the FM receiver did not exceed the maximum power output (MPO) recommendations generated by the DSL software (i.e., estimated uncomfortable loudness level [UCL]).[29] Although the AAA procedures recommend testing MPO at full volume, this was not done because this FM receiver is preprogrammed by the audiologist and cannot be adjusted by the child.[18] Our previous investigation also examined the effects of occluding the children's ears from the placement of the FM receiver and open dome.[18] The results in this previous study suggested minimal changes in the real-ear response from the FM receiver; therefore, this procedure was not conducted in the present study.

To begin the real-ear probe microphone measurements, the child's chronological age was selected, hearing thresholds were entered for each ear, and DSL was selected as the target. "On-ear" was selected as the mode, and "FM" was selected as the instrument. For the first measurement, the probe microphone was placed in the child's ear, the FM receiver was placed on the ear, and the transmitter microphone was placed inside the sound chamber. While using a real-speech input appropriate for a chest-level transmitter microphone (i.e., 84-dB sound pressure level [SPL]), the output from the FM receiver was measured at 1000, 2000, 3000, and 4000 Hz. If the DSL targets at 1000, 2000, 3000, and 4000 Hz were not met, the volume of the FM receiver was adjusted with the inspiro transmitter. This procedure was repeated until the targets were approximated at 1000, 2000, 3000, and 4000 Hz. For the second real-ear measurement, the previously described settings were maintained, but "MPO" was selected as the stimulus instead of the standard speech signal. The investigator examined the MPO to determine whether the output exceeded the estimated UCL provided on the probe microphone measurement screen.

BEHAVIORAL TEST MEASURES

After the fitting in the first session, the examiners attempted to assess the children's speech-recognition performance at a −5-dB SNR with four randomly selected BKB-SIN list pairs (16 sentences) in four randomized test conditions: no FM system, FM receiver on the right ear, FM receiver on the left ear, and bilateral FM receivers. In the FM system conditions, the transmitter microphone was directly in front (6 inches) of the signal speaker. The goal of the FM system conditions was to determine if there was better performance with one or two FM receivers. The examiners scored each list pair for the percentage of key words correctly repeated.

Following the completion of a particular speech-recognition condition, participants were asked to rate the loudness of four BKB-SIN sentences at a +5 SNR from another randomly selected BKB-SIN list pair. A loudness rating was determined for the same four randomized test conditions used to assess speech recognition.

In the final behavioral test measure, participants who were able were asked to complete The Listening Comprehension Test 2 in a randomly ordered no-FM and FM system condition. One condition was completed in each of the two test sessions. In the FM system condition, children wore bilateral FM receivers, and the FM transmitter microphone was placed on a stand, 6 inches from the signal speaker.

FM SYSTEM TRIAL PERIOD

Children were asked to use the FM system for at least 2 hours a day during a 4- to 6-week, home- or school-based trial period. Parents and children were given a verbal and written (handouts) orientation on use, care, and troubleshooting the system, and additional instruction handouts were provided for teachers.

QUESTIONNAIRES

Parents, children, and teachers were asked to complete the questionnaires before and after the trial period to represent a no-FM system and FM system listening condition. Questionnaires were compared for the two conditions to determine the presence of subjective benefit from the FM system.

RESULTS

FM System Fitting

The FM system fitting and real-ear measures were achieved in all 12 participants (24 ears). In the first real-ear measurement, the volume of the FM receiver was adjusted using the inspiro transmitter so that the output of the FM receiver would approximate DSL targets for each ear at 1000, 2000, 3000, and 4000 Hz. The investigators used conservative pure tone threshold estimates of 10-dB HL across all frequencies for the participant (no. 7) who could not complete the traditional screening and received an OAE screening. As shown in Table 1, the average FM-receiver volume level necessary to achieve DSL targets was 4.8 (SD = 3.5) out of a total range from −8 to +8, which not only suggests the need for individualized settings across the children's ears but also that the default volume of 0 was not appropriate for all ears. Most children required the same volume levels between ears, but three children needed volume levels between ears that differed by two volume units. The volume level necessary to approximate DSL targets was strongly correlated ($r = 0.67$) with the age of the child.

The average DSL targets and average outputs measured for 1000 to 4000 Hz in the 24 ears are shown in Fig. 1. To determine if the outputs, after the volume adjustments, differed significantly from the DSL targets, a two-way, repeated-measures analysis of variance (RM ANOVA) was conducted with the independent variables of output type (measured; target) and frequency (1000 to 4000 Hz). The statistical analysis revealed no significant main effect of output type ($F[1,192] = 0.90$, $p = 0.35$), a

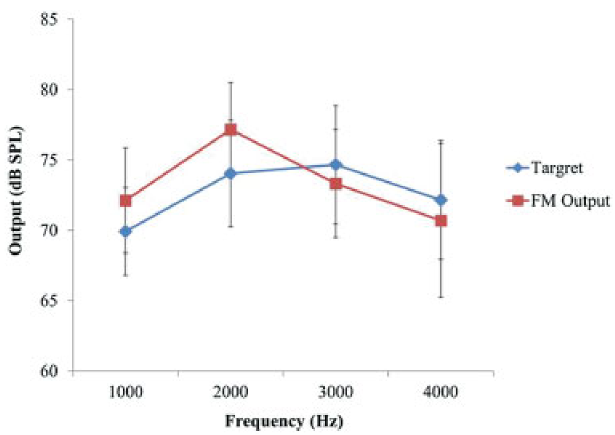

Figure 1 Average Desired Sensation Level output targets and average measured output in the 24 ears from 1000 to 4000 Hz. Vertical lines represent one standard deviation. Abbreviations: SPL, sound pressure level; FM, frequency-modulated system.

significant main effect of frequency ($F[3,192] = 47.9$, $p < 0.00001$), and a significant interaction effect between frequency and output type ($F[3,192] = 9.8$, $p = 0.00002$). As a result, there was no significant difference between the DSL targets and the measured output. The significant main effect of frequency was not meaningful in the analysis because differences in targets and outputs would be expected across the frequencies. Conversely, the interaction effect between frequency and output type suggested that the targets were significantly different from the measured outputs at certain frequencies. According to a post hoc Tukey-Kramer multiple-comparison test, the targets were not significantly different from measured outputs at 1000, 3000, and 4000 Hz, but on average, measured output (77-dB SPL) at 2000 Hz was significantly higher than the DSL target (74-dB SPL). In summary, target DSL output was met on average or slightly exceeded (by 3 dB).

The examiners visually compared the MPO output in the second real-ear measurement to the estimated UCLs across the frequency range from 250 to 6000 Hz. According to this comparison, the MPO never exceeded and was often substantially lower than the estimated UCL curve from the DSL software for frequencies ranging from 250 to 6000 Hz bilaterally in all ears. Because the estimated UCL was never exceeded, these data were not analyzed statistically.

Behavioral Test Results

Despite the fact that all children were able to tolerate wearing the bilateral FM receivers, some children could not complete the behavioral test measures because of their various disabilities and levels of cognitive functioning. Group data from the participants who could complete the testing will be provided for each measure as well as some individual analyses across disorder-specific groups.

SPEECH RECOGNITION IN NOISE

Average speech-recognition performance in noise at a −5 SNR for 10 of the 12 participants is shown in Fig. 2. Subjects 5 and 7, both diagnosed with ASD, were not able to complete the task. A two-way RM ANOVA revealed a significant main effect of condition ($F[3,40] = 54.3$, $p < 0.00001$). The post hoc analysis suggested that all three FM system conditions resulted in significantly better performance ($p < 0.05$) than the no-FM condition, with no significant differences ($p > 0.05$) among the remaining FM conditions. When examining the individual data, every child had better performance in all FM conditions relative to the no-FM condition, with benefit (i.e., best FM condition to no FM) ranging from 26 to 100%. However, there were some noticeable performance differences across the subjects in the no-FM condition. Some children, who were all diagnosed with APD, listening problems, or language disorders, scored 0% (subjects

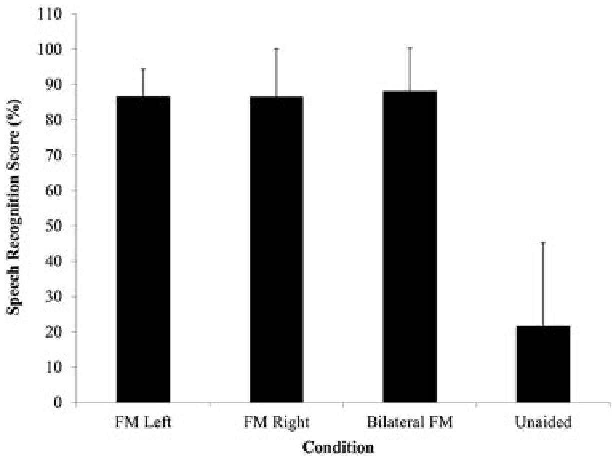

Figure 2 Average speech-recognition performance in noise in 10 participants. Vertical lines represent one standard deviation. Abbreviation: FM, frequency-modulated system.

3, 6, 7, 8, 10) and the remaining children scored between 29 and 54%. Additionally, there were some notable performance differences across the FM conditions within each subject. For example, subjects 3 and 9 had much higher (by up to 18%) performance in the FM right or bilateral FM conditions when compared with the FM left condition, and subject 11 showed a substantial left FM advantage (by 16 to 24%) over the other FM conditions.

LOUDNESS RATINGS

Nine of the 12 children (all but subjects 5, 6, 7) were able to rate the loudness of each FM system configuration as well as an unaided condition with BKB-SIN sentences and babble in a +5 SNR. The goal of this loudness assessment was to ensure that the unilateral and bilateral FM system fittings resulted in comfortable listening levels in the presence of background noise for the children. The average ratings across the four listening situations were similar: 4.1 for no FM system (SD = 0.6), 4.0 for the FM receiver on the right ear (SD = 0.87), 4.6 for the FM receiver on the left ear (SD = 0.73), and 4.0 for the bilateral FM receivers (SD = 1.6). According to the scale, these average ratings are consistent with a 4 ("comfortable") or 5 ("comfortable, but slightly loud") listening level for all conditions. A RM ANOVA was conducted across the four conditions with results suggesting no significant main effect of condition ($F[3,36] = 0.63$, $p = 0.60$). When examining individual data, only one child who had APD (subject 2) rated the no-FM condition as 7 ("uncomfortably loud") with all other subject ratings at or below 6 ("loud, but okay").

LISTENING COMPREHENSION IN NOISE

Eight of the 12 children were able to complete the Listening Comprehension Test 2 in noise in no-FM (unaided) and FM system listening conditions. None of the children with ASD were able to do the task (subjects 5 to 8). Fig. 3 displays average performance in noise in the no-FM and FM system conditions. To determine if there were any significant differences between conditions, a two-factor RM ANOVA was conducted with the independent variables of condition (no-FM; FM) and subtest (main idea, details, reasoning, vocabulary, and understanding messages). Results of this analysis suggested a significant main effect of condition ($F[1,80] = 893.2$, $p = 0.00002$), a significant main effect of subtest ($F[4,80] = 17.8$, $p < 0.0001$), and no significant interaction between condition and subtest ($F[4,80] = 0.36$, $p = 0.83$).

Post hoc analyses on the effect of condition suggested that performance in the no-FM condition was significantly worse ($p < 0.05$) than scores in the FM system condition. The post hoc analysis on the main effect of subtest showed that the main idea subtest resulted in significantly higher ($p < 0.05$) performance

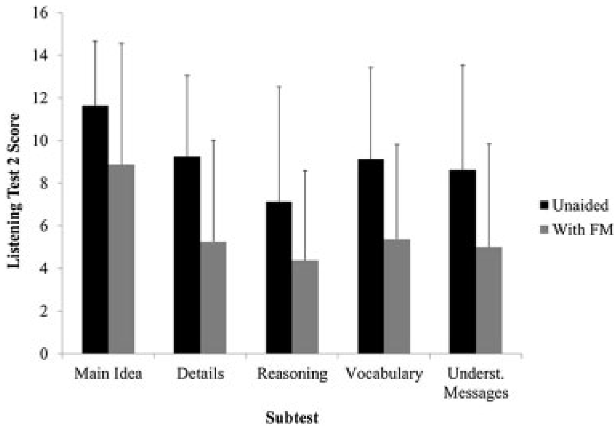

Figure 3 Average listening comprehension scores in noise in eight participants. Vertical lines represent one standard deviation. Abbreviations: FM, frequency-modulated system; Underst., understanding.

than all remaining conditions, with no other significant differences. All eight children substantially improved their total scores with improvements between the no-FM and FM system conditions ranging from 9 to 23 (mean = 16.9; SD = 5.1) units. When examining the individual data, three participants who were diagnosed with APD or language disorders were only able to answer two to three questions total without the FM system (subjects 2, 9, 10), and two of these children were some of the youngest in the study. These same children had substantial improvements with the FM system ranging from 17 to 23%.

Questionnaires

Given the varying degrees of language levels, cognitive functioning, and compliance on completing the questionnaires, subjective data could not be obtained from every participant. Some participants did not understand the task or could not reliably complete the questionnaires. Also, teacher questionnaires could not be obtained from some participants because several children were homeschooled, some were tested during the summer, and some did not opt to use the FM system at school.

PARTICIPANT QUESTIONNAIRES

Eight participants were able to complete the L.I.F.E.-R. Student Appraisal of Listening Difficulty questionnaire, and their average ratings are shown in Fig. 4 (all but subjects 5, 6, 7, or 9). Average unaided scores for the classroom-focused and social situations at school were 56.3 (SD = 10.2) and 41.6 (SD = 21.4), respectively. However, average scores in the same FM system conditions were 69.3 (SD = 13.7) and 41.1 (SD = 87.3), respectively. A one-way RM ANOVA suggested a significant effect of FM system use for classroom situations ($F[7,16] = 5.9$, $p = 0.05$), but no significant benefit from the FM in the social situations ($F[7,16] = 0.02$, $p = 0.90$).

Seven participants (all but subjects 1, 5, 6, 7, 12) were able to complete the C.H.I.L.D. regarding home use with the FM system, and their results are displayed in Fig. 5. A separate RM ANOVA was conducted for each subtest. There was a significant effect of the FM system in noise ($F[1,14] = 24.7$, $p = 0.003$) and in social situations ($F[1,14] = 5.7$, $p = 0.05$). However, no significant benefit of the FM system was reported in quiet ($F[1,14] = 0.08$, $p = 0.79$), at a distance ($F[1,14] = 2.5$, $p = 0.17$), and for media ($F[1,14] = 0.30$, $p = 0.60$).

PARENT QUESTIONNAIRE

Ten of 12 parents (all but subjects 6, 7) completed the Family Member C.H.I.L.D. regarding home use with the FM system (Fig. 6). Parents indicated that there was a significant effect of the FM system in quiet ($F[1,20] = 4.9$, $p = 0.05$), in noise (F

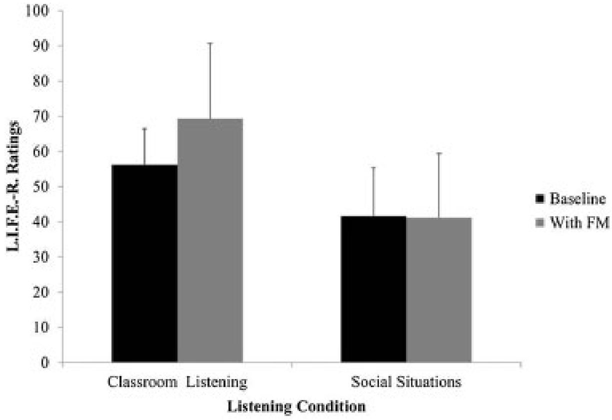

Figure 4 Average ratings from eight participants on the L.I.F.E.-R., Student Appraisal of Listening Difficulty questionnaire. Vertical lines represent one standard deviation. Abbreviations: FM, frequency-modulated system; L.I.F.E.-R., Listening Inventory for Education–Revised.

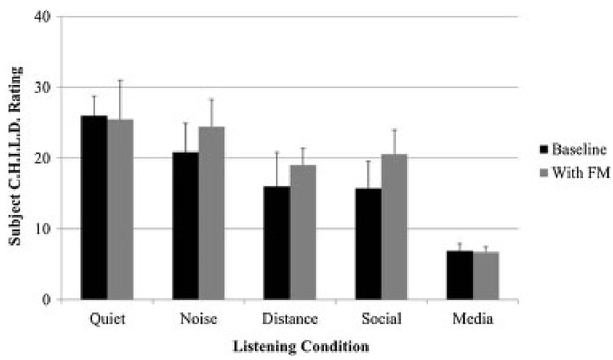

Figure 5 Average ratings from seven participants on the C.H.I.L.D. Vertical lines represent one standard deviation. Abbreviations: C.H.I.L.D., Children's Home Inventory for Listening Difficulty; FM, frequency-modulated system.

$[1,20] = 6.4$, $p = 0.04$), at a distance ($F[1,20] = 11.9$, $p = 0.007$), in social situations ($F[1,20] = 5.3$, $p = 0.05$), and for media ($F[1,20] = 9.9$, $p = 0.01$).

TEACHER QUESTIONNAIRE

The return rate of teacher questionnaires was poor, with only five teachers returning the L.I.F.E.-R. (for subjects 2, 5, 8, 9, 12) and four teachers returning the C.H.A.P.S. (for subjects 5, 8, 9, 12). As a result, only descriptive analyses could be provided for the teacher questionnaires. On the L.I.F.E.-R., the average baseline no-FM (unaided) teacher rating was 42.0 (SD = 15.9), indicating that children "sometimes experience listening challenges." When the FM system was used, the average rating was 53.8 (SD = 13), indicating that children have "occasional listening challenges." When examining individual data, two children had at least 17-point increases in ratings (subjects 2, 8), two had at least 9-point increases (subjects 5, 9), and one had only a 1-point increase (subject 12).

For the C.H.A.P.S., average difference scores were calculated for each listening condition between total score data in the baseline no-FM (unaided) and FM system condition. The absolute differences were 4.3 in quiet, 5.3 in noise, 0.25 for ideal situations, 1.5 for multiple inputs, −2.4 for auditory memory sequencing, and 4.8 for auditory attention span. As a result, average FM benefit was found in all listening conditions, with the exception of auditory memory sequencing where performance was

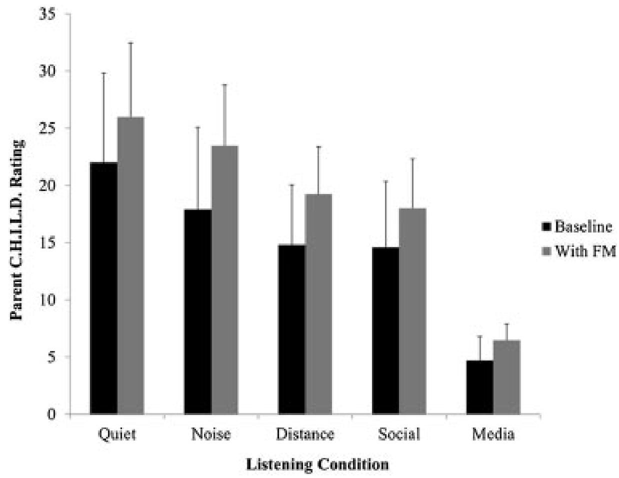

Figure 6 Average ratings from 11 parents on the C.H.I.L.D. Vertical lines represent one standard deviation. Abbreviations: C.H.I.L.D., Children's Home Inventory for Listening Difficulty; FM, frequency-modulated system.

rated higher in the unaided condition. When examining the individual data, all teachers rated the children as exhibiting better auditory performance with the FM system versus unaided in almost all listening conditions.

DISCUSSION

Fitting Data

The results of this study on children with normal hearing who have APD, reported listening problems, ASD, and language disorders provide preliminary support for the use of the AAA FM system real-ear fitting protocol in these disordered populations.[19] In this study, the real-ear protocol resulted in meeting or slightly exceeding DSL output targets with the FM receivers for 1000 through 4000 Hz. In addition, when the FM receivers were in use, the recommended MPO was not exceeded for any FM receiver. The results of the fitting procedures in this study were similar to what was reported in a previous investigation on typically developing, normal-hearing children.[18] In the previous study, target DSL output was achieved at 1000 and 2000 Hz, but was slightly lower than the target (by 2- to 3-dB SPL) at 3000 and 4000 Hz.[18] The results of the previous and present study lend further support of the real-ear protocol for ensuring a standardized fitting approach and an appropriate fit of FM systems on children with normal hearing.

Behavioral Measures

The behavioral measures were conducted to validate the fitting procedures and to examine the potential benefit of FM systems for normal-hearing children with significant cognitive challenges or milder disabilities, such as language impairments. Despite the presence of various disabilities, most children were able to complete the speech recognition in noise ($n = 10$), loudness rating ($n = 9$), and listening comprehension tasks ($n = 8$). The speech-recognition results in noise suggested significant benefit of unilateral or bilateral FM receivers over an unaided condition. Although average scores in the present study were notably poorer than those of typically developing children in a previous study, the pattern of better FM versus no-FM performance was equivalent between studies.[18]

However, as previously stated, there were differing patterns of benefit with some children performing better in unilateral and some children performing better in bilateral FM system conditions. As a result, audiologists will need to conduct individual evaluations, including speech recognition in noise, to identify greater benefit for one or both ears. However, in most cases, the investigators recommend a bilateral FM system fitting to achieve a balanced input between ears and to avoid preference and potential strengthening of only one side of the auditory system. Although not supported by any specific evidence, we hypothesize that use of only one FM receiver could potentially weaken speech-recognition performance in noise in the opposite ear and interfere in binaural processing.

Loudness ratings provided preliminary support toward the comfort of DSL targets for these normal-hearing populations of children who are diagnosed with various disorders. Ratings across an unaided and three FM system conditions yielded ratings associated with a comfortable or slightly loud perception of the sentences in noise (+5 SNR) from all children. Again, these findings are similar to what was reported by typically developing children in a previous study.[18]

Significant benefit of the FM system also was reported for the listening comprehension in noise task for all subtests except the main idea. As a result, children with these disabilities are able to identify the main idea of a story in the presence of background noise, but have significant difficulty with other comprehension tasks including recalling details, using reasoning, defining vocabulary, and understanding messages within the story. In comparison to data from a previous investigation on typically functioning peers, performance from the children in the present study is substantially poorer.[20] On average, scores for each subtest were 2 to 4 points higher for the typically functioning children in the previous study when compared with the children in the present study. Further research with larger sample sizes is necessary to examine the effect of noise on comprehension in each specific population; however, it is clear that an improved SNR from an FM system will enhance speech-recognition performance in this small sample of children with various disorders.

Questionnaires

The participant questionnaires were difficult to administer to some children due to comprehension issues; therefore, the investigators question the validity of some of the data. Nonetheless, on average, the children who could complete the questionnaires reported significantly improved performance with the FM system versus without the FM system at school in classroom listening situations and at home in noisy and social situations. Parents reported significant benefit of the FM system in all areas: quiet, noise, at a distance, in social situations, and for media. In the few teacher questionnaires returned, teachers rated performance with the FM system substantially higher than the unaided condition in most listening situations. Parent and teacher questionnaires may be an important assessment tool for assessing potential FM system benefit in children who are not able to participate in behavioral measures.

SUMMARY

According to the results of the present study, FM systems may be fit to DSL targets and verified using real-ear measures in children with normal hearing who have disabilities including APD, ADHD, ASD, and language disorders.[18,19] Once children are fit with the device, several test measures may be used to validate benefit from the FM system, such as speech recognition in noise, loudness ratings, and listening comprehension in noise. The children in this study showed substantially better speech recognition and comprehension when using the FM system, and the DSL targets provided a comfortable fitting when listening to speech in background noise. Questionnaires may be used to obtain subjective perception of FM system benefit from children, parents, and teachers, particularly when children, such as those with ASD in this study, cannot participate in behavioral measures.

REFERENCES

1. ASHA Practice PolicyAcoustics in Educational Settings: Position Statement. Washington, DC: American Speech-Language-Hearing Association; 2005
2. American National Standards Institute Acoustical Performance Criteria, Design Requirements, and Guidelines for Schools, Part 1: Permanent Schools. MelvilleNY2010. ANSI S12.60–2010

3. Knecht HA, Nelson PB, Whitelaw GM, Feth LL. Background noise levels and reverberation times in unoccupied classrooms: predictions and measurements. Am J Audiol 2002;11(2):65–71
4. Nelson EL, Smaldino J, Erler S, Garstecki D. Background noise levels and reverberation times in old and new elementary school classrooms. J Educ Audiol 2007/200814:16–22
5. Pugh KC, Miura CA, Asahara LLY. Noise levels among first, second, and third grade elementary school classrooms in Hawaii. J Educ Audiol 2006; 13:32–38
6. Jamieson DG, Kranjc G, Yu K, Hodgetts WE. Speech intelligibility of young school-aged children in the presence of real-life classroom noise. J Am Acad Audiol 2004;15(7):508–517
7. Neuman AC, Wroblewski M, Hajicek J, Rubinstein A. Combined effects of noise and reverberation on speech recognition performance of normal-hearing children and adults. Ear Hear 2010;31(3): 336–344
8. Schafer EC, Beeler S, Ramos H, Morais M, Monzingo J, Algier K. Developmental effects and spatial hearing in young children with normal-hearing sensitivity. Ear Hear 2012;33(6): e32–e43
9. Wróblewski M, Lewis DE, Valente DL, Stelmachowicz PG. Effects of reverberation on speech recognition in stationary and modulated noise by school-aged children and young adults. Ear Hear 2012;33(6):731–744
10. Sanders DA. Noise conditions in normal school classrooms. Except Child 1965;31:344–353
11. Valente DL, Plevinsky HM, Franco JM, Heinrichs-Graham EC, Lewis DE. Experimental investigation of the effects of the acoustical conditions in a simulated classroom on speech recognition and learning in children. J Acoust Soc Am 2012;131(1):232–246
12. Lagacé J, Jutras B, Giguère C, Gagné JP. Speech perception in noise: exploring the effect of linguistic context in children with and without auditory processing disorder. Int J Audiol 2011;50(6): 385–395
13. Rance G, Corben L, Delatycki M. Auditory processing deficits in children with Friedreich ataxia. J Child Neurol 2012;27(9):1197–1203
14. Schafer EC, Mathews L, Mehta S, et al. Personal FM systems for children with autism spectrum disorders (ASD) and/or attention-deficit hyperactivity disorder (ADHD): an initial investigation. J Commun Disord 2013;46(1):30–52
15. Johnston KN, John AB, Kreisman NV, Hall JW III, Crandell CC. Multiple benefits of personal FM system use by children with auditory processing disorder (APD). Int J Audiol 2009;48(6):371–383
16. Rance G, Corben LA, Du Bourg E, King A, Delatycki MB. Successful treatment of auditory perceptual disorder in individuals with Friedreich ataxia. Neuroscience 2010;171(2):552–555
17. Sharma M, Purdy SC, Kelly AS. A randomized control trial of interventions in school-aged children with auditory processing disorders. Int J Audiol 2012;51(7):506–518
18. Schafer EC, Bryant D, Sanders K, et al. Fitting and verification of frequency modulation (FM) systems on children with normal hearing. J Am Acad Audiol, In press
19. American Academy of Audiology Clinical Practice Guidelines. Remote Microphone Hearing Assistance Technologies for Children and Youth from Birth to 21 Years. Reston, VA: American Academy of Audiology; 2008
20. Schafer EC, Bryant D, Sanders K, et al. Listening comprehension in background noise in children with normal hearing. Journal of Educational Audiology 2013;19:58–64
21. BKB-SIN: Bamford-Kowal-Bench Speech in Noise Test. Elk Grove, IL: Etymotic Research; 2005
22. Shield B, Dockrell JE. External and internal noise surveys of London primary schools. J Acoust Soc Am 2004;115(2):730–738
23. Bowers L, Huisingh R, LoGiudice C. The Listening Comprehension Test 2. East Moline, IL: LinguiSystems Inc.; 2006
24. Schafer EC, Thibodeau LM. Speech recognition in noise in children with cochlear implants while listening in bilateral, bimodal, and FM-system arrangements. Am J Audiol 2006;15(2):114–126
25. Anderson KL, Smaldino J. Children's Home Inventory of Listening Difficulties. Available at: http://successforkidswithhearingloss.com/tests. June 18, 2014
26. Anderson K, Smaldino J, Spangler C. Listening Inventory for Education—Revised (L.I.F.E.-R.)—Student Appraisal of Listening Difficulty. Available at: http://successforkidswithhearingloss.com/wp-content/uploads/2011/09/LIFE-R_Photo_-and_Question_Gallery_RE.pdf. June 18, 2014
27. Anderson K, Smaldino J, Spangler C. Listening Inventory for Education—Revised (L.I.F.E.-R). Teacher Appraisal of Listening Difficulty. Available at: http://successforkidswithhearingloss.com/wp-content/uploads/2011/09/revised-Teacher-LIFE-R.pdf. June 18, 2014
28. Smoski WJ, Brunt MA, Tannahill JC. Children's Auditory Performance Scale. Tampa, FL: Educational Audiology Association; 1998
29. Scollie S, Seewald R, Cornelisse L, et al. The Desired Sensation Level multistage input/output algorithm. Trends Amplif 2005;9(4):159–197