VOLUME 19

2013
ISSN 1526-6096

JOURNAL OF EDUCATIONAL AUDIOLOGY

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Official Journal of the
Educational Audiology Association

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The Educational Audiology Association (EAA) is an international professional organization for audiologists who specialize in the management of hearing and hearing impairment within the educational environment. EAA was established in 1984 to advocate for educational audiologists and the students they serve. The American Academy of Audiology (AAA) and the American Speech-Language-Hearing Association (ASHA) recognize EAA as a related professional organization (RPO), which facilitates direct communication and provides a forum for EAA issues between EAA, AAA, ASHA, and other RPOs. Through the efforts of the EAA executive board and individual members, the association responds to issues and concerns which shape our profession.

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> *The Educational Audiology Association is an international organization of audiologists and related professionals who deliver a full spectrum of hearing services to all children, particularly those in educational settings.*
>
> *The mission of the Educational Audiology Association is to act as the primary resource and as an active advocate for its members through its publications and products, continuing educational activities, networking opportunities, and other professional endeavors.*

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Sarcasm Recognition in Children with Hearing Loss: The Role of Context and Intonation

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Learning to accurately identify sarcasm demonstrates theory of mind and is an important step in mastering adult discourse. We investigated whether a published method of assessing sarcasm could be applied to children with hearing loss. Adults and children typically use two linguistic cues differentially to identify sarcasm: context and intonation. We expected that children with hearing loss would interpret fewer stories as sarcastic and would rely less on intonation cues in their interpretations when compared to children who have normal hearing. The present study included children, aged 5-9 years-old, with normal hearing or mild to severe sensorineural hearing loss. Both groups of children listened to eight stories with varying combinations of context and intonation cues to sarcasm and then answered questions probing for the speaker's intent. Both groups relied less on intonation cues than on context cues to identify sarcasm, and children with hearing loss relied less on intonation cues than children with normal hearing. Children whose parents used more sarcasm were more likely to use sarcasm and more likely to identify sarcastic intent. Children in this age range are still developing understanding of sarcasm. The presence of hearing loss may impede acquisition of this mode of discourse, perhaps reflecting differences in language experience or theory of mind. Although children were assessed successfully following the published method, we recommend future studies include a condition reflecting presence or absence of facial cues of sarcasm and a measure of theory of mind.

Introduction

To develop into mature language users, children must transition beyond literal understanding of spoken language. In adult social discourse, listeners attend to more than the factual sense of words and sentences. Indeed, an utterance's literal meaning may intentionally misrepresent the speaker's intended message. This is especially apparent in verbal irony.

Irony is a language form in which a speaker communicates a meaning different than the literal sense of an utterance, frequently noting an unmet expectation (Bryant & Fox Tree, 2005). Types of irony include hyperbole, understatement, and sarcasm. In adult conversation, 7-8% of statements are ironic (Tannen, 1984; Gibbs, 2000). The most common form of irony used by adults is sarcasm (Capelli, Nakagawa, & Madden, 1990). Although the terms *irony* and *sarcasm* are often used synonymously, sarcasm is a specific type of irony. The intention of sarcasm is to mock or deride, and the target of sarcasm is always an individual (Lee and Katz, 1998; Laval & Bert-Erboul, 2005).

Sarcasm is a complex form of language, and relatively slow to develop. A child's understanding of sarcasm relies on a developed theory of mind. Theory of mind is the ability to recognize or infer the mental state of oneself and of others (Premack & Woodruff, 1978). When a child observes two persons in conversation and one person makes a sarcastic statement towards the other, to comprehend the statement as sarcastic, that child must recognize that the speaker intends a meaning different than the literal meaning of the utterance *and* that the speaker knows that the listener knows that the speaker did not mean to be taken literally (Capelli et al., 1990). This can be described in terms of first-order and second-order beliefs (c.f., Winner, 1997). To identify sarcasm, the child needs to understand that the belief of the speaker – the first-order belief – contradicts the spoken statement (e.g., "You have a beautiful voice" can only be understood as ironic if the child recognizes that the speaker does not believe the voice is beautiful). If the child fails to recognize the first order belief, the child will think the speaker is being complimentary – the literal interpretation of the statement – despite contextual cues that the voice is unpleasant. Additionally, the child needs to understand the speaker's and target's coordinated belief of the ironic statement – the second-order belief. If the child recognizes the second-order belief (e.g., that the speaker and target are both aware that the target's voice is not beautiful), then the child will recognize the statement as sarcastic. Conversely, if the child fails to recognize the second-order belief, the child will assume that the target does not recognize the irony (e.g., the child may think that the target believes the target's voice is beautiful, and will perceive the speaker's statement as supporting that belief – a way to preserve the target's feelings when the voice may in truth be unpleasant). Because of this complexity, it is hypothesized that there is a gradual developmental progression in comprehension of sarcasm, from a very primitive understanding to full appreciation (Capelli et al., 1990).

Yet, the exact developmental progression of irony is unclear. Children appear able to determine the non-literal meanings of irony by six years of age, but they do not distinguish between the pragmatic purposes of these speech acts (e.g., to mock, deride, or be funny), until later in middle childhood (Dews et al., 1996; Glenwright & Pexman, 2010). Young children are more likely to produce ironic statements in the form of hyperbole (e.g., "I have the biggest sandwich in the world") than in other forms, such as sarcasm or understatement (Recchia, Howe, Ross, & Alexander, 2010). Thus, only some aspects of irony are accessible to young children. Comprehension of irony, and in particular sarcasm, may depend on the strength of cues available to infer the speaker's intent (Nakassis & Snedeker, 2002). Adults take advantage of two primary cues for detecting sarcasm: the context in which the utterance is made and the intonation in which the utterance is spoken. The contextual cue is most consistent, as the literal meaning of the utterance is opposite from what the corresponding circumstances would justify. The presence of sarcastic intonation is less consistent; however, slower tempo, greater intensity, and a lower pitch level are significant indicators of sarcasm (Rockwell, 2000). The cues for sarcasm are independent. It is possible for sarcasm to be expressed without a specific intonation when contextual cues are available (Bryant and Fox Tree, 2005). Conversely, in the absence of contextual cues, listeners are able to discriminate between posed sarcasm (where a speaker reads an utterance "sarcastically") and non-sarcasm based on vocal cues alone (Rockwell, 2000). Children use context and intonation to understand sarcasm differently than adults. Whereas adults and middle-school aged children could identify sarcasm from contextual cues alone, third-grade children could only recognize sarcasm when both intonation and contextual cues were available (Capelli et al., 1990). A later study, using a closed-set response format found the same relationship in a group of younger children. Seven-year-old French-speaking children were able to recognize sarcasm on the basis of contextual cues alone whereas five-year-olds required an intonation cue to recognize sarcasm (Laval and Bert-Erboul, 2005). Both studies conclude that intonation is an earlier developing cue than context for understanding sarcasm. This finding is not universal. Winner and colleagues (1987) found that six-year-old children's understanding of sarcasm was equivalent in the presence or absence of intonational cues, and that intonation did not improve understanding of sarcasm until around eight years of age.

Less is known about how children with hearing loss develop understanding of sarcasm. Characteristics of this population may impede development of this skill. Children with poorer auditory resolution may be less sensitive to the pragmatic information provided by intonation cues. Children with cochlear implants are poorer than children with normal hearing at recognizing falling and rising contours of speech (See, Driscoll, Gfeller, Kliethermes, & Oleson, 2013) and at identifying emotions corresponding to affective speech prosody (Hopyan-Misakyan, Gordon, Dennis, & Papsin, 2009). Children with hearing aids have better perception of intonational cues than children with cochlear implants, possibly due to better frequency resolution in the low frequencies (Most & Peled, 2007).

Additionally, children with hearing loss may struggle with perceiving the intent behind sarcasm, as it requires theory of mind, an area where this population lags (Peterson, 2004; Schick, de Villiers, de Villiers, & Hoffmeister, 2007). There appears to be a linguistic influence on theory of mind development. For example, deaf children of hearing parents had worse theory of mind than deaf children of deaf parents (Schick, et al., 2007). This was attributed to poor language modeling to the deaf children when hearing parents were attempting to use manual communication, and to poor access to auditory language when hearing parents were using oral communication. Similarly, children with hearing loss who demonstrated better oral language skills developed competency in the false belief task earlier than children with worse oral language skills (Gonzalez, et al., 2007). Certain theory of mind tasks, such as understanding of false belief, resolve during adolescence in children with hearing loss (Gonzalez, Quintana, Barajas, & Linero, 2007).

A third factor which may influence comprehension of verbal sarcasm is experience with this language form. A child who is not exposed to sarcasm may not develop skills in comprehending and using this mode of discourse until later. Children with hearing loss may have delays in development of sarcasm comprehension due to lack of experience. The decreased auditory access of a child with hearing loss results in an overall lack of linguistic experience, including ironic discourse. Additionally, speech that parents direct to children with hearing loss may be different than that directed to children with normal hearing. Speech directed to children with hearing loss may be more directive or descriptive (Cheskin, 1981; Cheskin, 1982). Children with hearing loss who have more experience with conversational exchanges with their parents in turn demonstrate better receptive language ability (VanDam, Ambrose, & Moeller, 2012). We expect a similar effect of experience on children's ability to understand sarcasm.

Considering the influence of auditory and linguistic experience on identification of sarcasm, we hypothesized that children with hearing loss would have a poorer understanding of sarcasm than age-matched children with normal hearing. This hypothesis was based on the assumption that children who are hard-of-hearing have had reduced and altered auditory and language input and experience to assist them in developing awareness of sarcasm cues. Understanding how children with hearing loss interpret irony is important for developing targeted interventions supporting their acquisition of sophisticated adult discourse style. We report on our experience piloting a protocol investigating this hypothesis among a group of children using hearing aids.

Methods

Participants

Data from seven children with mild to severe sensorineural hearing loss fit bilaterally with hearing aids and seven age-matched children with normal hearing between the ages of 5 and 9 years were included in the study (Table 1). Pure-tone thresholds of children with hearing loss were measured and hearing aid function was verified electroacoustically. Normal hearing status of age-matched children was verified through pure-tone screening at 20 dB HL. Within the hearing loss group, four children were first fit with amplification prior to age 3 years and the remaining children were first fit between 3 and 4 years of age. Four children were diagnosed with congenital hearing loss; 1 child was diagnosed with progressive hearing loss; the etiology of the remaining children's hearing loss was unknown. Average maternal education level was 16.7 years for the hearing loss group and 17.9 years for the normal hearing group; the difference between groups was insignificant, $t(11) = 1.29$, $p = .24$. Average receptive vocabulary level (Peabody Picture Vocabulary Test raw score; Dunn, 2007) was 117.3 for the hearing loss group and 144.0 for the normal hearing group; children with normal hearing exhibited significantly larger vocabulary than children with hearing loss, $t(11) = -2.55$, $p < .05$. Children with hearing loss wore their hearing aids throughout the experiment. All parents spoke English as their native language and all children were learning oral English as their primary communication modality.

Test Materials

Eight story templates from Capelli et al. (1990) were used in the current study. Each story template had four different versions derived from each combination of two alternative story bodies and two alternative ending remarks (Appendix). Story bodies either provided information that was *discrepant* with the literal interpretation of the ending remark or information that was *neutral*, consistent with a literal interpretation of the ending remark. Discrepant contexts should lead to an interpretation of sarcastic intent, whereas neutral contexts should lead to a literal interpretation. All instances of sarcasm involved the form of irony in which speakers mean to convey the exact opposite of their literal meaning.

The stories were read by a male actor and digitally recorded in a sound-treated booth with a Marantz PMD671 audio recorder. Story bodies and endings were recorded separately. The two alternative ending remarks had identical wording; however, the remark was said in a neutral or sincere tone of voice in one case, and in a sarcastic tone of voice in the other. For the sarcastic intonation, the actor exaggerated the modulation of pitch and increased syllable duration relative to the neutral intonation. A group of adults listened to the ending remarks in isolation and were able to discriminate between the sarcastic and neutral intonations. The four permutations of each story were edited and matched for uniform root mean square amplitude levels using Adobe Audition (Adobe Systems Incorporated, 2007). Stories were not matched for length; however, there was no systematic variation in story length, i.e., sarcastic stories were sometimes longer and sometimes shorter than the neutral stories.

Story types were defined as:

- No Cue - neutral context with neutral prosody, providing no cues for sarcasm;
- Context Only - discrepant context with neutral prosody, providing only a context cue;
- Intonation Only - neutral context with sarcastic prosody, providing only an intonation cue; and
- Both Cues - discrepant context with sarcastic prosody, providing both context and intonation cues.

Table 1. Individual ages and mean age of children in each group. Individual data and mean data for aided speech intelligibility index (SII) and four-frequency pure tone average (PTA) of the better ear for children with hearing loss. Aided speech intelligibility index is an indicator of the proportion of speech cues that are audible to a child through their hearing aid. Unaided pure tone average is an indicator of the degree of the child's hearing loss.

Subject	Age (y;m)	Better ear aided SII	Better ear unaided PTA (dB HL)
HL1	6;1	.58	56.25
HL2	7;10	.69	48.75
HL3*	6;5	.88	17.50
HL4	7;8	.54	76.25
HL5	7;10	.74	55.00
HL6	8;11	.62	62.50
HL7	8;2	.49	75.00
MEAN (SD) CHL Group	*7;7 (1;0)*	*.65 (.13)*	*55.9 (19.8)*
NH1	9;4		
NH2	8;0		
NH3	7;11		
NH4	7;8		
NH5	5;7		
NH6	6;11		
NH7	7;7		
MEAN (SD) CNH Group	*7;7 (1;2)*		

Note: Subject HL3 had a precipitous high frequency hearing loss, and wore hearing aids bilaterally despite the normal pure tone average.

The No-Cue stories call for a literal interpretation of the utterance, whereas the Both-Cues stories call for an interpretation of sarcasm. Interpretation of the Context-Only stories is subjective – a sarcastic interpretation of the utterance is indicated by its conflict with the story context; however, the neutral intonation neither supports nor denies sarcastic intent from the speaker. An interpretation of sarcasm is most appropriate for this condition (Bryant & Fox Tree, 2005; Capelli et al., 1990). Interpretation of the Intonation-Only stories is also subjective – the literal meaning of the utterance is justified by the context, thus a literal interpretation is appropriate, but the sarcastic intonation of the speaker suggests that the speaker's intent is contrary to the literal meaning. Adults perceive the utterance as bizarre and incongruent; however, and previous research indicates that adults will typically classify the speaker intent as sarcastic (Bryant & Fox Tree, 2005; Capelli et al., 1990).

Procedure

Upon arrival to the appointment, the participant and parent reviewed and signed the consent form for inclusion in the study. The parent completed a questionnaire which asked for various demographic information including date of birth of the child, as well as information related to sarcasm exposure. Specifically, the parent was asked to rate on a four-point scale (never, rarely, occasionally, frequently) how often he/she uses sarcasm and how often he/she hears the participating child use sarcasm. The term sarcasm was not specifically defined to the parent.

Each child sat in the center of an acoustically-treated sound booth facing the sound-field speaker. The examiner read the following instructions to the child per Capelli et al. (1990): "I'm interested in how children understand stories. I'm going to play a tape of some stories and then ask you a few questions to find out what you thought about each story." The examiner allowed the child to ask any questions, and then presented the eight stories in turn via loudspeaker at 65 dB SPL.

After each story, the child answered four questions. Question 1 was open-ended, asking the child to classify speaker intent (e.g., "Why did Wendy say that?"). The response was categorized as sincere, sarcastic, lying, or other if the response did not fit the previous three categories. For example, "Because she was saying it to be mean" was coded as sarcastic; "Because she was probably excited" was coded as sincere; and "Because she didn't mean it, but she was just trying to be nice" was coded as lying. Question 2 was closed-ended, probing for understanding of story content (e.g., "Did Dick catch the ball or not?"). Question 3 was closed-ended, probing for understanding of speaker intent (e.g., "Did Wendy mean that Dick's catch was good or not good?"). Question 4 was open-ended, asking for the child's rationale for their response to the previous question (e.g., "How do you know that?"). The rationale was categorized as context, intonation, literal meaning, or other if the response did not fit the previous three categories. For example, "Because he didn't catch the ball" was coded as context; "Because she talked funny when she said it" was coded as intonation; and "Because she said it was a nice catch" was coded as literal meaning. Specific wording of questions for each story is available in Capelli, et al. (1990).

The children's responses to these questions were transcribed. The transcriptions were given to two blinded research assistants for coding of responses to the open ended questions. Reliability was at 71% for Question 1 and 59% for Question 4. A third blinded rater was brought in to code the responses where discrepancies between Rater 1 and 2 occurred. Reliability between Rater 1 and 3 was 93% for Question 1 and 93% for Question 4. Rater 1's ratings were used for analysis.

We made two predictions about the identification of sarcasm by children with hearing loss. First, we predicted that these children would perform worse than children with normal hearing in all conditions involving sarcasm, (i.e., Context-Only, Intonation-Only, and Both-Cues stories). This would be evident in performance differences for Question 1 and Question 3. Second, we predicted that children with hearing loss would demonstrate a reduced ability to use intonation cues to identify sarcasm. Thus, the addition of intonation cues would yield a negligible benefit over the contextual cue alone. We reasoned that children with hearing loss would be delayed in their ability to interpret the temporal and pitch differences of intonation cues to identify sarcasm due to overall limited access and exposure to auditory cues of speech. This would be evident in responses to Question 1 and Question 4. We did not predict differences in responses to Question 2, the probe for story context.

Results

Because our subject pool was small, we conducted nonparametric analyses to measure effects of hearing loss (Mann-Whitney test) and story type (Kruskal-Wallis test) on children's performance on the four questions.

Question 1 (speaker intent classification)

A series of Mann-Whitney tests was performed to identify an effect of hearing loss on classification of speaker intent. Children with hearing loss were significantly less likely than children with normal hearing to classify a speaker's intent as sarcastic, $U = 268.5$, $p < .01$. They were also significantly more likely to provide a classification of other, i.e., one that did not fit into a category of sincere, sarcastic, or lying, $U = 497$, $p < .05$. There was no difference between groups on the proportion of responses labeled sincere, $U = 392$, $p = 1.00$, or lying, $U = 394$, $p = .96$.

A series of Kruskal-Wallis tests was performed to identify an effect of story type on classification of speaker intent. Classification of speaker intent was found to be significantly different for the sincere story type only, $\chi^2(3, N = 56) = 17.2$, $p < .01$. Pairwise comparisons demonstrated that children were significantly more likely to rate these stories as 1 than 4, and more likely to rate these stories as 1 than 2. See Figure 1 and 2 for graphical comparisons between the two groups, as well as with the slightly older children and adults from Capelli et al. (1990).

Question 2 (story content comprehension)

A Mann-Whitney test indicated that children with hearing loss gave significantly more correct responses to Question 2 than children with normal hearing, $U = 1260$, $p < .01$. A Kruskal-Wallis test demonstrated no effect of story type on proportion of correct responses to Question 2, $\chi^2(3, N = 112) = 6.3$, $p = .10$. Figure 3 depicts proportion of correct responses to Question 2 for each group by story type.

Question 3 (speaker intent comprehension)

A Mann-Whitney test indicated no difference in the proportion of correct responses to Question 3 by children with hearing loss and children with normal hearing, $U = 1372$, $p = .18$. A Kruskal-Wallis test demonstrated a significant effect for story type, $\chi^2(3, N = 112) = 28.0$, $p < .01$. Pairwise comparisons analysis showed that children were significantly more likely to provide correct responses for the No-Cue and the Both-Cue stories than for the Intonation-Only and Context-Only stories. There was no significant difference in accuracy between the No-Cue and Both-Cue stories nor between the Intonation-Only and Context-Only stories. Figure 4 depicts proportion of correct responses to Question 3 for each group by story type.

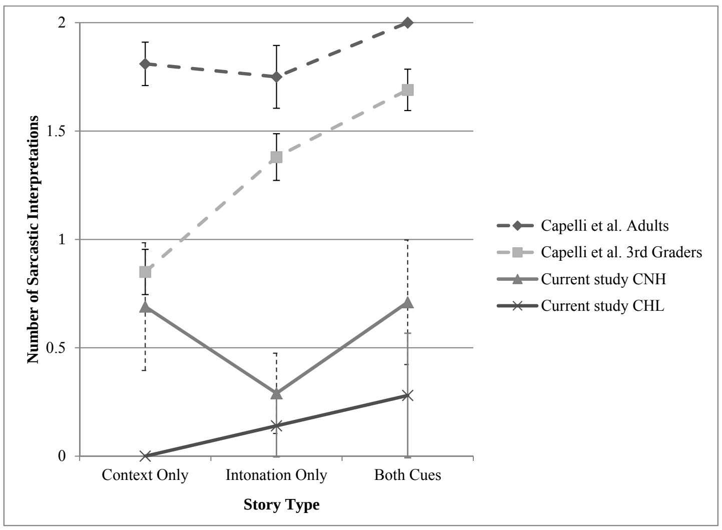

Figure 1. Mean number of interpretations of sarcasm for each of the three sarcastic story types (out of two possible), including results from the normal-hearing adult group and the normal-hearing third-grade group (most closely matched in age to the children in our study) from Capelli, Nakagawa, and Madden (1990). Error bars equal one standard error.

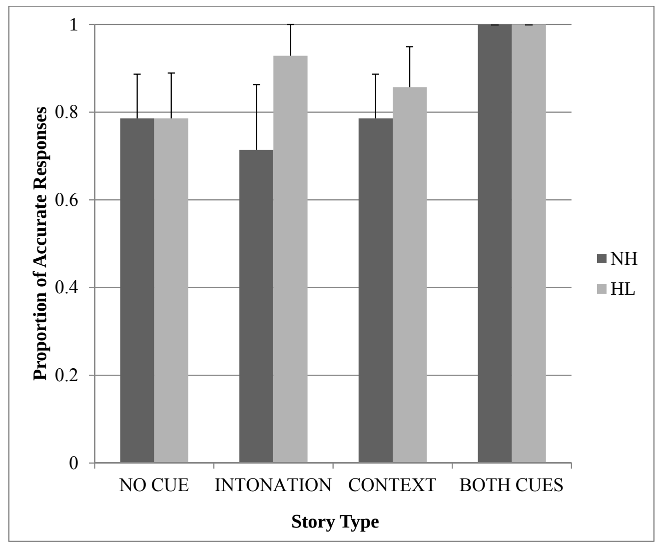

Figure 3. Proportion of accurate responses to Question 2 by story type. Question 2 probed for comprehension of the action in the story that prompted the sarcastic/neutral response. Error bars equal 1 standard error.

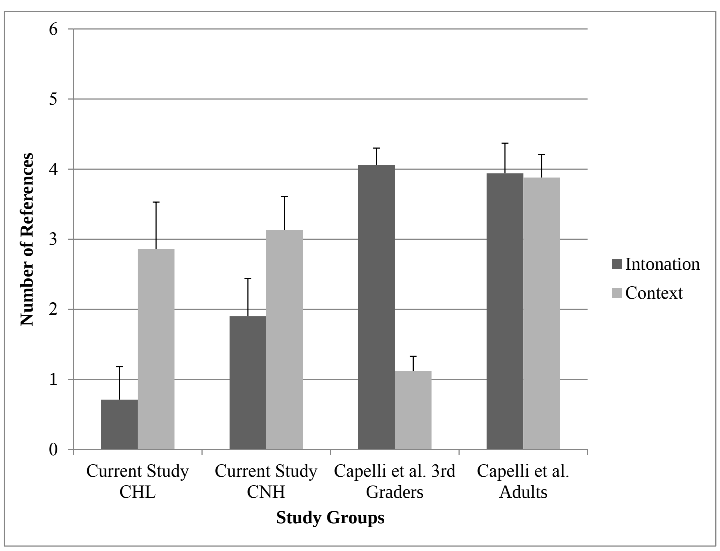

Figure 2. Mean number of times subjects referred to intonation and context for the sarcastic stories (out of six), including results from the normal-hearing adult group and the normal-hearing third-grade group (most closely matched in age to the children in our study) from Capelli, Nakagawa, and Madden (1990). Error bars equal 1 standard error.

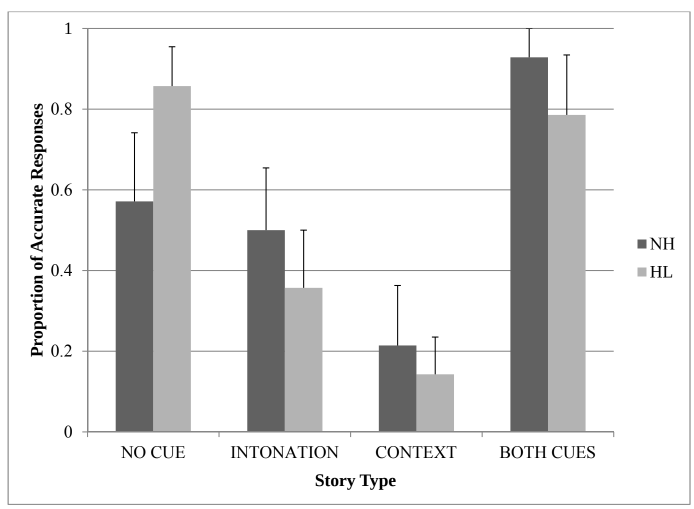

Figure 4. Proportion of accurate responses to Question 3 by story type. Question 3 probed for comprehension of the intent of the speaker of the sarcastic/neutral response. A response was considered accurate if the child's response matched the intonation of the speaker. Thus, in the context only condition, the response was scored as correct if the child responded that the speaker (using neutral intonation) meant what he/she said, even though it was contrary to the action of the story. Error bars equal 1 standard error.

Question 4 (response rationale)

A series of Mann-Whitney tests was performed to identify an effect of hearing loss on classification of the rationale for the speaker's response. As with Question 1, children with hearing loss were significantly less likely than children with normal hearing to classify a speaker's intent as sarcastic based on intonation, $U = 276$, $p < .05$, and also significantly more likely to provide a classification of other, i.e., one that did not fit into a category of context, intonation, or literal interpretation, $U = 502.5$, $p < .05$. There was no difference between groups on the proportion of responses labeled context, $U = 343$, $p = .39$, or literal interpretation, $U = 461.5$, $p = .12$. A series of Kruskal-Wallis tests was performed to identify an effect of story type on classification of speaker intent; no significant effects were found.

Parent ratings of sarcasm use

Parents rated their own and their children's sarcasm use on a four point scale, from 0, "Never uses sarcasm," to 3, "Frequently uses sarcasm". Average parent ratings of their own frequency of sarcasm use were the same, whether they had children with hearing loss, $M = 1.79$, $SD = .81$, or children with normal hearing, $M = 1.79$, $SD = .99$, suggesting that parents' frequency of sarcasm use did not depend on their child's hearing status. Children with hearing loss were rated as slightly less likely to use sarcasm, $M = 1.29$, $SD = .48$, compared to children with normal hearing, $M = 1.43$, $SD = .79$, but this was not significant, $t(12) = .41$, $p = .69$. Correlational analyses were performed to investigate how frequency of sarcasm use influenced performance on sarcasm identification. There was a large, positive correlation between parents' ratings of their frequency of sarcasm use and their child's frequency of sarcasm use, $r(12) = .58$, $p < .001$. Finally, there was a small, positive correlation between children's frequency of sarcasm use and correct identification of sarcastic intent for Question 1, $r(12) = .29$, $p < .01$.

Discussion

Children's Interpretations of Sarcasm

We predicted that children with hearing loss would be poorer identifiers of sarcasm than children with normal hearing. Our data supported this hypothesis as children with hearing loss showed fewer sarcastic interpretations to Question 1 (speaker intent classification), although their responses to Question 3 (speaker intent comprehension) were no worse than those of children with normal hearing.

We also predicted that children with hearing loss would be less sensitive to intonation as a cue to sarcasm compared to children with normal hearing. This hypothesis was substantiated as children with hearing loss showed fewer sarcastic interpretations to Question 1, fewer responses based on intonation to Question 4 (rationale for Question 3 response), and better accuracy for Question 2 (story content comprehension). This last finding was surprising as we expected there to be no difference in story content comprehension between groups. As evident from Figure 3, this was largely due to children with hearing loss more accurately comprehending the story content in the Intonation-Only stories. For example, in one Intonation-Only story, Dick successfully catches the ball but Wendy tells him "Nice catch" with sarcastic intonation. Children with hearing loss were more likely to accurately comprehend the story content (e.g., that Dick caught the ball). One possible explanation is that children with normal hearing were more influenced by the intonation of the speaker to revise their understanding of the story.

It is reasonable to expect hearing loss to affect development of comprehension of sarcasm. This ability relies on perception of a unique prosodic signature as well as developed theory of mind - two areas where children with hearing loss have identified weaknesses. Considering its prevalence in conversational speech, children who do not understand sarcasm may experience more frequent breakdowns in communication and may be perceived as communicatively awkward. Given the results of the correlational analysis, it appears that parents who use sarcasm more often, thereby increasing their children's exposure to verbal irony, may be helping their children develop comprehension of this mode of discourse.

This study is the first to our knowledge to assess sarcasm comprehension among children with hearing loss. The assessment framework published by Capelli, et al (1990) provided a foundation for this assessment. Children with hearing loss were able to follow the instructions and make classifiable responses. Many of the responses of children with hearing loss were similar to those of children with normal hearing.

We predicted that children with hearing loss would be poorer identifiers of speaker intent than children with normal hearing in story conditions involving sarcasm. Children with hearing loss identified the speaker's intent as sarcasm on the open-ended probe significantly less than children with normal hearing overall. This may indicate that children with hearing loss do not understand when sarcasm is present as well as children with normal hearing, or that they are poorer describers of the speaker's intent. On the closed-ended probe for comprehension of speaker's intent, children with hearing loss performed the same as children with normal hearing. Thus it would seem that children with hearing loss have a more difficult time describing a speaker's intent than they do at actually understanding the intent. This may be related to differences in expressive language skills or facility verbalizing concepts related to theory of mind, domains where children with hearing loss have been identified as being weaker (Fitzpatrick, Crawford, Ni, & Durieux-Smith, 2011; Peterson, 2004). Indeed, the children with hearing loss in this study demonstrated smaller vocabularies than the children with normal hearing.

We predicted that children with hearing loss would demonstrate a reduced ability to use intonation cues to identify sarcasm. In our sample, the role of intonation in children's identification of sarcasm was small, regardless of hearing status. Children relied heavily on contextual cues provided by the story to determine whether a speaker's intent was contrary to their literal statement. This is consistent with the findings of Winner (1987) showing that intonation was not a relevant cue until children were 8 years of age and older.

As mentioned, differences between children with hearing loss and children with normal hearing on sarcasm identification were subtle. However, regardless of hearing status, children in our sample were not able to identify sarcasm as well as the third-grade students in Capelli et al. (1990). This comparison is based on children's ability to report sarcasm as the speaker's intent in response to an open-ended question. Of the groups of children studied by Capelli, our children were closest in age to her third-grade group (8-9 year olds); however, on average, the children in our study were younger than the children in her study. Thus, the difference in performance may be an effect of development. It is interesting to note that all children in the present study were able to correctly infer the speaker's intention for the sarcastic stories when given a forced-choice question. This finding suggests that five- to nine-year-old children may be able to grasp some aspects of sarcasm and non-literal language, but do not have the vocabulary or skills to describe their interpretation as well as Capelli's third-graders. This conclusion is consistent with the research of Glenwright & Pexman (2010) which found that children were able to determine the non-literal meanings of both sarcasm and irony by six-years-old, but did not distinguish between the pragmatic purposes of those speech acts until later in middle childhood.

Role of Experience

An additional finding of this study was the relationship between use of sarcasm and sarcasm identification. Children who used sarcasm more often were more likely to identify it. These children had parents who used sarcasm more often, as well. This demonstrates that at least some children with hearing loss are able to identify and interpret sarcasm correctly. Ross Brackett and Maxon (1991) advocate the implementation of communication management principles in auditory habilitation. This includes focus on social interactions such as conversational rules and situational context. Assessing children's understanding of spoken irony in communication management programs for older children with hearing loss may be appropriate considering 7-8% of informal adult discourse is ironic.

Interpretation of this data should be tempered due to the nature of a pilot study. The small number of subjects led us to use nonparametric analyses of the sarcasm data. Even with this small data set, the results did not discourage our hypotheses regarding the delayed development of this pragmatic skill in children with hearing loss.

Further research is warranted to understand how intonation and context interact to direct a child's focus to the intended meaning of a speaker's utterance. Capelli et al. (1990) found that adults relied heavily on both context and intonation when inferring a speaker's meaning whereas children relied less on context. Laval and Bert-Erboul (2005) found that French five-year-olds interpreted sarcasm based on intonation, and seven-year-olds used context and intonation. Conversely, Winner (1987) found that intonation was not a cue supporting identification of sarcasm until age 8 years. Our results are more in line with those of Winner in that five- to nine-year-old children used contextual cues to infer a speaker's meaning, but derived minimal benefit from intonation cues. Research on a larger group of children with hearing loss may reveal additional significant outcomes.

Our methods and materials were taken from those used in a previous study (Capelli, et al, 1990) and applied to children with hearing loss. This is the first investigation of sarcasm comprehension in this population to our knowledge. Children with hearing loss are at risk for delays in theory of mind (Schick, et al, 2007) and comprehension of abstract forms of communication, both areas tapped by sarcasm. After our experience with this initial investigation of the understanding of non-literal speech forms in children with hearing loss, we would recommend that future studies include older children with hearing loss to examine whether their abilities diverge from children with normal hearing as they mature. In addition, we recommend including measures of theory of mind and expressive language.

Future researchers may consider experimenting with other contextual cues, such as visual cues and speaker familiarity. Non-acoustic features of sarcasm have been identified, including flattening of facial expression, eye-rolling, eye-blinking, and smirking, with the strongest cues coming from the mouth (Attardo, Eisterhold, Hay, & Poggi, 2003; Rockwell, 2001). Typical children reportedly recognize sarcasm correctly from non-acoustic cues earlier than they do from linguistic and contextual cues (Laval & Bert-Eboul, 2005). This may explain why many parents in our study were comfortable using sarcasm with their children. Indeed, family use of sarcasm may play a role in children's understanding. In the present study, parents who used more sarcasm rated their children as more frequent users of sarcasm. Additionally, some parents reported anecdotally that their children seemed to understand sarcasm better when it came from older siblings. Intonational cues of sarcasm vary stylistically from speaker to speaker. Thus the intonational cues available from the unknown speaker in this study may be different from a familiar family member – one whose style of sarcastic intonation the child may recognize.

Sarcasm is an ideal domain for testing the influence of auditory and visual modalities on language comprehension. Future investigations will provide additional insight on the development of adult discourse styles in children with hearing loss.

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Appendix

The eight stories used in this study were taken verbatim from Capelli, et al (1990); please see their original study for more details. Each story has four alternative versions, using combinations of two different story bodies – neutral or discrepant – and two different intonations – neutral or sarcastic. Below is an example of the neutral and discrepant versions of the first story. Note that Wendy's utterance (underlined) could be spoken with neutral or sarcastic intonation depending on story type.

Story 1 – Neutral context conditions (No Cue; Intonation Only)

Dick and Wendy were playing catch with a football at recess. Wendy threw out a long pass, and Dick went running full speed for it. He jumped in the air and then had to fall over backwards to catch it. "<u>Oooh, nice catch</u>," said Wendy.

Story 1 – Discrepant context conditions (Context Only; Both Cues)

Dick and Wendy were playing catch with a football at recess. Wendy threw out a long pass, and Dick went running full speed for it, when he slipped in the mud. His feet flew out from under him and he landed flat on his bottom. The ball bounced off his head and landed next to him in the mud. "<u>Oooh, nice catch</u>," said Wendy.

Effects of Voice Priority in FM Systems for Children with Hearing Aids

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Recently introduced frequency modulation (FM) systems provide an adaptive adjustment to the emphasis of the FM system through the user's hearing aid via VoicePriority *i*™ (VP*i*). VP*i* measures the noise level at the listener's hearing aid microphone and adds gain to the FM signal when the background noise increases to a detrimental level. However, the potential benefit of VP*i* technology has yet to be determined. Therefore, the goals of this investigation were to determine behavioral performance and subjective ratings with VP*i* as compared to traditional, fixed-gain FM systems or hearing aids alone. According to speech-recognition performance in noise, VP*i* provided significantly better scores when compared to the traditional FM system in conditions with high levels of noise. Acceptable noise levels were also significantly better with VP*i* over the traditional FM system and the study hearing aids alone. Speech intelligibility ratings with both FM systems were significantly higher than ratings with study aids alone. Parent and child questionnaires yielded similar findings to the behavioral results, with significantly higher ratings for the FM system with VP*i* over the study and personal hearing aids alone. In conclusion, the FM systems with VP*i* provided superior performance and subjective ratings relative to traditional, fixed-gain FM systems or hearing aids alone.

Introduction

Children and adolescents with hearing loss experience significant declines in speech-recognition performance in the presence of background noise when compared to performance in a quiet condition and to peers with normal hearing (Leibold, Hillock-Dunn, Duncan, Roush, & Buss, 2013; Nittrouer et al., 2013; Schafer, Pogue, & Milrany, 2012-b; Schafer et al., 2012-d). These significant declines in performance in noise are concerning given that typical classrooms have high unoccupied noise levels and reverberation times (Knecht, Nelson, Whitelaw, & Feth, 2002; Nelson, Smaldino, Erler, & Garstecki, 2008; Pugh, Miura, & Asahara, 2006), which do not meet recommendations from the American Speech-Language Hearing Association (2005) or the American National Standards Institute (2010).

The most direct approach to improving the speech-recognition deficits in noise of children with hearing loss is the use of remote-microphone technology, such as a frequency modulation (FM) system (Pittman, Lewis, Hoover, Stelmachowicz, 1999; Wolfe et al., 2013). FM systems consist of a microphone and transmitter for the talker and a receiver for the listener. FM systems greatly improve the signal-to-noise ratio (SNR) at a listener's ear by transmitting the primary talker's signal to the listener's ear via soundfield speakers, an electromagnetic receiver (neckloop) worn by the listener, or a personal receiver that is directly connected to the listener's hearing aids or cochlear implants. The more direct signal and improved SNR obtained with the FM system helps to combat poor classroom acoustics.

Children with hearing loss show significantly better speech-recognition performance when using FM systems as compared to their hearing aids or cochlear implants alone in noisy situations (Pittman et al., 1999; Wolfe et al., 2013). Even with the addition of advanced features in hearing aids, such as directional microphones, speech-recognition performance with FM systems is superior to performance with hearing aids alone (Lewis, Crandell, Valente, & Horn, 2004).

The most recent research on children with mild to profound sensorineural hearing loss and hearing aids shows that children perform significantly better with personal soundfield, a single loudspeaker placed on student's desk, or personal FM systems when compared to hearing aids alone or classroom (multiple loudspeakers) soundfield FM systems (Anderson & Goldstein, 2004; Anderson, Goldstein, Colodzin, & Iglehart, 2005). Another study by Boothroyd (2004) further supports the significant benefit of FM systems over performance with hearing instruments alone. In addition, when compared to hearing aid alone, use of personal FM systems by children with moderate to profound hearing loss significantly improves listening comprehension and functional listening skills at home according to ratings from parents and children (Flynn, Flynn, & Gregory, 2005).

The FM systems used in most of the aforementioned 2004 and 2005 studies utilized a fixed FM-gain setting, which is most often set to provide a 10-dB advantage over the microphone input from the hearing aid as recommended by the American Academy of Audiology (AAA, 2008). The exact origin of the +10 dB recommendation is undefined, but recent research suggests that SNRs ranging from 9 to 16 dB are required for children with normal hearing to repeat an average of 95% of words correctly (Bradley & Sato, 2008; Neuman, Wroblewski, Hajicek, & Rubinstein, 2010). Furthermore, children with hearing loss require approximately 4 to 8 dB better SNR to obtain speech-recognition performance similar to normal-hearing peers (Neuman, Wroblewski, Hajicek, & Rubinstein, 2012).

More recent FM systems allow for programmable adjustments of FM gain provided to the listener. When coupled to a hearing aid, the FM gain adjustment controls the relationship between inputs from the FM system and hearing aid, whereby higher programmable FM gain settings would result in greater emphasis for the signal from the FM system. As stated previously, when using a programmable FM system, it is important to achieve an advantage of **at least** +10 dB for the FM signal while still maintaining audibility of other sounds through the hearing aid microphones (AAA, 2008). To our knowledge, there is no published research on the effects of programmable, fixed FM-gain settings on speech-recognition performance of individuals with hearing aids. However, a study with adults using unilateral cochlear implants suggests that higher FM-gain settings result in significantly better speech-recognition performance in noise for some participants (Schafer, Wolfe, Lawless, & Stout, 2009).

More recently, technological improvements to Oticon and Phonak FM systems allow for the automatic adjustment of FM emphasis in an adaptive manner based on the background noise level in the environment. The goal of this approach is to provide substantial FM emphasis in situations with high levels of noise and to provide lower FM emphasis in less noisy situations. Using this adaptive approach, consistent audibility for the primary talker is maintained regardless of the noise level in the environment. In Phonak FM systems with this Dynamic FM feature, the necessary FM emphasis is determined at the location of the teacher's transmitter. When background noise levels are below 57 dB SPL, the FM receivers are set to provide a +10-dB FM advantage. However, when the noise level measured at the FM transmitter exceeds 57 dB SPL, the FM transmitter broadcasts a signal to the FM receivers to systematically increase FM receiver gain until the maximum setting of +24 is achieved. In 2010, Thibodeau reported a significant benefit of Dynamic FM gain at higher noise levels for 10 adults and adolescents with hearing aids. Specifically, when using Dynamic FM, speech-recognition performance was significantly better in 68 and 73 dBA noise conditions when compared to performance with a fixed-gain programmable FM system set to +10-dB FM advantage in the same noise conditions. Participants also preferred the Dynamic over the traditional FM when participating in two classroom activities and six lessons in a public aquarium. Wolfe et al. (2009) reported similar findings of significantly better performance with Dynamic FM versus traditional FM systems for adults and children with cochlear implants.

One potential disadvantage of measuring the noise level at the location of the transmitter is that the noise levels located at the teacher and child may differ to some degree. Background noise may be diffuse or more intense (localized) in a particular area in the classroom. In a larger classroom, noise levels across the room may vary due to the source(s) of the background noise, reverberation time in the classroom, and the presence of reflective or absorbent surfaces in a given area. More localized noise may be generated near the back of a classroom during small group activities or near hallways, windows, computers, or other noise-producing equipment. Even when localized and diffuse noise sources are of equal intensity at the listener's ears, the location or distance of the noise sources from the teacher or listener may impact performance due to more direct versus reflected sound and temporal differences.

The recently released Oticon Sensei hearing aid with the dedicated Amigo R12 FM receiver and Amigo T30 transmitter also allows for automatic and adaptive adjustment of FM emphasis (i.e., VoicePriority *i* [VP*i*]), but the necessary FM input is determined at the location of the hearing aid. When background noise levels are below 57 dBA, the FM receivers coupled to Oticon Sensei hearing aids are set to the +8 dB FM-receiver value. The +8 dB setting is recommended by Oticon because it is the setting necessary to achieve electroacoustic transparency, or equal outputs from the hearing aids and FM system when providing equal inputs to the two devices, which is recommended by AAA (2008). Also, when used in a realistic situation the +8 dB setting is designed to provide a consistent +10 dB FM advantage over the input from the hearing aid microphone. When the noise level measured at the aid exceeds 57 dBA (65 dB SPL), the VP*i* in the hearing aid systematically increases the direct audio input (DAI) signal until the maximum DAI input is achieved (i.e., 13 dB increase in DAI signal). The VP*i* gain changes occur rapidly, with attack and release times of 30 and 600 ms, respectively. The FM gain returns to the default +8 dB setting once the noise level decreases below 57 dBA. As a result, this system will provide the most favorable FM input for each child in a classroom and should account for any variation in acoustics at the location of a particular child relative to his or her peers. At this time, there is no published research examining or comparing the potential benefits of VP*i* and traditional fixed-gain FM system on children with hearing aids. Therefore, the primary goals of the present investigation were to compare behavioral and subjective performance with two types of FM systems. First, speech-recognition performance in noise was compared with two FM-system settings: FM receivers programmed to provide fixed-FM gain and the same FM receivers programmed to provide VP*i* (i.e., adaptive FM emphasis). Second, acceptable noise levels (ANLs) and speech intelligibility ratings (SIRs) of children were compared when children were using (1) bilateral Oticon hearing aids alone, (2) the same hearing aids with the fixed-gain FM, and (3) the aids with the FM and VP*i*. Finally, the listening abilities of children were determined via parent and child questionnaires while using the Oticon hearing aids alone and while using the aids coupled to the FM system with VP*i* during a four-week trial period with the devices. In general, the investigators hypothesized that use of the VP*i* technology would result in significantly improved behavioral performance over traditional, fixed-gain FM, and subjective ratings relating to performance with VP*i* would reveal significant improvements over the hearing aid alone when listening in noisy situations.

Methods

Research Design

A within-subjects, repeated measures design was used for this study. Participants and parents completed subjective scales before and after a trial period. Behavioral measures were completed after the trial period and included speech-recognition performance with the VP*i* and fixed-gain FM as well as ANL and SIRs with the study aid alone and in the two FM system conditions (VP*i* and fixed-gain FM).

Participants

Twenty children, 10 males and 10 females, ages 5;3 years to 18;0 years (M=10;5, SD=3;5) participated in the study. Demographic information about the children is provided in Table 1. Nineteen children had symmetrical moderate to severe mixed (n=1) or sensorineural (n=18) hearing losses; the average pure-tone air-conduction thresholds for these children is provided in Figure 1. One child had a unilateral profound sensorineural hearing loss, but was included in the study given difficulty recognizing speech in the presence of background noise and his bilateral acoustic neuromas. His speech-recognition scores were comparable to other participants. Hearing thresholds were determined prior to the study with recent hearing evaluations (< 6 months old) or with a new hearing evaluation prior to the study. With the exception of the one child with unilateral hearing loss (Subject 11) who was not aided, children were required to have permanent hearing loss, spoken English as their first and primary language, and bilateral hearing aids. One child (Subject 20) had bilateral hearing aids that were used in school, but the child was not a consistent user. As a result, the parent completed the subjective scales in the unaided condition, and these data were not included in the questionnaire analyses.

Procedures and consent/assent forms used in this study were approved by the University of North Texas Institutional Review Board. Parents of children less than 18 years of age and the adolescent who was 18 years completed a consent form prior to the study. In addition, children who were seven years and older completed an assent form prior to the study.

Equipment and Fitting Procedures

An outline of the two test sessions is provided in Table 2.

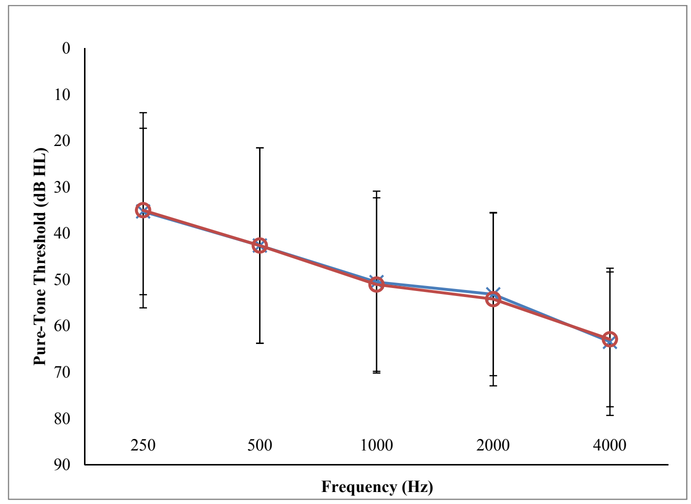

Figure 1. Pure-tone air-conduction thresholds of 19 participants with bilateral sensorineural or mixed hearing loss. *Note.* Vertical lines represent one standard deviation.

During the first test session, children were fit with bilateral Oticon Sensei Pro behind-the-ear (BTE; n=12) or receiver in the ear (RITE; n=8) hearing aids. Children used their personal earmolds or an appropriate-sized dome with the RITE aids. The type of hearing aid used in the study was determined by the type of personal hearing aid currently in use by the child. In other words, the investigators did not want to confound results of the study by changing the type of aids used previously by the child. The aids were programmed with Oticon Genie software to provide Desired Sensation Level (DSL v5; Scollie et al., 2005) prescribed gain for the child's chronological age and hearing loss. Default manufacturer settings on the hearing aids of all children included active directional microphones (Auto Tri-Mode and Opti Omni Surround Mode) and noise management. The investigators chose to activate volume controls for all children to ensure comfort during the trial period with this new hearing aid. All of these settings were active with the hearing aid alone and with both FM-system settings. In addition, all aid and FM signals were subjected to Super Silencer, which aims to provide additional circuit noise reduction when speech from the FM transmitter is absent. Following the fitting, the investigators conducted real ear measures on each ear with the Speechmap function (Std. Speech signal) of the Audioscan® Verfit™ to ensure that the DSL v5 prescriptive targets were met within ± 5 dB at 55, 65, and 75 dB SPL for frequencies between 0.25 to 4 kHz. The investigators also measured real ear maximum power output (MPO) with a 90 dB SPL pure-tone sweep to ensure that output would not exceed the estimated uncomfortable loudness levels (UCLs) for the child's age. If the targets were not met, outputs exceeded the UCLs, or the subject reported discomfort, appropriate adjustments were made using the Genie software.

Once the hearing aids were fit and verified with real ear measures, bilateral Oticon R12 FM receivers were attached, and the Oticon T30 transmitter with omnidirectional lapel microphone was activated. Following a listening check to ensure audible

Table 1. Demographic Information About Study Participants and Answers to General Questions on the Auditory Performance Scale for FM Systems

Subj #	Age (yrs)	Personal Aids	Avg FM Use (hrs)	Where Most Helpful?	Liked Most About FM?	Liked Least About FM?	Interference?	Recommend to Others?
1	8	Phonak Naida V SP BTE	2	At mall & in car	Long range; could hear whispers	Charging	No	Yes
2	11	Unitron Element 8BR RITE	2	Voices far away and didn't carry	Multiple uses, use as headphones	Mic clip not durable, too big	No	Yes
3	9	Unitron Next 4 HP BTE	1-2	Car, getting attention from another room	Automatic frequency connection, small FM	Flashing light, batteries	No	Yes
4	11	Unitron Element 16 BTE	6-10	Coaching, presentations, school	Portable	*	*	*
5	13	Unitron Element 16 BTE	6-10	Coaching, presentations, school	Easy to use, portable, hear clearly at distance and background noise	Feedback	Yes, when out of range and randomly	Yes
6	18	Phonak Solana Micro P BTE	1-2	When person was in different room, TV	Worked well, reliable	Look, size	No	Yes
7	6	Phonak Nios Micro III BTE	8-10	In car, TV	Could hear much better, easy to use	Bulky transmitter, mic detached easily	Not too much	Yes
8	14	Phonak Extra 311 AZ BTE	2	In car, TV	Easier to understand people, TV connection	Feedback	If far from receiver	Yes
9	6	Oticon Safari 900 BTE (Couldn't verify, emailed mom)	8	School, shopping	Very easy to use, small	*	No	Yes
10	9	Phonak Nios Micro V BTE (Couldn't verify, emailed mom)	3	Happy to hear better	Helps a lot, proud of it	Makes some unwanted noise	Yes	Yes
11	10	None	2	Event outside with large group; grocery shopping	Child could hear <u>all</u> words said and didn't ask 'huh?', heard better outside the home	Need more than one transmitter: for each parent	No	Yes
12	9	Starkey Zon 7 RITE	4	Classroom, large noisy rooms	Simplicity, size	*	2-3 times after charging; fixed after battery reinserted	Yes
13	7	Phonak Naida UP BTE	6-7	Noisy places	Small, easy to use	Little buzzing, clip	Yes, like a noisy waterfall	Yes
14	16	Phonak Certena Micros Open BTE	5	Hear better, gets attention more	Music player, mic was sensitive	Yes, when talking or a lot of noise	*	*
15	11	Phonak Audeo RITE	3-4	iTouch, classroom, teacher instructions	Clarity	Static, size	When cord touched another part of the cord	Yes
16	13	Phonak Audeo RITE	4-5	Classroom	Clarity when there was no static	Size	Yes, static many times	Yes
17	12	Oticon Safari 600 Power BTE	1-2	Hear from different room, in noise	Mom doesn't have to yell	*	Static when close to computer speakers	Yes
18	14	Phonak Versata Micro	3	Noise	Distance, directly to ears	Teachers would not mute, interfered with participation in class	Yes, nearly all the time	Not in the classroom setting
19	7	Phonak Nios Micro III	1	Restaurant, another room	Could hear from different room, when it was loud	Transmitter didn't clip well, too heavy on shirt	No	Yes
20	5	None	1	Restaurant, another room	Heard much better without needing to be loud or yell	Transmitter was too heavy to clip on shirts without pockets	No	Yes

Note. The type of personal aid also relates to the type of aid used in the study. BTE=behind the ear hearing aid; FM=FM system; RITE=receiver in the ear; Subj.=subject; *participant did not provide information.

output from the hearing aid and FM system (i.e., FM+M), the transparency (i.e., equal output with equal input) of the FM system to the hearing aid was determined with electroacoustic test procedures recommended by AAA (2008). The Audioscan® Verfit™ was used to measure and compare the output of the hearing aid alone coupled to a 1-cc (RITE) or 2-cc (BTE) coupler and then the hearing aid coupled to the FM receiver with input to the FM transmitter when using a 65 dB SPL speech input (Std. Speech signal). Transparency was achieved for all hearing aids and FM systems with the manufacturer default settings on the FM receiver (+8 dB gain).

After the fitting, children and parents were given an orientation on use, care, and maintenance of the hearing aids and FM system. Written instructions were also provided. Following the fitting session, children were asked to use the equipment over a four-week trial period. Specifically, children were asked to use the FM system for a minimum of two hours a day and to use the Oticon Sensei aids the remainder of their day. The investigators believed two hours per day over a period of four weeks would provide the children and parents with ample experience to rate subjective performance with the devices. Use of the hearing aids during waking hours was confirmed for all children following the study using the Activity Analyzer feature in the manufacturer programming software. The VP*i* feature (automatic adjustments to FM emphasis in hearing aid) was activated for the trial period, and participants were instructed to leave the FM receiver attached to the hearing aids for the entire trial period. When the transmitter was turned on, the FM receiver was automatically activated.

Equipment and Behavioral Testing

After the four-week trial period, children returned for the second test session (Table 2), which included three behavioral test measures: speech recognition, ANLs, and SIRs.

Speech recognition in noise. Speech recognition included 12 listening conditions with randomly-selected sentence lists from the Hearing in Noise Test for Children recorded on a CD (HINT-C; Nilsson, Soli, & Gelnett, 1996) and four-classroom noise (i.e., noise from four classrooms digitally overlapped) from the Phrases in Noise Test (Schafer et al., 2012-a; Schafer & Thibodeau, 2006). Each sentence list consisted of approximately 50 words, and children's responses were scored according to the number of words he or she repeated correctly. In a total of 12 conditions and HINT lists, children were tested in both traditional fixed-gain FM and VP*i* FM conditions in two loudspeaker arrangements described below (diffuse; localized) and at three SNRs measured at the participant's head: (1) speech 65 dBA/ noise 55 dBA: +10 dB SNR, (2) speech 70 dBA/ noise 63 dBA: +7 dB SNR, and (3) speech 74 dBA/ noise 70 dBA: +4 dB SNR. These SNRs were based on the expected increase in speech level with an increase in noise level and were used in a previous investigation on effects of automatic adjustments to FM gain (Wolfe et al., 2009). The intensity of the speech signal across the three SNR conditions at the location of the transmitter microphone was 82, 87, and 91 dBA, respectively. Speech-recognition performance was not assessed with the study aid alone because of the expected fatigue in the children, and there is no speech-recognition test that is appropriate for younger children that also has the necessary number test lists to add six more hearing-aid-alone conditions (i.e., for a total of 18 conditions).

The speech-recognition testing was conducted in a 20 ft. by 13 ft. classroom setting (Figure 2) with an average unoccupied noise level across eight locations of 43.9 dBA, and an average reverberation time of 0.39 seconds across octave frequencies between 500 and 4,000 Hz as measured with a sound level meter (Larson Davis System 824). Speech was presented from a single head-level loudspeaker located at 0-degrees azimuth using a compact disc (CD) player (Sony CD-Radio-Cassette-Corder). Uncorrelated four-classroom noise was presented from four head-level loudspeakers (Bose Companion 2 Series II Multimedia Speaker System) and two portable CD players (INSIGNIA NS-P5113). As shown in Figure 2, two different noise loudspeaker arrangements were used during speech-recognition testing; however, speech was always presented from 0-degrees azimuth. When the FM transmitter was in use, the transmitter microphone was placed on a stand six

Table 2. Overview of Study Sessions and Test Conditions

Session 1	Session 2
1. Informed consent/assent obtained 2. Parents completed case history form 3. Parents and children completed the C.H.I.L.D. and APS scales: performance with his/her personal aids 4. Hearing test conducted, if necessary 5. Study hearing aids programmed and verified using real ear measures 6. FM connected and transparency verified using electroacoustic test measures 7. Verbal and written orientation to devices provided 8. Participants asked to use devices over a 4-week trial period	1. Parents and children completed the C.H.I.L.D. and APS scales for performance with: (a) study aids alone; (b) aids with VP*i* 2. Speech recognition in noise with traditional fixed-gain FM and VP*i* in 2 loudspeaker arrangements (Figure 2) each at 3 SNRs: 65/55; 70/63; 74/70 3. Acceptable Noise Levels with (a) study aids alone; (b) traditional FM; (c) VP*i* 4. Speech Intelligibility Ratings in Noise with (a) study aids alone; (b) traditional FM; (c) VP*i*

Note. APS=Auditory Performance Scale for FM Systems; C.H.I.L.D.=Children's Home Inventory for Listening difficulties; SNRs=signal-to-noise ratios; VP*i*=VoicePriority *i*.

inches from the single-coned loudspeaker. Intensity levels of all stimuli were calibrated with a sound level meter. The examiners were required to re-program the hearing aids between some randomized test conditions using a laptop computer and the Oticon Genie software for the two FM settings: (1) traditional fixed-gain FM at a +8 dB and (2) VP*i* (automatically adjusts FM emphasis based on noise measured by hearing aid). Participants were given a break between the conditions to allow the examiner to reposition and recalibrate the four loudspeakers and/or adjust the FM settings.

Acceptable noise levels. The children's ANLs were determined in three conditions with speech and multi-talker babble noise recorded on a CD (ANL, 2009) from spatially-separated loudspeakers (speech at 0 degrees; noise at 180 degrees). The conditions included (1) the study aid alone, (2) the study aid plus FM system set to traditional fixed-gain (+8 dB) FM, and (3) the study aid plus FM system with VP*i* enabled. Children were given a paper-based loudness rating scale to use during these conditions. To measure ANL, the examiner determined the child's most comfortable listening level (MCL) for running (continuous) male speech at 0-degrees azimuth by adjusting the intensity of the speech stimuli in 5-dB HL steps to a level that was 'too loud' and a level that was 'too soft'. The speech was then adjusted in 1-dB HL steps in between levels that were rated as 'too loud; or 'too soft' to find the child's MCL. After the MCL was determined, the examiner continued to present speech at the MCL while adding background noise at 180-degrees azimuth. The background noise level (BNL) was adjusted in 5-dB HL and then 1-dB HL steps until the child indicated that he or she would be willing to 'put up with' the noise level for a long period of time. The MCL and BNL procedures were conducted twice, and the signal levels in each procedure were averaged before calculating ANL (i.e., ANL= MCL – BNL).

The ANL was conducted in a sound-treated booth with a GSI 61 Clinical Audiometer and two head-level Grason-Stadler loudspeakers. The signal speaker was located at 0-degrees azimuth and the noise loudspeaker was located at 180-degrees azimuth. The ANL stimuli were presented from a CD played on a Dell Latitude E6530 laptop computer. When the FM system was in use, the FM transmitter microphone was placed on a stand six inches in front of the signal speaker. Stimuli intensity levels were calibrated with a sound level meter.

Speech intelligibility ratings. These intelligibility ratings were determined in three conditions with the Revised Speech Intelligibility Ratings (R-SIR) speech and multi-talker babble stimuli (Speaks, Trine, Crain, & Niccum, 1994). Similar to the ANL procedure, running speech was presented at 0-degrees azimuth, and background noise was presented at 180-degrees azimuth. However, for this procedure, the speech stimuli were fixed at 60 dBA, and only the noise levels were adjusted. The SIR procedures began in a study-aid alone condition where the examiner adjusted the noise level in 5-dB HL steps until the child indicated on a paper scale, ranging from 0% (none) to 100% (all) of words heard, that he or she heard approximately 50% of the speech passage. Along with the speech presented at 60 dBA, the noise level determined in the first hearing-aid-only test condition was used for the remaining two conditions, which included (1) the study aid plus FM system set to traditional fixed-gain (+8 dB) and (2) the study aid plus FM system set to VP*i*. In these two conditions, children were also asked to use the paper scale to rate the percentage of the words, ranging from 0% (none) to 100% (all), in the passages that were heard. Two

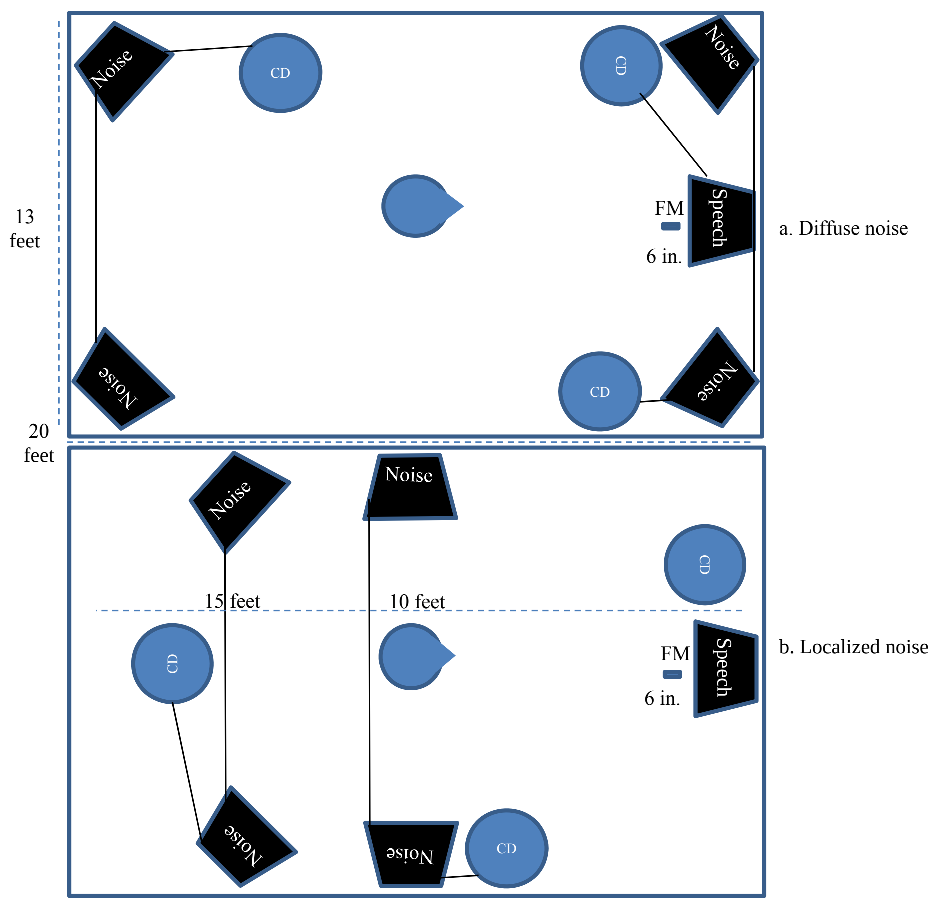

Figure 2. Classroom test arrangement for the (a) diffuse noise loudspeaker arrangement and for the (b) localized noise loudspeaker arrangement.

passages were given in each condition, and the children's ratings within each condition were averaged. For some children, the SIR procedures were slightly adapted (i.e., shortened) from the original version to address the short attention spans of many of the younger participants. When procedures were shortened, participants would listen to two to three sentences per condition rather than an entire passage. The equipment used for the SIR was identical to the equipment for the ANL, but the SIR stimuli were in digital format (.WAV) and were presented using the laptop soundcard.

Subjective Measures

Following consent/assent to participate, all participants and parents completed the same subjective rating scales before and after the four-week trial period with the devices. In the first session, participants and parents completed one set of questionnaires related to hearing performance with the child's current personal hearing aids, with the exception of Subjects 11 and 20 who were not using personal hearing aids and were excluded from the analyses of the questionnaires. In the second session, the participants and parents completed two sets of the same questionnaires to provide ratings for (1) the new hearing aid alone and (2) the new hearing aid plus the FM system with VP*i* enabled. In total, the three administrations of the questionnaires enabled the investigators to determine benefit of the hearing aid alone relative to the personal aid and benefit of the FM system.

The subjective rating scales included the parent and child versions of the Children's Home Inventory for Listening Difficulty (C.H.I.L.D.; Anderson & Smaldino, 2011) and a laboratory-developed questionnaire, the Auditory Performance Scale for FM systems (APS-FM; Schafer, Romine, Musgrave, Momin, Huynh, in press). The family and child versions of the C.H.I.L.D. included 15 items, which can be separated into five categories: hearing in quiet (four questions), media (one question), social situations (three questions), noise (four questions), and at a distance (three questions). For specific information regarding the items associated with each category, the reader is referred to the web link of the questionnaire, which is provided in the Anderson & Smaldino (2011) reference. A rating 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). As stated previously, parents and children provided (1) baseline ratings on the C.H.I.L.D. at the beginning of the study for performance with the child's personal hearing aids. Following the four-week trial period, parents and children completed the same C.H.I.L.D. scale for (2) the child's hearing with the study aid alone (Oticon Sensei) and (3) the child's hearing with the study aid plus the FM system with VP*i* enabled (Oticon Sensei; R12 receiver; T30 transmitter). As a result, there were three C.H.I.L.D. scales obtained from the parent and three questionnaires obtained from the participant.

The APS-FM, originally designed to assess performance with FM systems and cochlear implants, was slightly modified from its original version to make it appropriate for hearing aids and to focus on questions related to a primarily home-based trial period (Schafer et al., in press). At baseline, the child completed (1) an APS-FM questionnaire consisting of 17 questions focused on hearing at home (6 questions) and hearing in social situations (11 questions). Each item on the scale was assigned a modifier and rating to indicate the child's level of difficulty hearing in each situation. Ratings ranged from 'Can Do This Well' (rating of 0) to 'Cannot Do This At All' (rating of 6). After the four-week trial period, the children completed the APS-FM for (2) hearing with the study aid alone and (3) hearing with the study aid plus the FM system. In addition to the 17 questions included in the baseline APS-FM, an additional 12 statements were included on the third administration of the APS-FM (during Session 2) to assess the child's opinions about the FM receiver and FM transmitter. Additionally, eight open-ended questions were asked regarding duration of FM system use, where it was most and least helpful, presence of any interference, experience connecting to other devices (i.e., TV, computer, etc.), and whether they would recommend it to others. Examiners and parents provided the children reading assistance on the C.H.I.L.D. and APS-FM scales, if necessary. After each of the two test sessions, participants were paid for their time and effort over the two sessions and four-week trial period, and parents were reimbursed for mileage expenses.

Results

Subjective Ratings Scales

Participant C.H.I.L.D. Average ratings from 18 participants across the three conditions (personal hearing aid; study aid; study aid plus FM with VP*i*) and five listening situations on the C.H.I.L.D. are provided in Figure 3. Participants 11 and 20 were excluded from the analysis because they were not using personal aids at the time of the study. Also, one child (Participant 18) chose to use the FM system only at school rather than at home because he wanted to determine if it would be helpful in the classroom. The remainder of children primarily used the FM system during a home-based trial during the summer.

Data for each listening situation were analyzed in separate one-factor repeated measures analysis of variance (RM ANOVA), and post-hoc analyses on the main and interaction effects were conducted with the Tukey-Kramer Multiple Comparisons Test. Results of these analyses are provided in Table 3 and suggest that children provided significantly higher ratings for the FM system relative to the personal aid and/or study aid.

Family C.H.I.L.D. Ratings were collected from 17 of the 20 parents, and average ratings are provided in Figure 4. One

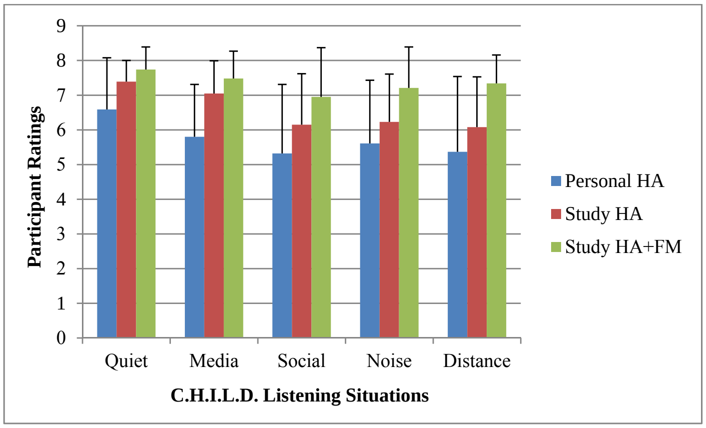

Figure 3. Average participant ratings on the Children's Home Inventory For Listening Difficulties (C.H.I.L.D.) *Note.* On scale, 5=okay but not easy; 6=pretty good, 7=good, 8=great. HA=hearing aid; FM=frequency modulation system. Vertical lines represent one standard deviation.

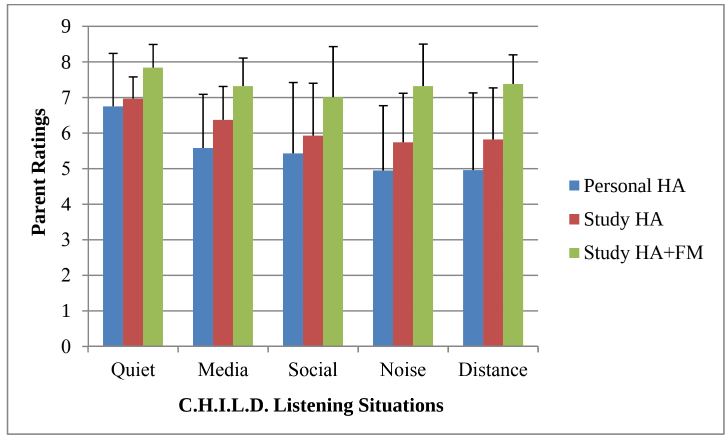

Figure 4. Average parent ratings on the Children's Home Inventory for Listening Difficulties (C.H.I.L.D.) *Note.* On scale, 5=okay but not easy; 6=pretty good, 7=good, 8=great. HA=hearing aid; FM=frequency modulation system. Vertical lines represent one standard deviation.

parent declined to complete the ratings scales because the child (Participant 18) chose to use the FM system more at school versus home, and two children were excluded due to non-use of personal hearing aids (Participants 11 and 20). The ratings in each listening situation were analyzed in separate one-factor RM ANOVAs and post-hoc analyses. Results are provided in Table 3, and on average, the family member rated the FM system significantly higher than the personal aid and the study aid in every condition. Also, the study aid was rated significantly higher than the personal aid for media, in social situations, in noise, and at a distance.

APS-FM. Ratings were collected from 18 of the 20 participants (Participants 11 and 20 excluded), and average ratings are provided in Figure 5. On this questionnaire, lower ratings (i.e., closer to zero) represent more favorable ratings. The RM ANOVAs on listening at home and in social situations yielded statistically significant benefit for the FM system over the study and personal hearing aid. In addition to the situation ratings, all 20 children completed 12 questions about the functionality of the FM transmitter and receiver. Average ratings on all 12 questions ranged from .57 to 1.67, indicating that the children 'liked it very much' or 'it was pretty good'. Specifically, most children indicated that the FM receiver was comfortable, easy to use, reliable, clear, cosmetically appealing, and helped them hear. Also, according to the ratings, most children reported that the FM transmitter was comfortable, cosmetically appealing, good sized, easy to use, and worked well. Answers to the open ended questions on the APS-FM are provided in Table 1. Overall, this questionnaire suggested that the FM system was highly beneficial at home and in social situations. Most children liked using the system, thought it was helpful, and would recommend its use to other children.

Table 3. Statistical Results from the C.H.I.L.D. Questionnaire Ratings Across Three Device Conditions: Personal Hearing Aid, Study Hearing Aid, and FM System

	Listening Situation	*F*-ratio	*p* value	Significant Post-hoc results (*p* < .05)
Participant C.H.I.L.D.	Quiet	12.3	.00009	FM better than personal aid
	Media	12.8	.00007	FM better than personal aid
	Social	8.6	.0009	FM better than personal aid
	Noise	13.5	.00004	FM better than study aid & personal aid
	Distance	10.9	.0002	FM better than study aid & personal aid
Family C.H.I.L.D.	Quiet	26.3	< .00001	FM better than study aid & personal aid
	Media	19.1	< .00001	FM better than study aid & personal aid; study aid better than personal aid
	Social	40.6	< .00001	FM better than study aid & personal aid; study aid better than personal aid
	Noise	52.1	< .00001	FM better than study aid & personal aid; study aid better than personal aid
	Distance	45.7	< .00001	FM better than study aid & personal aid; study aid better than personal aid
Auditory Performance Scale - FM	Home	6.2	.005	FM better than study aid & personal aid
	Social	6.2	.005	FM better than study aid & personal aid

Note. FM=study aid plus FM with VoicePriority *i*.

Behavioral Measures

Speech recognition in noise. Figure 6 displays the average speech-recognition performance of the 20 children across the three SNRs, two loudspeaker arrangements, and two FM conditions. On average, scores in the VP*i* condition were always higher than scores in the traditional FM condition, and as expected, scores decreased in higher noise levels.

The speech-recognition data were analyzed using a three-factor RM ANOVA with the repeated variables of SNR (65/55; 70/63; 74/70), loudspeaker arrangement (localized; diffuse), and FM technology (traditional; VP*i*). The analysis revealed a significant main effect of SNR, F (2, 240) = 45.9, p < .00001, significant main effect of loudspeaker arrangement, F (1, 240) = 9.7, p = .006, and significant main effect of FM condition, F (1, 240) = 10.6, p = .004. In addition, there were significant interaction effects between loudspeaker arrangement and SNR, F (2, 240) = 12.1, p = .00009, between loudspeaker arrangement and FM condition, F (1, 240) = 7.2, p = .01, and between SNR and FM condition, F (2, 240) = 6.8, p = .003.

Post-hoc analyses on the main and interaction effects were conducted with the Tukey-Kramer Multiple Comparisons Test. First, the post-hoc analysis on SNR revealed significant differences (p < .05) in the comparisons between all three SNRs, with the best performance in the 65/55 dB condition followed by the 70/63 dB and 74/70 dB conditions. Second, significantly better performance (p < .05) was measured in the diffuse noise loudspeaker arrangement when compared to the localized noise conditions. Finally, across all conditions, performance with VP*i* was significantly better (p < .05) than performance with the traditional FM.

Post-hoc analyses on interaction effects on loudspeaker arrangement and SNR suggested that performance in the 74/70 localized noise condition was significantly worse (p < .05) than performance in all remaining conditions. Additionally, performance in the 74/70 diffuse condition was significantly poorer (p < .05) than all remaining conditions, with the exception of the 74/70 localized noise condition. Finally, performance in the localized and diffuse 65/55 conditions were significantly better (p < .05) than all 74/70 and 70/63 conditions.

Post-hoc analyses on the loudspeaker arrangement versus FM condition showed that performance with the traditional FM in the localized noise conditions were significantly worse (p < .05) than traditional FM in diffuse noise and VP*i* in diffuse or localized noise conditions. The analysis on the SNR by FM condition interaction effect suggested that performance in the 74/70 condition with traditional FM was significantly poorer (p < .05) than all remaining conditions. No other significant differences (p > .05) were detected when comparing conditions within the same noise levels.

Acceptable noise levels (ANL). All but one young child were able to complete the ANL condition. Average MCLs, BNLs, and ANLs are shown in Figure 7. First, the participants' ANLs across three conditions (hearing aid alone; traditional FM; VP*i*) were analyzed with a one-way RM ANOVA. According to this analysis, there was a significant main effect of condition (F [2, 57] = 22.5, p = < .00001) with post-hoc analyses suggesting significant differences (p < .05) across all conditions. The best (lowest) ANL was measured in the VP*i* condition, followed by traditional FM and hearing aid alone. To further examine the differences in ANL across the conditions, a second ANOVA was conducted to examine if these results were due to significant changes in MCL or BNL levels. This two-factor RM ANOVA revealed no significant main effect of measure (i.e., MCL vs. BNL; F [1, 114] = .28, p = .60), but a significant main effect of test condition (F [2, 114] = 12.1, p = .00009). Additionally, there was an interaction effect between measure and test condition (F [2, 114] = 15.3, p = .00002). Post-hoc analyses suggested that the hearing aid alone condition resulted in significantly higher MCLs and BNLs across the two measures

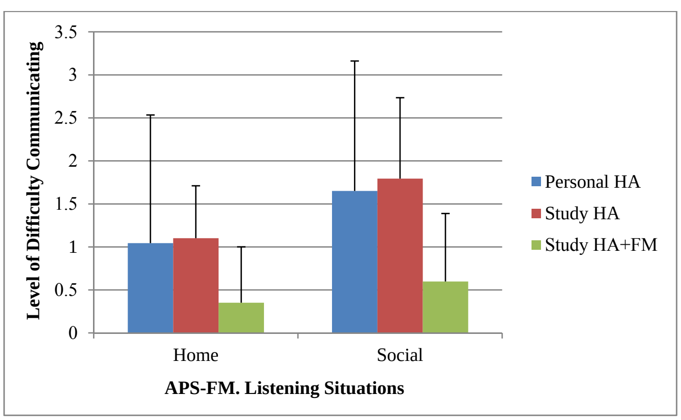

Figure 5. Average participant ratings on the Auditory Performance Scale for FM (APS-FM). *Note.* On the scale, 0=can do this well; 1=small difficulty; 2=some difficulty. HA=hearing aid; FM=frequency modulation system. Vertical lines represent one standard deviation.

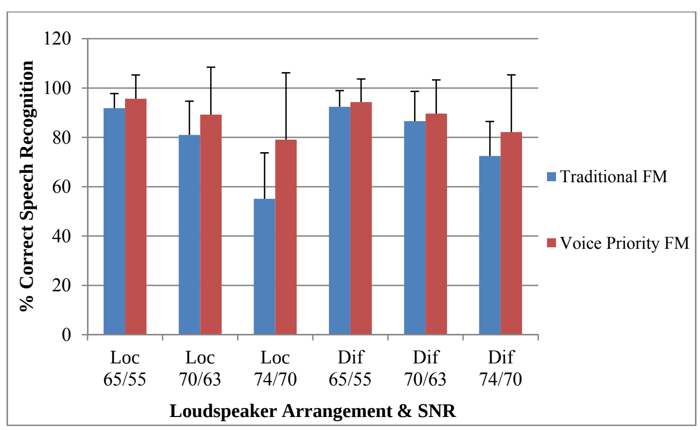

Figure 6. Average speech-recognition performance in noise on the Hearing in Noise Test. *Note.* Numbers represent speech/noise intensities. Dif=diffuse noise; Loc=localized noise; FM=frequency modulation system; vertical lines represent one standard deviation.

when compared to the traditional FM or VP*i* levels. The post-hoc analysis on the interaction effect revealed the most important findings. First, the hearing aid alone MCL was significantly higher in intensity ($p < .05$) than all remaining conditions. Second, the MCL and BNL with the traditional FM did not differ significantly ($p < .05$). Finally, between the two VP*i* conditions, the average BNL was significantly higher ($p < .05$) than the MCL, which suggested that participants could tolerate the most background noise with VP*i*.

Speech intelligibility ratings. All 20 children were able to complete the SIR. The average intelligibility ratings on a 0% to 100% scale across the three listening conditions are shown in Figure 8. A one-way RM ANOVA suggested a significant main effect of condition (F [2, 57] = 118.9, $p < .00001$), and post-hoc analysis suggested that children provided significantly higher ($p < .05$) intelligibility ratings for the traditional FM and VP*i* conditions relative to the hearing aid alone condition, with no significant differences ($p > .05$) between the two FM conditions.

Discussion

Subjective Measures

Participant C.H.I.L.D. On average, children rated the FM system significantly higher than their personal aid alone in every listening situation and the FM system significantly higher than the study aid alone in noise and at a distance. Specifically, these results suggest that the FM system was beneficial in quiet, in noise, in social situations, at a distance, and with media, such as televisions, computers, and personal audio devices (i.e., MP3 player).

Family C.H.I.L.D. Average parent ratings for the FM system were significantly higher than those for the personal aid alone and the study aid alone in every condition. In addition, the study aid alone was rated significantly higher than the personal aid for media, in social situations, in noise, and at a distance. As a result, parents perceived a high level of listening benefit when children were using the FM system as well as the study aid in most situations. One interesting aspect of the ratings was that parents rated the study hearing aids alone higher than the personal aids in most situations. The children had hearing aids from various manufacturers including Oticon, Phonak, Unitron, and Starkey, and the examiners were in no way involved in these fittings and were not aware of the fitting strategy used. Therefore, the difference between personal and study aids could be related to the prescriptive strategy (DSL v5 in this study; unknown for personal aids) or the fitting approach in the present study with real ear measures. The investigators do not know whether the personal aids were fit and verified using real ear measures. Additionally, parents may have comingled perceptions about the study aids alone and the study aids with the FM system, thus inflating the study aid alone ratings. If this occurred, some parents may have rated the study aid alone higher because of enhanced SNR and the Super Silencer function that was active when the FM system was in use. As stated previously, Super Silencer aims to reduce circuit noise, which would be audible to children with some low-frequency residual hearing when listening in quiet situations with the FM system. Additionally, the reported child and parent benefit from the devices could be simply because they were using a new device (i.e., Halo effect; Thorndike, 1920). At the same time, the subjective ratings are well-supported by the significantly improved behavioral performance on three separate measures.

APS-FM. The results on this subjective measure were similar to what was found on the participant and parent C.H.I.L.D. scales. The participants reported significantly less difficulty hearing at home and in social situations when using the FM system relative to the study and personal aids. On this scale, however, the study aid was not rated higher than the personal aid. This finding may be related to the different situations on the two questionnaires as well as the lengthier, more detailed description of the listening situations on the C.H.I.L.D.

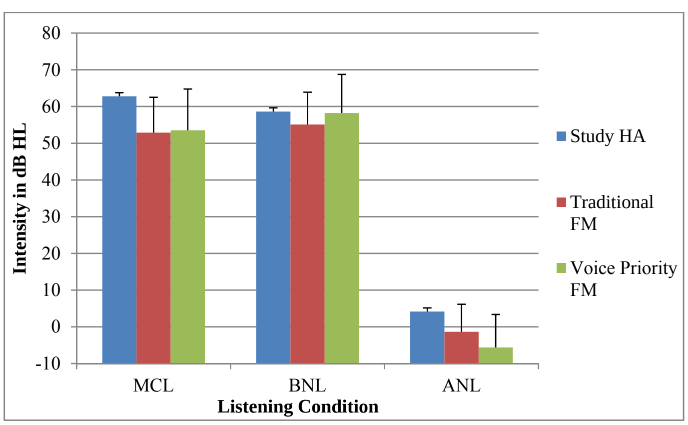

Figure 7. Most comfortable listening levels (MCL), background noise levels (BNL), and acceptable noise levels (ANL) averaged across participants. *Note.* Vertical lines represent one standard deviation.

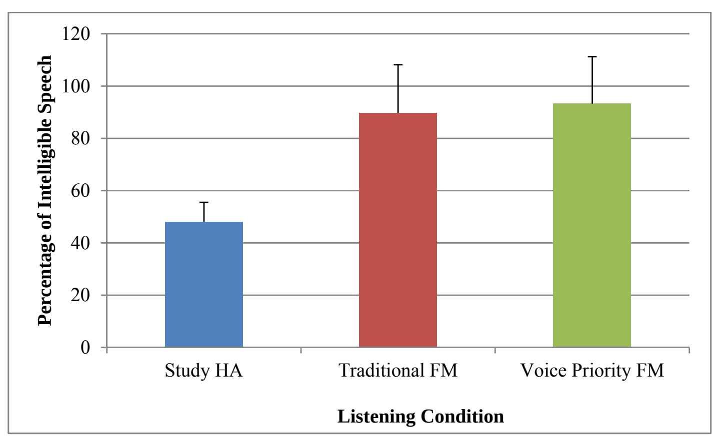

Figure 8. Participant-rated percentage of speech understood from passage on the Revised Speech Intelligibility Rating (SIR) test. *Note.* Vertical lines represent one standard deviation.

Behavioral Measures

Speech recognition in noise. Performance across the speech-recognition conditions yielded several notable findings related to the effects of SNR, noise location, and the benefit of VP*i* in FM systems. First, as expected, performance across all FM conditions declined significantly as the SNR declined and noise level increased. Each post-hoc comparison between SNRs yielded significant differences. Similar declines in speech-recognition performance in increasing noise levels were reported in previous studies with FM systems (Thibodeau, 2010; Wolfe et al., 2009).

Second, there was a significant effect of loudspeaker location on speech-recognition performance across all FM conditions despite the fact that the same intensity levels were used between the diffuse and localized conditions. The localized noise loudspeaker arrangement resulted in poorer speech-recognition performance than the diffuse noise, which has been used previously in classroom-based speech-recognition studies on adaptive FM systems (Thibodeau, 2010; Wolfe et al., 2009). In the present study, the largest deficit due to localized noise occurred at the 74/70 dBA signal levels with the traditional FM system where an average difference of 17% between diffuse and localized noise was found. This novel finding, in particular, provides evidence that localized noise is highly detrimental to children's speech-perception performance, and identification of this type of noise in a classroom may provide further support toward a child's need for hearing assistance technology with adaptive FM gain.

Third, across all SNR conditions and loudspeaker arrangements, performance was significantly better with VP*i* when compared to scores with the traditional FM. As the noise level increased above 65 dB SPL, VP*i* in the hearing aid systematically increased up to an additional 13-dB emphasis for the FM signal. Therefore, the greatest benefit from VP*i* occurred in at the highest noise level (74/70) with a difference between traditional FM and VP*i* of 27%. Even with the less detrimental diffuse noise arrangement, the benefit of VP*i* over traditional FM was 10%. In fact, one of the most notable findings on the speech-recognition testing was the fact that the loudspeaker arrangement had less of an effect on a listener's speech recognition when VP*i* was used. Specifically, at the highest noise level (74/70 dBA), the percent correct difference between localized and diffuse scores for traditional FM was 17% and for VP*i* was 3%. Although less noteworthy, differences between localized and diffuse scores were also found in the moderate noise condition (70/63 dBA) with a 6% difference for traditional FM and a 0.4% difference for VP*i*. The benefit achieved from VP*i* (up to 27%) in the present study was comparable to the benefit achieved in a previous study (Thibodeau, 2010) on Phonak systems with adaptive FM gain (36%). The percent-correct differences between these two studies may be explained by device differences including compression characteristics of the hearing aids, compression and gain settings within the FM systems, and the location where the adaptive gain was determined. In the Thibodeau (2010) study, the gain was determined at the location of the FM transmitter while in the present study, the gain was determined at each child's hearing aid. In addition, the goal of the Oticon system is to quickly restore audibility of others through the hearing aid when the teacher/parent is not speaking; this is achieved with the fast attack and release times with VP*i* functionality. Also, differences between studies could be due to methodological variances including classroom environments, stimuli (HINT vs. HINT-C), SNRs, and the younger sample used in the present study. Overall, the results of the speech-recognition testing suggested that VP*i* significantly improves performance relative to a fixed-gain FM system, particularly in high levels of noise that is localized and directed toward the participant's head.

Acceptable Noise Levels (ANL). The participants' ANLs were better (lower) with VP*i* when compared to the study hearing aid alone and the traditional FM system. Additionally, the ANL for the traditional FM was better than that of the hearing aid alone. An additional analysis revealed that these differences were primarily due to acceptance of an increased background noise level (BNL) in the FM conditions.

The ANLs obtained in the present study are much better than those obtained in previous investigations (Freyaldenhoven & Smiley, 2006; Moore, Gordon-Hickey, & Jones, 2011) because of the spatial separation of the speech (0 degrees) and noise (180 degrees) loudspeakers in the present study. For example, Freyaldenhoven and Smiley measured an average ANL of 11 dB (range -3 to +22 dB) in children with normal hearing. Therefore, the average ANL of +4 dB for the children in the aided condition in the present study makes sense given the substantial listening advantage of separating the speech and noise sources. Both FM settings resulted in negative ANLs, which suggest that when the FM system is in use, participants could tolerate a higher background noise level than speech level. Because VP*i* increased the FM emphasis as the examiner increased the BNL, the participants could tolerate a slightly higher BNL (and lower ANL) when compared to the traditional FM condition. These results suggested that children may be more comfortable in higher noise levels when using VP*i* over a traditional FM system.

Speech Intelligibility Ratings (SIR). The results of the SIR showed that both FM conditions provide equal intelligibility for a speech passage at a fixed SNR when compared to a rating with the hearing aid alone. The examiners purposefully found the dB SNR for 40 to 50% intelligibility with the hearing aid alone and then completed the traditional FM and VP*i* conditions at the same fixed SNR. The lack of difference between the FM conditions for this measure was likely related to the fixed SNR. Future investigations may include increasing levels of noise to examine potential FM differences at varying SNRs.

Study Limitations

As stated earlier the first two potential limitations in this study relate to (1) the potential for comingled perceptions about the study aids alone and the study aids with the FM system and (2) the potential of inflated ratings because they were using a "new" device. Another limitation of the questionnaires relates to the inability to verify the validity of the subjective responses. Although the average use time of the FM system is reported in Table 1, the investigators could not determine exactly how long and where the FM system was used or how these factors potentially influenced participant and parent ratings. The ability to adequately judge benefit for the FM system across a variety of listening conditions could be different for children who used the FM systems for a longer versus a shorter period of time.

Another limitation of the study was that children were only acclimatized to the hearing aid and FM system with VP*i* and not the traditional, fixed-gain FM system. However, an acclimatization effect was not expected because the investigators have previously examined this potential effect with FM systems used by adolescents and adults, and there were no significant changes in speech-recognition performance in noise after a four- to six-week trial period with an FM system (Schafer, et al., in press; Schafer, Romine, Huynh, Jimenez, 2012-c).

Conclusions

The behavioral measures in this study showed significant benefit of the FM system with VP*i*. Specifically, speech-recognition performance in noise was significantly better with VP*i* as compared to a traditional FM, especially in conditions with high-level, localized noise. The ANLs were significantly better with both of the FM settings over the study hearing aids alone. Further, the FM system with VP*i* resulted in better ANLs than the traditional FM due to an increased acceptance of background noise levels. The SIRs with both FM settings were significantly higher than the SIR with study aid alone. Parent and child questionnaires yielded similar findings to the behavioral results, with significantly higher ratings for the FM system with VP*i* over the study and/or personal hearing aids alone. In summary, the FM systems with VP*i* provided superior performance and subjective ratings relative to traditional, fixed-gain FM systems or hearing aids alone.

Acknowledgements

Funding for this study was provided by Oticon Denmark. The funds were used to compensate participants for their time, efforts, and mileage to the test center and to fund a research assistant. The primary investigator received no monetary compensation related to the study.

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Hearing Conservation Programs for Drum and Bugle Corps: Implications for Educational Audiologists

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The purpose of this study was to evaluate the effectiveness of a comprehensive hearing conservation program for increasing noise awareness and willingness to wear hearing protection devices (HPDs) among drum and bugle corps members. A hearing conservation program was provided to drum and bugle corps percussionists including the use of otoacoustic emission screenings. A questionnaire was administered pre- and post-intervention to assess changes in knowledge and attitude towards hearing conservation and HPD use. Exposure to the conservation program led to a significantly positive change in percussionists' attitudes towards HPDs. Educational programming was also effective in establishing more realistic expectations and addressing misconceptions about noise exposure, damage, and treatment. Training was also effective in helping participants understand ways to reduce exposure. Simulations of hearing damage, use of otoacoustic emission (OAE) screening results and increasing awareness about hearing protection designed specifically for musicians were effective in increasing the likelihood of HPD use. Educational audiologists are uniquely positioned to develop positive relationships with band directors/instructors and students within their school district. In that role, they can provide a comprehensive hearing protection program through programs like Adopt-a-Band (Etymotic, n.d.) or by working with the program to create an individualized program.

Background and Introduction

Many people are exposed to noise on a daily basis, but none are more at risk than those whose occupations and lifestyles revolve around noise or loud music. Excessive, long-term exposure to loud sounds can lead to permanent hearing loss, and an estimated eleven million individuals suffer from some degree of noise-induced hearing loss (NIHL) (Bogoch, House, & Kudla, 2005; Crandell, Mills, & Gauthier, 2004). Recent reports suggest that NIHL is becoming a concern for people at increasingly earlier ages; 16-20% of adolescents/young adults (ages 12-19) have some kind of hearing loss. Researchers have speculated that there is a link between the increase in hearing loss and regular exposure to excessively loud music (Shargorodsky, Curhan, Curhan, & Eavey, 2010). Groups of adolescents and young adults with especially high noise exposure include drum and bugle corps (drum corps) and marching band members, who are regularly exposed to intense noise during the course of their rehearsals and performances.

Drum and bugle corps are made up of elite musicians and athletes who spend an entire summer (80+ days) practicing for as long as 14 hours a day in order to perform in different cities across the country (Drum Corps International, n.d.). Marching band students also participate in long days of rehearsals during band camps each summer and into competition season in the fall months. Additionally, some students also participate in indoor marching percussion ensembles during the winter months. Upwards of 5,000 young people, ages 13 to 22 years, participate in Drum Corps International (DCI) member corps each year; many more individuals participate in marching bands around the country. Researching the habits and attitudes of drum and bugle corps members may provide insight into the knowledge that marching band members have about hearing conservation. Additionally, over half of the participants plan to become music educators (Drum Corps International, n.d.), and it is possible that attitudes and behaviors developed during their time with the group will likely be conveyed to future students.

For musicians, sound exposures can range from 72 dBA while playing an acoustic guitar to 115 dBA while playing a snare drum. Unlike steady-state noise in industrial settings, music intensity varies greatly over time, with sound levels that peak as high as 120 dB (National Institute for Occupational Safety and Health [NIOSH], 1998). In an analysis of noise exposure in drum and bugle corps members, Presley (2007) found that percussionists are exposed to average sound levels ranging from 94.4 to 103.1 dBA, and most exposures ranged from ten times to as great as 94 times the recommended dose of noise in the course of a 12 hour rehearsal. According to Presley (2007), hearing protection device (HPD) use was limited in this population.

While there is substantial literature regarding the dangers of noise exposure and the increasing incidence of noise induced hearing loss in the young adult population, less is known about effective approaches for teaching children and young adults how to prevent hearing loss and how to detect signs and symptoms of hearing problems. Children have limited knowledge about hearing conservation in general, but are especially naïve in their knowledge of noise hazards, which may be the most common barrier to protective actions (Chen, Huang, & Wei, 2008). Professional musicians, however, appear to be aware of long-term hearing damage and directly report symptoms related to over-exposure (Curk & Cunningham, 2006) including tinnitus and hearing problems. As many as 27% of musicians report these problems (Laitinen, 2005; Presley, 2007) and these symptoms have also been linked to increased stress levels and sensitivity to noise (Laitinen, 2005). While some musicians indicate awareness of the dangers of noise exposure, others continue to believe that damage will not occur following significant exposures to loud sounds (Bogoch et al., 2005).

Hearing protection use in musicians is low. None of the participants wore HPDs in Presley's 2007, and only 13% reported daily use in Jin, Nelson, Schlauch, & Carney (2012) with more than half of the marching band members reporting that they never wore HPDs. In the latter study, HPD use was greater in percussionists when compared to the rest of the marching band. Curk and Cunningham (2006) determined that almost half of study participants reported that they did not wear HPDs when performing, but approximately two-thirds did wear them while practicing.

Musicians have expressed concern that their own performance could be adversely affected by HPDs, and were concerned about their ability to hear other players (Chesky et al., 2009). Other barriers include unpleasant sensation/discomfort, difficulty with insertion, problems with communication (loss of speech intelligibility), cosmetics, cost, and existing hearing loss that exacerbated the listening situation (Bogoch et al., 2005; Chesky et al., 2009; Laitinen, 2005). Therefore, Chesky et al. (2009) advised that HPDs be recommended only after attempts to reduce or eliminate noise exposure in other ways had been exhausted. In contrast, several other studies have supported education and provision of high-quality hearing protection (Jin et al., 2012; Palmer, 2009; Schmuziger et al., 2006).

Hearing conservation programs do exist for school-age children and include programs such as Dangerous Decibels and Wise Ears, among others, but are not generally required (Blessing, 2008; Griest, Folmer, & Martin, 2007). Interestingly, none of the above programs are directed towards the prevention of music induced hearing loss, especially for young musicians. At the time of this study, there were only a few new programs being introduced, including one targeting school-age musicians (Palmer, 2009) and another in college schools of music that was developed through the National Association of Schools of Music and the Health Promotion in Schools of Music project to focus on health of musicians (Chesky, 2011). Data on the efficacy of these programs were unavailable at the time of this study.

Throughout the literature, the general consensus is that more hearing conservation programming is needed, especially for musicians. To increase the effectiveness, several studies have suggested that experience with hearing symptoms, simulated or real, is what is more critical for attitude and subsequent behavior change (Laitinen, 2005; Widen et al., 2009). In addition, incorporating hearing screenings, using dosimeters and "dose percentages", participating in interactive discussions, and including personal testimonies from musicians who suffer from hearing loss are beneficial (Curk & Cunningham, 2006; Palmer, 2009; Rawool & Colligon-Wayne, 2008; Widen et al., 2009). Presumably the more engaged the audience, the better they will be able to understand the significance of the risks they take and the consequences associated with their behavior, which will subsequently encourage HPD use as well as other protective measures (Rawool & Colligon-Wayne, 2008; Widen et al., 2009).

Limited research exists to evaluate the need for and effectiveness of hearing conservation programs for young adults involved in musical and athletic activities like drum and bugle corps. The purpose of the current study was to examine the effects of a hearing conservation program, including otoacoustic emissions screenings, on the attitudes of percussionists in drum and bugle corps. In doing so, we sought to answer the following research questions: (1) What are the currently held general and specific attitudes towards hearing conservation in drum corps percussionists?; (2) What levels of knowledge do they have regarding noise exposure, long-term exposure and hearing loss, and the use of HPDs as it relates to drum corps? We hypothesized that drum corps members have limited awareness of NIHL, hearing conservation, and the use of hearing protection, and that a hearing conservation program targeted at these percussionists would result in an increased knowledge about NIHL and a positive change in attitude about wearing HPDs. Additionally, we evaluated what areas of the hearing conservation program were particularly beneficial and what areas needed further research and development.

Methods

Participants

Participants were recruited from two Midwestern drum and bugle corps. Additional drum corps were invited to participate, but declined due to time and travel constraints. Seventy-four participants over the age of 18 enrolled in the study while 69 participants completed the entire study (93% return rate). Age of participants was limited to those over 18 years of age due to difficulty obtaining parental consent when the prospective participant was on tour. Participants consisted of marching members (those actually performing) and their instructors. Marching members ranged from 18 to 22 years of age ($m = 20.2$ years), while instructors' ages ranged from 22 to 31 years. Most (81%) of the marching members were male. Marching members represented a variety of percussion instruments: snare drums (n=15), quad/tenor drums (n=10), bass drums (n=10), cymbals (n=6), and front ensemble/pit percussionists who played a variety of instruments including tympani, marimba, bells, xylophone, and electronic keyboard (n=28). Additional demographic information was obtained regarding the participants' hearing health background and history of HPD use (Table 1).

Construction of Questionnaire

The pre-and post- questionnaires used in this study were adapted from two separate published surveys. Widen

Table 1. Summary of Participants' Experience with Hearing Healthcare

Question	% of Participants
Has had previous hearing test	62
Has worn hearing protection devices (HPDs) before	97
Has used foam earplugs	75
Has used non-foam earplugs	39
Has used earmuffs	19
Has used high fidelity earplugs (ETY-plugs™)	28
Has used custom Musicians Earplugs™	25

and colleagues (2009) developed the *Hearing, Use of Hearing Protection and Attitudes Towards Noise Among Young American Adults Questionnaire* for young adults, and Chen and colleagues (2008) designed the *Elementary School Children's Knowledge and Intended Behavior Towards Hearing Conservation Questionnaire* for use with elementary school children. Additional investigator-developed questions were added to address attitudes and knowledge specific to drum and bugle corps musicians. The questions were presented in random order and this order differed between the pre-and post- intervention surveys to reduce bias in completing the forms. The post-intervention survey included three additional questions to assess the effect of the hearing conservation program on HPD use. (Survey provided in Appendix A).

Questions on both pre- and post-intervention surveys were constructed to obtain both negative and positive type responses. A five-point Likert Scale was used with response choices coded as (5) Totally agree, (4) Partly agree, (3) Neutral, (2) Partly Disagree, and (1) Totally Disagree. (See Table 2 for Focus Questions)

Hearing Conservation Programming

The hearing conservation program was multi-faceted. Each participant received an Otoacoustic Emission (OAE) screening, which is explained in the following section. The OAE results were used as part of the hearing conservation program to allow for discussion with corps members about NIHL, the potential to identify outer hair cell damage before it can be seen on a hearing evaluation, and to support the need to wear hearing protection. The remainder of the program consisted of an interactive power point presentation and the use of a dosimeter.

Otoacoustic emissions screening. Otoacoustic emissions (OAEs) are generated by the outer hair cells in the cochlea in response to an acoustic stimulus. Specifically, distortion product OAEs are generated when the outer hair cells are stimulated by two pure-tones simultaneously; the response generated by the outer hair cells is a combined tone at frequencies arithmetically related to the stimulating pure tones (2f1-f2) (Dhar & Hall, 2012). OAEs are sensitive to cochlear damage related to noise and ototoxicity and are, thus, used frequently for monitoring cochlear status in hearing conservation programs (Muller, Dietrich, & Janssen, 2010; Pride & Cunningham, 2005). For the purposes of this study, OAE screenings were conducted using the Ero-Scan™ Pro (Maico, n.d.), which is resistant to ambient noise up to 70dB. Testing was completed pre-intervention for most participants. The OAE protocol was set up to test using distortion product otoacoustic emissions (DPOAEs) at seven frequencies: 2000, 3000, 4000, 5000, 6000, 8000, and 10,000 Hz. The stimuli were presented using an intensity level (L) of 65 dB SPL for L1 and 55 dB SPL for L2, which corresponds to f1, and f2 in the arithmetic equation mentioned above. This is the most common stimulus paradigm used in clinical DPAOE measurements (Dhar

Table 2. Sample of Prompts Used in Hearing Conservation Survey, Subdivided by Perspective

A4: The sound level in my drum corps is comfortable to me.
A5: Noise and loud sounds are natural parts of our society.
A7: I need to hear everything in my environment, regardless of how loud.
B5: Drum corps and marching percussion groups should have some rules or regulations about the use of hearing protection devices in order to prevent hearing loss.
B8: I am prepared to give up activities where the sound level is too loud.
B9: I am prepared to do something to protect my hearing.
C4: Hearing will not be harmed by listening to an iPod or playing music at intense sound levels for extensive amounts of time.
C7: If I can't tell I have a hearing problem, then I probably don't have any hearing loss.
C10: I know when it is no longer safe to listen to loud sounds and use hearing protection.
D11: Using hearing protection will make it hard to hear instruction from instructors on the field and in the (press) box.
D12: If I wear hearing protection, I will play harder.
D13: If I wear hearing protection, I will experience pain and tension from playing too hard.
D14: If I wear hearing protection, there is no way to overcome this way of playing louder and causing injury.
D15: I will have difficulty hearing others around me as clearly.
D16: I will have difficulty hearing the other instruments in the corps if I wear hearing protection.
D17: I think hearing conservation and hearing protection devices should be a concern in drum corps.
Post Intervention 1: Knowing about my options for earplugs designed for musicians, I am more likely to wear earplugs.
Post Intervention 2: After learning the results of my tympanometry and OAE screening, I am more likely to wear hearing protection regularly.
Post Intervention 3: After hearing simulations of hearing loss and tinnitus, I am more likely to wear hearing protection regularly.

& Hall, 2012). A "refer" result was obtained when one or more frequency's emissions did not exceed a 6 dB signal-to-noise ratio (SNR). When participants referred on the OAE screening, the Ero-Scan™ Pro automatically conducted a tympanometry screening using a 226 Hz probe tone to evaluate the presence of middle ear or ear canal pathologies that might confound OAE results. For the tympanometry screening, a "refer" was assessed if peak pressure was significantly negative (< -150 daPa) or significantly positive (> +50). A referral was also assigned when peak compliance was less than 0.1mL or greater than 1.5 mL. These tympanometry referral guidelines were the default settings in the Ero-Scan™ Pro device.

Approximately 30% of participants passed the OAE screening in both ears; 30.4% passed in the right ear only, and 10.1% passed in the left ear only. Twenty-nine percent failed both ears. Of 147 ears tested, 75 (51%) ears referred. Further analysis of OAE results indicated that 35 ears referred at only one frequency, 20 ears referred at two frequencies, four ears referred at three frequencies, nine ears referred at four different frequencies, and seven referred at five frequencies. No ears referred at more than five frequencies.

Of the 75 ears that referred on OAEs, only eight ears referred on tympanometry results as well. Three participants had significant negative pressure; five ears had peak compliance that exceeded the maximum level suggesting hypermobile eardrum movement. Additionally, one ear yielded a small ear canal volume, which may be attributed to cerumen impaction or a blocked probe. Tympanometry results were unavailable for one ear.

Educational portion and noise dosimetry. The educational portion of the hearing conservation program consisted of a 45 minute interactive Microsoft PowerPoint presentation (Appendix B). The presentation targeted four main areas: general introduction to the ear and hearing, noise exposure and long term effects, and safe listening techniques including hearing protection device use and noise dosimetry. Noise dosimeters were also employed during rehearsal on a cymbal player for one group and a snare player for another group in order to further support the need for hearing conservation in a "see it to believe it" approach. The dosimeter is a small device used to measure sound levels over a period of time and is particularly useful in environments when duration and intensity varies. It is used to determine the "dose" of noise during the exposure period. These results, including dose percentages, were shared with the group following rehearsal and were consistent with results obtained by in the Presley study (2007).

Procedures

The study was explained to participants and consent forms, along with the pre-survey, were disseminated among all participating members over the age of 18. Consent forms and pre-surveys were collected at the time of the OAE screening or prior to the educational portion (if the screening was unable to be completed before the presentation). Due to the nomadic nature of the drum corps, most of the forms were completed on the bus as the group traveled to the next housing/rehearsal site. OAE screenings were completed in a quiet hallway during the participant's breakfast, lunch, dinner, and snack breaks. The educational presentation occurred during a meal break in order to avoid rehearsal conflicts. Following the presentation, each participant was given a pair of EtyPlugsÔ which are high-fidelity hearing protection that are designed to provide equal reduction in sound levels across all frequencies without adversely affecting speech or music clarity (Etymotic Research, n.d.), and one volunteer participant was provided with a dosimeter to wear for the duration of a rehearsal day. Following the presentation, the participants were given one week to return the survey. No rehearsal time was disrupted during the study, recognizing the elite status of these performers and their need to maintain a consistent rehearsal schedule.

Data Analysis

For inclusion in data analysis, complete data on both pre- and post-intervention survey questions were required. Data were analyzed using the Chi-Square "Goodness of Fit" Test (Lowry, 2011). The Chi-Square analysis was conducted to determine statistical significance between pre- and post- survey responses.

Results

Due to the large pool of data collected in this study, only significant results and those that directly corresponded with the research questions will be presented here.

General results of the questionnaire suggested a significant positive change in attitude toward HPDs from pre- to post-intervention (N = 68, p= .021). No individuals declared a "negative" attitude toward hearing protection in pre- or post-results; seven percent were "somewhat negative" pre-intervention while only four percent maintained a somewhat negative attitude post-intervention (Table 3).

Beyond basic attitude change, this study targeted three areas of participant knowledge: (1) noise exposure; (2) NIHL, damage, and treatment; HPDs. Several findings were statistically significant from pre- to post- intervention. These findings are highlighted in the following sections.

Noise Exposure

Prior to intervention, most participants (97%) considered noise and loud sounds to be a natural part of our society. That perspective was changed significantly post-intervention, χ^2 (1, N =67) = 6.32 p =.01; however, the percentage of participants who believed that noise was a natural part of society remained high (91%). Most individuals (69%) also expressed an initial opinion that they need to hear everything in their environment, regardless of how loud. Post-intervention, only 46% maintained that negative belief following intervention, which was a significant change, χ^2 (1, N = 68) = 14.24, p < .001.

More than two-thirds (71%) of participants felt that adjusting

Table 3. General Attitudes towards Hearing Conservation and Hearing Protection

General Attitude	Pre-intervention n (%)	Post-Intervention n (%)
Positive	34 (50%)	41 (60%)
Somewhat Positive	15 (22%)	17 (25%)
Neutral	14 (21%)	7 (10%)
Somewhat Negative	5 (7%)	3 (4%)
Negative	0 (0%)	0 (0%)

the volume of the iPod louder could not make the noise go away when the environmental noise is too high. A significantly greater number of participants (91%) agreed with the statement following intervention, $\chi^2(1, N = 69) = 12.83, p < .001$). Seventy-eight percent of participants responded positively to the statement: If we have to stay in a noisy environment, moving to quieter places would decrease the harmful effects of noise prior to intervention. As a result of the intervention, that percentage significantly increased to 90%, $\chi^2(1, N = 68) = 5.3, p = 0.02$.

Noise Induced Damage and Treatment

Prior to educational intervention, over half of the participants (56%) were unaware that medication and surgery cannot cure hearing loss. This was the most significant improvement post intervention, $\chi^2(1, N = 66) = 18.84, p < .001$), with 83% acknowledging after the training session that medication and surgery is not a resort if hearing is not protected. Twenty-two percent were not aware prior to intervention that they could have hearing loss without noticing, which decreased to 10% following intervention, $\chi^2(1, N = 68) = 4.81, p = 0.03$.

Hearing Protection Use

Prior to the educational program, nearly half (48%) of the participants did not feel hearing protection was necessary when at a rock concert, dance, or sporting event. That number significantly decreased to 35% following intervention, $\chi^2(1, N = 69) = 4.2, p = 0.04$. A common complaint seen as a barrier to HPD use was the difficulty hearing instructions on the field and in the press box during rehearsals. Three-quarters of participants (76%) agreed, prior to intervention, that HPD use causes difficulty hearing instruction from instructors on the field and in the press box during rehearsals, but that number significantly decreased to 64% post intervention, $\chi^2(1, N = 67) = 4.62, p = 0.03$.

When provided with further questions regarding these common complaints identified by Chesky and colleagues (2009), all responses improved post-intervention, while only one question demonstrated significant improvement post-intervention. For questions and results, see Table 4. One of the most common complaints was that individuals wearing hearing protection will play harder and as a result experience pain and tension leading to overuse injuries. Pre-intervention, 16% held that concern, while 9% remained concerned post-intervention (see Table 4). When asked whether hearing conservation and HPDs should be a concern in drum corps, 69% agreed while that number increased only slightly post-intervention (70%).

General Attitudes Based on Outcomes of Training

Three additional questions in the post-intervention survey assessed the effectiveness of the training on HPD use. Participants expressed that they were more likely to wear HPDs as a result of being educated about the options regarding hearing protection designed for musicians (87%), learning the results of their individual OAE screening (90%), and experiencing simulations of tinnitus and hearing loss (86%).

Discussion

Noise Exposure

The survey results indicated that many young musicians have received limited education regarding the dangers of noise exposure. The educational program, in general, appeared to positively impact attitudes towards noise and helped to build a basic knowledge base regarding the dangers of noise exposure. The program also helped convey the importance of using techniques to reduce excessive noise exposure. The next step may be to help music students advocate for the use of treated acoustic environments where possible. This may be more difficult for drum corps and marching band percussionists who are often restricted to untreated acoustic environments, such as gymnasiums and hallways, when unable to practice/perform outside. Educational audiologists can serve as valuable resource to help students and teachers address concerns about noise exposure, especially in less than ideal environments.

Noise Induced Damage and Treatment

Participants in this study had rudimentary knowledge of symptoms of noise induced hearing loss (NIHL) and prior to intervention, did not seem to understand the repercussions of this damage. Intervention resulted in an increased knowledge base; yet, it was not as effective as originally anticipated as only two main questions regarding noise induced hearing damage and treatment showed significant improvement from pre- to post-intervention.

Table 4. Hearing Protection Use

Question and Number of Overall Responses (*N*)	Pre-Intervention Positive Response n (%)	Post-Intervention Positive Response n (%)	Chi-Square Statistic χ2 *p value*
D11: Using hearing protection will make it hard to hear instruction from instructors on the field and in the (press) box. (*N* = 67)	16 (24%)	24 (36%)	4.62 *p* = .03*
D12: If I wear hearing protection, I will play harder. (*N* = 66)	41 (62%)	44 (67%)	0.4 *p* = .53
D13: If I wear hearing protection, I will experience pain and tension from playing too hard. (*N* = 66)	54 (82%)	60 (91%)	3.08 *p* = .08
D14: If I wear hearing protection, there is no way to overcome this way of playing louder and causing injury. (*N* = 67)	56 (84%)	61 (91%)	2.2 *p* = 0.14
D15: I will have difficulty hearing others around me as clearly. (*N* = 66)	20 (30%)	24 (36%)	0.88 *p* = .35
D16: I will have difficulty hearing the other instruments in the corps if I wear hearing protection. (*N* = 64)	18 (28%)	24 (38%)	2.34 *p* = .13
D17: I think hearing conservation and hearing protection devices should be a concern in drum corps. (*N* = 67)	46 (69%)	47 (70%)	0.02 *p* = .89

n = number of positive responses; *p* values significance: Tier 1 (*) *p*<0.05, Tier 2 (**) *p*<0.01, and Tier 3 (***) *p*<0.001.

Educational audiologists can introduce healthy listening habits when musicians are in their formative years of learning their instrument and developing their performance qualities. Young musicians need to be made aware of the implications of excessive exposure to loud noise and music. Also, as evidenced by the results of this study, it is imperative that they understand that treatment options are limited and less than ideal because medical treatments are not available to reverse the effects of noise induced hearing loss and hearing aids are not able to restore normal auditory perceptions, especially not fine musical nuances that these performers rely on.

Audiologists can also help place particular emphasis on acting early and consistently to protect hearing. In that way, young musicians may be more willing to address their hearing and safe listening as part of the learning process (Palmer, 2009).

Hearing Protection Use

The results revealed an increase in participants who agreed that earplugs are necessary in loud environments, but while study participants and percussionists seem to know they need to wear hearing protection, data on hearing protection wearing patterns in these groups is not commonly documented. In Chesky and colleagues' research (2009), drummers' reaction to the wearing of hearing protection devices was identified as a great concern. For that reason, part of the intervention was aimed at discussing some of the concerns related to these beliefs. All responses improved post-intervention, while only one question demonstrated significant improvement post-intervention. Intervention appears to have positively affected participants' beliefs regarding those concerns, although not significantly (see Table 4).

Addressing these specific misconceptions and concerns regarding HPD use within the educational programming appears to help change opinions and attitudes and instill healthy hearing habits. Further, instructors may benefit from coaching/specialized training in how to provide feedback to a musician about changes in performance with hearing protection in place. Again, educational audiologists can work with groups and individuals to find creative solutions to the barriers listed above..

General Attitudes Based on Outcomes of Training

An overwhelming majority of participants indicated that real-life experiences and exposure to hearing related symptoms (tinnitus and simulated hearing loss), along with earplugs designed for musicians and participating in hearing screenings increased the likelihood of HPD use. However, we are unsure as to what the follow-through rate is in this population. It would be helpful to determine whether the three conditions mentioned above truly lead to increased HPD use.

In general, because this topic is quite broad in scope for musicians, it seems possible that briefer, more focused educational pieces could be presented over the course of a season rather than all at once. These shorter educational sessions can be delivered in a prescribed order so that developing a knowledge base and a safe listening attitude can be developed over time. This study also identified the need to further emphasize the long-term effects of excessive noise exposure and the importance of regular hearing screenings to monitor hearing status and address auditory symptoms, such as tinnitus, diplacusis, and pain as early as possible. Educational audiologists can work with the music teacher/director to develop and schedule a series of presentations and hearing screenings over the course of the semester.

Finally, a majority of participants (70%) agreed that hearing conservation and HPDs should be a concern in drum corps, further supporting the need for developing and promoting the use of a systematic hearing conservation program for marching bands and drum corps. In recent years, the Drum Corps Medical Project (DCMP) was formed. It is a group of allied healthcare professionals who works together to support marching arts organizations with the goals of promoting health and wellness and preventing injury and illness for participants. With support from the audiology consultant on the DCMP and assistance from independent audiologists and educational audiologists in areas where these groups practice and perform, hearing conservation programs can be implemented in drum corps and as part of high school marching band programs to address the concerns identified in this study. It is within the scope of an educational audiologist to provide these types of programs to the music programs within the districts they serve.

Limitations

Several limitations must be considered when interpreting the findings of this study. A sample of convenience was used with a relatively small number of participants. Random selection of participants was not possible, which may affect the ability to generalize the findings. Further, the opportunities to recruit participants were limited by geography and the drum corps' tour schedules. Some instructors'/educators' beliefs may have been shared with participants that were not controlled for and were not expressed when these researchers were present.

The DPOAE screening was administered during subjects' break times, and therefore, each subject's time and duration of exposure to loud music prior to the screening was not controlled for, but was rather used as an informational measure to demonstrate the potential for noise/music induced damage.

The survey and presentation were created by the researchers to target the main areas that are typically part of a hearing conservation program and felt to be important features specific to the drum corps population. Because this was the first time the survey and presentation were used, the validity and reliability of the survey and appropriateness of presentation need to be evaluated and if necessary, revised to incorporate a health promotion theoretical framework.

HPDs were donated to the corps members as part of their participation (see Procedures) and as part of the hearing conservation presentation. Some participants had experience with these earplugs, while others did not which might affect initial responses to the questionnaires. They were distributed immediately following the presentation, and their use was neither encouraged nor discouraged. Therefore, use of HPDs or lack thereof following the presentation may have affected responses to the post-questionnaire.

Implications for Further Research

As a result of this study, several additional research questions have been developed in order to create a more efficient and accessible program that educational and clinical audiologists can administer with musicians in schools and private groups. These questions include: (1) What are the factors contributing to use and non-use of HPDs?, (2) What are the wearing patterns for these musicians and what keeps them from wearing HPDs all the time or at all?, (3) Are there specific barriers or problems that are the reasons behind non-use (e.g. difficulty hearing those around them playing or speaking, difficulty localizing sound, problems with discomfort, and problems with overplaying to overcome the attenuation, potentially resulting in overuse injuries)?, (4) What are the effects of HPD use on listening and playing in an ensemble, and what are some methods for overcoming any negative effects?, (5) Do instructors' attitudes and awareness adversely affect use of HPDs in students?, (6) How do we help instructors facilitate the adjustment period as these musicians become acclimated to wearing HPDs?

Uniform use of HPDs is desired to prevent noise induced hearing loss and damage in these populations. Etymotic Research, Inc. reports that EtyPlugs™ and custom musicians' plugs using filters also made by Etymotic Research, Inc. (ER-9, ER-15, ER-25) were designed to provide a flat response without rolling off high frequencies necessary for hearing and playing music (Etymotic, n.d.). These are also designed to reduce distortion and allow for more focused playing, but it is important that musicians understand what and how they are hearing through repetition. This comes from education, and instructors and students are equally charged with that responsibility. Working together with instructors and students may lead to safer playing, but might also lead to improved sound quality and performance techniques.

Conclusion

Hearing is one of the musician's most important assets, but it may easily be taken for granted. For drum corps and marching band participants and instructors, hearing conservation and use of hearing protection is a relatively new topic, and those that have used HPDs in the past may not have been aware of a variety of options for hearing protection. Furthermore, many have not experienced an educational program designed specifically for them and are unaware of the dangers of over-exposure to sound.

Overall, the findings of this study support the hypothesis that a comprehensive hearing conservation program would promote positive change in drum corps members' attitudes and improve drum corps percussionists' knowledge about the importance of hearing conservation and the use of high-fidelity hearing protection. The same may be possible for marching band students and participants in indoor, competitive percussion ensembles.

Long-term effort is required to achieve the "buy in" to the need for awareness surrounding hearing conservation and HPD use. As drum corps members are considered the "elite" of marching musicians, high school marching bands, in turn, look to these groups as role models and the same goes for middle school musicians to high school musicians. This "trickle down" effect may help promote earlier adoption of hearing protection and safe listening, especially if hearing conservation programs designed specifically for these musicians are available to all groups around the country, starting as early as elementary school and extending into middle and high school programs.

It is essential that these programs are specifically targeted for drum corps and marching bands. Currently, commercially available hearing conservation programs such as Dangerous Decibels (Dangerous Decibels, n.d.), ASHA's Public Service Program: "Listen to Your Buds" (ASHA, n.d.), and the American Academy of Audiology's "Turn it to the Left" program (AAA, n.d.) are not targeted for students in concert bands, marching bands, and drum corps who have unique needs related to musicianship and athleticism. Adopt-a-Band supported by Etymotic (n.d.) is perhaps one of the only programs that targets this specific population.

Educational audiologists have ready access to school programs, and they may be the most effective way to spread the word and make sure that every adolescent and young adult is made aware of the risk and the need for intervention. Educational audiologists can work as advocates through the Adopt-a-Band program and can help facilitate the ordering and distribution of hearing protection and also ensure that students understand the importance of hearing conservation practices by using the Adopt-a-Band educational material, by developing their own materials, or adapting others or using a combination of different methods. (contact the author for copies of the program used in this study). In addition, educational audiologists can initiate a relationship with the directors/instructors so that they can provide ongoing support to the programs and establish a positive relationship with the instructors and students to promote healthy hearing, ensuring that these musicians will be able to continue their musical aspirations throughout their lifetime.

Acknowledgements

The authors would like to acknowledge Etymotic Research, especially Gail Gudmundsen, Carolynn Travis, Dana Helmink, and Patty Johnson for their guidance with the educational portion of this study, donation of high fidelity ETYPlugs™, and loan of the EroScan™ Pro and Personal Noise Dosimeters for use in this study. They authors would also like to thank Dan Farrell, Program Director, and Rick Valenzuela, Executive Director, of the Phantom Regiment Drum and Bugle Corps, Rockford, IL, and Greg Orwoll, Director of Development, Colts Drum and Bugle Corps, Dubuque, IA for their support of this study. Additional thanks go to Max Mullinix, and Ellis Hampton, percussion instructors at the time of this study for their help with scheduling, logistics and support of the study.

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Appendix A. General assessment of knowledge towards noise exposure and hearing conservation, including hearing protection devices.

Pre/Post Survey

Initials: ________________________ Age: ___________

Drum and Bugle Corps Name: ____

Please check one: ________ Member ________ Instructor

Years in marching percussion (indoor and outdoor), down to the quarter year: _________

Have you ever had your hearing tested? Yes No

If yes, what were the results? ____

____

Have you ever worn hearing protection? Yes No

If yes, what type have you worn? (Circle all that apply):
foam ear plugs reuseable non-foam earplug earmuffs
non-custom filtered musicians earplugs custom musicians earplugs

In general, what is your attitude towards the use of hearing protection:
Positive Somewhat positive Neutral Somewhat Negative Negative

Please read and answer the following survey items completely. Please avoid interacting with others around you so that the opinions or information expressed are yours alone.

Perspectives on Noise Exposure and the potential impact:

	Totally agree (5)	Partly Agree (4)	Neutral (3)	Partly disagree (2)	Totally disagree (1)
Our ears can get used to loud music and noise. Our ears will then be protected and it makes no difference how long we stay in noisy environments					
If the environmental noise is too high, adjusting the volume of iPod louder could make the noise go away					
Drum corps is a noisy environment/activity					
The sound level in my drum corps is comfortable to me.					
Noise and loud sounds are natural parts of our society					
The sound level at dances, rock concerts and sporting events is not a problem					
I need to hear everything in my environment, regardless of how loud					
I don’t like it when it is quiet around me					

Perspectives on Hearing Protection:

	Totally agree (5)	Partly Agree (4)	Neutral (3)	Partly disagree (2)	Totally disagree (1)
Hearing could be protected by using earplugs or wearing earmuffs					
Putting cotton or tissue paper in ears is an effective method for protecting hearing from loud noise.					
If a sudden loud sound is heard, blocking ears with fingers would decrease the possible harmful effect from the loud sounds					
There is no way to protect my hearing when listening to my iPod.					
Drum corps and marching percussion groups should have some rules or regulations about the use of hearing protection devices in order to prevent hearing loss.					
Hearing protection affects my appearance and does not always work.					
I think it is unnecessary to use earplugs when I am at rock concert, dance, or sporting event.					
I am prepared to give up activities where the sound level is too loud.					
I am prepared to do something to protect my hearing.					

Perspective on long term effects of noise exposure and hearing loss:

	Totally agree (5)	Partly Agree (4)	Neutral (3)	Partly disagree (2)	Totally disagree (1)
Medication and surgery are able to cure hearing loss and bring it back to normal levels.					
Temporary hearing loss, which is caused by intense sounds, could be cured by taking some rest.					
Once hearing loss becomes permanent, hearing will not go back to normal even with a lot of rest.					
Hearing will not be harmed by listening to an iPod or playing music at intense sound levels for extensive amounts of time.					
Intense sound would elevate our hearing sensitivity temporarily.					
It is hard for one to know that his or her hearing sensitivity will decrease gradually due to long-term exposure to loud sounds.					

If I can't tell I have a hearing problem, then I probably don't have any hearing loss.					
If we stay in a noisy environment daily, the deterioration of our hearing would not be that much if we do not go to other places which have loud sounds.					
If we have to stay in a noisy environment, moving to quieter places would decrease the harmful effect of noise.					
I know when it is no longer safe to listen to loud sounds and use hearing protection.					
High impact noise could harm our hearing even if it occurs only once.					

<u>Personal assessment of hearing and use of hearing protection</u>

	Always (5)	Often (4)	Sometimes (3)	Rarely (2)	Never (1)
I experience ringing or buzzing in my ears: Right after playing for long periods (5+ hrs)					
I experience ringing or buzzing in my ears: Right after playing for short periods of time (0-4 hours)					
I experience ringing or buzzing in my ears: It eventually goes away/resolves.					
I experience pain, pressure, or a feeling of fullness in my ears. Right after playing for long periods (5+ hrs)					
I experience pain, pressure, or a feeling of fullness in my ears. Right after playing for short periods of time (0-4 hours)					
I experience pain, pressure, or a feeling of fullness in my ears. It eventually goes away/resolves.					
I experience a feeling of reduced sound in my ears where sounds are softer and voices appear muffled. Right after playing for short periods of time (0-4 hours)					
I experience a feeling of reduced sound in my ears where sounds are softer and voices appear muffled. Right after playing for long periods (5+ hrs)					
I experience a feeling of reduced sound in my ears where sounds are softer and voices appear muffled. It eventually goes away/resolves					
I have trouble understanding voices or sometimes miss words, particularly in background noise and it seems to have gotten worse over time. (Permanent change, does not seem to recover.)					

	Totally agree (5)	Partly Agree (4)	Neutral (3)	Partly disagree (2)	Totally disagree (1)
Using hearing protection will make it hard to hear instruction from instructors on the field and in the (press) box.					
If I wear hearing protection, I will play harder.					
If I wear hearing protection, I will experience pain and tension from playing too hard.					
If I wear hearing protection, there is no way to overcome this way of playing louder and causing injury.					
I will have difficulty hearing others around me as clearly.					
I will have difficulty hearing the other instruments in the corps if I wear hearing protection.					
I think hearing conservation and hearing protection devices should be a concern in drum corps.					

Appendix B. Presentation as part of the research project: An Assessment of Attitudes towards Hearing Protection Devices among members and instructors involved in Drum and Bugle Corps.

Outline

I. Introduction
II. Overview of Anatomy (using photos and graphic pictures).
  a. Outer ear
  b. Middle ear
  c. Inner ear
    i. Cochlea
    ii. Outer Hair Cells
  d. Hearing with the brain
III. Noise Exposure
  a. What is it?
  b. Familiar Sounds/ Loud Sounds in our Environment (Graphs and Figures)
  c. How do we measure it?
  d. Standards: National institute for Occupational Safety and Health (NIOSH)
    i. Recommended standards for sound-level exposure in various work environments.
    ii. Dose percentage and formulas to consider safe amount of exposure.
  e. Doug Presley Research (2007): An Analysis of Sound Level Exposure in Drum& Bugle Corps
    i. Group participation: What type of sound level for each instrument.
    ii. Group participation: How long can each instrumentalist play before exceeding the recommended daily dosage?
    iii. Group participation: What is each instruments' dose percentage for 4 and 8 hours?
IV. Long term effects of noise exposure.
  a. Myths about noise and damage.
  b. Hearing loss/damage
    i. How does hearing damage occur?/What causes it?
    ii. Signs and symptoms of hearing damage
    iii. Simulations of hearing loss
V. Instrumentation and Measurement of damage/hearing loss.
  a. Otoacoustic Emissions/Tympanometry
  b. Audiometric Screening/full diagnostic testing
VI. Prevention of Hearing Loss/Hearing Conservation
  a. Ways to keep yourself protected
    i. Regular hearing screenings/full evaluations
    ii. Distance
    iii. Duration
    iv. Use of dosimeters
  b. Hearing Protection Devices
    i. Pros and Cons of each type of protection
    ii. How to use them correctly.

Assessment of Central Auditory Processing Disorders (CAPD) Evaluation Protocol in a Clinical Setting

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A review of forty clinical records of patients evaluated for central auditory processing disorders (CAPD) was conducted to investigate the utility of the screening and assessment protocol implemented in a university clinic setting. Results indicated that the clinic protocol has reduced the number of patients requiring CAPD assessments by more than half. It also showed that screening with the SCAN test positively identified patients with CAPD with a hit rate (sensitivity) of 50%. Overall, about 20% of the patients referred to the clinic were diagnosed with CAPD.

Introduction

The presence of central auditory processing disorders (CAPD) affects the central nervous system's ability to effectively and efficiently use auditory stimuli (American Speech Language Hearing Association, 2005), and therefore, could have a profound influence on the individual's ability to listen, learn, and navigate through social environments.

The complexity of the evaluation and the diagnosis of CAPD mandates the need for screening tools to identify individuals who are at risk for CAPD prior to the initial evaluation (Bellis, 2003). The purpose of the CAPD screening is to obtain preliminary information about an individual's auditory functional abilities and to determine the need for further comprehensive diagnostic testing (ASHA, 2005; American Academy of Audiology, 2010; Bellis, 2003). Another reason to screen for CAPD is to reduce the number of inappropriate referrals of individuals with higher order global deficits (attention, language, memory) who are mistakenly suspected of having CAPD. An effective screening protocol would also reduce overall cost, save time, and avoid unnecessary stress of individuals suspected of having CAPD and their families.

Several scholars have developed screening protocols, which may involve the administrations of standardized questionnaires or behavioral checklists, specific screening tools or audiometric procedures (Bellis, 2003; Jerger & Musiek, 2000; Musiek et al., 1990). Questionnaires or behavioral check lists can be used to sample the behaviors associated with CAPD. However, they do have limitations as being subjective measures that could be affected by respondent bias, or misinterpretation (Schow & Seikel, 2007).

One of the most widely used screening tests for CAPD is the SCAN test with its two versions; SCAN-A Test of Auditory Processing Disorders in Adolescents and Adults (Keith, 1994) and SCAN-C Test of Auditory Processing Disorders in Children- Revised (Keith, 2000b). The popularity of this test was demonstrated by survey data from Emanuel (2002), Chermak et al. (1998) and Emanuel et.al (2011).The reason for its popularity stems from the fact that it is easily administered and has well documented normative data for scoring and interpretation. The SCAN consists of four tests (Filtered Words, Auditory Figure Ground, Competing Words, and Competing Sentences). Therefore, it only examines two (binaural/dichotic and monaural low-redundancy test) of the seven test areas recommended by ASHA (2005). ASHA's seven test areas are: auditory pattern/temporal tests, monaural low-redundancy tests, binaural/dichotic speech tests, binaural interaction tests, auditory discrimination tests, electroacoustic tests, and electrophysiologic tests. Furthermore, some studies have shown that the SCAN has relatively unstable test-retest reliability (Amos & Humes, 1998), is highly dependent upon verbal knowledge (Chermak & Musiek, 1997), and its sensitivity did not ever reach 50% (Domitz & Schow, 2000).

Recently, the test has been largely modified and is known now as the SCAN-3:A/SCAN-3:C (Keith 2009 a, 2009 b). Some of the modifications in the SCAN-3 test included having separate sets of screening and diagnostic testing and adding Gap Detection as part of the screening tests. Specifically, the screening part of the SCAN-3 consists of three tests (Gap Detection, Auditory Figure Ground, and Competing Words- Free Recall), and therefore, tapping the area of auditory pattern/temporal tests, along with the other two areas included in the older version of the SCAN.

Clinical decision analysis procedures have been used to evaluate the effectiveness of audiological tests (Turner & Nielson, 1984) and CAPD tests (Hurley& Musiek, 1997).

Clinical decision analysis examines a sample by determining the relationship between presence or absence of a disorder and whether or not test results were positive or negative. These can be represented in a 2x2 decision matrix with 4 possible outcomes as shown in Table 1; the most commonly measured are the hit rate (sensitivity) and the false positive (false alarm) rate.

In this study, clinical decision analysis was used to evaluate the sensitivity of the SCAN and the SCAN-3 tests, in identifying individuals with CAPD.

Guidelines for CAPD assessment by ASHA (2005) and AAA (2010) indicated that the CAPD test battery should be based on the individual's case history and other information provided to the audiologist, rather than a preset battery of tests for all patients. Both ASHA and AAA recommend a set of principles that should be applied when determining the composition of a test battery, which include: (a) CAPD assessment should be multidisciplinary; (b) diagnosis and management should be guided by case history and diagnostic findings; (c) diagnostic test batteries should include both verbal and nonverbal stimuli to assess different levels of the central auditory nervous system (CANS); (d) the test battery should examine different processes, regions, and levels of CANS; (e) behavioral tests and other screening tools (including questionnaires) should be well validated, have good test-retest reliability, and demonstrate high sensitivity and specificity; (f) testing should be completed within a reasonable period of time; (g) the audiologist needs to be sensitive to subject-related attributes that may influence the individual's test performance, such as chronological age and mental age, attention to task, fatigue, and native language; and (h) testing should not be test driven but rather motivated based on the referring complaint.

Despite these guidelines, there seems to be a lack of consensus among both researchers and clinicians regarding the tests that should be part of a basic CAPD test battery, as depicted in most studies that surveyed audiologists regarding their clinical practices in CAPD testing (Chermak et al., 2007; Chermak et al., 1998; Emanuel, 2002; Martin et al., 1998). Results from the most recent survey by Emanuel et al. (2011), indicated that the majority of audiologists, who described CAPD testing as an area of their expertise, reported using additional tests in their CAPD battery based on the individual case history and age, and therefore, were more inclined to follow these best practice guidelines. Furthermore, there appears to be some agreement among audiologists on the screening and assessment protocol being utilized (Emanuel et al., 2011).

Purpose

The purpose of this study was to evaluate a clinic protocol for CAPD screening and evaluation. The protocol was developed and implemented at a university clinic setting to streamline the screening and the assessment process and to reduce the number of inappropriate referrals. The goals of this study were to (a) examine the sensitivity of the SCAN-A/SCAN-C, and SCAN-3:A/SCAN-3:C tests in identifying individuals with CAPD; and (b) compare the clinic's protocol to best practices reported in the literature .This has been accomplished through analysis of clinic records of individuals evaluated for CAPD.

Table 1. Decision Matrix Outcomes for Diagnostic Tests (Turner & Nielsen 1984)

		Confirmation Test (Diagnostic)	
		Positive	Negative
Screening Test	Positive	Hit	Miss
	Negative	False Alarm	Correct Rejection

Methods

A clinical protocol was developed and implemented to streamline the screening and assessment process for CAPD. Four years later, the records of patients who visited the clinic for CAPD testing were reviewed and analyzed to evaluate the protocol. Figure 1 presents the flow chart of the CAPD protocol. For school age children, the protocol included an initial screening by completing teachers' questionnaires: Children's Auditory Performance Scale (CHAPS; Smoski, Brunt, & Tannahill, 1992) and the Screening Instrument for Targeting Educational Risk (SIFTER; Anderson, 1989), along with a short CAPD questionnaire (see Appendix A).

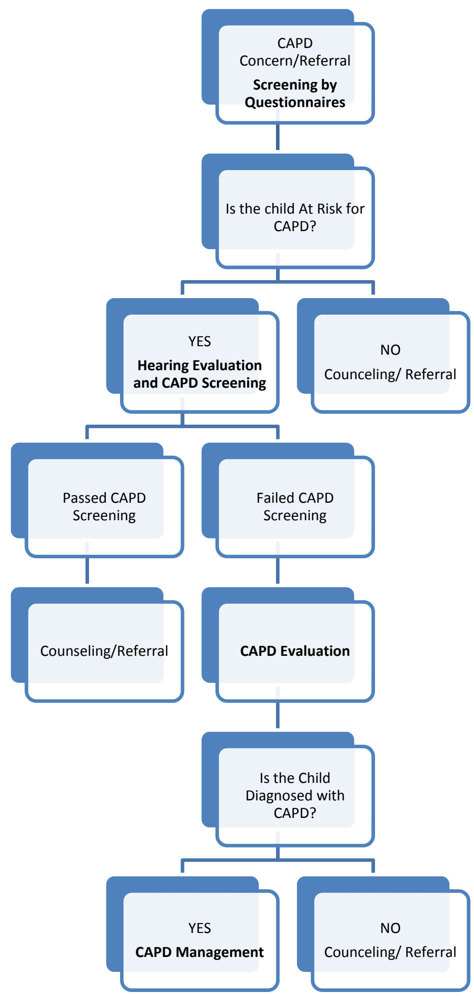

Figure 1. Flow chart of the CAPD clinic testing protocol

The audiological assessment included otoscopy, immittance measures (tympanometry and acoustic reflex measurements), pure tone audiometry and speech audiometry. Individuals with documented hearing loss were counseled and were not further evaluated for CAPD. The CAPD screening included the SCAN-A/SCAN-C and SCAN-3:A/SCAN-3:C (screening) tests. The CAPD assessment consisted of a minimum test battery of four tests. More tests were added based on the case history and age of the patient. The battery was administered for those who did not pass the screening and their profile pointed to the presence of CAPD tendencies. Following the Bellis/Ferre model (Bellis & Ferre, 1999), four groups of tests were employed:

- Binaural speech tests including the Dichotic Digits Test (DDT; Musiek, 1983), the Staggered Spondaic Word test (SSW; Katz, 1962), and the Competing Sentences Test (CST; Willeford & Burleigh, 1994).
- Temporal processing tests including the Random Gap Detection Test (RGDT; Keith, 2000a), the Frequency Pattern Test (FPT; Pinheiro & Patcek, 1971), and the Duration Pattern Test (DPT; Pinheiro & Museik, 1985).
- Monaural low-redundancy tests including the QuickSIN test (Etymotic Research, 2001) and the NU-6 30% compressed speech (Beasley, Schwimmer, & Rintelmann, 1972).
- Binaural interaction tests including mainly the Masking Level Difference test (MLD) (Hirsh, 1948).

The patients' clinic records were reviewed and handled in accordance with the University IRB regulations/ committee on the use of human research subjects. Descriptive statistics were used to summarize the demographic data. Clinical decision analysis was applied to examine the sensitivity of the SCAN tests in identifying individuals with CAPD.

Results

Clinic records of 40 patients, 23 males (57.5%) and 17 females (42.5%), were reviewed. Patients were divided into two school age groups: 7-11years (n=17), 12-17 years (n=11), and one adult group: ≥18 years (n=12). Table 2 demonstrates the number of patients referred by different sources. It is clear that the schools were the most prevalent source of referral to the clinic (37.5%), followed by parental or self-referral (12.5% each), physicians, college counselors, vocational rehabilitation counselors (10% each), and (7.5%) from other health professionals.

Results of the audiological evaluation revealed hearing to be within normal limits (≤ 15 dB HL in children & ≤ 25 dB HL in adults at frequencies 250-8000Hz) in 35 of the 40 patients. Therefore, the CAPD screening was completed on 35 patients, and of those, 19 failed the screening as shown in Figure 2. Overall, 23 patients were screened with the SCAN, and of those, 13 patients failed the test: 11 of 13 patients failed the SCAN-A, and two of 10 failed the SCAN-C. The newer version of the test, the SCAN -3, was administered to 12 patients. Half of the patients failed the screening section, with one of four failing the SCAN-3:A, and five of eight failing the SCAN-3:C.

Figures 3 and 4 present the distribution of the SCAN and the SCAN-3 subtests failed respectively. It is notable that more patients failed the SCAN-A than the SCAN-C. The most commonly failed tests on the SCAN-A were Competing Words, Competing Sentences, and Auditory Figure Ground. Interestingly, more patients failed the SCAN-3:C than the SCAN-3:A, mainly on Auditory Figure Ground and Competing Words- Free Recall.

The CAPD test battery was completed on 18 of the 19 individuals who failed the screening. The battery was completed

Table 2. CAPD Referral Sources

Referral Sources	Number of Patients
School	15
Parent	5
Self	5
Physician	4
College Counselor	4
Vocational Rehabilitation	4
Others	3

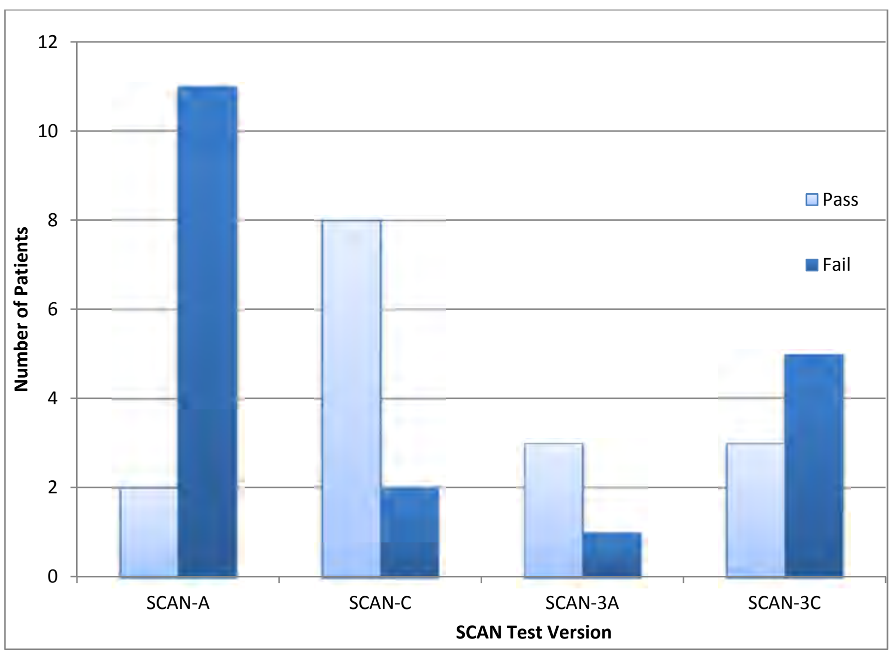

Figure 2. Number of patients who passed (light blue) and failed (dark blue) the SCAN and SCAN-3 tests

on 9 males and 9 females, with three age groups: 7-11 years (n =6), 12-17 years (n= 5), 18 years or older (n= 7). Fourteen of the patients were administered four or more tests, and the remaining four patients were only administered three tests due to test duration and attention. Figure 5 illustrates the number of patients within each age group that were evaluated in the four categories of the CAPD test battery. It should be noted that, across age groups, more patients were evaluated with the dichotic speech tests and the temporal processing tests than the monaural low-redundancy speech tests. The binaural interaction tests were administered only to the 18 years or older group. The most frequently administered tests were the Dichotic Digits (n=15), the Frequency Patterns (n=13), the Random Gap Detection (n=10), and the QuickSIN (n=8).

Results of the CAPD evaluation indicated that 8 of the 18 patients who completed the test battery were diagnosed with CAPD based on the criterion recommended by ASHA (2005) and AAA (2010). Table 3 compares the number of individuals screened, evaluated, and diagnosed with CAPD across the three age groups. Out of the 40 patients referred, 35 were screened, 18 of them were evaluated, and only 8 had the diagnosis of CAPD. Thus, only 45% of the patients screened needed a full assessment (18/35), and therefore reduced the number of unnecessary evaluation by 55%. It is clear that more children at the youngest age group of 7-11 years were referred compared to the other two groups, and only two of the 17 children screened within this age group were diagnosed with CAPD, indicating a large number of over-referral. Results also showed that one fifth (20%) of those referred to the clinic have the diagnosis of CAPD.

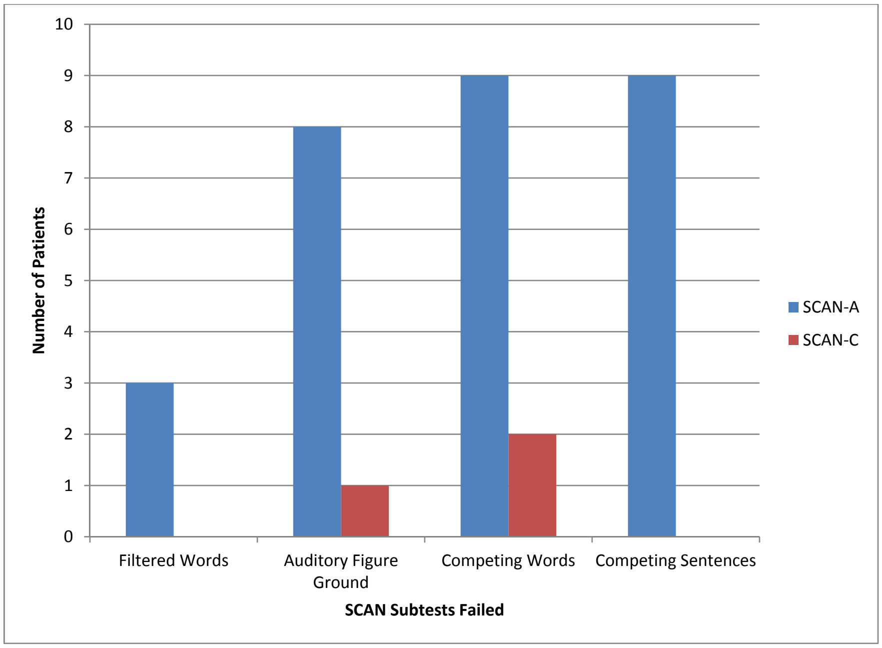

Figure 3. Distribution of the SCAN-A (Blue) and SCAN-C (Red) subtests failed

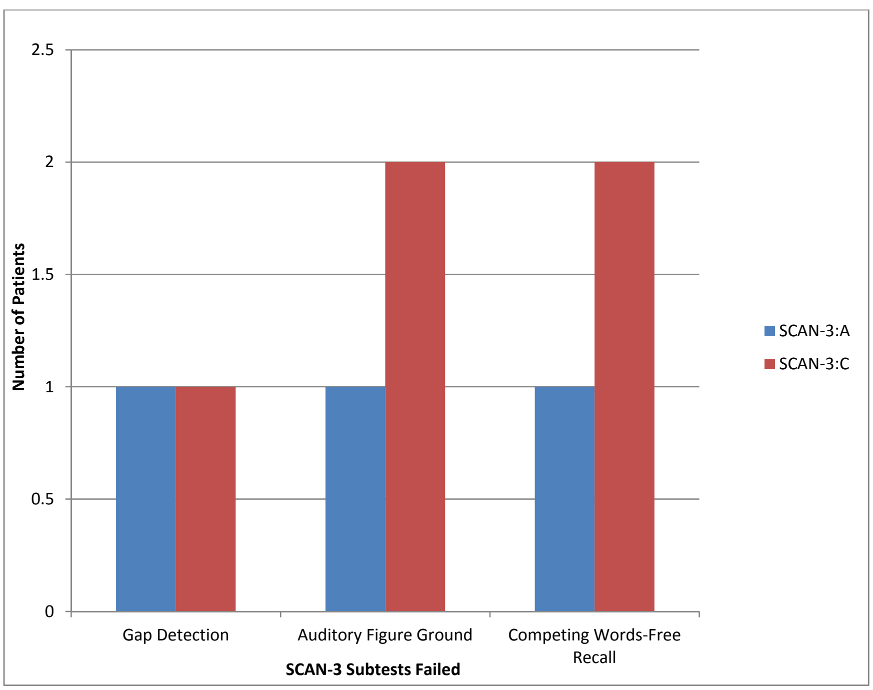

Figure 4. Distribution of the SCAN-3:A (blue) and SCAN-3:C (red) subtests failed

Applying the clinical decision analysis on those patients who failed the SCAN, and were diagnosed with CAPD, indicate that the SCAN positively identified patients with a hit rate (sensitivity) of 50% (six patients were diagnosed out of 12 failed), as seen in Figure 6. Results of the SCAN-3 showed a lower hit rate of 33% (two were diagnosed out of six failed). Figure 7 depicts the hit rate of individual tests, showing the SCAN-3:C to be the least sensitive, as it correctly identified only one of five patients (20%). It also showed a sensitivity of 45.5% for SCAN-A (5/11), 100% for SCAN-C (1/1), 100% for SCAN-3:A (1/1).

Discussion

This study evaluated a protocol for screening and assessment of CAPD at a university clinic setting. The protocol consisted of initial screening, which included the use of teachers' checklists and questionnaires for the school age group of patients. The purpose of these questionnaires was to obtain teachers' input on the child's behavior as compared to others in the classroom. Although there has been some concerns regarding the use of these subjective checklists

Table 3. Number of Patients per Age Group at Different Stages in the CAPD Testing Protocol

Age Groups	Screened	Evaluated	Diagnosed
7-11 years	17	6	2
12-17 years	9	5	2
≥18 years	9	7	4
Total	**35**	**18**	**8**

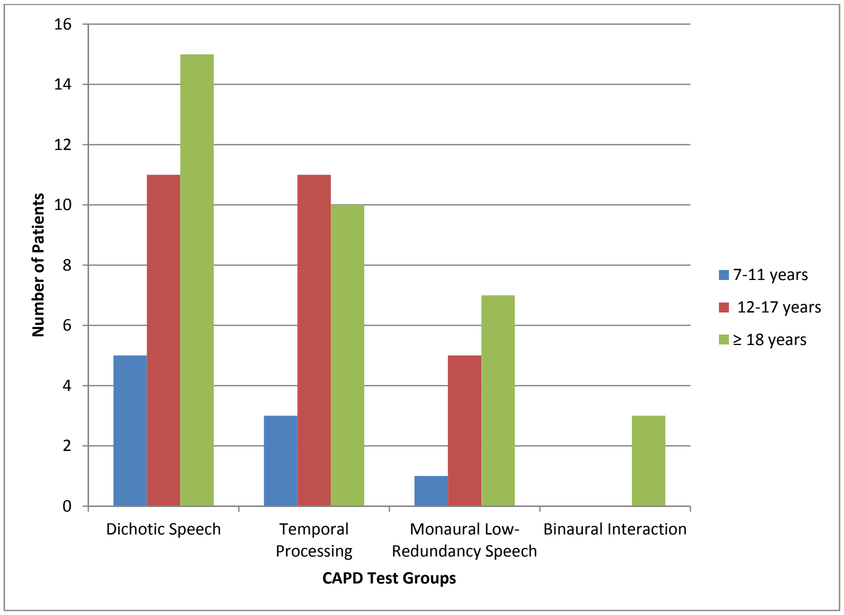

Figure 5. CAPD test battery categories administered to patients by age group: 7- 11years (blue), 12-17 years (red), and ≥ 18 years (green)

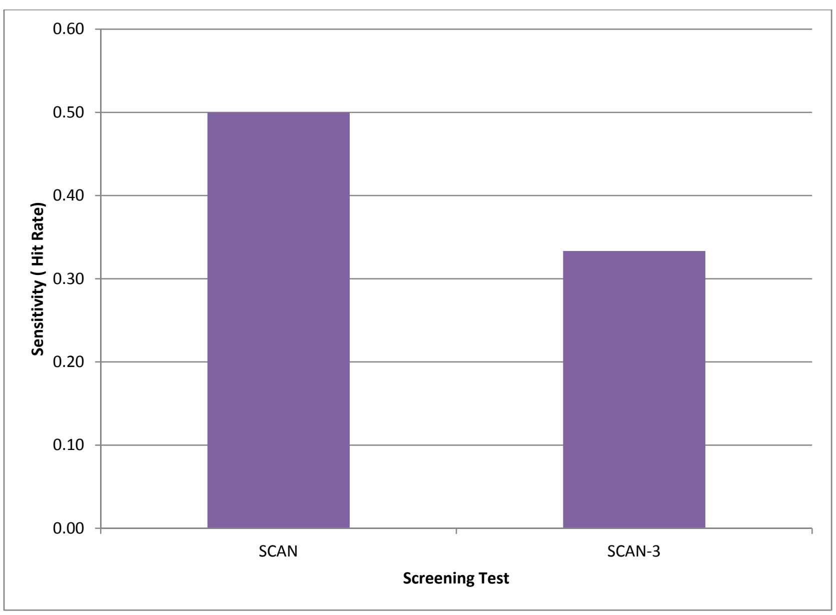

Figure 6. Sensitivity (hit rate) of the SCAN and the SCAN-3 tests

due to poor specificity and possible increase in over-referrals, they do provide valuable information about the auditory function in a variety of situations, such as listening in noisy backgrounds, following directions, and understanding rapid or distorted speech (Jerger & Musiek, 2000). Therefore, these checklists could be considered part of the case history, which guide the clinician in developing the appropriate test battery for each individual (AAA, 2010). They could be also used to supplement and contextualize the behavioral test findings after a diagnostic battery confirms CAPD (Schow & Seikel, 2007).

Audiological assessment was performed on all patients, as part of the initial screening, to rule out peripheral hearing as a factor in their possible CAP difficulties. This important step is recommended by ASHA (2005), and it has resulted in the exclusion of five patients from the poll due to the presence of hearing loss, which in itself could cause auditory processing difficulties.

The screening for CAPD was completed using the SCAN test, as it is cited to be the most widely used test for CAPD screening (Emanuel, 2002; Chermak et al., 1998; Emanuel et al., 2011). The reason for its popularity was described by Emanuel (2002) as being easily administered and having well documented normative data for easy scoring and interpretation. Some studies, however, have shown that the SCAN has relatively unstable test-retest reliability (Amos & Humes, 1998) and is highly dependent upon verbal knowledge (Chermak & Musiek, 1997). Two versions of the SCAN were used by the clinic, the SCAN-A/SCAN-C, and with most recent cases, the SCAN- 3:A/SCAN- 3:C were employed. As described in the results section, 19 of 35 patients failed the screening, and of those, 18 were evaluated with the CAPD test battery. This finding indicates that the screening protocol used by the clinic reduced the number of unnecessary assessments by more than half. This resulted in saving clinic resources, reducing patients/ family stress, and saving resources of the referring agencies, such as the schools.

The CAPD test battery was completed on 18 patients who failed the screening. On average, four tests were given to each patient. The battery included the four main groups of tests in the Bellis- Ferre Model: dichotic speech tests, temporal processing tests, monaural low-redundancy speech tests, and binaural interaction tests. This is fairly consistent with the results from a recent survey of audiologists who reported CAPD as a specialty area by Emanuel et al. (2011). The most popular tests administered in the battery were dichotic, monaural low-redundancy speech, and temporal processing tests (Emanuel et al., 2011).

The screening protocol used in this study is also consistent with the above mentioned survey findings. The majority of audiologists completed a screening for CAPD (69%), and they used mainly the SCAN-A and SCAN-C. More than half of the audiologists surveyed (56%) used questionnaires instead of, or in addition to, the screening.

CAPD test battery diagnosed eight patients with CAPD based on the criterion recommended by ASHA (2005) and AAA (2010) of having poor performance of two standard deviations (or more) below the mean on two or more tests in at least one ear. Computing the sensitivity of the SCAN tests revealed that the sensitivity (hit rate) of the SCAN is 50%, as six of 12 patients who failed this version were positively identified with CAPD. This result is comparable with the 45% SCAN sensitivity reported by Domitz & Schow, (2000). A lower hit rate of 33% was computed for the SCAN-3, only two of the six patients who failed the screening with the SCAN-3 version were diagnosed with CAPD. This small hit rate for the SCAN-3 could be attributed to the sensitivity of 20% for SCAN-3:C observed in this study. Looking at the results of individual SCAN-3 subtests, it appears that more children failed the Auditory Figure Ground and the Competing Words- Free Recall, than the Gap Detection test. Overall, the number of patients screened with the SCAN-3 is much lower than those screened with the SCAN due to the relatively recent availability of the SCAN-3 in the clinic.

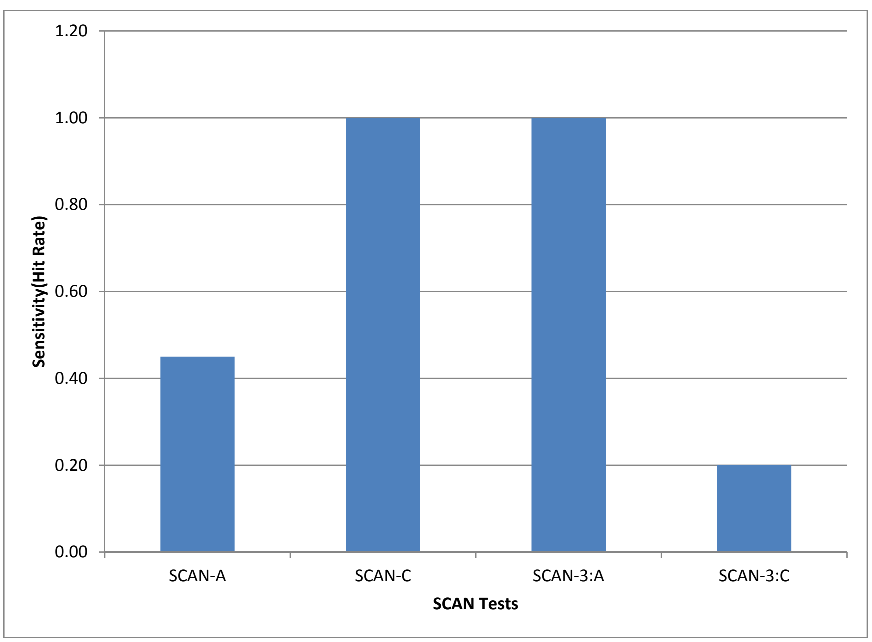

Figure 7. Sensitivity (hit rate) of individual SCAN tests

Comparing the initial number of patients referred for CAPD by age group and the number of those diagnosed with CAPD showed that out of 17 children who were initially referred, only two children in the 7-11 age group was diagnosed with CAPD. This high rate of over-referral is more pronounced in the youngest age group and could be explained by the difficulty in the differential diagnosis of CAPD, as symptoms and behaviors of other disorders, such as attention deficit disorders and language disorders, are closely similar to those of auditory processing disorders.

Conclusions and Future Directions

In summary, the clinic protocol evaluated in this study was consistent to what has been recently reported by other practicing audiologists. According to the latest survey by Emanuel et al., (2011) there seems to be a relatively consistent approach among audiologists towards the assessment and diagnosis of CAPD. This study showed that the protocol reduced the number of unnecessary CAPD assessments by 55%, and consequently helped save clinic and referring agencies' resources as well as reducing patients' anxiety and testing time. Screening with the SCAN test positively identified patients with a sensitivity of 50%, which is comparable to what has been reported in other studies.

The study also depicts a large number of over-referrals, especially for the age group of 7-11 years old. This finding could be explained by the inherent difficulty in the differential diagnosis of CAPD, as symptoms and behaviors of other disorders, such as attention deficit disorders and language disorders are closely similar to those of auditory processing disorders. This problem could be minimized by continuing to implement and advocate for the use of a multidisciplinary approach to the CAPD evaluation. The number of patients who were screened with the new SCAN-3 was limited because the test was recently administered in the clinic. More research is needed to investigate the effectiveness of the screening portion of the SCAN-3 in identifying individuals with CAPD.

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Appendix A. Central Auditory Processing Disorders Referral / Questionnaire

Please consider the following criteria when requesting or referring for CAPD evaluation:

- Age is 7 years or older
- Normal hearing in both ears
- IQ is 85 or better (normal overall cognitive status)
- Good speech intelligibility
- Adequate English language skills
- No severe emotional and /or behavioral disorders
- Copy of a recent psycho-educational evaluation (if available)
- Copy of a recent speech and language evaluation (if available)

Please take a few minutes to answer the following questions about your child:

1- How well is your child doing in school?

	Doing Fine	Having Difficulty	Comment
Academically	__________	_______________	__________________________
Socially	__________	_______________	__________________________
Behaviorally	__________	_______________	__________________________

2- Please describe any academic problems in:

Spelling ____

Reading ____

Phonics ____

Others ____

3- How are your child's organizational skills?

What does his/her room look like?

________Organized ________Somewhat organized _______Messy

What does his/her desk at school look like compared to other students?

________Organized ________Somewhat organized ________Messy

4- Does your child have trouble getting class assignments done on time?

______In class assignments ______Homework assignments ______No trouble

5- Is your child diagnosed with attention deficit disorders (ADHD, ADD)?
______Yes _______No

If yes, is he/ she on medication? ______Yes _______No

Does medication seem to help? ______Yes _______No

Please make sure that your child continues taking his/her medication on the day of the appointment.

6- Please use the space below (or use extra sheets) to provide any additional information that you think might be useful.

Preschool Hearing Screenings: A Comparison of Distortion Product Otoacoustic Emission and Pure-Tone Protocols

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Distortion product otoacoustic emissions (DPOAE) are sensitive to both sensorineural and conductive hearing losses and have the potential to be used as an effective screening measure across all populations, including children. DPOAE offer a quick and straightforward hearing screening technique for the pediatric population that is not influenced by subjective testing and is highly reproducible. In this study, the mean test times and pass/fail rates from 198 preschool participants were compared between two DPOAE screening protocols (1-5 kHz and 2-5 kHz) and a pure-tone screening protocol (1, 2 and 4 kHz). Significantly less time was needed to conduct the DPOAE screenings compared to the pure-tone screenings. Results suggested similar pass/fail rates for both DPOAE protocols compared to pure-tone screenings. Without diagnostic audiologic test results, the sensitivity and specificity of the screening protocols could not be determined. Until the true sensitivity and specificity of DPOAE and pure-tone screening protocols can be determined, it is recommended that clinicians consider adding DPOAE to their current screening protocol, or at least having DPOAE available to screen children who cannot or will not participate in pure-tone screenings.

Introduction

It is well known that early intervention improves speech and language development as well as cognitive outcomes, diminishing the need for special education services and improving the overall quality of life of children with hearing loss (e.g., Moeller, 2000; Yoshinaga-Itano, Sedey, Coulter, & Mehl, 1998). Therefore, hearing screening programs are utilized across all pediatric age ranges and populations to detect potential hearing loss and to combat delayed language development (Gelfand, 2009). Hearing screenings are designed to provide a quick and cost-effective method of separating individuals into two groups: individuals at risk for hearing loss and individuals not at risk for hearing loss.

Today, hearing screenings begin at birth and continue throughout an individual's school years, when conditions occur that increase risk for hearing loss, or when mandated by state and local laws or practices (Cunningham & Cox, 2003). Professional organizations such as the American Speech-Language-Hearing Association (ASHA) and the American Academy of Audiology (AAA) have established screening protocols for both hearing sensitivity and middle ear disorders (e.g., otitis media) to separate individuals with and without suspected hearing loss. Both AAA (1997) and ASHA (1997) recommend combining the use of pure-tone and tympanometric screening protocols for the detection of hearing loss and middle ear disorders. However, the use of pure-tone audiometry as part of a screening protocol is often criticized (Lyons, Kei, & Driscoll, 2004).

Pure-tone audiometry requires a higher level of cognitive functioning to produce appropriate responses (Lyons et al., 2004). This requirement becomes especially problematic with the pediatric and developmentally-delayed populations who may be incapable of providing such a response. In recent years, the need for objective, non-invasive tests for monitoring hearing loss in children has become apparent. The use of otoacoustic emissions (OAE) hearing screening protocols for pediatric populations has been suggested because the test is objective (Kei, Brazel, Crebbin, Richards, & Willeston, 2007).

Because OAE are sensitive to both sensorineural and conductive hearing loss, they have the potential to be an effective screening tool across all populations, including children (Kei et al., 2007). However, little research on the use of OAE as a screening method with preschool aged children has been conducted. OAE screening appears to be promising in assessing the integrity of cochlear function and has a major practical advantage over subjective threshold measurements. Offering a quick and straightforward approach to testing pediatric populations, OAE are not influenced by subjective interpretations, making them highly reproducible and more precise than audiometry (Kemp, Ryan, & Bray, 1990). However, in the past, research has indicated that the use of OAE is most effective in ruling out hearing loss when used as part of a multifaceted diagnostic battery. Because limited data have been collected on the use of distortion product otoacoustic emissions (DPOAE) as a first-stage screening protocol in preschool children, further research is needed.

The Effect of Noise on DPOAE

The most common environment to screen for hearing in school-aged children is the educational environment, which is quite different from a clinical setting. Differences between these settings include: the amount of noise in the environment, the amount of time available to conduct the screening, the overall health of the child, the prevalence of hearing loss in the school-aged population, the child's familiarity with the personnel conducting the testing, and the surrounding environment (Sideris & Glattke, 2006). Often, hearing screenings are conducted in non-sound-treated rooms or nurses' offices that were not designed to provide desirable acoustic attenuation (Hallett & Gibbs, 1983).

Conducting OAE testing in settings with high environmental noise levels may affect the detectability of the emission given from the ear. As a result, ambient noise will always be a contributing factor to hearing screening results (Nozza et al., 1997). It should be noted that DPOAE at or below 1000 Hz are difficult to obtain even in a sound-treated booth with adults due to physiological noise (Gorga, Neely, Johnson, Dierking, & Garner, 2007). Obtaining DPOAE in high background noise levels becomes even more difficult. Typically, noise has adverse effects on the measurement of otoacoustic emissions at low frequency levels (at and below 1000 Hz), but minimal effects on the high frequencies (Kei et al., 2007; Torre, Cruickshanks, Nondahl, & Wiley, 2003). For these reasons, most screening protocols recommend not testing DPOAE at 250 and 500 Hz, even though valuable information regarding the status of the inner ear can be obtained at these frequencies (Kei et al., 2007). Screening DPOAE at and below 1000 Hz in high noise level environments should be conducted with caution due to potentially low hit and high false alarm rates due to both physiological and background noise (Gorga et al., 2007; Torre et al., 2003). An optimal solution to the noise problem in educational settings is the use of sound treated rooms or portable tests booths; however, this solution is often unattainable due to cost, availability, and space issues.

Hearing Screening Protocols

In previous years, there has been some debate over the goal of school-age hearing screening programs and whether to screen for hearing loss alone or hearing loss and middle ear disorders (otitis media) (Gelfand, 2009; Nozza, Sabo, & Mandel, 1997). The recommended screening procedure for infants and young children varies slightly among professional organizations and across age category. Typically, the screening protocols in existence today utilize pure-tone and tympanometric screening in the protocol (AAA, 1997; ASHA, 1997; Lyons et al., 2004). The use of both of these techniques allows for the detection of sensorineural hearing loss, as well as conductive hearing loss caused by pathologies such as otitis media with effusion or impacted cerumen (Lyons et al., 2004). Separate follow-up screening protocols have been established as well to identify sensorineural hearing loss or middle ear disorders independently.

Pure-tone Screening Protocol

The American Academy of Audiology Position Statement (1997) and Clinical Practice Guidelines (2011) also recommend pure-tone screening at 1000, 2000, and 4000 Hz at 20 dB HL. The goal of screening for hearing loss in preschoolers (ages 3-5 years) is to identify children most likely to have hearing loss that may interfere with communication, development, health, or future school performance. In addition, because hearing loss in this age range is so often associated with middle ear disease, it is also recommended that children in this age group be screened for outer and middle ear disorders. The screening protocol for children aged three to five years old typically involves pure-tone testing under earphones at 1000, 2000, and 4000 Hz at 20 dB HL using conditioned play audiometry. If a child cannot attend to the testing or does not have the cognitive ability to participate in conditioned play audiometry then visual reinforcement audiometry may also be used.

In order for a child to pass the hearing screening, he or she must respond to at least two out of three pure-tone presentations at all frequencies in both ears (ASHA, 1997). If a child fails the screening, they must then be referred for a full audiological evaluation. Children who are thought to have failed the screening due to their inability to be properly conditioned may be screened using screening procedures designed for younger children.

The AAA (1997) guidelines also recommend air conducted pure-tone screening at 1000, 2000, and 4000 Hz at 20 dB HL. However, AAA does not specify which type of audiometry (visual reinforcement or conditioned play) should be utilized, only that a type of manual method is conducted. Failure to respond at any one frequency in either ear constitutes failing the screening, and the child should then be referred for a full audiological evaluation. AAA (1997) recommends that all children should be screened for hearing loss: (a) at least once during the preschool years, (b) if a parent expresses concerns about a child's hearing ability, and (c) if a child is being considered for entrance into a special education.

Pure-tone screening closely follows typical diagnostic techniques used in an audiology practice; however, certain limitations exist when utilizing this type of screening procedure for children (Sideris & Glattke, 2006). Pure-tone audiometric testing requires a conditioned response that some children may not be capable of giving. A study conducted by Decreton, Hanssens, and De Sloovere (1991) suggested that as many as one in every ten children could not be assessed using an overt response to pure tones and that these children may be overlooked until a reliable response to the recommended pure-tone screening protocol is given.

Screening for Middle Ear Disorders

To screen for outer and middle ear pathologies in children, ASHA (1997) established a second screening protocol that includes the use of tympanometric measures. Children whose test results include a flat tympanogram should be referred for medical evaluation. Other abnormalities such as drainage from the ear, ear pain, perforations, impacted cerumen, foreign bodies, and the presence of blood during the otoscopic evaluation should also be medically evaluated.

Set-Up for Screening Programs

Discrepancies between screening programs, such as the instruments used during testing, the amount of training the testers have received, the amount of ambient noise present during the hearing screening, and the pass/fail criteria used, will affect the overall effectiveness of the program (Nozza, 2001). Generally, a screening test should adhere to certain criteria. Tests should be simple, easy to administer, comfortable to the client, inexpensive, and short in duration (Nozza, Sabo, & Mandel, 1997). The costs of personnel, instrumentation, testing space, and other miscellaneous expenses should not be overlooked and often play a crucial role in the decisions made about screening programs. The level of expertise and education of the screening personnel may be considered important at one location and irrelevant at another.

Use of OAE in a Screening Protocol

More recent ASHA guidelines for audiologic screening of children ages birth to 5 include consideration of the use of otoacoustic emissions among other procedures and protocols in the detection of hearing loss and middle ear disorders (ASHA 2004). Evoked OAE have been used in newborn hearing screenings since it was determined that OAE technology could be applied to the screening of hearing in infants. One study evaluated the use of a TEOAE and DPOAE screening protocol as part of a newborn hearing screening program (Hatzopoulos, et al., 2001). In terms of screening performance, both OAE screening protocols performed well, with equally high sensitivity and specificity rates when later compared to ABR test results. Also, the amount of time needed to complete each screening was evaluated. Timing results indicated that the DPOAE protocol was 50% shorter than the TEOAE protocol. The results suggested that DPOAE and TEOAE were useful in newborn screening. However, further research needs to be conducted on the use of DPOAE in other populations.

To date there has been little research on the use of DPOAE in the preschool population. Dille et al. (2007) compared referral rates between DPOAE and TEOAE protocols and found no statistically-significant difference in the referral rate at any of the frequencies compared. They concluded that both TEOAEs and DPOAEs were equally suitable for screening the hearing of preschool-aged children. It has been suggested that DPOAE may serve as a non-invasive, objective clinical tool for use in the assessment of the cochlea, across all age ranges (Norton & Widen, 1990). However, it is necessary to compare the effectiveness of the use of diagnostic OAE versus the effectiveness of screening OAE used in a screening protocol. Several automated OAE screening devices are being used clinically; however, limited data exist on the accuracy of these devices in hearing screening protocols in school children.

The amount of time necessary to conduct OAE screenings on adults has been evaluated. A study conducted by Parthasarathy and Klostermann (2001) evaluated the use of the three hand held screeners (Audioscreener, EroScan, and AuDX). Each piece of equipment was set to the default criteria and run on a total of 42 adult subjects. The results of the study indicated that the use of the screening devices took an average of 17 seconds per ear. These machines were preset to utilize statistical criterion to determine if the emission was present or not, leading to a pass versus fail criterion that does not have to be interpreted by a licensed audiologist. This may also diminish the cost needed to utilize effective hearing screenings across populations.

The amount of time necessary to complete pure-tone screening in comparison to DPOAE has yet to be evaluated. However, Sideris and Glattke (2006) compared the use of conventional pure-tone behavioral screening to the use of TEOAE screening in the preschool population under the conditions common to educational settings. Participants included 200 children ranging in age from 2 years 1 month to 5 years 10 months. Pure-tone screening was conducted under earphones using conditioned play audiometry. The screening level was 20 dB HL for the frequencies 1000, 2000, and 4000 Hz. A child passed the screening if he or she responded to the 20 dB HL tone at all frequencies in both ears. A lack of response to the 20 dB HL test tone at any frequency in either ear, or the inability of a child to condition to the task, constituted a screening failure. The audiologist used a stopwatch to note the time required to condition and test each child. Mean testing time for pure-tone screening was 137.6 seconds. In contrast, the mean testing time for TEOAE screening was 113.4 seconds. A matched *t*-test was conducted and revealed that pure-tone screening took significantly longer to complete than TEOAE screening emphasizing the time effectiveness of TEOAE.

Several studies evaluating the use of TEOAE as part of a hearing screening protocol have been conducted (e.g., Nozza et al., 1997; Sideris & Glattke, 2006; Yin, Bottrell, Clarke, Shacks & Poulsen, 2009). However, limited research on the performance level of DPOAE in preschool or school-aged children exists. In one study, 1003 elementary school children were tested using pure-tone screening, tympanometry, and DPOAE (Lyons et al., 2004). Testing the performance of DPOAE in this population was concluded to be more accurate at high frequencies compared to low frequencies. When DPOAE screening was evaluated against pure-tone testing, a hit rate of .62-.68 was determined; meaning the use of DPOAE alone would have missed approximately 32-38% of the children failing the pure-tone screening. In addition, this study determined that the use of DPOAE and tympanometry screening in identifying school aged children with auditory dysfunction is superior to using DPOAE screening alone.

Dille, Glattke, and Earl (2007) compared referral rates between DPOAE and TEOAE protocols for 33 children in preschool settings. They found no statistically-significant difference in the referral rate at any of the frequencies compared. They concluded that both TEOAE and DPOAE were equally suitable for screening the hearing of preschool aged children.

More recently, Smiley, Shapley, Eckl, and Nicholson (2012) compared pure-tone and DPOAE screenings in 565 school-age children. They reported that 67% of the children passed both screenings and 7% failed both screenings. The remainder of the children either passed the pure-tone screening and failed the DPOAE screening (11%) or passed the DPAOE screening and failed the pure-tone screening (14%). The authors recommended that a full diagnostic evaluation would be needed to determine true sensitivity and specificity of DPOAE and pure-tone screenings. In addition, they concluded that use of DPOAE in screening protocols should continue to be evaluated and that “more research is needed to evaluate the cost- and time-effectiveness of DPOAE screening protocols for the school-age population” (Smiley et al., 2012, p. 36).

Purpose of Study

The use of DPOAE as part of a screening protocol appears to be feasible because they are easy to administer, quick, objective, and present in virtually all individuals with normal peripheral auditory function. Several studies have reported anecdotally that screening with otoacoustic emissions is faster than screening with pure tones in the pediatric population. However, there remains limited data comparing time to complete DPOAE screening and pure-tone screening and the pass/fail rates of these protocols in the preschool population. The aim of this study was to compare the time needed to complete, and the pass/fail rates of, DPOAE screening from 2-5 kHz, DPOAE screening from 1-5 kHz, and pure-tone screening within the preschool population.

Methods

Participants

Participants were 198 volunteers (101 male, 97 female; mean age 4.5 years, range: 3.0 to 6.5 years) in various preschools that take part in Towson University’s speech and hearing screening program. Specifically, children in the following preschools participated in the study: Timonium United Methodist Nursery School, Dulaney Day School, Holy Spirit Early Childhood Learning Center, Mayfield Christian Preschool, Yeshivat Rambam School, Bais Yaakov School for Girls, Beth Tfiloh Preschool, and Ward’s Chapel Preschool. No pre-selection criteria were used to determine study participants. To be included in the screenings, each participant had to be cooperative throughout testing. A child was considered uncooperative if the child did not allow the examiner to complete screening in an efficient manner. Of the 198 children, two females (ages 3 years 10 months and 4 years 2 months) could not complete the pure-tone screenings either due to the child’s lack of cooperation or their inability to condition to the task. Conditioned play audiometry has previously been shown to be difficult for some preschoolers (Northern & Downs, 2002), as it requires a level of cognitive functioning that children may not yet possess; whereas, DPOAE do not. All 198 children were able to complete the DPOAE screenings in this study, suggesting that pure-tone screenings were a slightly more difficult task for some participants to complete. Descriptive statistics of participant gender and ages by schools are presented in Table 1.

Table 1. Descriptive Statistics of Participants across Preschool Sites

		SITE								
		TUM	DDS	HSP	MCP	YRS	BYS	BTP	WCP	TOTAL
Mean Age (years)		4.4	4.6	4.5	4.7	4.5	4.2	4.4	4.5	4.5
Gender	Male	19	4	8	8	20	0	7	35	101
	Female	13	6	12	8	18	8	11	20	97
Total Participants		32	10	20	17	38	8	18	55	198

Note. TUM=Timonium United Methodist Nursery School, DDS= Dulaney Day School, HSP= Holy Spirit Early Childhood Learning Center, MCP= Mayfield Christian Preschool, YRS= Yeshivat Rambam School, BYS= Bais Yaakov School for Girls, BTP= Beth Tfiloh Preschool, WCP= Ward’s Chapel Preschool

Procedures

Three Grason-Stadler Incorporated (GSI) model 17 portable audiometers with TDH 39 headphones were used for all pure-tone hearing screenings. Although the use of insert earphones decreases the amount of ambient noise allowed into the ear canal, they could not be used for financial reasons. The AuDX II Pro, manufactured by Bio-logic Systems Cooperation, was used to obtain all DPOAE measurements.

All children were screened individually, in a seated position, in a quiet room provided within each school. Although ambient noise levels were not measured using a sound level meter, each room was subjectively evaluated and set up so that maximum responses could be obtained during testing. Test rooms were examined for ambient noise sources that may interfere with obtaining OAE responses. OAE equipment was then set-up as far away from these sources as possible. Children were brought to the screening room individually or in groups of no more than four or five. Each OAE tester attempted to put the child at ease and explained the screening by stating, "Today you are going to sit in the chair and listen to some beeps. I just need you to sit still and be as quiet as a statue." Each person screening via pure tones explained testing by stating, "We are going to play a listening game today. I want you to put a block in the bucket/basket when you hear the tiny beep." The screener then conditioned the child to the task. Any additional explanation was provided as needed. Children began the screening process at either pure-tone or DPOAE screening. For both screening procedures, the right ear was always screened first. Children also received a tympanometry screening. The order of screening for these tests was determined by the availability of instruments and the flow of students through the screening protocol. In order to minimize the potential confounding effects of changes in the child's health or cooperation, all three procedures were completed on the same day.

Bilateral pure-tone screening using conditioned play audiometry was conducted on all cooperative participants. Based on ASHA (1997) recommendations, pure-tone screening was conducted at 1 kHz, 2 kHz, and 4 kHz at 20 dB HL. If the child responded to the tone as presented at 20 dB for all of the frequencies, then that ear was categorized as a pass. If the child failed to respond to 20 dB HL in one or more test frequencies, that ear was categorized as a "refer". Children failing in one or both ears were referred for further diagnostic testing.

In order to limit tester error, audiology doctoral students who had courses and clinical work on the use of DPOAE screening conducted all DPOAE screenings. Speech-language pathology and audiology graduate students, who also had undergone training, conducted all tympanometry and pure-tone screenings. All students were supervised by a licensed and certified speech-language pathologist. Prior to DPOAE screening, otoscopy was performed using a Welsh-Allyn otoscope. A series of simultaneous pure-tone pairs, frequencies f1 and f2, at intensities of 65 and 55 dB SPL respectively, were delivered to the test ear. These simultaneous intensity levels were chosen based on the recommendations concerning optimal results in humans (Kimberley, Hernadi, Lee, & Brown, 1994; Stover et al., 1996). The test frequency ratio (2f2/f1) was set at 1.2 to optimize DPOAE results (Abdala, 1996; Gaskill & Brown, 1990; Harris et al., 1989). The frequency protocol was: 1, 2, 3, 4, and 5 kHz, in reverse order. This protocol was used to obtain the most amount of information about the integrity of the outer hair cells. In order to pass the screening, the child had to pass all five frequencies in each ear. A series of stop criteria were also included to maximize screening time within the schools. Pass/refer criteria included: DP-NF 8 dB, DP amplitude minimum -5 dB, NF amplitude minimum -17 dB, time out 14 seconds. These criteria are utilized by the Special Olympics Healthy Hearing screening program (Herer & Montgomery, 2006), where screenings are often performed in sub-optimal noise levels. In a pilot study, these criteria provided equal sensitivity outside of and inside of a sound-treated booth (G. Herer, personal communication, October 18, 2013).

Each screening protocol was timed in order to evaluate any possible differences between the three protocols. For the pure-tone screening, the time began as soon as the child was seated and quiet. The tester gave instructions, conditioned the child to the task, and then tested the child's right ear. Once the child's right ear was complete, the time was stopped and noted. Then, the time was started again and the tester continued testing the child's left ear. Once this was complete, the time was stopped again and noted. When testing the DPAOE screenings, timing did not begin until after otoscopy was complete. Otoscopy was not needed for the pure-tone screening due to the use of supra aural headphones. However, it was necessary for DPOAE because insert ear probe tips were used. Following otoscopy the time was started and the child was instructed. Again, the tester began with the right ear to limit variability. Following instructions, the tester reviewed the screening results for each frequency as they were obtained on the AuDX II Pro screen. Split test times were acquired between 2-5 kHz and 1 kHz. Following the completion of 1 kHz the overall time was stopped and noted. This process was then repeated for the left ear. Because instructions were already given in the beginning, the child was not reinstructed between ears for either screening. A child received a pass if both ears passed the screening. The child was referred for further testing if one or both ears were referred from the screening.

Parents were provided with a report of the screening results. Any child who received a refer outcome for DPOAE, pure-tone, and/or tympanometric screening was referred for further diagnostic testing.

Statistical Analyses

Statistical analysis was completed using SPSS version 15.0 for Windows. SPSS was used to calculate descriptive statistics for age, gender, pass/fail rates and the amount of time necessary to conduct each of the three screening protocols. Paired-sample *t*-tests, with a Bonferroni family-wise correction (α = .05/3 =.017) applied to guard against the possibility of a Type I error, were used to compare the mean amount of time needed to complete each of the three screening protocols. Two-by-two contingency tables were used to compare pass/fail rates for the pure-tone screening protocol (1, 2, 4 kHz) with the five frequency DPOAE screening (1-5 kHz) and the four frequency DPOAE screening protocol (2-5 kHz). Pearson chi-square analysis for independence (χ^2) tests were then completed in order to determine possible relationships of the pass/fail rates of each of the DPOAE protocols to those of the pure-tone screening protocol.

Post-hoc analyses were also conducted to examine any possible differences between gender and age of the pediatric participants. Pearson product-moment correlation coefficients (*r*) for continuous variables were used to analyze relationships between the ages of participants to the amount of time necessary to complete each protocol. Finally, chi-square analysis for independence (χ^2) tests was used to compare participant genders to the pass/fail rates of each of the three screening protocols.

Results

Time to Complete Screening Protocols

Figure 1 displays the mean time to complete each of the screening protocols. Paired-samples *t*-tests, using a Bonferroni family-wise correction was made (α = .05/3 =.017) to guard against the possibility of a Type I error, were conducted to compare the mean time to complete the DPOAE 1-5 kHz (*M*=94.52, *SD*=60.12), DPOAE 2-5 kHz (*M*=55.19, *SD*=40.19), and pure-tone (*M*=213.14, *SD*=168.09) screening protocols. Results suggested statistically-significant differences between the mean times to complete all three protocols. Specifically, the DPOAE 2-5 kHz was significantly faster than both the DPOAE 1-5 kHz (t[197]=19.13, p<.001) and pure-tone (t[195]=13.57, p<.001) screenings. Additionally, the DPOAE 1-5 kHz was significantly faster than the pure-tone (t[195]=10.14, p<.001) screening.

Screening Pass/Fail Rates

Pass/fail rates were examined for each of the three screening protocols. The descriptive statistics for the pass/fail rates of five-frequency DPOAE screening protocol, the four-frequency DPOAE screening protocol, and the pure-tone screening protocol are displayed in Table 2. Data were analyzed via chi-squared (χ^2) tests for independence to determine if the pass/fail rates were significantly related between each of the DPOAE screening protocols and pure-tone screening. Both analyses showed a statistically-significant relationship (DPOAE 1-5 kHz to pure-tone [df=1; 6.61; p<.05]; DPOAE 2-5 kHz to pure-tone [df=1; 9.61; p<.05]). These results suggested there is a relationship between the pass/fail rates of both DPOAE screening protocols and the pure-tone screening protocol.

Post-Hoc Statistics

Pass/fail rates of males versus females were examined for each of the three screening protocols. A Chi-Squared (χ^2) calculation (2-tailed) was completed to determine if a relationship existed between gender and the pass/fail rates in the five frequency DPOAE screening, the four frequency DPOAE screening, or the pure-tone screening. Findings were not statistically significant (*p*=.075, *p*=.165, and *p*=.934, respectively). These results suggest that the genders of the participants were not related to the pass/fail rate for any of the three screening protocols.

Pearson product-moment correlation (*r*) was used to evaluate the relationship between age and the amount of time it took each participant to complete each of the screening protocols. Preliminary analyses

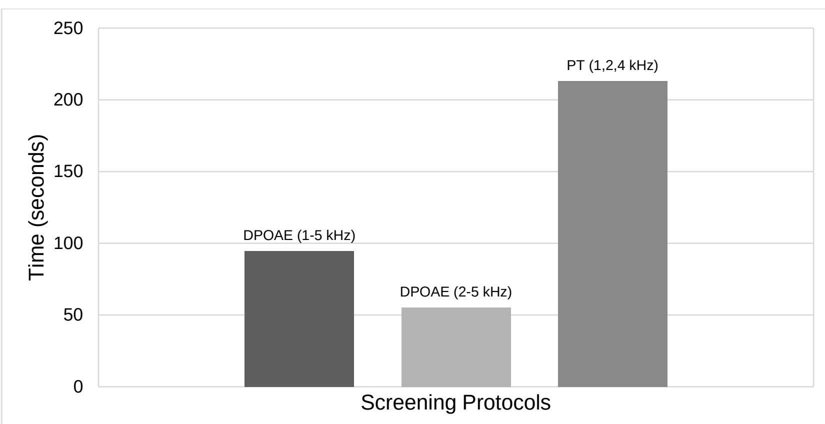

Figure 1. Mean time to complete each screening protocol.

Table 2. Pass/Fail Rates for DPOAE (1-5 kHz), DPOAE (2-5 kHz) and Pure-Tone (1,2,4 kHz) Protocols

Protocol	Pass	Fail	Total
DPOAE (1-5 kHz)	134	64	198
DPOAE (2-5 kHz)	141	57	198
Pure-Tone (1,2,4 kHz)	175	21	196

Note. DPOAE=Distortion Product Otoacoustic Emissions. Two children would not cooperate to be screened using pure tones.

were performed to ensure no violation of the assumptions of normality, linearity, and homoscedasticity. A small negative correlation was found between the participant's age and the pure-tone screening (r = -.15, p =.035). In other words, as the age of a participants increased, there was a slight decrease in the amount of time it took them to complete the pure-tone screening. No significant correlations were found between the participants' ages and the five-frequency DPOAE screening (r = -.06, p =.369) or the participants' ages and the four-frequency DPOAE screening (r = -.06, p =.369).

Discussion

The aim of this study was to evaluate the use of DPOAE as a first line screening tool in a pediatric population and to compare their referral rate against a traditional pure-tone screening battery. The results of this study indicated that significant time differences between the mean time to complete the screening protocols, with the DPOAE 2-5 kHz screening taking the least time and the pure-tone screening taking the most time. Extended testing times were expected for the five frequency protocol due to the incidence of higher levels of ambient noise present in lower frequencies. In addition, it was anticipated that the pure-tone screening would take longer to complete due to the increased amount of time needed for instruction and conditioning versus the DPOAE screenings. These timing results are significant for preschool screening programs. With either DPOAE protocol taking significantly less time to complete than pure-tone screenings, personnel would be able to screen more children on a day to day basis. In addition, the screener may have the opportunity to rescreen children who may not have passed the screening the first time.

No previous studies have compared the amount of time necessary to complete a five frequency DPOAE screening and a pure-tone screening; however, a study by Sideris & Glattke (2006) evaluated the amount of time needed to complete a TEOAE screening (1-4 kHz) and traditional school based hearing screenings. They found significant differences, with mean screening times of 137.6 and 113.4 seconds for the pure-tone and TEOAE screenings, respectively. Comparing the results of Sideris & Glattke (2006) with the current study, it appears that DPOAE screening may take less time on average than TEOAE screening; however, this conclusion should be interpreted with caution as the background noise levels were not recorded for either study.

In the present study, a statistically-significant relationship was noted between the pass/fail rates of both the four and five frequency DPOAE screening protocols and the pure-tone screening protocol. In similar studies by Taylor and Brooks (2000) and Sideris and Glattke (2006), significant relationships were found between the pass/fail rates of a TEOAE screening protocol and pure-tone screening protocol in the pediatric population. The results of this study suggested the comparable use of DPOAE to pure-tone screenings in the detection of hearing loss.

The pass/fail rates for the present study were relatively similar to Sideris and Glattke (2006), who also conducted their screenings in preschools. Pure-tone screening pass rates for this study were 88.4% and were 78.5% as reported by Sideris and Glattke (2006). They obtained a pass rate for TEOAE screenings of 79% while we obtained pass rates for DPOAE of 71.2% (for 2-5 kHz) and 67.7% (for 1-5 kHz). In contrast, the pass rates were higher for TEOAE screening in the Taylor and Brooks (2000) study than in the present study. The main reason for this difference is likely due to the effect of noise within the screening environments. Taylor and Brooks (2000) conducted all testing within a sound-treated room, whereas we conducted the screenings in regular rooms within each preschool. Taylor and Brooks (2000) reported sensitivity and specificity by comparing the TEOAE screening results with pure-tone screening results. On the other hand, we do not report sensitivity and specificity of the DPOAE protocols.

Our reasoning for not reporting sensitivity is as follows. First, true sensitivity or specificity of the screening protocols cannot be determined unless a diagnostic evaluation of each preschooler would have been completed in a sound-treated booth. Similar to other studies that conducted screenings at the school sites (Sideris & Glattke, 2006; Smiley et al., 2012); we were unable to obtain diagnostic test results. Second, without the true gold standard of a diagnostic evaluation, we are left with less-than-ideal choices for reporting sensitivity and specificity. These choices include 1) making the assumption that every child tested was indeed normal and therefore calculating sensitivity and specificity based on this assumption; or, 2) making the assumption that pure-tone screening results can serve as the gold standard; thus, comparing DPOAE screening protocols to the pure-tone screening protocol results to calculate sensitivity and specificity of the DPAOE protocols. No screening test is completely accurate; however, we concur with the principle that "by continuing to compare screening tools and by reporting sensitivity and specificity without follow up diagnostic testing, the possibility of over-referrals (or worse, under-referrals) remains" and will do nothing to improve our knowledge base (Smiley et al., 2012, p. 35).

Nevertheless, the results of the present study suggested that DPOAE screenings could be used in a preschool population. Clinicians should be aware that each screening measure has its merits. A "pass" for a child using a DPOAE screening does not necessarily mean that the child will "pass" a pure-tone screening, and vice versa (Smiley et al., 2012). Again, there is no way to know which screening measure is more accurate without the diagnostic evaluation results. More generally, DPOAE could be used as part of a screening protocol to aid in the detection of hearing loss in the pediatric population (Dhar & Hall, 2012). We suggest that using DPOAE screening may allow intervention services to begin sooner for children whose screenings may have otherwise been delayed until the child's cognitive level matured. As previous research has reported, the provision of early intervention services improves a child's speech and language development as well as cognitive outcomes and overall quality of life (Moeller, 2000; Yoshinaga-Itano et al., 1998).

A small negative correlation was found between the participant's age and the amount of time necessary to complete the pure-tone screening protocol. A minimal correlation is understandable because of the participant's need for higher cognitive functioning to condition to the task. However, no significant correlations were found between the participants' age and either DPOAE screening. No correlation was expected because no conditioning was needed and instructions for the DPOAE were minimal. In addition, no significant relationship was expected or found when gender and pass/fail rates of the three screening protocols were compared. This again emphasizes the practicality of using DPOAE across the young pediatric population in detecting hearing loss.

Limitations

All of the participants were recruited from various schools within a limited geographical area (Baltimore County, Baltimore City, and Carroll County). It is important to note that the participants may not be a full representation of the prevalence of middle ear disorders within various socioeconomic statuses or ethnicities. A more heterogeneous participant group would be desirable. Another limitation to note is that a certain amount of error in timing may have occurred when the examiners finished testing and when they stopped timing the procedure. Although all examiners were instructed on the timing protocol in the same manner, it is possible that there was some variation between examiners. Another limitation of the study was the variability of the testing environments. In every school, the quietest possible testing environment was chosen to conduct DPOAE screenings. In some instances the DPOAE screening was conducted in a room unto itself, and in other sites, pure-tone screenings were being conducted in the same room as the DPOAE screenings.

Future Research

While we are cautiously optimistic regarding the applications of these findings to preschool hearing screening protocols, further research is needed to test the true sensitivity and specificity of using DPOAE screenings in comparison to pure-tone hearing screenings in this population as well as others. In future studies, we suggest that a full diagnostic hearing test battery should be completed to determine the efficacy of these screening procedures. Obtaining diagnostic results (perhaps with the use of a portable sound-treated booth) on the same day the screenings take place would finally answer the questions regarding sensitivity and specificity of these various screening methods within the natural screening environment of a preschool. In addition, future research should evaluate whether conducting screenings on different populations, including cognitive ability, age, socioeconomic status, and ethnicity, would produce similar pass/fail rates. For instance, DPOAE screening protocols may be more useful than pure-tone screening protocols for other populations, such as individuals with intellectual disabilities. Lastly, a more heterogeneous participant group should be used, if possible.

Conclusion

This study investigated pass/fail rates and the time to complete protocols using DPOAE in comparison to pure-tone hearing screening in a preschool population. The data adds to the body of literature concerning the time-effectiveness of DPOAE screening compared to pure-tone screenings, including the feasibility of including 1 kHz in the DPOAE screening protocol in a preschool population, and provides further data regarding pass/fail rates of those protocols. Results suggested that the use of DPOAE is faster than pure-tone screening with relatively similar pass/fail rates. We recommend that clinicians consider adding DPOAE to their current screening protocol (not substituting DPOAE for pure-tone screening), or at least having DPOAE available to screen children who cannot or will not participate in pure-tone screenings. The ease of administration and lack of behavioral response needed from the child make the use of DPOAE screening desirable for the preschool population. The results of this study demonstrated that DPOAE can potentially aid in identifying hearing loss that can interrupt normal language development, impede cognitive growth, and delay the development of a child's socialization skills. Despite the findings of this study, we suggest that further research is needed to compare these various screening methods with the gold standard of diagnostic audiologic test results in the pediatric population and other populations.

Acknowledgements

These data were collected while the first and fourth authors (Brian M. Kreisman and Nicole V. Kreisman) were at Towson University. The authors would like to thank the parents of the participants for giving their consent for their children to participate in this study, the children who participated, and the graduate student clinicians who helped with the hearing screenings. We also thank the three anonymous reviewers for their constructive feedback, which considerably improved the quality of this paper.

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Listening Comprehension in Background Noise in Children with Normal Hearing

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In typical school classrooms, children are required to listen in environments with poor acoustics and to process and comprehend complex messages from the teacher and from peers in order to achieve academic success. To predict children's listening abilities in the classroom, research is warranted to begin to examine the specific aspects of comprehension that are most affected when listening in background noise. Comprehension tasks include (1) listening for the main idea, (2) identifying the details, (3) inferring information, (4) defining vocabulary, and (5) determining the most pertinent information. There is an existing measure that provides normative data from children with normal hearing when performing these five aspects of comprehension in a quiet environment (Bowers, Huisingh, & LoGiudice, 2006); however, to our knowledge, there is no test measure to examine these components of listening comprehension in the presence of background noise. As a result, we examined the five aforementioned areas of listening comprehension in background noise in eighteen, six- to ten-year-old children with normal hearing. The results suggested that children's listening comprehension is significantly affected by the presence of excessive (i.e., -5 dB signal-to-noise ratio) background noise, but different patterns of results were found across the subtests. Children had the greatest difficulty in the *details, reasoning,* and *understanding messages* subtests.

Introduction

Audiologists and hearing professionals working with children in the schools most often focus on assessing hearing thresholds and speech-recognition abilities during audiological evaluations. Threshold tasks with pure-tone stimuli require children to indicate when they detect the presence of a sound, while the assessment of thresholds with speech stimuli require children to repeat, point to, or write the auditory stimulus heard. Speech recognition, which is conducted at suprathreshold levels, also requires children to repeat, point to, or write the speech stimulus heard. These threshold and suprathreshold tasks may give some indication of a child's hearing abilities; however, these tasks do not realistically determine children's classroom listening abilities. The complexity of classroom listening is difficult to simulate in the clinic because it requires a higher auditory skill level, involves numerous developmental factors, and encompasses noisy and reverberant environments.

Auditory listening comprehension is the highest auditory-skill level according to Erber (1977) and requires cumulative mastery of less complex auditory skills including detection, discrimination, and identification (i.e., recognition). Listening comprehension has been defined as an interactive, complex task whereby "spoken language is converted to meaning in the mind" (Lundsteen, 1979). In the classroom, comprehension is critical for mastering numerous academic skills, such as determining the main idea and details within a message, following directions, answering questions, and participating in class discussions. A child's listening-comprehension abilities will vary based on his or her sensory processing (auditory and visual), attention span, grammatical and lexical knowledge, working memory, cognition, past experiences, and mental and physical state (Wolvin, 2009). Several extrinsic factors will also influence a child's comprehension abilities including characteristics of the talker's voice and the complexity of the message. However, likely the most influential external factor on auditory performance of school-aged children is the acoustics of the classroom or environment.

The acoustics of the environment are of great concern because numerous studies report that typical classroom acoustics do not meet recommendations from the American Speech-Language-Hearing Association (2005) or American National Standards

Institute (2010) for unoccupied noise levels or reverberation times (Knecht, Wilson, Whitelaw, & Feth, 2002; Nelson, Smaldino, Erler, & Garstecki, 2007/2008; Pugh, Miura, & Asahara, 2006). In several studies that simulate typical classroom environments, noisy and reverberant listening conditions significantly degrade the threshold or suprathreshold speech-recognition abilities of children with normal hearing (Jamieson, Kranjc, Yu, & Hodgetts, 2004; Neuman, Wróblewski, Hajicek, & Rubinstein, 2010; Schafer et al., 2012; Wróblewski, Lewis, Valente, & Stelmachowicz, 2012). In all of these studies, children's speech-recognition performance in noise significantly worsened as the age of the child decreased and as levels of noise and reverberation increased. In fact, Neuman and colleagues (2010) report that children with normal hearing, ages 6 to 12 years, require a signal-to-noise ratio (SNR) of at least +10 to +20 dB to achieve average speech-recognition performance of 95% correct at the back of the classroom, with younger children needing even higher. The necessary SNR of +10 to +20 dB will be unachievable in school classrooms with typical acoustics (Knecht et al., 2002; Sanders, 1965). These studies clearly outline the significant declines in speech-recognition performance in the presence of background noise; however, these results may not represent the deficits in listening comprehension.

More specifically, recent research suggests that speech-recognition performance in noise does not necessarily predict how well children comprehend complex messages (Valente et al., 2012). In one simulated classroom experiment, Valente and colleagues evaluated sentence recognition performance in noise at a +10 dB SNR and story comprehension in the same noise at a +10 dB SNR in two conditions (teacher lecture with speech stimuli from one loudspeaker; class discussion with speech stimuli from five loudspeakers) in 40 adults and 50 children ages 8 to 12 years. Children and adults had excellent performance (~95% correct) on the sentence-recognition task, but children performed significantly worse than adults on the comprehension tasks, with the poorest child performance in the class discussion condition. In a second experiment (Valente et al., 2012), speech recognition and comprehension, in the same teacher lecture and class discussion conditions, was assessed at two SNRs (+7 dB; +10 dB) and at two reverberation times (0.6 s; 1.5 s) in 30 adults and 60 children ages 8 to 11 years. Analyses of the results showed good speech-recognition performance for all participants (> 82%), but the younger children had poorer scores than older children and adults, particularly in the more adverse listening conditions. Performance on both comprehension tasks was substantially poorer than performance on the speech-recognition tasks, with significantly poorer performance in the condition with the poorer SNR and higher reverberation time. In summary, comprehension was more affected in background noise than speech-recognition performance, and younger children's comprehension is even more affected than that of older children and adults. As stated previously, the discrepancy in performance between the recognition and comprehension conditions is likely related to many factors including differences in stimuli (sentences vs. stories), task complexity (recognition vs. comprehension), cognition, working memory, and attention.

Given the full range of auditory demands placed on children in typical school classrooms and the importance of listening comprehension for academic success, additional research is warranted to begin to examine the specific aspects of comprehension that are most affected when listening in background noise. Comprehension of a message is a multifaceted task, which involves (1) listening for the main idea, (2) identifying the details, (3) inferring information, (4) defining vocabulary, and (5) determining the most pertinent information. There are existing test materials that provide normative data on how typically-functioning children perform on these various aspects of comprehension in a quiet environment (Bowers, Huisingh, & LoGiudice, 2006); however, to our knowledge, no test measures or previous research studies have examined these components of listening comprehension in the presence of background noise. As a result, the purpose of this exploratory study was to examine the five aforementioned areas of listening comprehension in 6- to 11-year-old typically-functioning children with normal hearing.

Methods

Participants and Procedures

Eighteen children, ages 6;9 years to 10;11 years (M=9;1, SD=1;4), with normal hearing sensitivity and no reported disabilities participated in the study. Parental consent to participate in the study was obtained for all children. Parents completed case history forms, which ruled out a history of special education support, speech-language delays/disorders, presence of other disabilities, hearing loss, and recurrent ear infections or disorders. Prior to testing, all children received a pure-tone hearing screening including octave frequencies from 250 to 8000 Hz with the passing criteria of 20 dB HL at each frequency tested in both ears. Following the screening, each participant completed The Listening Comprehension Test 2™ (Bowers et al., 2006), which required approximately 30 minutes to complete. Children were given a break, if necessary.

Test Stimuli & Equipment

The Listening Comprehension Test 2™ (Bowers et al., 2006) is used to determine children's listening comprehension skills in classroom situations. This test consists of 25 stories, with story length varying from two to ten sentences each, and three to four questions associated with each story. Each question evaluates a particular listening behavior or skill that falls within one of the five subtests: *main idea, details, reasoning, vocabulary,* and *understanding messages*. The *main idea* subtest requires the child to identify the primary topic of the story, and the *details* subtest focuses on recall of one or more details presented within the story. The *reasoning* subtest asks the child to answer or infer answers from the information provided in the story while the *vocabulary* subtest requires children to define a specific word in the story. The *understanding messages* subtest asks children to extract the most pertinent information from the story and to answer questions about this information. In the test manual, a list of acceptable and unacceptable answers is provided to the examiner for each question. A raw score is calculated by summing the number of correct responses within each subtest area and for the entire test. The test manual provides the mean raw score and a standard deviation by chronological age for each subtest presented in a quiet condition. Using these data, 95% confidence intervals were calculated for each chronological age group and were then used for comparison to the individual subtest scores from the children in the present study. Because the children in the present study were typically developing and normal hearing, the examiners assumed that their performance in quiet would be within the 95% confidence intervals of the data published in the test manual.

Traditionally, this test is presented to a child in a quiet environment using live voice, but in the present study, a recorded version of the test with a female talker was created and edited using acoustic software (Cool Edit Pro, 2003). The talker was instructed to record the passages and associated questions in a conversational manner with normal inflection and intonation. Once the stimuli were recorded, the stories and associated questions were saved in separate digital, two-channel (stereo) files. The speech stimuli, recorded on Channel 1, were then equated for average root-mean-square (RMS) intensity using the acoustic software. Continuous four-classroom noise (Schafer & Thibodeau, 2006; Schafer et al., 2012), which was equated for the average RMS and shaped to the long-term-average spectrum of the speech stimuli, was added to Channel 2 of each digital file. The stimuli were then burned onto a compact disc (CD) for presentation in a double-walled sound booth. During testing, the child was seated in the middle of the sound booth. The equipment used to present the stimuli included a clinical audiometer, CD player, and four loudspeakers. The speech stimuli were presented from one head-level loudspeaker located at 0 degrees azimuth and multi-classroom noise was presented from three head-level speakers located at 90, 180, and 270 degrees azimuth. During testing, the speech stimuli were presented at an average of 60 dBA. Noise was spatially separated and presented at an overall level of 65 dBA (-5 SNR) for the three noise speakers combined, which was intended to simulate listening in a noisy classroom during group activities or projects. Noise was presented during the stories as well as during the questions. The spatial separation of the speech and noise sources is likely to make the comprehension task less difficult than that of previous studies with no spatial separation (i.e., both from same speaker) of the speech and noise (Valente et al., 2012).

Results & Discussion

The raw scores for all 18 participants across the five subtests as well as the 95% confidence intervals calculated from the data provided in the test manual are plotted in the figures. In each figure of raw data, the children's raw scores were plotted as a function of age in order to examine potential effects of age.

Main Idea

When examining the data in Figure 1 from the *main idea* subtest, eight of the children were above the 95% confidence interval, nine were below, and one was within. As a result, half of the children had significant difficulty identifying and verbalizing the main idea of the passages when listening to the stories in the poor SNR. On average, performance of the children and in the test manual was similar with an average score for the children in this study of 12 (SD=2.3) and an average of the normative data in quiet of 12 (SD 1.8).

To quantify the relationship between age and comprehension of the main idea in noise, a correlation analysis was conducted between the children's raw scores and his or her age. Results of this analysis suggested a significant medium (Cohen, 1988) positive relationship of between age and comprehension of the main idea of the passages ($r[16] = .44$, $p < .0001$).

When considering performance in this subtest relative to remaining subtests, participants may have shown better performance because mastery *main idea* did not require audibility of the entire story. The *main idea* of a story could be determined by repeated vocabulary or associated terminology provided throughout the story. Therefore, a child may have been given several opportunities within a story to identify the *main idea*.

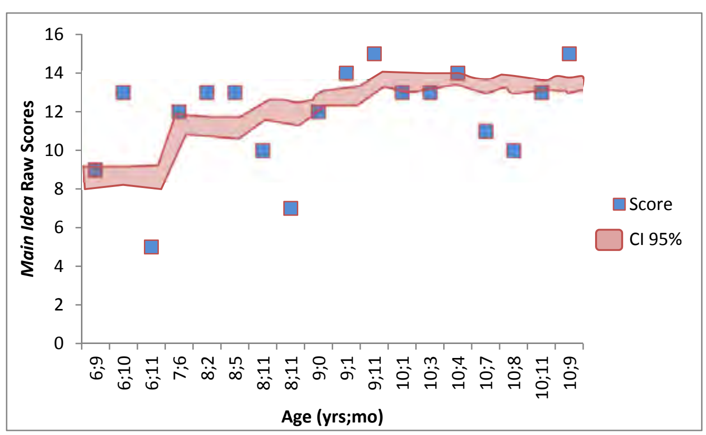

Figure 1. Raw scores from the participants and the 95% confidence intervals in the shaded region for performance in quiet from the test manual for the *main idea* subtest.

Table 1. Correlation Analyses Between Listening Test 2 Scores and Age

Subtest	Correlation Coefficient (*r*)	Statistical Significance (*t* test)
Main Idea	.44	$t(17) = 25.7, p < .000001$
Details	.70	$t(17) = 29.1, p < .000001$
Reasoning	.58	$t(17) = 28.5, p < .000001$
Vocabulary	.63	$t(17) = 28.3, p < .000001$
Understanding Messages	.62	$t(17) = 29.5, p < .000001$

Details

In contrast to the results for the *main idea* subtest, Figure 2 shows that, in the *details* subtest, only two children were above the 95% confidence interval, 14 were below, and two were within. When examining average performance, the average score in the present study was 8 (SD=3.8), and the average score in the test manual was 11 (SD=1.9).

The substantially poorer comprehension performance for most children on the *details* subtest may relate to several issues including inaudibility of the entire passage, difficulty determining the most important information, increased distractibility in the presence of noise, or the possibility of reduced short-term memory when listening in background noise. Additionally, as shown in Figure 3, there was a significant strong relationship between children's performance on the *details* subtest ($r[16] = .70$, $p < .0001$), which could be related to developmental effects of speech recognition in noise or developmental effects of comprehension.

Reasoning

For the *reasoning* subtest in Figure 4, one child was above the 95% confidence interval while the remaining 17 were below the interval. The average score for the children in this study in noise was 6 (SD=3.3), and the average of the normative data in quiet was 10 (SD 2.0).

The *reasoning* subtest was likely the most difficult subtest because it required the participants to generate inferences and conclusions based on what they heard in the story. For example, after a story about severe thunderstorms with high winds, a question in this subtest might have asked, "Why shouldn't the mother leave the front door of the house open during the storm?" The story would have provided information about the high winds, blowing leaves, and sideways rain, but the child would be required to describe to the examiner that the leaves and rain would get into the house. As a result, the information the child must provide is not given in the story; he or she must consider what is heard and then hypothesize what may happen. This task would be particularly difficult if the child did not hear the entire passage or did poorly in the *details* subtest. In addition, there was a strong, significant, positive relationship between the child's age and comprehension performance on the reasoning subtest ($r[16] = .58$, $p < .0001$).

Vocabulary

The data in Figure 5 suggested that, in the *vocabulary* subtest, seven children were above the 95% confidence interval, 10 were below, and one was within. The average score from the children in noise was 9 (SD=3.6) and from the normative data was 9 (SD=2.8).

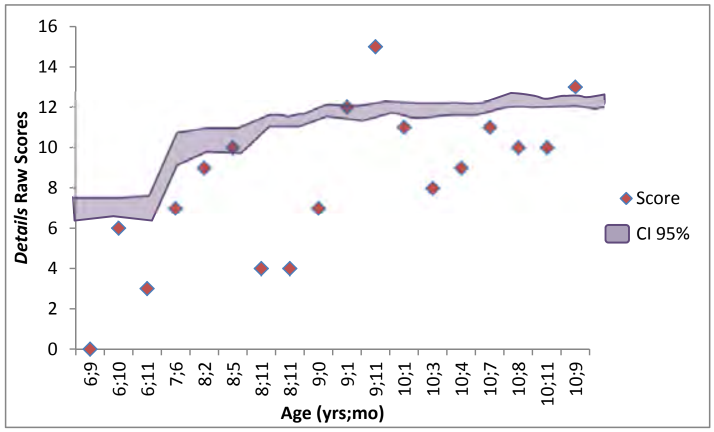

Figure 2. Raw scores from the participants and the 95% confidence intervals in the shaded region for performance in quiet from the test manual for the *details* subtest.

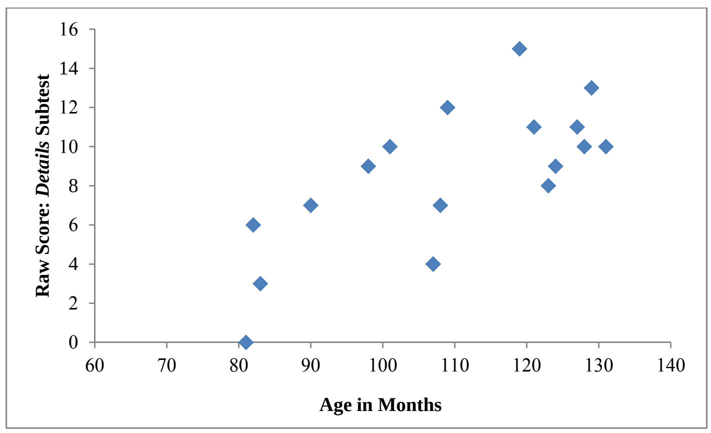

Figure 3. Scatter plot of age in months and raw scores in the *details* subtest.

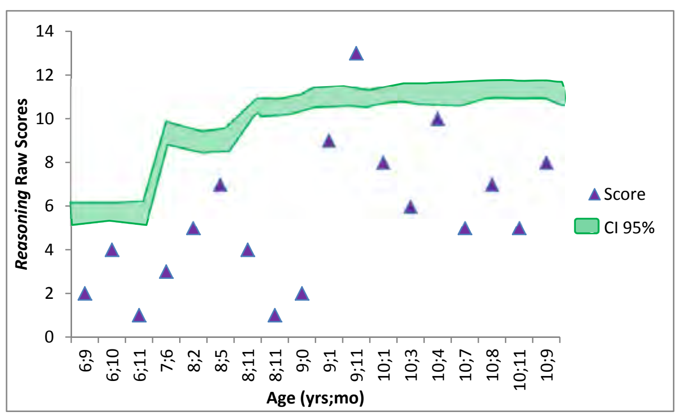

Figure 4. Raw scores from the participants and the 95% confidence intervals (vertical lines) for performance in quiet from the test manual for the *reasoning* subtest.

This subtest involved defining one word from a sentence in the passage. For example, a question in this subtest might have been, "What does the word *brush* mean in this sentence, "The dentist told the boy to *brush* his teeth." As a result, it is plausible that, in some children, the story was completely inaudible to the child, but he or she could define the vocabulary word correctly in the sentence provided. However, it is evident that most participants were not able to define the words due to inability of the story, inaudibility of the question, developmental effects for this task, or limited knowledge of the vocabulary in the passages. When examining the potential effect of age, there was significant, strong, positive relationship calculated between the child's age and performance on the *vocabulary* subtest ($r[16] = .63$, $p < .0001$). .

Understanding Messages

Finally, for the *understanding messages* subtest, Figure 6, one child was above the interval, 13 were below, and four were within.

The *understanding messages* subtest required the child to repeat the important information that he or she heard during the story. For example, in a story about a mother going to the store, the examiner might ask, "What time was mother going to the store?" Most often, there was only one opportunity to hear the information necessary to answer the questions in this subtest; therefore, inaudibility or auditory memory may have been an issue. Similar to all other subtests, there was a significant, strong, positive relationship calculated between the child's age and performance on the *understanding messages* subtest ($r[16] = .62$, $p < .0001$)

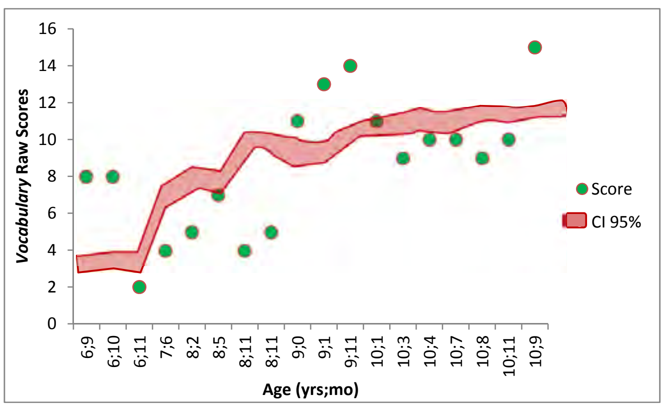

Figure 5. Raw scores from the participants and the 95% confidence intervals in the shaded region for performance in quiet from the test manual for the *vocabulary* subtest.

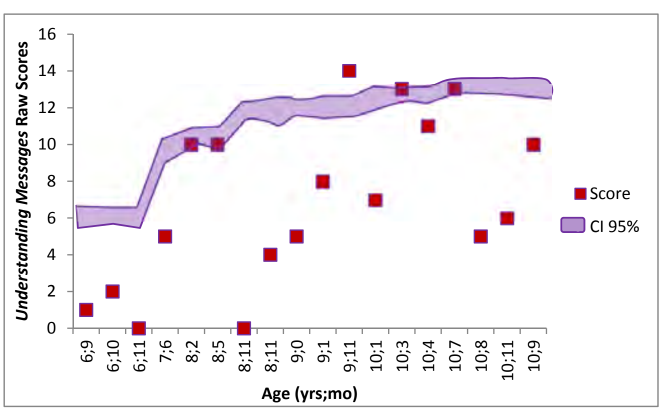

Figure 6. Raw scores from the participants and the 95% confidence intervals (vertical lines) for performance in quiet from the test manual for the *understanding messages* subtest.

Comparisons Across Subtests

A greater number of children were above or within the 95% confidence intervals for identifying the *main idea* of the story (n=9) and defining *vocabulary* from the stories (n=8). Nonetheless, nine children in the *main idea* subtest and ten children in the *vocabulary* were below the 95% confidence intervals, suggesting significant difficulty for at least half of the children. Most of the children's raw scores were below the 95% confidence intervals for the three subtests requiring higher-order comprehension: *details* (n=14), *reasoning* (n=17), and *understanding messages* (n=13) subtests. In fact, six children were below the 95% confidence interval for two of the aforementioned subtests, and ten children were below the confidence interval for all three subtests. As a result the *details*, *reasoning*, and *understanding messages* subtests require similarly high levels of comprehension in the children in this study. In contrast, nine of the children had scores above or within the 95% confidence interval for both the *main idea* and *vocabulary* subtests, and all but three children passed at least one of these subtests. When examining the children who exhibited the poorest scores across the five subtests, seven children were below the 95% confidence intervals for all five subtests (n=3) or four of five subtests (n=4). In the four children who only passed only one subtest, it was always the *vocabulary* subtest.

Children's ages were significantly correlated with their raw scores across each subtest, which suggests that younger children performed more poorly than older children. It is difficult to pinpoint the exact origin of this relationship. In part, it is likely related to the developmental effects of auditory comprehension because, according to the raw scores in the test manual, typically developing children show a substantial improvement in listening comprehension with increasing age. For example, the mean raw score of six-year-old children in the *understanding messages* subtest in a quiet condition was 5.6 (SD=3.3) while the raw score of 11-year-old children was 12.7 (SD=2.6). Additionally, the medium and strong correlations reported in this study could be related to developmental effects of auditory perception in noise (e.g., Jamieson et al., 2004; Neuman et al., 2010; Schafer et al., 2012).

Study Limitations

First, the results of this exploratory investigation included 18 typically-functioning participants with normal hearing, which is a relatively small sample size. Different results could have been obtained from a larger or different sample of children, and it is highly likely that dissimilar results would be measured in populations of children with hearing loss or other auditory disorders. Second, the children in the present study were not tested in a quiet condition. Instead, data from the test manual were used for comparison purposes. Data from the manual included sample sizes of 117 to 133 typically-developing children per age group. These data were chosen for comparison to the data from the present study because the examiners our sample represented typically-functioning children. However, it is possible that our sample of children had different performance in quiet than those in the normative sample. In fact, it is clear that one nine-year-old child had performance above the 95% confidence interval, even in the noise condition. Third, only one test of listening comprehension, one loudspeaker arrangement, and one SNR was utilized in the present study. Based on the results, variable listening comprehension abilities would be expected based on the types of questions asked about the passage/story (i.e., main idea, details, etc.). The three-loudspeaker arrangement was used to simulate a preferentially seated child, in the front of the classroom, with noise from peers at the sides and back. Noise presented from other locations may result in better or worse performance. In addition, a more or less favorable SNR would certainly alter listening comprehension. Further research will be necessary to replicate these results, determine the effects of SNR and loudspeaker arrangement, and to examine other populations of children.

Conclusions

As expected, children's listening comprehension is significantly affected by the presence of excessive (i.e., -5 dB signal-to-noise ratio) background noise, but different patterns of results were found across the subtests. Children had the greatest difficulty in the *details*, *reasoning*, and *understanding messages* subtests. The findings in this study further support the need for developing tests of auditory comprehension in background noise to better represent listening expectations in school classrooms. Future research will focus on the development of listening comprehension tests, with particular attention on tasks that involve the deficit areas in the present study: recalling details, reasoning, and understanding the message. Once a valid and reliable measure of listening comprehension in background noise has been developed, additional populations of children may be assessed including those with hearing loss, auditory processing disorders, and auditory dysfunction. Given the listening requirements of typical classrooms, performance on a listening comprehension test in background noise may be more sensitive for detecting children with educational need for hearing assistance technology in the classroom than measures of speech-recognition performance in noise.

Acknowledgements

Funding for this study was provided by Phonak AG. The funds were used to compensate participants for their time, efforts, and mileage to the test center. The primary investigator received no monetary compensation related to the study.

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Evaluation of Speech Recognition with Personal FM and Classroom Audio Distribution Systems

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Speech recognition in quiet and in noise was evaluated for children with normal hearing, children with hearing loss, and adults with normal hearing. Performance was evaluated in a classroom environment without use of wireless radio frequency (RF) hearing assistance technology (HAT) and with two different types of classroom audio distribution (CAD) systems (a fixed-gain multiple loudspeaker system and an adaptive single-tower CAD system). Children's speech recognition was also assessed with an adaptive personal frequency modulation (FM) system coupled to their personal hearing aids as well as with simultaneous use of the personal FM system with the aforementioned CAD systems.

The results of this study indicated that performance in quiet was similar between the condition without RF use and each of the conditions with use of RF HAT. However, speech recognition in noise was significantly better with use of each of the RF HAT. Use of the adaptive single tower CAD system provided better speech recognition in noise than use of the fixed-gain multiple loudspeaker CAD system. The best performance was achieved with the adaptive personal FM system and simultaneous use of the personal FM and adaptive single tower CAD system with no differences between those conditions. Performance with simultaneous use of the personal and adaptive CAD system was considerably better than performance obtained with simultaneous use of the personal and fixed-gain, multiple loudspeaker system. Adults with normal hearing achieved better performance across all conditions when compared to children with normal hearing, while children with normal hearing outperformed children with hearing loss.

Introduction

It is well known that children require a more favorable signal-to-noise ratio (SNR) than adults in order to understand speech in the presence of noise. Specifically, the typical five-year- old child requires an SNR that is around 5 dB higher than an adult in order to recognize words in noise with a similar level of accuracy as adults (Boothroyd, 1997). Research has shown that children with hearing loss are even more likely to experience difficulty understanding speech in noise. For instance, Finitzo-Hieber and Tillman (1978) evaluated speech recognition in noise and showed that children with mild to moderate hearing loss had speech understanding scores that were twenty to thirty percentage points lower than children with normal hearing. Additionally, Crandell (1993) compared speech recognition in noise between children with typical hearing and minimal hearing loss and found that children with minimal hearing loss scored 25 percentage points poorer at a -6 dB SNR.

Numerous studies have shown that children with hearing loss experience a considerable reduction in speech recognition in reverberant environments (Finitzo-Hieber & Tillman, 1978; Nabelek & Nabelek, 1985; Neuman, Wroblewski, Hajicek, & Rubinstein, 2012). For instance, Finitzo-Hieber and Tillman (1978) measured speech recognition at different signal-to-noise ratios and reverberation levels and reported that speech recognition scores typically decreased by about 20 percentage points when reverberation time was increased from 0 to 1.2 seconds. Furthermore, research has shown that persons with hearing loss begin to show deterioration in speech recognition when the reverberation time exceeds 0.4 to 0.5 seconds (Crandell, 1991, 1992; Crandell & Bess, 1986).

Additionally, research has shown that children encounter significant difficulty with understanding speech that originates a great distance from the source (Crandell & Bess, 1986). Specifically, Crandell and Bess (1986) measured speech recognition of 5 to 7 year-old children in a typical classroom environment. The children scored 89% correct on a word recognition task when the words were presented from six feet away, but their performance decreased to 36% correct when the source of the signal of interest was located 24 feet away.

Our national guidelines pertaining to classroom acoustics suggest that the ambient noise level of an unoccupied classroom should not exceed 35 dBA and reverberation times should not exceed .6 seconds (American National Standards Institute, 2010). Furthermore, the SNR should ideally be 15-20 dB, and the reverberation time should be less than 0.4 seconds in order for children with hearing loss to communicate effectively. However, numerous studies have shown that the acoustics of typical classrooms do not meet these criteria. For example, Choi and McPherson (2005) reported that mean ambient noise levels in a group of typical occupied classrooms in Hong Kong were 61 dBA. Likewise, Massie and Dillon (2006) measured noise levels in occupied classrooms in Australia and reported ambient noise levels ranging from 64 to 72 dBA. Similarly, Sanders (1965) measured the SNR in classrooms and noted a mean SNR of -1 dB in 17 kindergarten classes and +5 dB in 24 elementary and high school classes. Other studies have reported classroom SNRs ranging from -7 to +4 when the classroom is occupied (For a review, see Crandell and Smaldino [2000a]). Finally, research has shown that reverberation times in typical classrooms range from .6 to 1.2 seconds (Knecht, Nelson, Whitelaw, & Feth, 2002).

Use of remote microphone hearing assistance technology (HAT) is the most effective method to improve speech recognition in classrooms with challenging acoustics. Remote microphone wireless systems are available in a variety of configurations and include classroom audio distribution (CAD) systems (also known as soundfield amplification systems), personal soundfield systems, or personal radio frequency (RF) systems. Please note that remote microphone wireless assistance technology refers to a system that contains a transmitter that captures a signal of interest (typically via a microphone) and wirelessly transmits that signal to a personal RF receiver coupled to a child's hearing aid or cochlear implant sound processor or to a loudspeaker or multiple loudspeakers. CAD systems are comprised of a microphone coupled to a transmitter which wirelessly delivers the signal captured by the microphone to one or more loudspeakers that are strategically placed in the classroom. Some CAD systems feature one loudspeaker to distribute the sound, while others include multiple loudspeakers (two to four, typically) in an attempt to provide a more uniform distribution of the signal of interest across the classroom. Although there would seem to be a theoretical advantage in using multiple loudspeakers in a CAD system so that the signal of interest may be distributed evenly throughout the classroom, there are currently no known studies comparing performance obtained with multiple loudspeaker and single loudspeaker CAD systems.

In general, the objective of a CAD system is not to amplify the signal of interest to a high level, but instead, to provide an even distribution of the signal throughout the classroom so that each child has consistent access to the primary signal regardless of the position of the teacher or students. The improvement in SNR provided by CAD systems depends upon a number of factors, including the quality and position of the loudspeakers, the position of the students relative to the loudspeakers, and the acoustics of the classroom. Because of these various factors, previous research in classrooms with children with normal hearing has suggested that CAD systems improve the SNR by as little as 2 dB and as much as 11 dB (Larsen & Blair, 2008; Massie & Dillon, 2006). Other studies have also shown that use of CAD systems results in improvements in literacy development, standardized test scores, and classroom behavior, as well as a reduction in teacher absences (Chelius, 2004; Flexer & Long, 2003; Gertel, McCarty & Schoff, 2004; Massie & Dillon, 2006; Massie, Theodoros, McPherson, & Smaldino, 2004).

A personal soundfield system is another form of a remote microphone wireless system designed for classroom use. A personal soundfield system is essentially comprised of the same components as a CAD system, but the loudspeaker is smaller and intended to be placed on the desk of the child with hearing loss. The close proximity of the loudspeaker to the child is intended to provide a more favorable SNR than a CAD system. There is a paucity of research examining the SNR improvement provided by personal soundfield systems. One of the few extant studies, by Crandell, Charlton, Kinder, and Kreisman (2001) found significant speech-perception benefit for a desktop portable soundfield system over unaided listening, but the desktop system was less effective than a body-worn personal frequency modulation (FM) receiver. Iglehart (2004) reported improved speech perception by children using cochlear implants with desktop and soundfield FM systems, but no difference between the two types in a quiet room and an advantage for the desktop system in noisy rooms.

Remote microphone personal radio frequency (RF) systems (historically referred to as personal FM systems) are comprised of a microphone, which is coupled to a transmitter that wirelessly delivers the signal captured by the microphone to RF receivers that are directly coupled to the child's hearing aids or cochlear implants. Personal RF systems provide the most improvement in SNR, ranging from as little as 5-15 dB (when the microphones of the RF system and hearing aid are both active) to as great as approximately 15-25 dB when the RF microphone is active and the hearing aid microphone is disabled (Boothroyd & Iglehart, 1998; Hawkins, 1984). Typically, the microphones of the RF system and the hearing aid are both enabled so the child has access to the signal from the RF systems, his/her own voice, and other speech and environmental sounds throughout the classroom. Personal RF systems can improve speech recognition in noise by as much as 50 to 60 percentage points when compared to performance without a personal RF system (Schafer & Thibodeau, 2004).

For all three types of remote microphone wireless systems, the signal of interest may be delivered from the transmitter to the receiver using a variety of methods. Most personal systems and some CAD systems and personal soundfield systems deliver the signal of interest via a RF transmission. Historically, FM radio frequency transmission has been used to deliver the signal of interest. The advantages and limitations of different types of transmission are provided in Table 1.

Recently, digital RF transmission has been used to deliver the signal of interest from the transmitter to the receiver (Table 1). The specific method of digital RF transmission varies across devices and may include amplitude shift keying, Gaussian frequency shift keying, or phase shift keying. Although there are theoretical advantages and limitations associated with each method, there are no published studies showing one method to be superior to another when used with hearing technology. As mentioned in Table 1, one of the primary advantages of digital RF is that there is a reduced risk of interference (crossover) when two children use digital RF systems in close proximity to one another. In fact, some digital RF systems utilize a protocol in which code is established between the transmitter and receiver during a "grouping" (or "pairing") process, and communication can only occur between the transmitter(s) and receiver(s) that have been grouped together. This type of approach eliminates the potential of signal interference from crossover between devices. Additionally, the digital control of the signal has the potential to allow for a more accurate analysis and delivery of the signal of interest from the transmitter to the receiver. Research has shown that subjects achieve better speech recognition in noise with personal digital RF systems compared to their performance with personal FM systems (Thibodeau, 2012; Wolfe et al., 2013a; Wolfe et al., 2013b).

Many CAD systems use infrared technology to transmit the signal of interest from the transmitter to the receiver. The pros and cons of infrared technology are also provided in Table 1. Specifically, the primary advantage of infrared transmission is the fact that it does not travel through walls, so interference/ crossover between classrooms is not a problem. However, infrared technology requires a direct line-of-sight in order to transmit to the receiver, and it is susceptible to signal interruption when the classroom is brightly lit (i.e., by sunshine). Few studies have conducted direct comparisons across transmission types (i.e., infrared vs. conventional FM or digital FM). Furthermore, there are a few studies that have compared speech recognition obtained with CAD systems, personal soundfield systems, and personal RF systems. In one of the few studies to compare personal versus soundfield reception, as well as FM versus infrared transmission, Anderson and Goldstein (2004) measured speech recognition in noise for eight children (9-12 years of age) who had mild to severe hearing loss. Participants in this study used a personal FM system, a personal soundfield system, and an infrared CAD system with multiple loudspeakers located throughout the classroom. Sentences were presented in a classroom with a SNR of

Table 1. Advantages and Disadvantages of Types of Transmission

Infrared Transmission		Frequency Modulation (FM) Transmission		Digital Radio Frequency (RF)Transmission	
Advantages	Disadvantages	Advantages	Disadvantages	Advantages	Disadvantages
Not susceptible to crossover in adjacent classrooms	Requires line of sight between transmitter and receiver	Does not require line of sight between transmitter and receiver	May be susceptible to crossover in adjacent classrooms	Does not require line of sight between transmitter and receiver	None
Unlimited number of carrier frequencies	May be susceptible to interference from bright light sources	Not susceptible to interference from bright light sources	Finite number of transmitting frequencies	Not susceptible to crossover in adjacent classrooms	
			Possible interference from strong FM broadcasters, such as radio stations & police/emergenc y services	Not susceptible to interference from bright light sources	

+10 dB and a reverberation time of 1.1 seconds. The investigators reported that the infrared CAD system did not provide a significant improvement in speech recognition, but both the personal soundfield and personal FM systems provided a significant improvement in speech recognition in noise. There was no difference in performance between the two.

Anderson, Goldstein, Colodzin, and Inglehart (2005) also compared speech recognition obtained with a personal FM, personal soundfield (desktop FM), and CAD system for 28 children (8-14 years of age) using hearing aids or cochlear implants. Overall, children performed better with the personal FM and personal soundfield when compared to the CAD system and their hearing aids or cochlear implant alone. On average, participants did not show improved performance with the CAD system relative to their hearing aids and cochlear implants alone.

It should be noted that many professionals advocate for the combined, simultaneous use of personal RF and CAD systems (Cole & Flexer, 2007). However, there are no studies suggesting that performance with simultaneous use of personal RF and a CAD system is significantly better than performance with personal RF alone. Additionally, it should be mentioned that recent reports suggest that children with hearing aids and cochlear implants perform better when using personal RF systems featuring adaptive technology (Thibodeau, 2010; Wolfe, Schafer, Heldner, Mulder, Ward, & Vincent, 2009).

Traditionally, personal FM systems have been fixed-gain systems, where the strength of the signal from the FM receiver to the hearing aid is fixed at a pre-determined value. The American Speech-Language Hearing Association (ASHA) clinical practice guideline (2002) suggested that the output of the speech signal delivered from the FM system should be 10 dB higher than the output of the same speech signal at 65 dB SPL delivered to the microphone of the hearing aid. This was referred to as a 10-dB FM advantage and was recognized to be a compromise for what the user might prefer across the broad range of acoustical environments encountered from day to day. However, Lewis and Eiten (2004) showed that FM users preferred a small FM advantage when listening in quiet environments, but a very favorable advantage (+24 dB) when listening in high-level noise environments. As a result, the 10 dB FM advantage was acceptable, but not ideal across all environments.

Adaptive RF technology (also known as Dynamic FM/Digital RF) seeks to address the need for a range of FM advantages across various listening situations. Adaptive RF systems provide no gain from the RF receiver when there is no signal of interest present (i.e., speech) from the RF transmitter. When a signal of interest is present in a quiet environment, the RF gain is set to a default of 10 dB. From that point, the gain from the RF receiver is adaptively increased once the ambient noise level at the RF microphone exceeds 57 dB SPL to a maximum RF setting of +24 dB at an ambient noise level of approximately 80 dB SPL. Research has shown that adaptive RF technology provides substantial improvement in speech recognition in noise when compared to fixed-gain RF systems (Thibodeau, 2010; Wolfe et al., 2009). It should be noted, however, that there are no studies examining the potential benefit of adaptive technology for use with CAD systems. As a result, the purposes of this study were:

(1) To compare speech recognition in quiet and in noise for adults with normal hearing, children with normal hearing, and children with hearing loss in a classroom environment when using a fixed-gain, multiple loudspeaker, infrared CAD system and an adaptive, single-tower loudspeaker array, digital RF CAD system.

(2) To compare, for children with hearing loss, speech recognition in quiet and in noise between (a) a fixed gain, multiple loudspeaker, infrared CAD system, (b) an adaptive, single-tower array digital CAD system, (c) use of personal FM alone, (d) simultaneous use of a personal FM with a fixed gain, multiple loudspeaker, infrared CAD system, and (e) simultaneous use of a personal FM with an adaptive, single-tower array digital CAD system.

Materials and Methods

Participants

Study participants included 10 adults with normal hearing (mean age: 34 years; range: 18-48 years of age), 15 children with normal hearing (mean age: 8 years; range: 5-12 years of age), and 15 children with hearing loss (mean age: 9.5 years; range: 6-13 years of age). The following inclusion criteria were used for selection of participants:

Adults with Normal Hearing

1. At least 18 years old and less than 60 years old.
2. Air-conduction audiometric thresholds of 15 dB HL or better at octave frequencies from 250 to 8000 Hz.
3. No conductive hearing loss (i.e., air-bone gap not to exceed 10 dB at octave frequencies from 500 to 4000 Hz.
4. No history of significant otologic problems.
5. All participants used English as their primary language.

Children with Normal Hearing

1. At least 5 years old and less than 13 years old
2. Air-conduction audiometric thresholds of 15 dB HL or better at octave frequencies from 250 to 8000 Hz.
3. No conductive component (i.e., air-bone gap not to exceed 10 dB at octave frequencies from 500 to 4000 Hz).
4. No history of significant otologic problems.
5. All participants used English as their primary language.
6. No history of language, auditory processing, or attention disorders per parent report.

Children with Hearing Loss

1. Mild to severe sensory hearing loss as defined by a four-frequency pure-tone average between 35 to 75 dB HL for at least the better ear. The mean audiogram for participants with hearing loss is provided in Figure 1.
2. Full-time wearer of bilateral hearing aids.
3. The output of each of the children's hearing aids was matched (+/- 5 dB) to the DSL m[i/o] v 5.0 prescriptive target for standard speech presented at 55, 65, and 75, dB SPL as indicated by probe microphone measures made with the Audioscan Verifit. Furthermore, the output for an 85 dB SPL swept pure tone was within +/- 5 dB of the maximum output targets as indicated by the DSL m[i/o] v 5.0 method.
4. No conductive component (i.e., air-bone gap not to exceed 10 dB at octave frequencies from 500 to 4000 Hz).
5. No history of significant otologic problems, including auditory neuropathy spectrum disorder.
6. All participants used English as their primary language.
7. No history of language delay, auditory processing disorder, or attention disorder per parent report.
8. All participants in this study utilized spoken language as their primary mode of communication. Additionally, an Auditory Verbal therapist who was familiar with the spoken language aptitude of each pediatric subject confirmed that the pediatric subjects were capable of completing open-set Hearing in Noise Test (HINT) sentence testing (Nilsson, Soli, & Sullivan, 1994).

Remote Microphone Wireless Hearing Assistance Technology

In this study, speech recognition in quiet and in noise was evaluated while subjects used several different types of hearing assistance technology (i.e., test conditions):

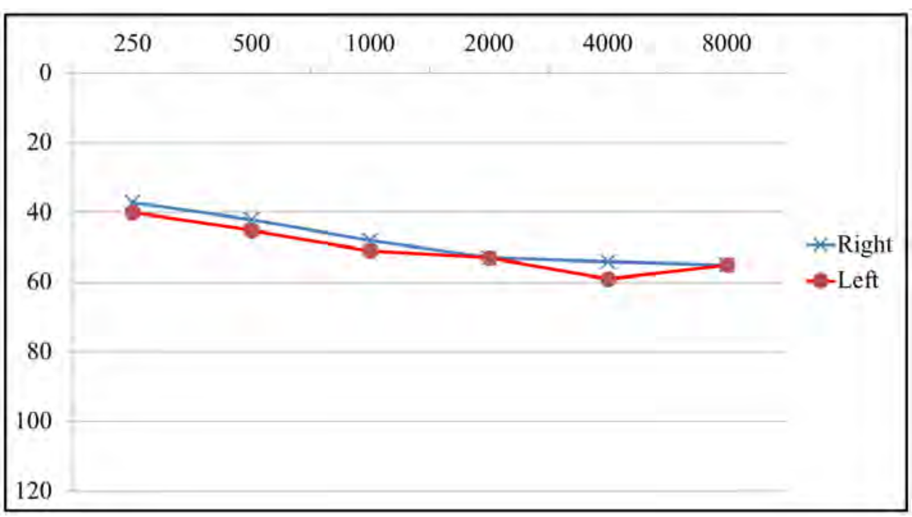

Figure 1. Average audiograms for children with hearing loss

1. No HAT condition: The speech recognition abilities of adults and children with normal hearing were evaluated in the unaided condition. The speech recognition abilities of children with hearing loss were evaluated while the children used their personal hearing aids. The children with hearing loss also used their own hearing aids in all of the remaining conditions.

2. Fixed-gain, multiple-loudspeaker infrared CAD system condition: The Audio Enhancement Elite II utilizes a uni-directional (cardioid polar plot pattern) Audio Enhancement *Tear Drop* microphone, which is designed to be clipped on the shirt or worn on a lanyard around the neck of the talker so that it is about 6-8 inches from the mouth. The *Tear Drop* microphone delivers the signal of interest via infrared (IR) transmission (2.3 megahertz was the IR frequency used in this study) to the infrared dome sensor (IR receiver), which is hard-wired to the Elite II audio receiver/amplifier. The Elite II audio receiver/amplifier features a 30-watt, two-channel amplifier, which is hard-wired to four wall-mounted WS09 monopole loudspeakers strategically placed in the classroom. The Elite II audio receiver/amplifier possesses a gain control to allow for adjustment of the output level of the system. The primary objective is to position the loudspeakers and set the gain control to ensure that an audible and uniform distribution of the signal of interest is provided throughout the classroom. The gain of the system is fixed regardless of the ambient noise level in the classroom.

3. Adaptive single-tower array digital CAD system condition: The Phonak DigiMaster (DM) 5000 is comprised of multiple components including the Phonak inspiro transmitter, which is coupled to a lavaliere-style clip-on directional microphone (hyper-cardioid polar plot response pattern). The Phonak inspiro transmitter is capable of delivering the signal of interest via FM or digital RF transmission. For the DM 5000 system, the signal of interest is captured by the microphone and delivered to the loudspeaker tower via digital RF on the 2.4 gigahertz band (2.4000 to 2.4835 GHz). Audio signals are digitized and packaged in very short (160 µs) digital bursts of codes and broadcast several times each at different channels in the 2.4 GHz band. The frequency-hopping behavior across channels is intended to avoid interference that may exist with traditional FM transmission. The Phonak DigiMaster 5000 loudspeaker tower is actually an array of 12 loudspeakers stacked in a vertical column. The distance between the centers of two adjacent loudspeakers is 54 mm, and the overall design of the system is reported to emit sound primarily within the horizontal plane with very little vertical spread. As a result, the impact of reverberant sound is intended to be reduced. The array of loudspeakers stands on a support pole and is positioned so that the loudspeakers reside at a height ranging from 33 to 63 inches. This height is designed to coincide with head level while students sit at a desk. A "pairing process" is required to couple the Phonak inspiro transmitter to the DigiMaster 5000 system.

The Phonak DigiMaster 5000 is an adaptive CAD system in that it automatically increases the gain of the signal of interest once the ambient noise level exceeds 54 dB SPL. Specifically, for a typical classroom (reverberation time of .9 seconds), when the ambient noise is below 54 dB SPL, the gain is kept at a value of 6 dB. This should result in an SNR of no less than 12 dB in the middle of a typical classroom given a quiet condition. When the ambient noise levels ranges between 54 and 66 dB SPL, the gain of the DigiMaster 5000 is automatically increased with the goal of maintaining an SNR of +10 dB. The maximum gain the system delivers is 20 dB. Further, the frequency response of the system changes automatically. At low gain levels the direct sound of the voice of the teacher is taken into account to attain a flat (transparent) response of the combined direct plus amplified sound. At high gain levels, where the critical bands in the cochlea are wider, some high pass filtering is applied to reduce upward spread of masking. Finally, the Phonak DigiMaster 5000 system possesses an adaptive feedback cancellation system, which is intended to reduce the chances of acoustic feedback when the wearer of the inspiro transmitter/microphone is located in close proximity to the loudspeaker array tower.

4. Personal FM condition: The Phonak Dynamic MLxi personal FM system, only used by children with hearing loss, was directly coupled to the children's personal hearing aids via the appropriate FM receiver adapter and the Phonak inspiro transmitter. The Phonak inspiro transmitter delivered the signal of interest to the Phonak MLxi FM receiver via FM transmission at 216 megahertz (i.e., channel 1). The MLxi receiver was programmed to provide a default FM advantage of 10 dB when speech was present in a quiet environment (ambient noise level of less than 57 dB SPL). Adaptive increases in FM advantage were automatically provided as the ambient noise level exceeded 57 dB SPL. The maximum gain of the MLxi adaptive FM receiver was 24 dB. The Phonak MLxi receiver was coupled to each of the children's personal hearing aids via the appropriate hearing aid/FM receiver adapter.

5. First combined-device condition (fixed-gain infrared CAD system + personal FM): The first combined condition entailed simultaneous use of the Audio Enhancement Elite II classroom audio distribution system along with the Phonak MLxi personal FM system directly coupled to the children's personal hearing aids.

6. Second combined-device condition (adaptive digital RF CAD system + personal FM): The second combined condition entailed simultaneous use of the Phonak DM5000 classroom audio distribution system along with the Phonak MLxi personal FM system directly coupled to the children's personal hearing aids.

In the condition in which the Phonak DigiMaster 5000 CAD system and Phonak MLxi adaptive personal systems were used simultaneously, the Phonak inspiro transmitter was used to simultaneously transmit the signal of interest to the Phonak CAD system and personal FM receiver by way of digital RF and FM transmission, respectively. In the condition in which the Audio Enhancement Elite II CAD system and Phonak MLxi adaptive personal systems were used simultaneously, the Audio Enhancement *Tear Drop* microphone/transmitter was used to deliver the signal of interest by way of IR transmission to the Audio Enhancement Elite II audio receiver/amplifier from where it was delivered to the four Audio Enhancement Elite II WS09 loudspeakers. The Phonak inspiro transmitter was coupled to the audio output port of the Audio Enhancement Elite II receiver, and was used to deliver the signal from the Audio Enhancement receiver to the Phonak MLxi adaptive personal receiver by way of FM transmission. The order of the test conditions was counter-balanced across participants.

Stimuli, Equipment, & Room Arrangement

Testing in this study was completed in a classroom measuring: 22 feet, 4 inches in length; 15 feet, 5 inches in width; 8 feet, 9 inches in height (Figure 2). The ambient noise level of the unoccupied room was 45 dBA. The level of the ambient noise, test sentences, and competing classroom noise was measured with a Quest Technologies Model QC-20 Type 1 sound level meter.

Per the recommendation of the manufacturer, the Phonak DigiMaster 5000 CAD system was placed in the front of the classroom (see Figure 2). Also per the recommendation of the manufacturer, the classroom was divided into quartiles, and the four wall-mounted WS09 loudspeakers of the Audio Enhancement system were mounted at these quartile locations at a height of 40 inches at the center of each loudspeaker (see Figure 2), which corresponded to the estimated head level of the seated subjects.

Speech recognition abilities in quiet and in noise were evaluated in each condition using one list of randomly-selected HINT sentences (10 sentences per list) scored by the percentage of key words repeated correctly. HINT sentences were delivered from a Dell Latitude E6500 laptop computer with an IDT High Definition Audio codec sound card and presented from a Fostex 6301 B single-cone loudspeaker with a built-in amplifier. The loudspeaker used to present the test sentences was positioned in the front and center of the classroom (17 feet from the subject at 0 degrees azimuth), and the microphone of the inspiro FM transmitter was positioned on a microphone stand eight inches directly in front of this loudspeaker, simulating the distance from the transmitter microphone to a teacher's mouth (Figure 2). The calibration signal for the HINT sentences was set to 76 and 70 dBA measured at 50 cm and 100 cm, respectively, from the center of the loudspeaker, which results in a level of about 85 dBA if measured eight inches from the center of the loudspeaker. When an RF system is used according to the manufacturer's settings, the speech of the talker is approximately 85 dBA at the microphone of the transmitter. The calibration measures were made at 50 cm and 100 cm in this study to reduce the possibility of errors associated with a near-field measure made 20 cm from the center of the loudspeaker. The sentences were presented at approximately 85 dBA at the location of the FM transmitter microphone and 64 dBA at the location of the subject. The gain control of the Phonak DM 5000 CAD system was set to the manufacturer's default, which resulted in the signal of interest arriving at the location of the subject at 68 dBA. The gain control of the Audio Enhancement Elite II CAD system was set to also deliver the signal of interest at a level of 68 dBA at the location of the subject. As a result, the level of the target sentences was identical between the two CAD systems in the quiet condition.

Four-classroom noise (Schafer & Thibodeau, 2006), which has a difference of 2.95 dB between the minimum and maximum root-mean-square (RMS) values, served as the competing noise signal. The competing noise signal was generated by a Dell Latitude D-520 notebook with a SigmaTel High Definition Audio CODEC sound card, amplified by a Radio Shack 250 Watt PA amplifier, and presented from four KLH B-Pro6 Titan Series loudspeakers located in the four corners of the room. The loudspeakers used to present the speech and competing noise were positioned at approximately the same height as the typical pediatric subject's head (40 inches at center of loudspeaker). The noise was presented from the two sets of loudspeakers (i.e., the noise from the front two loudspeakers was correlated, and the noise from the back two loudspeakers was correlated; uncorrelated noise refers to a situation in which the temporal characteristics of the noise from two or more loudspeakers are different, whereas correlated noise refers to a situation in which the temporal characteristics of a noise signal from multiple loudspeakers are the same.). The rationale for the aforementioned loudspeaker arrangement was to simulate listening in a noisy environment at a distance from the talker of interest (i.e., typical classroom environments). The competing noise signal was presented at 50, 55, 60, 65, 70, and 75 dBA when measured at the location of the subjects' head and at the position of the transmitter microphone.

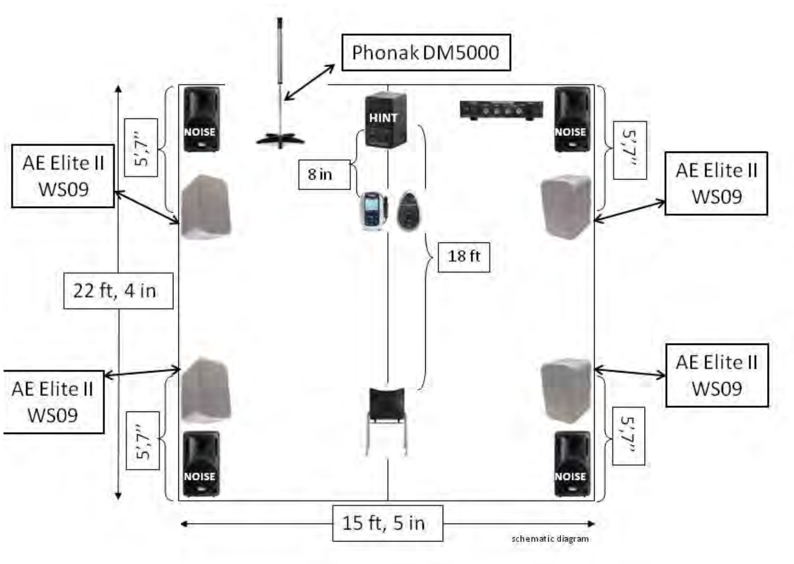

Figure 2. Test environment and equipment. AE Elite II WS09 =Audio Enhancement Elite II WS09 wall-mounted sound field speaker; HINT=Loudspeaker used to present Hearing In Noise Test sentences; Noise=Loudspeaker used to present classroom noise; Phonak DM5000=Phonak Digimaster 5000 classroom audio distribution system.

Procedures

Adults and children with normal hearing were assessed in a total of 21 conditions, while children with hearing loss were assessed in a total of 42 conditions. For all participants, open-set sentence recognition was assessed in quiet and in the presence of noise at multiple levels without FM and with both of the CAD systems. Additionally, speech recognition of the children with hearing loss was assessed in in quiet and in noise with use of the Phonak MLxi adaptive personal FM system and also with simultaneous use of each of the CAD systems and the Phonak MLxi adaptive personal FM system. The participants were instructed to repeat what they heard, and two examiners presented the recorded sentences and documented participant responses to ensure reliable scoring. The order of device conditions and signal levels (i.e., quiet vs. noise at various levels) were randomized. The HINT sentence test possesses 25 sentence lists. These lists were not repeated while assessing the adults and children with normal hearing (as they were assessed across 21 conditions). However, the children with hearing loss were evaluated across 42 conditions, so it was necessary to repeat the presentation of some lists while evaluating children with hearing loss. Care was taken to use lists in which a poor score was obtained during the first time it was used for assessment. This was done to reduce the likelihood that repeating a list would increase performance for a given condition. It is, however, possible that a child may have performed better on a list that was repeated than he/she would have on an original list, because of familiarity with the speech materials. It should be noted that the test conditions were evaluated in a randomized manner, so the repeating of lists should not have resulted in an increase or decrease of a particular condition. Only 13 of the original 15 children with hearing loss were able to complete the conditions with the personal FM system, and as a result, data from only 13 children were analyzed. The two children who dropped out of the study did so because of fatigue. Their results for the completed conditions were similar to the group as a whole, so their exclusion should not affect the final analysis.

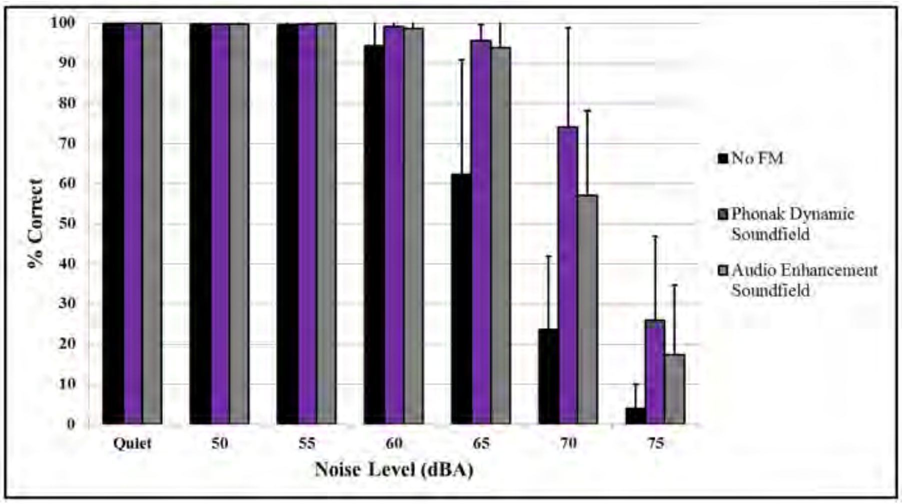

Figure 3. Average speech-recognition scores across the noise conditions for adults with normal hearing without and with the classroom audio distribution (CAD) systems.

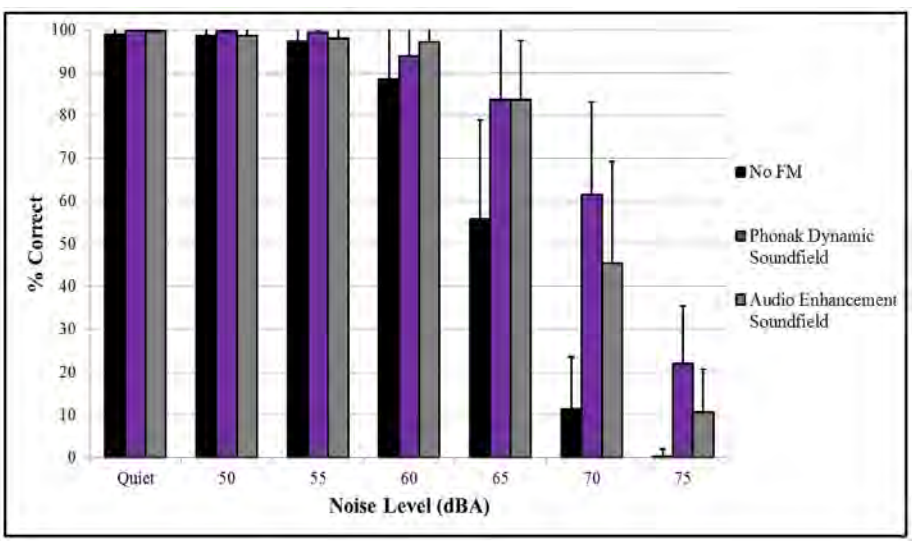

Figure 4. Average speech-recognition scores across the noise conditions for children with normal hearing without and with the classroom audio distribution (CAD) systems.

Results

The average speech-recognition scores obtained with no FM and with the CAD systems are shown in Figure 3 for the adults with normal hearing, Figure 4 for children with normal hearing, and Figures 5 and 6 for children with hearing loss. The data for the CAD systems were analyzed with a three-way, repeated measures analysis of variance (RMANOVA) with one between-subjects variable of group (i.e., adults with normal hearing, children with normal hearing, children with hearing loss) and two within-subject variables of device condition (no FM; Audio Enhancement Elite II CAD; Phonak DigiMaster 5000 CAD) and signal level (quiet, 50, 55, 60, 65, 70 75). This analysis revealed a significant main effect of group (F [2, 840] = 15.1, p = 0.00002), a significant main effect of device condition (F [2, 840] = 254.4, p < 0.00000), and a significant main effect of signal level (F [6, 840] = 909.2, p < 0.00000). Several interaction effects were also detected and included a significant interaction effect between device condition and signal level (F [12, 840] = 45.3, p < 0.00000) and between signal level and group(F [21, 1184] = 65.6, p < 0.00000). A significant interaction effect was also detected between group and signal level (F [12, 840] = 4.4, p = 0.000003).

Post-hoc analyses were conducted with the Tukey-Kramer Multiple Comparisons Test to examine the significant differences detected for the main and interaction effects. For the main effect of group, the children with hearing loss performed significantly worse (p < .05) than both the groups with normal hearing. The analysis for the main effect of device condition suggested that all CAD systems were significantly better than the no-FM condition (please note the no-FM condition refers to the situation in which no remote microphone technology was used by the subjects; however, the children with hearing loss did use their hearing aids (without the personal FM receiver) during assessment in the no-FM condition) (p < .05), and scores between the CAD systems were significantly different (p < .05). The best performance was obtained with the Phonak DigiMaster 5000. When examining the main effect of signal level, almost all signal level conditions were significantly different ($p < .05$) with the exception of the quiet condition as compared to 50 or 55 dBA noise condition and the 55 dBA noise condition as compared to the 60 dBA noise condition.

Post-hoc analyses were also conducted for the most relevant significant two-way interaction effect, the interaction effect between device condition and signal level, using the Tukey-Kramer Multiple Comparisons Test. This analysis revealed several notable findings. First, the no-FM conditions in quiet and in noise at 50 and 55 dBA were not significantly different ($p > .05$) from performance with the two CAD systems at the same signal levels. However, in all remaining signal level condition, the two CAD systems produced significantly better ($p < .05$) performance than the corresponding no-FM condition. When comparing the two CAD systems, the Phonak system resulted in significantly better ($p < .05$) performance than the Audio Enhancement system in the 70 and 75 dBA noise conditions,

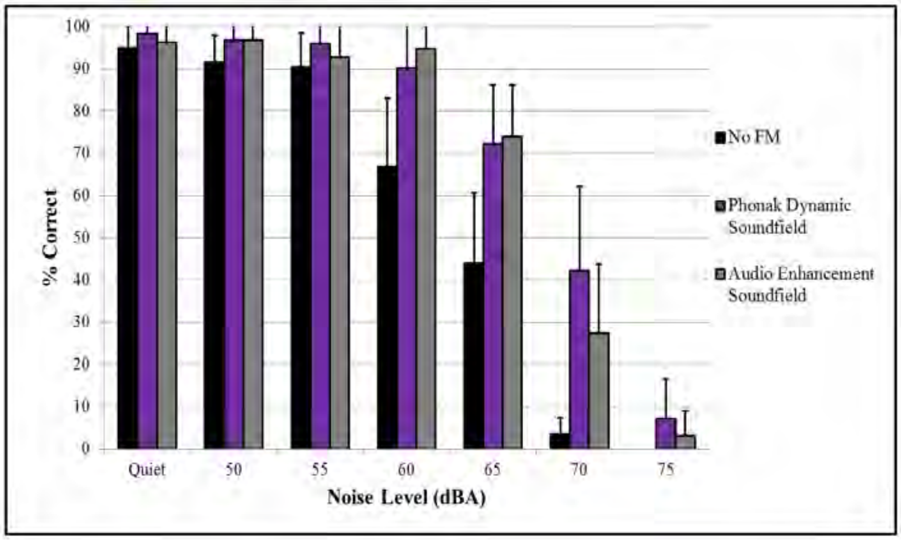

Figure 5. Average speech-recognition scores across the noise conditions for children with hearing loss without and with the classroom audio distribution (CAD) systems.

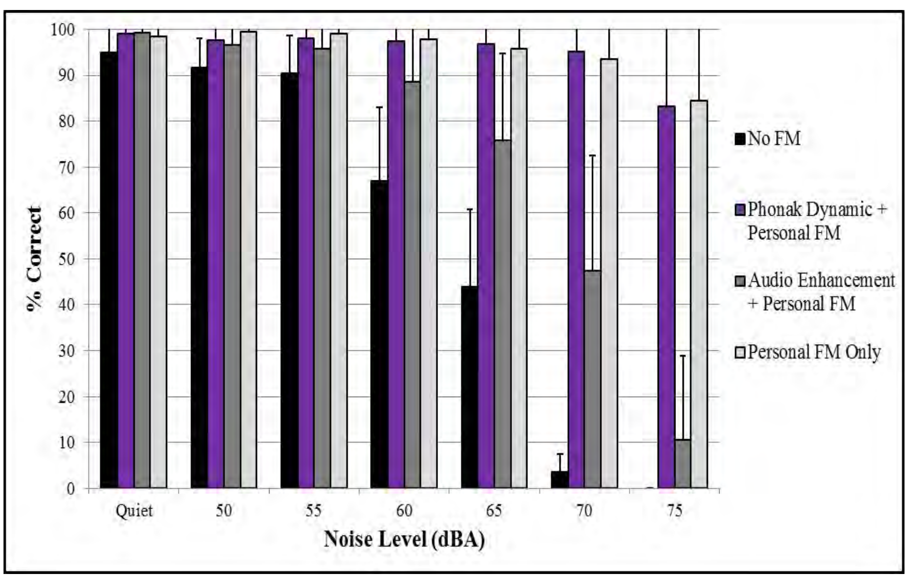

Figure 6. Average speech-recognition scores across the noise conditions for children with hearing loss without and with the classroom audio distribution (CAD) and frequency modulation (FM) systems.

The second RM ANOVA involved data from the 13 children with hearing loss who were able to complete the three extra device conditions. This RM ANOVA included two within-subject variables: signal level (quiet, 50, 55, 60, 65, 70 75) and device condition ([1] no FM; [2] Audio Enhancement Elite II CAD; [3] Phonak DigiMaster 5000 CAD; [4] Phonak MLxi personal FM; [5] Audio Enhancment Elite II CAD and Phonak MLxi personal FM combined; [6] Phonak DigiMaster 5000 CAD and Phonak MLxi personal FM combined). The analysis revealed a significant main effect of signal level (F [6, 546] = 338.6, $p < 0.00001$), significant main effect of device condition (F [5, 546] = 115.7, $p < 0.00001$), and significant interaction effect between signal level and device condition (F [30, 546] = 51.3, $p < 0.00001$).

The Tukey-Kramer Multiple Comparisons Test was used to conduct post-hoc analyses on the significant main effects and interaction effect. Similar to the previous post-hoc analysis of signal level, performance in the quiet condition was not significantly different ($p > .05$) than performance in the 50 or 55 dBA noise conditions; performance in the 55 dBA noise condition was not different ($p > .05$) from performance in the 60 dBA noise condition. Performance at all remaining signal levels was significantly different ($p < .05$) from all other signal levels.

The post-hoc analysis on conditions suggested that all device conditions were significantly better ($p < .05$) than the no-FM condition. The device conditions with the Phonak MLxi personal FM and the MLxi combined with the Phonak DigiMaster 5000 CAD resulted in significantly better ($p < .05$) performance than all remaining device conditions. There were no significant differences in performance across the remaining device conditions (Audio Enhancement Elite II CAD; Phonak DigiMaster 5000 CAD; Audio Enhancment Elite II CAD and Phonak MLxi personal FM combined).

There were several important findings from the post-hoc analysis of the two way interaction effect between signal level and condition. First, the no-FM conditions in quiet and in noise at 50 and 55 dBA were not significantly different

($p > .05$) from performance in any device conditions at the same signal levels. At all remaining signal levels, all devices produced significantly better performance ($p < .05$) than the corresponding no-FM condition. In the 60 dBA noise condition, there were no significant differences ($p > .05$) across the devices. However, at the 65, 70, and 75 dBA noise conditions, performance with the Phonak MLxi receiver alone and MLxi combined with the Phonak DigiMaster 5000 CAD was significantly better ($p < .05$) than all remaining device conditions. There were no other significant differences ($p > .05$) across devices at the 65 and 75 dBA noise levels; however, at the 70 and 75 dBA noise levels, use of the Phonak CAD resulted in significantly better performance ($p < .05$) than use of the Audio Enhancement CAD.

Discussion

The authors identified several objectives for this study. A primary goal was to determine if differences exist in speech recognition performance in quiet and in noise with the use of a fixed-gain, multiple loudspeaker CAD system versus an adaptive gain, single tower loudspeaker array CAD system. A secondary goal was to compare speech recognition in quiet and in the presence of competing noise in a classroom situation for adults with normal hearing, school-aged children with normal hearing, and school-aged children with hearing loss. Finally, speech recognition in quiet and in noise was compared between the use of the CAD systems alone, versus use of a personal FM system alone, versus simultaneous use of each CAD system along with the personal FM system.

Speech Recognition in Quiet

All three groups of subjects approached ceiling-level performance on speech recognition tasks in quiet, even without the use of the HAT. As a result, there were no significant differences in performance in quiet across the three groups of subjects as well as across the different types of HAT. In this study, the speech signal reached the user at a level of 64 dBA, which approximates, or is slightly higher than, average conversational level speech (Pearsons, Bennett, & Fidell, 1977). As a result, performance likely reached asymptotic levels even without the HAT. Indeed, previous research has indicated that children with moderate hearing loss typically achieve ceiling-level performance on tests of speech recognition in quiet when using contemporary hearing aid technology (Wolfe, John, Schafer, Nyffeler, Boretzki, & Caraway, 2010). Of course, anecdotal experience would suggest that persons with normal hearing would be likely to experience few or no problems with understanding sentences presented in quiet.

Speech Recognition in Noise

In contrast to the results in quiet, significant differences in sentence recognition in noise did exist across the three subject groups and the various HAT conditions. Additionally, all three subject groups experienced substantial difficulty understanding speech in the presence of moderate-level noise, particularly without the use of HAT. For instance, at a competing noise level of 60 dBA (SNR = +4 dB), children with normal hearing began to show a reduction in their ability to understand sentences through audition alone without the use of HAT. Even greater difficulty was observed for children with hearing loss for whom a 30 percentage point reduction in speech recognition was observed between performance measured in quiet and their performance at a competing noise level of 60 dBA (+4 dB SNR without the use of HAT).

The results from these data are concerning for several reasons. First, they underscore the well-known fact that children with hearing loss are likely to have substantially greater difficulty hearing in noise than adults and children with normal hearing. Second, the difference in speech recognition in noise between children with hearing loss and children with normal hearing is actually greater than the difference observed between children and adults with normal hearing. In other words, the presence of moderate hearing loss has a greater effect on hearing performance in noise than the maturation of the auditory nervous system associated with age. Additionally, these data are alarming because previous research has suggested that typical classroom SNR range from 0 to + 5 dB (Sanders, 1965). As such, the results of this study suggest that children with hearing loss are quite likely to struggle understanding speech in academic settings.

The data further indicate that children and adults with normal hearing also experience difficulty understanding speech in noise when the SNR is unfavorable (competing noise level = 65 dBA resulting in an SNR of -1 dB without HAT). Again, this is a disturbing finding when one considers the fact that previous research has suggested that the SNR in a typical kindergarten classroom is approximately -1 dB (Sanders, 1965). Young children do not have the same command of linguistics as adults, and consequently, they are less able to “fill in the gaps” when they are unable to capture all of the signal of interest via audition alone. Furthermore, students are often unable to look at the teacher’s face when she is talking. For instance, they may have to focus on a lesson being demonstrated on a “smart board,” while the teacher provides verbal instruction. These data suggest that even young children with normal hearing are likely to experience some difficulty following a teacher’s instructions through audition alone in the typical classroom setting. Considering these data, it should come as no surprise that children with normal hearing achieve better levels of academic success and demonstrate better behavior in classrooms with CAD systems, which likely improve the SNR of the environment (Berg, Bateman, & Viehweg, 1989; Bitner, Prelock, Ellis, & Tzanis, 1996; Langlan, Sockalingam, Caissie, & Kreisman, 2009).

Fortunately, performance in noise obtained with all of the HAT systems evaluated in this study was significantly better than the no-FM condition, particularly when compared at the moderate to high noise levels. This finding is encouraging for the CAD systems given the lack of benefit from CAD systems in previous investigations (Anderson & Goldstein, 2004; Anderson et al., 2005). For this study, all three groups showed improvements in speech recognition in noise with CAD use beginning at the competing noise level at which they begin to experience difficulty without HAT. For example, adults and children with normal hearing suffered approximately a 35 and 40 percentage point reduction in speech recognition, respectively, when performance without HAT in quiet was compared to performance without HAT at a competing noise level of 65 dBA (-1 dB SNR). However, both groups achieved an approximately 30 percentage point improvement in speech recognition at the 65 dBA competing noise level with the use of the CAD systems. Likewise, children with hearing loss received an approximately 25 percentage point improvement in speech recognition in noise from CAD use at the 60 dBA competing noise level and about a 30 percentage point improvement in speech recognition in noise with CAD use at 65 dBA. These noise levels and unaided SNR are common in academic settings. The present findings support the idea that CAD use would be beneficial in typical classroom environments.

One important finding of this study was the fact that use of the Phonak DigiMaster 5000 single-tower loudspeaker array, adaptive CAD system resulted in equivalent performance at moderate noise levels (with an SNR ranging from +4 to -1 dB without the use of remote microphone CAD technology, which are quite common for typical classrooms) when compared to the Audio Enhancement Elite II multiple-loudspeaker, fixed-gain CAD system. Additionally, performance with the adaptive, single-tower loudspeaker array CAD system was actually better at the higher competing noise levels of 70 and 75 dBA (with an SNR ranging from -6 and -11 dB SNR without the use of remote microphone CAD technology, and although such unfavorable SNR are uncommon during classroom instruction, they are likely to occur occasionally when classroom noise levels are high and the teacher is standing across the classroom from a student or group of students) for all three groups when compared to performance obtained with the Audio Enhancement Elite II multiple-loudspeaker, fixed-gain CAD system. This finding has potential clinical relevance for a number of reasons. First, the primary difference between the two systems that is most likely to explain the better performance obtained with the Phonak DigiMaster 5000 system is the fact that the Phonak system possesses the adaptive increases in CAD gain with increases in ambient noise level. Each system was matched in output level (68 dBA) for speech in quiet. It is unlikely that it would be appropriate to increase the gain setting for quiet environments as doing so would result in a speech level that would approach a psychophysical percept associated with loud speech. However, at higher noise levels, it is appropriate to increase the level of the speech signal (Pearsons et al., 1977). It appears as though the automatic increases of the Phonak DigiMaster 5000 system provided an improvement in the SNR and a subsequent improvement in speech recognition at the higher competing noise levels. Additionally, the single-tower loudspeaker array is comprised of an array of 12 single-cone loudspeakers arranged in a vertical column in order to provide an even distribution of the audio signal throughout the classroom with minimal vertical spread. This feature may have also contributed to the relatively favorable results obtained with the adaptive, single-tower CAD system, even though the position of the single-tower loudspeaker array was much further from the subject (approximately 18 feet) than the distance between the subject and the rear loudspeakers of the multiple-loudspeaker, fixed-gain CAD system (approximately six feet).

Further examination of the data indicates that children with hearing loss continue to experience substantial difficulty understanding speech in noise levels of 65 dBA and greater, even with the use of the CAD systems. In contrast, Figure 6 shows that children with hearing loss perform quite well, even at the highest noise levels, when using a personal FM system coupled to their personal hearing aids. In fact, many of the children continued to perform near ceiling levels at a competing noise level of 70 dBA. This finding is consistent with previous studies showing considerable improvement in performance in noise from use of an adaptive personal RF system (Thibodeau, 2010, 2012). Given the results of this study, audiologists working with children should consider the provision of adaptive personal FM or digital RF technology as mandatory for children with significant, bilateral hearing loss.

Furthermore, installation of the single tower, adaptive CAD system used in this study requires approximately 15 minutes. In contrast, installation of a multiple loudspeaker CAD system, in which the loudspeakers must be mounted to the wall or ceiling and hard-wired to a CAD receiver/amplifier, which in turn is also hard-wired to an infrared receiver, requires a substantially longer amount of time. The installation of the latter system also requires some expertise in order to securely mount the loudspeakers and to run the loudspeaker cables through the ceiling or wall. The findings of this study are important, because they indicate that performance with an adaptive single-tower loudspeaker array CAD system which is relatively simple to install is at least as good, if not better, than performance obtained with a fixed-gain, multiple-loudspeaker CAD system, which does require more time and expertise to install.

Previous research has suggested that audiologists are more likely to recommend multiple loudspeaker CAD systems than a single-tower system (Crandell & Smaldino, 2000b). Specifically, Crandell and Smaldino (2000b) surveyed 241 audiologists regarding their current practices pertaining to the provision of CAD systems in school settings. Five percent of the respondents recommended a one-speaker system, while the overwhelming majority noted that it was ideal to provide a CAD system with at least two to four loudspeakers strategically placed in the classroom. Of course, CAD system technology has changed significantly since the Crandell and Smaldino (2000b) study, so it is possible that audiologists would respond differently if a similar survey were administered today. Indeed, the results of this study suggest that it is possible to obtain speech recognition that is at least as good, if not better, with a single-tower loudspeaker array compared to a multiple loudspeaker system. Clearly, more research is needed to compare different speaker arrays to maximize the benefit that can be provided by CAD systems.

Two additional clinically relevant findings were observed when analyzing the results obtained with simultaneous use of the CAD systems along with the personal FM system. First, speech recognition in noise with combined use of either the CAD system and the personal FM system did not improve when compared to performance obtained with the personal FM system alone. It is possible that the children reached asymptotic levels of performance with use of the adaptive personal FM alone, and there was simply no room for additional improvement from the CAD. This explanation is quite plausible for performance measured at noise levels ranging from 60 to 70 dBA. However, it does not appear as though the children with hearing loss approached ceiling-level performance at a competing noise level of 75 dBA. The fact that use of the CAD system did not provide an improvement in speech recognition at the 75 dBA noise level is most likely explained by the fact that the modest gain provided by a CAD system is not resulting in a tangible improvement in SNR at such a high noise level.

Finally, speech recognition at moderate and high noise levels (60 to 75 dBA) was considerably better with the combined use of the Phonak DigiMaster 5000 CAD system and the Phonak adaptive personal FM system when compared to performance obtained with the Audio Enhancement Elite II CAD system and the Phonak adaptive personal FM system. The difference obtained between CAD systems in the combined use mode ranged from 10 percentage points at a competing noise level of 60 dBA to 75 percentage points at a competing noise level of 75 dBA. When the performance of children with hearing loss using FM in classrooms with the DigiMaster and Audio Enhancement Elite II CAD systems was compared, the performance with the personal FM system plus Phonak DigiMaster 5000 CAD system was equivalent to performance with the personal FM alone. A very disconcerting finding was the fact that performance with the personal FM system plus Audio Enhancement CAD system was poorer than performance with the personal FM system alone (a reduction of 20% or more was observed at the moderate to high noise levels). This reduction in performance with personal FM system alone was not evident in classrooms that had better SNR (+9 - +14). In a noisy classroom, use of the DigiMaster did not decrease performance of use of the personal FM system, but use combined of the Audio Enhancement CAD system and personal FM system in a noisy classroom did result in poorer performance than what was obtained with the personal FM alone.The educational audiologist should administer validation measures of the child's performance with the use of remote microphone technology when a personal FM system is used simultaneously with a CAD system in order to ensure that the CAD system is not causing negative impact to the personal FM. Again, it should be noted that these findings are concerning given the common recommendation that personal FM and CAD systems should be used simultaneously in a classroom environment.

There are several reasons which may explain why performance decreased when the personal FM system was used with the Audio Enhancement CAD system. First, when the Phonak inspiro transmitter was coupled to the audio output port of the Audio Enhancement Elite II CAD system (by way of an auxiliary cable), the adaptive nature of the inspiro system was eliminated. As a result the increases in FM gain that have been shown to improve speech recognition at moderate to high noise levels may have been eliminated (Thibodeaus, 2010; Wolfe et al., 2009; Wolfe et al., 2013a).

Secondly, the Phonak inspiro transmitter possesses multiple forms of pre-processing, including a directional microphone with a hyper-cardioid response and digital noise reduction. It is possible, but not certain, that these noise technologies may provide a more favorable SNR than the directional microphone of the Audio Enhancement *Tear Drop* microphone. Again, these noise technologies are eliminated when the inspiro transmitter is coupled to the receiver of another CAD system. Finally, it is possible that the output signal of the Audio Enhancement Elite II CAD was not sufficient in level to deliver a robust signal via the Phonak inspiro transmitter. If this was indeed the case, there was not a simple method to ameliorate the problem, as there was not a gain control for the audio output port.

There are at least two solutions that may address the insufficient gain problem. First, rather than coupling the Phonak inspiro transmitter directly to the audio output port of a CAD system of another manufacturer, the teacher may simultaneously wear the microphones/ transmitters of both CAD systems (AAA Clinical Practice Guidelines, 2008). This would preserve the adaptive and noise reduction technologies of the adaptive personal RF system and presumably support at least the same level of performance in noise as obtained with use of the personal system alone. Of course, this solution does require the teacher two wear two transmitters/ microphones, which may be awkward and uncomfortable.

Another solution would be to use a special interface device referred to commercially as the Phonak DigiMaster X. The DigiMaster X may be coupled to an existing CAD system by way of an auxiliary audio cable connected to the audio input port of the receiver of the CAD system. The DigiMaster X receives the signal of interest by way of RF transmission from the inspiro transmitter and delivers it to the existing CAD system by way of an auxiliary audio cable connected to the audio input port of the receiver/amplifier. This solution allows for preservation of the adaptive gain feature and noise reduction technologies for the signal delivered from the inspiro transmitter to a Phonak adaptive personal RF receiver, and it also converts the existing CAD system to an adaptive system. The downside of this solution is that it requires a separate piece of equipment (the DigiMaster), so it is more expensive than using two microphones/ transmitters.

Study Limitations

Only two types of CAD systems and one type of adaptive personal FM were evaluated in this study. Numerous differences exist in the design and technology incorporated in existing CAD and personal RF systems. Consequently, the results of this study may not apply to all CAD systems. Furthermore, the results obtained with the adaptive personal FM system are likely to be more favorable than results obtained with a fixed-gain, personal FM system, especially when compared at higher competing noise levels (Thibodeau, 2010; Wolfe et al., 2009). Additionally, performance with an adaptive digital personal RF system is likely to be more favorable than the performance obtained with an adaptive personal FM system. Finally, classroom acoustics vary considerably from school to school, so the results obtained in the classroom used for data collection in this study may not represent what may be observed in every classroom. As such, it is important that educational audiologists validate the performance and benefit a child achieves with remote microphone technology in the classroom.

Conclusions

Based on the data presented in this paper, the authors propose the following conclusions:

(1) Adults with normal hearing understood speech in noise better than children with normal hearing. Adults and children with normal hearing both experienced some difficulty understanding speech in moderate to high level noise (unfavorable SNR; e.g., -1 dB to -6 dB SNR) via audition alone.

(2) Children with normal hearing understood speech in noise better than children with hearing loss. Children with hearing loss experienced difficulty understanding speech at noise levels and SNRs commonly encountered in typical classroom settings.

(3) CAD systems improved speech recognition in noise for children with hearing loss and also for children and adults with normal hearing.

(4) An adaptive, digital CAD system with a single-tower array of loudspeakers has the potential to provide equal or better speech recognition in noise than fixed-gain, infrared CAD system with multiple loudspeakers.

(5) Personal FM provided significantly greater improvement in speech recognition in noise than what is obtained from use of CAD systems.

(6) Combined use of the adaptive, digital single-tower CAD system + Personal FM (each was designed by the same manufacturer) provided better performance in noise than combined use of the fixed-gain, infrared CAD system with multiple loudspeakers + Personal FM (each system designed by a different manufacturer). In other words, it was evident that use of the CAD system negated some of the benefit provided by the personal FM system. It is important for educational audiologists to administer validation measures to evaluate performance and benefit of remote microphone technology when CAD systems and personal FM systems are used simultaneously. This study suggests that this validation is particularly important when combining personal FM and CAD systems manufactured by two different companies.

(7) There was little to no improvement in speech recognition in noise with simultaneous use of a Phonak CAD system and personal FM system compared to performance with a personal FM alone.

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Interpretation of Functional Listening Evaluation Results of Normal-Hearing Children with Reading Difficulties

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This report follows up on the article by Dodd-Murphy & Ritter (2012) that presented Functional Listening Evaluation (FLE) group data for normal-hearing children with reading difficulties. The current study describes a retrospective analysis of the same database, focusing on clinical interpretation of individual FLE results. The FLE (Johnson & VonAlmen, 1997), frequently used by educational audiologists to assess the need for classroom accommodations in children with hearing loss, is a protocol that measures the effects of noise, distance, and visual information on speech recognition under typical classroom listening conditions. FLE summary forms were reviewed for each child to determine whether the results would support the recommendation of hearing assistance technology (HAT) in the classroom. Judgments were made based on potentially significant noise and/or distance effects on speech recognition from the FLE interpretation matrix. Specific criteria and examples of FLE profiles are provided. The FLE pattern of results was judged to support HAT recommendation for 44% of the children. Mean speech recognition scores for the children who were not HAT candidates were 90% or above in all listening conditions. Mean scores for children judged to need HAT in the classroom were below 90% in all conditions. The FLE may provide evidence of classroom listening needs that assist the clinician in making appropriate intervention recommendations for this population. Further prospective research is needed to evaluate the efficacy of the FLE in predicting which children may benefit from the use of HAT in the classroom.

Introduction

Educational audiologists have long been aware of the benefit that classroom hearing assistance technology (HAT) can provide for children with hearing impairment (Johnson & Seaton, 2012; Lewis, 2010). In recent years, there has been a greater awareness of how poor classroom acoustics can reduce access to auditory learning not only for children with hearing loss, but for children in general (Jamieson, Kranjc, Yu, & Hodgetts, 2004; Nelson & Soli, 2000; Stelmachowicz, Hoover, Lewis, Kortekaas, & Pittman, 2000; Stuart, 2008). Though not as extensive as the literature related to the use of HAT with children who are deaf or hard of hearing, a growing body of evidence has indicated that remote microphone technology can improve classroom behavior and academic performance in children with normal hearing belonging to various clinical populations (Darai, 2000; Dockrell & Shield, 2012; Flexer, Millin, & Brown, 1990; Johnston, John, Kreisman, Hall, & Crandell, 2009; Sharma, Purdy, & Kelly, 2012). Professional guidelines published by the American Academy of Audiology (2008) identify children with normal hearing and special listening requirements as one of three groups who are candidates for the use of remote microphone HAT. Crandall, Smaldino, & Flexer (2005) enumerate at-risk populations that would benefit from an increased signal-to-noise ratio (SNR) such as that provided by classroom HAT, including children with typical hearing who have learning disabilities, language disorders, attention deficits, and/or children who are English language learners. Not all children in these groups would require HAT for improved access to auditory learning; thus, careful assessment of the educational need for HAT is critical in this population (Johnson, 2010; Johnson & Seaton, 2012; Lewis, 2010; Schafer, 2010). This type of assessment typically includes classroom observation, teacher questionnaire, and a direct measurement of functional listening abilities (AAA, 2008; American Speech-Language-Hearing Association, 2002; Johnson, 2010; Schafer, 2010).

The Functional Listening Evaluation (FLE, Johnson & VonAlmen, 1997) is an assessment tool commonly used by educational audiologists to determine the need for hearing assistive technology (HAT) and/or other classroom accommodations. The FLE was designed to show the effects of noise, distance, and visual input on the speech recognition performance of children with hearing loss under conditions simulating a typical classroom environment. Eiten (2008) stressed the importance of using quantifiable measures and providing supporting information related to a child's speech recognition performance without HAT when determining candidacy. The FLE fulfills both of these objectives. Additionally, the FLE can satisfy the requirement of Individuals with Disabilities Education Act (IDEA) for functional evaluation in the child's regular classroom environment. The FLE is valued as a direct measurement of a child's performance to corroborate and supplement other findings such as child, teacher, or parental reports of speech recognition difficulties.

It is crucial for audiologists to justify any recommendation of hearing assistive technology (AAA, 2008; Eiten, 2008; Johnson, 2010; Johnson & Seaton, 2012). This would be particularly true when working with children who have normal hearing sensitivity, who are typically not expected to need hearing-related interventions. In addition, their classroom listening problems may be much more subtle than those of children with hearing loss. In their research, Dodd-Murphy and Ritter (2012) used the FLE to evaluate a group of children with normal hearing who were diagnosed with language and reading impairment. They concluded that the FLE was potentially useful to justify the recommendation of HAT (e.g., personal FM systems or classroom audio distribution systems [CADS]) and other accommodations in children with normal hearing and special listening needs, particularly with modifications to the speech material and the protocol to increase the FLE's sensitivity in assessing children with normal hearing. This report describes the results of a retrospective analysis of individual FLE results from the same database to evaluate each child's educational need for HAT.

Methods

Participants

Participants were recruited from children who attended a university-sponsored language and literacy intervention program, held in the summer as an intensive month-long day camp. A group of 39 children (27 males) between the ages of 7;0 and 10;11 (years; months) participated in the project. All children were diagnosed by certified, licensed speech-language pathologists with oral and written language disorders affecting literacy and had passed a hearing screening. Following approval from the university Institutional Review Board, informed parental consent was obtained for each child, and monetary compensation was given for participation.

Materials

The researchers used the 2002 revision of the FLE (Johnson & VonAlmen, 1997) as described below to evaluate the need for HAT. The most recent version of the FLE protocol and form is available from ADEvantage (http://adevantage.com/uploads/FLE_2013v2a-saveable_autocalculable.pdf). The FLE allows examiners a choice of speech materials. For this study, the BKB-SAE sentences (Bamford, Kowal, & Bench, 1979) were the stimuli. There are eight different lists of short sentences; the sentence list order was counterbalanced. A different list was presented in each of the FLE listening conditions. The scorebox in Figure 1 shows the eight conditions; the sequence order for each condition is designated by the number in the top left hand corner of each data cell. The listening condition sequence was kept the same for each child.

Procedure

For a more detailed discussion of the methodology, see Dodd-Murphy & Ritter (2012). The FLE was administered by two undergraduate student researchers trained and supervised by a licensed, certified audiologist. Testing was conducted in an unoccupied classroom in the same building as the day camp the children were attending. During the FLE, the child sat in a desk, and the examiner read the sentences from three feet away in the 'Close' conditions and from 15 feet away in the 'Distant' conditions. For the 'Noise' conditions, a recording of multi-talker babble was adjusted so that its level averaged 60 dBA SPL at the child's ear. An acoustically transparent screen covered the examiner's face during the 'Auditory only' conditions.

The student researchers worked as a pair; one examiner presented the sentences via monitored live voice, and the other examiner marked the child's responses on a score sheet. An average of 75 dBA SPL speech presentation level was maintained using a sound level meter one foot away from the speaker. Every sentence was presented only once, and the child was asked to repeat each sentence exactly as the speaker read it. A wireless lapel microphone, worn by the child during the testing session, transmitted responses to a digital voice recorder, which enabled the session recording to be saved as a sound file. Responses were scored as correct if the entire sentence was repeated correctly. The FLE scorebox on the summary form (Figure 1) shows a score for each condition.

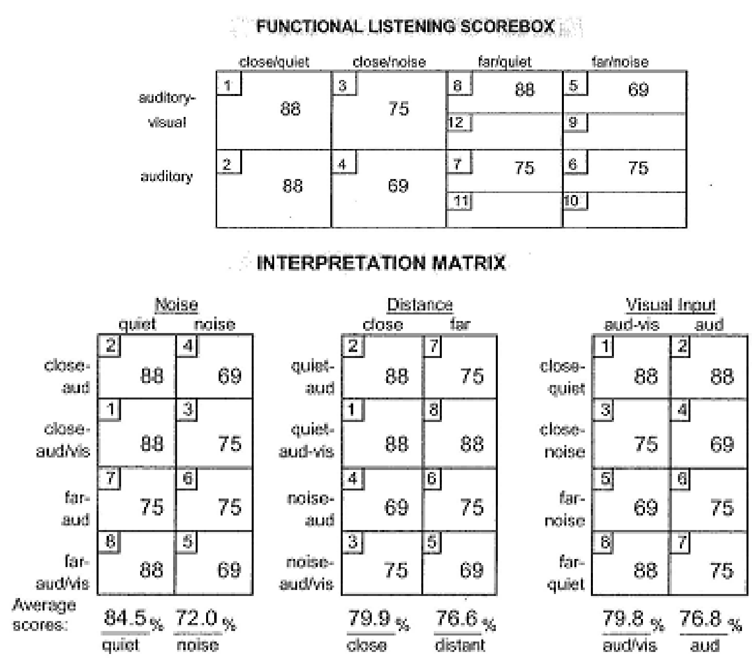

Figure 1. Individual FLE profile for child with educational need for HAT

A certified audiologist with experience in both clinical and educational audiology reviewed the FLE summary and interpretation forms for individual children to evaluate whether the pattern of results would support the recommendation of classroom HAT. The FLE interpretation matrix (see Figure 1) allows the examiner to observe the effects of noise, distance, and/or the presence of visual cues on speech recognition overall. For example, the average score for all conditions in quiet may be compared to the average score for all conditions presented with background noise; if the 'noise' score is significantly lower than the 'quiet' score, there is a detrimental effect of noise.

After an extensive literature search, the authors found no specific criteria that define what amount of noise or distance effects shown by the FLE would be considered educationally significant. Criteria were developed based on research using either the BKB-SAE materials or BKB-SIN to test the speech recognition in noise of children with normal-hearing and typical development, particularly those reports that provided sentence recognition scores in percent correct for multiple signal-to-noise ratios and that included children in the same age range as the current study (Crandell & Smaldino, 1996; Lewis, Hoover, Choi, & Stelmachowicz, 2010; Neuman, Wroblewski, Hajicek, & Rubinstein, 2010; Wroblewski, Lewis, Valente, & Stelmachowicz, 2012). Ceiling effects were indicated, particularly for quiet conditions and those with SNRs of +3 to +5 dB; standard deviations were low (rarely exceeding 5%) across studies and conditions for single measures of speech recognition. In addition, normative data for recognition of monosyllabic words at varying signal-to-noise ratios indicates children who were typically-developing averaged scores at 90% and above, even for the most difficult condition (0 dB SNR with the speech level at 35 dB HL; Bodkin, Madell, & Rosenfeld, 1999). The proposed criteria also took into consideration the FLE performance of five typically-developing children obtained as pilot data and using the same protocol as described in this report; these children showed uniformly excellent results across the conditions. The criteria used to indicate the need for HAT were the following: 1) noise effect of 5% or greater and average score in noise less than 90%; 2) distance effect of 6% or greater and average score in distance less than 90%; 3) average score < 80% in quiet conditions; or 4) any combination of the above.

Results

FLE profiles of 44% (17/39) of the participants were judged to indicate the need for HAT in the classroom. Almost half of the potential HAT candidates met the noise effect criteria alone, while six children met the criteria based on distance alone. Two children showed adverse effects of both noise and distance, while one child had a small noise effect in the auditory-only conditions and low scores overall (see Figure 2). The mean sentence recognition scores for children with FLE profiles supporting HAT recommendation were below 90 % in all conditions (ranging from 73 to 86%), while the mean sentence recognition scores for children without the need for classroom HAT were 90 % or greater in all FLE conditions. The largest group differences between children with and without educational need for HAT were present in the conditions combining noise and distance (Auditory-Visual/Distant/Noise: 78 vs. 94%; Auditory/Distant/Noise: 73 vs. 94%).

Two examples of individual FLE results are shown, one from a child judged to need HAT (Figure 1) and another from a child judged not to need HAT (Figure 3). Figure 1 shows the FLE interpretation matrix for a male aged 10;11 with sentence recognition scores less than 90% across all eight conditions. His average score for sentence recognition in quiet was 84.5% compared to an average score of 72% for sentences presented in noise, yielding a 12.5% noise effect that met the criteria for the need for classroom HAT. Figure 3 displays the FLE results for a nine-year-old female who demonstrated high scores overall, with no clear noise or distance effect. Her FLE profile did not meet the criteria for potential HAT candidacy.

Discussion

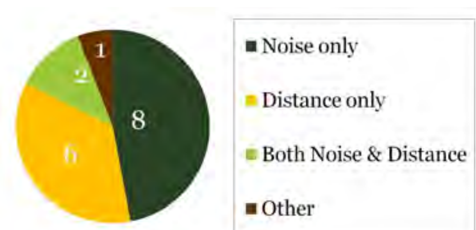

Figure 2. Distribution of criteria categories for children needing HAT

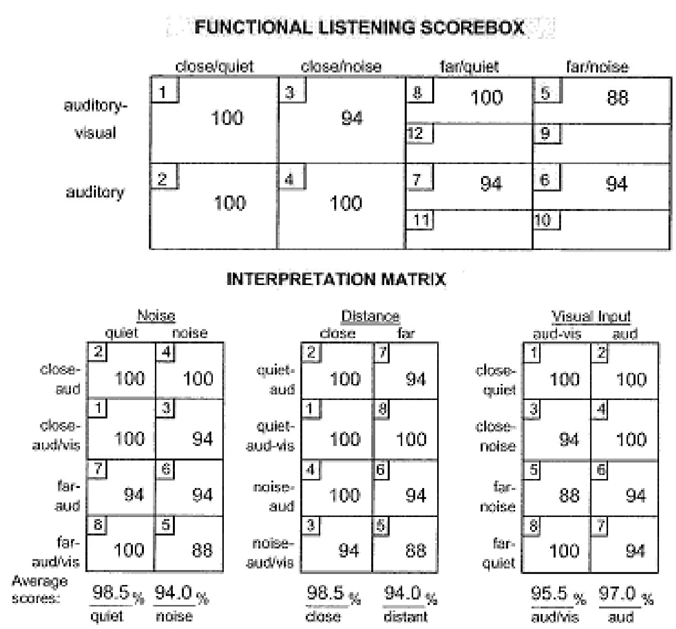

Figure 3. Individual FLE profile for child with no educational need for HAT

The current study is an extension of Dodd-Murphy & Ritter (2012) that focused on whether information gained from the FLE might facilitate professional decision-making by demonstrating the educational need of HAT for individuals within a clinical population—children with language and reading impairment who have typical hearing. FLE results provided quantitative evidence of adverse noise and/or distance effects on sentence recognition in a classroom setting for a large proportion (44%) of children with reading impairments and normal hearing. In addition, the better of the two FLE scores for the close, quiet conditions (with or without visual cues) can be used as a goal for speech recognition performance with HAT in conditions with noise and distance (Johnson, 2010). For example, for the child whose FLE results are shown in Figure 1, performance with classroom HAT would be expected to improve scores in all conditions with noise and/or distance to at least 88% sentence recognition.

In the current study, the focus is on interpretation of the FLE and what information it may supply on its own; however, comprehensive multi-faceted evaluation of HAT candidacy is considered best practice. The FLE would not be used alone to support the recommendation for HAT use, rather it would be one of multiple measures that clinicians integrate in determining HAT candidacy for a particular child (AAA, 2008; Eiten, 2008; Johnson, 2010; Schafer, 2010).

Participants of this study would qualify for school accommodations or special services (based on academic/reading delays and/or language impairment), as would many children with normal hearing and special listening requirements. The retrospective interpretation of the FLE in this analysis revealed that for slightly over half of the participants, the FLE did not show clear negative effects of noise and/or distance on sentence recognition. Even for children whose FLE results indicated reduced sentence recognition under typical classroom conditions, further targeted measures such as teacher rating scales and classroom observations would be necessary to supplement the results when requesting a school district to provide HAT. The current study focused on FLE testing without technology; however, demonstrating the potential for HAT to improve access to speech in noise or distance can be accomplished by adding conditions with and without technology to the noise/distance conditions of the FLE. This practice is recommended whenever possible to strengthen the documentation of educational need for HAT.

Classroom HAT is designed to improve the speech-to-noise ratio for a particular child, overcoming difficulties with increased noise level and distance between the speaker and listener. Accordingly, those FLE profiles that indicated negative effects of noise and/or distance on sentence recognition scores were considered to show educational need for HAT. Relatively low scores overall were also considered. The detrimental noise and/or distance effects were relatively small--the largest noise effect (i.e., average score for four quiet conditions minus the average score for the four noise conditions) among the children judged to need HAT was 16%, and the largest distance effect within the same group was 14%. When comparing the children who were judged to be potential HAT candidates with those who were not, the largest between-group performance differences were for the Distant/Noise conditions, reflecting the criteria for HAT candidacy. There are no specific indications in the literature for the FLE about what magnitude of noise or distance effect would be considered sufficient to support the recommendation of HAT; the flexibility of the protocol and the variety of speech materials that could be used prevent the establishment of criteria that would be accurate in all cases. Research measuring speech recognition in noise using the BKB sentences (Lewis, Hoover, Choi, & Stelmachowicz, 2010; Wroblewski, Lewis, Valente, & Stelmachowicz, 2012), as well as some normative word recognition data using similar SNRs (Bodkin, et al., 1999) suggest that typically-developing children with normal hearing of similar ages as those in the current study would perform similarly to older children and adults for SNRs as low as 0 dB. Even small decrements in speech recognition in adverse listening conditions may be educationally significant for children in a clinical population when compared to very high scores and low variability from typically-developing peers with normal hearing (Anderson, 2012).

There is a lack of available data regarding the FLE, particularly regarding its use for children with normal hearing. Expected FLE results for typically-developing children of various ages are needed. Dodd-Murphy and Ritter (2012) suggested modifications to the protocol that may help sensitize the FLE to listening difficulties that some children with typical hearing face, such as lowering the signal level to decrease SNR and using more difficult speech material. Future prospective research comparing FLE performance differences between normal-hearing children with language and reading impairments (or other special listening needs) and a matched control group is necessary to establish what magnitude of negative noise and/or distance effects could be considered educationally significant. Furthermore, comparing outcomes for children in this population with and without HAT use in the classroom would help guide audiologists as they make their recommendations. Finally, evidence is needed to determine how other direct measurements of speech recognition in noise compare to the FLE in their ability to predict which children are most likely to benefit from HAT in the classroom.

In conclusion, the FLE can contribute potentially valuable information about classroom listening function for typically-hearing children with language and reading impairment. Clinical interpretation of the FLE indicated that almost half of this group of children may have special listening needs that could be associated with academic delays. Findings from the FLE should be used within the context of a comprehensive evaluation of HAT candidacy on a case by case basis. Further prospective research is needed to evaluate the efficacy of the FLE in predicting which children will benefit from the use of HAT in the classroom.

Acknowledgements

Funding for this work was provided by a Baylor Undergraduate Research and Scholarly Achievement (URSA) Award. We would like to express appreciation to the Camp Success faculty, parents and children, as well as the Baylor student researchers, particularly Rebecca Brock and Kelly Rogers.

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