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ARTICLES

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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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>
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Auditory Processing Training with Children Diagnosed with Auditory Processing Disorders: Therapy Based on the Buffalo Model

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Audiologists are concerned with the outcomes of treatments for children identified with various audiological disorders, such as auditory processing deficits (APD). Questions arise whether treatments provided to children who have undergone training to improve auditory processing have significant outcomes.

The present study focused on 20 children who received auditory processing training from one of the authors (Kavita Kaul). The other author (Jay Lucker) completed all statistical analyses to study the outcomes of the auditory processing training provided. Therapy was provided using recorded information with controlled volume settings via the audiometer or through an iPad. Live voice was used to provide additional visual cues, only when recorded voice was difficult to process and understand.

Pre-and post-treatment scores were compared statistically. The tests and treatment batteries were the same for all children although treatment procedures were modified and customized for each child. The length of therapy depended on the age and severity of the APD as well as how the child responded to the treatments provided. Evaluation and therapy procedures were based on the Buffalo Model.

Seventeen different scores were obtained and compared before and after therapy using a battery of tests based on the Buffalo Model. Additionally, the Buffalo Model Questionnaire (BMQ) was administered pre-therapy and post-therapy and results were compared.

Results of the statistical analyses indicated significant improvements in auditory processing following therapy for 12 of the 17 measures used. Also, a trend towards significance was found for two additional measures. Typically, parents reported noticeable improvements in listening, auditory processing, learning, academic performance, and social communication interactions based on the Buffalo Model Questionnaire results. These results provide evidence that auditory processing training can positively impact auditory processing abilities in children, and direct treatment services can lead to improvements in auditory processing skills.

Introduction

Parents and professionals who work with children diagnosed with auditory processing disorders (APD) seek research demonstrating the outcomes of therapies to overcome problems in listening and learning for these children. Although there are resources to help people better understand APD with discussions of different intervention options, much of this material describes and recommends programs that may not have empirical evidence to support the outcomes of any specific treatments or therapies (ASHA, 2005; Bellis, 2011; Edell, Lucker, & Alderman, 2008; Geffner & Ross-Swain, 2012; Moore, 2006; Musiek, Shinn, & Hare, 2002). Often, the only recommendations made to help such children are environmental modifications (such as reducing the noise in the classroom), use of accommodations (e.g., FM systems), or preferential seating (such as having the child sit closer to the teacher). Review of the ASHA Technical Report on auditory processing and its disorders (2005) reveals a general discussion of treatments, but provides no specific data to identify therapy outcomes. Another source that discusses treatment is Moore's (2006) presentation of both environmental management and therapies, but he, too, does not present empirical research supporting their outcomes.

A literature review published on treatments for auditory processing disorders indicates very limited evidence demonstrating the outcomes from any specific treatments. Musiek, Shinn, and Hare (2002) discuss what are called deficit specific areas of auditory processing and some treatments recommended for each area, but their review of the literature on these treatments is more a discussion of the treatments and the general outcomes one would expect after using them rather than specific empirical evidence demonstrating changes in auditory processing after the use of such treatments. The same is found in Bellis' (2011) and Geffner and Ross-Swain's (2012) books in which treatments are discussed, but the chapters of these books looking at different treatments do not identify specific research analyzing the outcomes focusing on auditory processing disorder in children who have gone through these treatments. Actually, both Musiek, Shinn, and Hare and Bellis state that there is a lack of evidence supporting the efficacy and effectiveness of outcomes from the various treatments discussed. Furthermore, there are many online programs claiming to improve auditory processing skills. However, these programs lack well developed empirical research studies supporting their outcomes. It is felt that unless these programs are used in conjunction with direct therapy provided by a professional who understands auditory processing deficits, improvement may not carry over to other areas of real life situations such as communication, academic, and emotional development.

Looking at the research on treatments, Fey et al (2011) discuss a systematic review of evidence regarding treatment outcomes for computer based programs. They looked specifically at Earobics and Fast ForeWord, two programs discussed in Geffner and Ross-Swain's book (2012). They also discussed an internet search on publications focusing on treatment outcomes for children with auditory processing disorders. In the end, of the 192 studies initially identified, only 23 provided appropriate evidence to be analyzed systematically. In the end, after completing an analysis of these 23 publications, it was concluded that there was really "no compelling evidence that existing auditory interventions make any significant contributions to auditory, language, or academic outcomes of school-age children who have been diagnosed with APD or language disorder" and that "clinicians who choose to continue using auditory interventions should do so in conjunction with interventions that target specific language, communication, and academic goals" (p.254).

In a more recent publication, DeBonis (2015) reported concerns regarding the outcomes of interventions for APD. DeBonis stated that efficacy and effectiveness of therapies has not been established. As such, he questions the validity of the APD diagnosis in school-aged children. DeBonis' argument and review of the literature cited above reveals limited evidence supporting the specific outcomes of therapy for APD. Thus, the authors undertook the following retrospective study to determine the outcomes of treatments provided for children having auditory processing disorders (APD). The present article presents a discussion of an empirical analysis of the outcomes of auditory processing treatment in children.

METHODS

Research Design

The research design focused on obtaining answers for questions that asked if the treatments resulted in significant changes in auditory processing test findings, and how much improvement was found after treatment. Many procedures or approaches to answer these research questions could present with significant biasing errors. For example, if a group of children were provided with a specific therapy using a test-retest protocol, there is possibility of researcher bias to support the hypothesis that the particular therapy is effective in improving auditory processing abilities. In the present study, using a retrospective approach helped reduce such therapist bias.

The original purpose in collecting the data was to determine the presence of APD problems in these children. Based on the findings, therapy was provided to remediate areas of difficulties for these children. At the end of therapy, re-evaluation was completed to assess changes in auditory processing abilities. Additionally, feedback regarding the children's performance in school and at home related to listening and learning was obtained from parents. These results were then subjected to statistical analyses to determine the significance of the changes that occurred after therapy. In order to reduce further bias, all statistical analyses were completed by one of the authors (JRL) who was not involved in any of the data collection or therapies provided.

Participants

Twenty files were retrospectively chosen for the present study. All 20 subjects were diagnosed with auditory processing disorders (APD) based on the normative data for each test administered and were consequently provided therapy using the same treatment protocol. Their ages ranged from 5 to 15 years with a mean age of 8.4 years (standard deviation of 2.52 years). The length of therapy varied from 11 to 25 sessions with a mean of 15.1 sessions (standard deviation of 3.75 sessions).

One may question testing children for auditory processing at such young ages as 5 and 6 years. However, the research has demonstrated that (a) there is great benefit and need to evaluate children this age, and (b) there is no evidence to support waiting until a specific age to evaluate children for APD (Ackie, 2013; Bander, 2004; Geffner, 2011; Katz, 2005; Keith et al, 2014; Lucker, 2005a & b, 2015a & b; Tillery, 2005; White-Schwoch et al, 2015). Furthermore, both professional associations involved with auditory processing (i.e., AAA and ASHA) have guidelines and technical reports that neither limit the age at which children should be evaluated nor state that there is a specific age cut-off below which children cannot or should not be assessed for auditory processing (AAA, 2010; ASHA, 2005a & b). Furthermore, most assessments of auditory processing having norms for children down to five years of age (e.g., Auditory Skills Assessment, SCAN-3:C, SSW, Word Recognition in Quiet and Noise, etc.). Thus, including these young children is very appropriate based on these factors.

Approach to Auditory Processing

In this study, diagnosis and treatment of auditory processing skills included qualitative signs (delays in responses, impulsive quick responses, need for multiple repetitions, need for task simplification, etc.) and quantitative signs (low scores compared to norms). At the end of therapy, both the quantity and quality scores were used to assess improvement. The weaknesses in auditory processing were treated from a multi-system coordination of skills perspective. This included whole body focus, attention, ability to endure sustained attention for repetitive tasks, ability to stay seated for longer periods of time, decreased need for verbal reminders, improved eye contact, ability to wait for the information to be presented in full, ability to self-monitor and self-correct responses, ability to self-regulate body posture for active listening, ability to self-regulate emotional reactivity to simple tasks that were perceived as difficult or aversive, improved stamina and energy, ability to connect meaningfully to the task rather than mechanically completing task from rote memory, ability to connect to the task at a linguistic level to meaningfully process the information in connected speech, ability to self-advocate when the task is too difficult or to ask for clarification, etc.

Therapies Used

All of the children's files used for analyses in the present study included children who received the same treatments. Therapy was based on Jack Katz's Buffalo Model of Auditory Processing Therapy (Katz, 2007, 2009; Katz & Fletcher, 2004) which included phonemic synthesis training, phonemic awareness and recognition training, auditory attention, whole body active participation and listening training, endurance for auditory listening, short-term memory (repeating words, numbers, phrases, and sentences), working memory/organization training (ability to repeat longer units of numbers forwards and backwards), dichotic and monaural listening training, selective ear listening training, speech in noise training for each individual ear, ear separation listening, auditory ear lateralization, and auditory processing integration training. Therapy was provided using recorded information with controlled volume settings via the audiometer or through an iPad. Live voice was used to provide additional visual cues, only when recorded voice was difficult to process and understand. When recorded messages were incorporated, the volume level was set to provide a comfortable listening level via headphones or loudspeakers depending on the child's ability to tolerate wearing the headphones. The loudness level was typically set at 55-60 dB HL for all therapy sessions.

When we consider the selective ear training, it could be confused with some other therapies. However, for the present therapy provided, selective ear training was conducted using the "Differential Processing Training Program Acoustic Tasks" CD program from LinguiSystems (http://www.linguisystems.com/products/product/display?itemid=10474). This training involves a variety of listening tasks including, but not limited to, repeating numbers or words presented in the right ear or left ear only (selective ear listening), repeating numbers in the right or left ear while ignoring items presented to the opposite ear at the same time (ear separation using dichotic presentations), and repeating numbers, words, or phrases presented in both ears (dichotic listening). The children were also asked to point to the ear in which a specific number, word or phrase (ear lateralization) was presented. This helped develop lateralization, selective listening, and auditory attention. Accuracy was determined by correct responses provided, and training continued until the child was accurate on all practice items.

Although the same types of therapies were provided, the tasks were customized to suit the needs of the child based on frustration level, endurance, stamina, level of difficulty, age, their specific areas of weaknesses related to the Buffalo Model Auditory Processing Categories (Katz, 2007, 2009; Katz & Fletcher, 2004).

Although these therapies were provided for all children, the specific number of treatment sessions and amount of therapy provide varied. All children completed 15 Phonemic Synthesis lessons in which progress was based on the child's accuracy of response in blending the phonemes into words. The speed of blending as well as any qualitative methods the child used for obtaining a correct response were used as a guide to determine when a child was identified as having met the criteria for each Phonemic Synthesis activity before the next, more difficult, activity was introduced. Thus, the number of sessions differed depending on the accuracy and how quickly a child met the criteria for correct identification of the words when blending phonemes into words.

Eight lessons consisting of 80 monosyllabic word were used for the speech in noise training. The children were asked to repeat the monosyllabic words presented via headphones with varying degrees of noise from signal-to-noise ratios (S/N) of +15 down to +5. The speech and noise were presented to the same ear. Cafeteria noise was used as the background noise. All training started with the easiest S/N of +15. Therapy progressed to a level where the noise was louder (S/N+5). Ten monosyllabic words were used for each S/N level. The words were repeated at each level along with therapist assistance as needed to achieve accurate recognition of each word presented at the various S/N ratio. The goal in this therapy was to improve decoding skills at word level, in the absence of contextual cues, while ignoring extraneous and distracting background information (desensitization to background noise).

Dichotic Offset Training or DOT was another training provided for 6 children to further improve dichotic listening skills. Not all children were able to tolerate this task. Each of the 8 lessons had a specific offset time for presentation of information between the 2 ears simultaneously (500 ms; 400 ms; 300 ms; 200 ms; 150 ms; 100 ms; 50 ms; 0 ms). Each lesson consisted of 10 right ear first presentation (REF) and 10 left ear first presentation (LEF). Each item was repeated during the lesson until the child was able to repeat the 4 letters in the same sequence accurately (2 letters in each ear). Reversals and any errors in recognizing the letters accurately (V for Z ; P for B, etc.) resulted in repeating that item until accuracy was achieved. At times the child was made to listen to each ear individually and then then dichotically to achieve success in repetition of the task.

EVALUATION MEASURES

All 20 children received a battery of tests to measure auditory processing skills before and after therapy. The test battery was based on the Buffalo Model for APD diagnosis and treatment developed by Jack Katz (Katz, 2007; Katz & Fletcher, 2004). The list of tests are as follows.

Speech Understanding in Quiet and Noise

Speech understanding in quiet and noise was assessed for all children using word recognition measures in quiet and noise and comparing the differences between quiet and noise (called the Quiet/Noise difference). The specific word recognition measure used for all children was the W-22 Word Lists presented at 40dBSL for each child. Initially, the children were given the W-22 recognition task in quiet and then in noise at a signal-to-noise ratio (S/N) of +5dB in which the speech (words) was 5dB more intense than the noise in the same ear. The test in quiet and noise was conducted for each individual ear according to the standard method for assessment of auditory processing based on the Buffalo Model (Katz, 2007; Katz & Fletcher, 2004). Thus, four measures were able to be obtained both pre-treatment and post-treatment. These four measures included right ear in quiet, left ear in quiet, right ear in noise and left ear in noise. Additionally, the quiet/noise difference was computed for each individual ear. These were also computed for each individual ear. As such, six measures of speech understanding in quiet and noise were obtained.

SSW Test

The second formal, standardized measure of auditory processing was the SSW Test (Katz, 2007; Katz & Fletcher, 2004). This test has a number of measures, but only the individual condition scores and the total error scores were included in the statistical analyses. The individual scores were for the right and left ears for the non-competing items (RNC and LNC) as well as for the right and left ears for the competing items (RC and LC).

Dichotic Listening Measures

Katz (2015) identified two additional measures that examine dichotic listening. The first is the Standard Integration Ratio based on the competing message scores (RC and LC) on the SSW. Standard Integration Ratio or SIR compares left and right ear response errors in the presence of competing messages. SIR score of +1.0 or greater is significant and an indication of the Auditory Integration problem. Second is the Dichotic Offset Measure or DOM. In this dichotic task, letters of the alphabet are presented at different offset times of 0 milliseconds to 400 milliseconds. The offset time indicates the time gap between the competing signals going into each ear. A 0 millisecond gap means the competing signals to the right and left ears arrive at roughly the same time during the presentation of the items. Here two letters of the alphabet are presented to each ear. Each ear hears one letter of the alphabet without competition, i.e., non-competing signals, and two letters with competing signals at different offset measures. The results for the DOM and SIR were also collected and analyzed.

Phonemic Synthesis Test

The Phonemic Synthesis Test in the APD test battery looks specifically at phonological processing. This test has two methods of scoring called Quantitative and Qualitative. The PST has 25 items and one scoring method is merely to identify whether each item is correct or incorrect. This is the numeric or quantitative score. However, sometimes a correct response is provided with much effort using many coping strategies that impact the efficiency of the response. This would be counted as a PST qualitative error. Norms for both Quantitative and Qualitative results are available so that APD findings can be identified based on both scores.

Phoneme Recognition and Phoneme-Word Association Test

The Phoneme Recognition Test from the test battery was presented via speakers at comfortable level (55-60 dB HL). The subjects were asked to recognize, identify, and repeat the phonemes heard. Additionally, they were also asked to associate the phoneme to a meaningful word (/p/ - POT; /d/- BAG; etc.). The test was presented pre and post therapy. Therapy included exercises to recognize and identify phonemes as well as match the sound to symbol as well as to match sound to word each session. The goal in therapy was for both effective and efficient responses. Delays in phoneme-word association were also noted before and after therapy for response efficiency.

Thus, a total of 17 measures were used for APD assessment both before and after therapy (6 speeches in quiet and noise measures; 5 measures related to the SSW; 2 measures for Dichotic Listening; 2 for PST, 2 for Phoneme Recognition and Word Association Test).

All 17 measures were subjected to the initial statistical analysis to determine significance of the differences before and after therapy. Then, those measures found to have significant differences or trends towards significance were subjected to another statistical analysis to determine the effect size of the change after treatment.

Buffalo Model Questionnaire

Parents were asked to complete a questionnaire to report areas of weakness related to Auditory Processing Deficits for various listening and learning tasks at school and at home. These skills are organized under the specific Buffalo Model Categories of Auditory Processing Disorders (Decoding; Noise Tolerance; Short-Term Memory; Integration; Organization). Additionally, there are a list of questions related to generalized processing difficulties which do not fit any specific Buffalo Model classification. Thus, an additional category called OTHER was included for analysis. The last factor is the overall or TOTAL SCORE which is merely the sum of the number of items identified for all categories on the BMQ.

Each of the Auditory Processing Deficits categories is described below:

- Decoding (DEC) refers to the ability to quickly and accurately hear, listen, and process speech.
- Tolerance-Fading Memory (TFM) refers to a combination of poor understanding of speech in the presence of background of noise as well as difficulty with short-term auditory memory. This category is divided into two sub-categories called auditory noise Tolerance (TOL) and Short Term Auditory Memory (STM).
- Integration (INT) refers to a wide variety of symptoms and problems that differ from child to child. The basic characteristic appears to be difficulty in bringing information together.
- Organization (ORG) refers not only to the ability to organize one's thoughts but also to sequence information. But, ORG is a labor-intensive problem requiring a great deal of monitoring of both information that is heard or seen (likely because we say things to ourselves) as well as what the person says and writes. This takes away brain capacity from other important tasks. ORG, when combined with other APD problems, reduces the person's capacity and increases frustration and confusion.

PROCEDURES

The 20 children whose files were used in this retrospective study were evaluated by the first author (KK) and identified as having auditory processing deficits. This same professional then provided the therapy (describe earlier) and retested each child after therapy was completed. The files were arbitrarily selected so long as they met the selection criteria previously discussed.

The raw data for each of the measures pre- and post- treatment along with the children's ages, number of treatment sessions, and the various treatments provided were then given to the author (JRL) who did not provide the testing or therapy. That author conducted the statistical analyses as follows.

Since the raw data (see Table 1) varied between measures, an analysis of variance was determined not to be appropriate. For example, high scores on measures such as the PST indicate response accuracy whereas high scores on the SSW indicate response errors. Additionally, the Quiet and Noise measures use a percent correct compared with the absolute number of correct responses for the PST quantitative analysis and the number of errors for the SSW. Thus, it was determined that paired sample t-tests would be most appropriate for the analysis to see if any changes after therapy were significant. Table 2 presents the results of these analyses.

Table 1. Descriptive data (ranges, means, and standard deviations (SD)) for the pre-treatment and post-treatment auditory processing test results for the 20 participants used in the present study.

APD Test	Measure	When Tested	Range	Mean	SD
Speech in Quiet	Right Ear	Pre-Treatment	80 - 100%	92.2%	5.27
		Post-Treatment	80 - 100%	94.2%	5.11
	Left Ear	Pre-Treatment	80 - 100%	89.8%	5.69
		Post-Treatment	84 – 100%	92.4%	5.93
Speech in Noise	Right Ear	Pre-Treatment	36 - 84%	65.8%	13.39
		Post-Treatment	44 - 88%	73.2%	11.25
	Left Ear	Pre-Treatment	36 - 84%	61.8%	13.45
		Post-Treatment	2 – 92%	68.1%	19.96
Quiet Noise Difference	Right Ear	Pre-Treatment	8 - 52%	26.4%	12.87
		Post-Treatment	8 – 48%	21.0%	10.69
	Left Ear	Pre-Treatment	8 - 52%	28%	12.67
		Post-Treatment	0 – 98%	24.3%	20.79
SSW Test	RNC	Pre-Treatment	0 – 15	4.2	4.05
		Post-Treatment	0 – 5	1.6	1.40
	RC	Pre-Treatment	1 – 32	10.2	7.62
		Post-Treatment	0 – 16	5.2	3.82
	LC	Pre-Treatment	6 – 32	17.8	8.58
		Post-Treatment	1 – 29	11.4	7.25
	LNC	Pre-Treatment	1 – 20	6.0	5.10
		Post-Treatment	0 – 9	3.3	2.69
	Total NOE	Pre-Treatment	11 – 96	38.1	22.86
		Post-Treatment	4 – 56	21.4	13.87
	DOM	Pre-Treatment	4 – 41	14.9	11.98
		Post-Treatment	1 – 30	8.0	12.35
	SIR	Pre-Treatment	-1.73 - 5.53	1.5	2.34
		Post-Treatment	-4.01 – 3.93	0.6	1.76
Phonemic Synthesis Test	Quantitative	Pre-Treatment	11 – 24	18.7	4.28
		Post-Treatment	16 – 25	22.7	2.72
	Qualitative	Pre-Treatment	4 – 24	13.4	6.15
		Post-Treatment	10 – 25	19.7	5.16
Phoneme Recognition Test		Pre-Treatment	50 – 87	75.0	11.21
		Post-Treatment	80 – 86	61.5	22.77
Word Association Test		Pre-Treatment	76 – 100	90.0	6.00
		Post-Treatment	79 – 100	91.6	7.47

Table 2. Results of paired sample t-tests for each of the measures comparing results post-treatment vs. pre-treatment.

APD Test	Measure	t	df	p
Speech in Quiet	Right Ear	1.697	19	0.106**
	Left Ear	1.740	19	0.098**
Speech in Noise	Right Ear	3.832	19	0.001*
	Left Ear	1.119	19	0.277
Quiet/Noise	Right Ear	-2.220	19	0.039*
	Left Ear	0.597	19	0.558
SSW Test	RNC	-3.510	19	-0.002*
	RC	-4.355	19	0.000*
	LC	-5.819	19	0.000*
	LNC	-3.739	19	0.001*
	Total NOE	-6.693	19	0.000*
	DOM	-4.389	3	0.022*
	SIR	-1.179	19	0.253
Phonemic Synthesis	Quantitative	5.226	18	0.000*
Test	Qualitative	4.783	18	0.000*
Phoneme Recognition Test		6.471	19	0.000*
Word Association Test		6.024	19	0.000*

*significant at $p<0.05$ **trend at $p<0.10$ but >0.05

RESULTS

Table 1 presents the ranges, means, and standard deviations for the 20 subjects on each of the 17 pre- and post- therapy measures (not including the results on the BMQ). It was decided to consider the BMQ data separately since it was not a formal test, but a questionnaire completed by parents. Review of table 1 indicates pre- and post-therapy differences, where some tests showed increased scores to indicate improvement (such as speech recognition in quiet and noise and the PST quantitative measures), while others showed decreased scores to demonstrate less errors as a result of therapy (as in SSW measures and for the PST qualitative analysis)

Since post-therapy changes suggest improvement as a result of intervention, paired sample t-tests were conducted for each of the 17 measures. Table 2 presents the results of these t-tests. Review of that table indicates that significant ($p<0.05$) differences occurred for 12 of the 17 measures (Speech in Noise for the Right Ear, Quiet/Noise Difference for the Right Ear, all SSW measures except for SIR, both Phonemic Synthesis Test measures, Phoneme Recognition and the Word Association Test). In addition to these 12 significant findings, a trend towards significance (i.e., $p<0.10$ but $p>0.05$) was found for two measures (the Right Ear and Left Ear Speech in Quiet measures). In addition to the SIR measure for the SSW test, a lack of significance was also found for the Speech in Noise for the Left Ear as well as the Quiet/Noise difference for that same ear. Since the SIR is not a common measure used by audiologists who administer auditory processing tests, the lack of significant findings does not detract from the high number of significant findings. However, the lack of significant findings for the Noise Left Ear measure and Quiet/Noise Left Ear measure is important because speech understanding in quiet and noise is often used by audiologists.

Results of therapy used in the present study revealed a significant difference in auditory processing abilities for most of the measures (12 of the 17 with a trend towards significance for two additional measures). In order to determine the magnitude of the improvement found, effect size measures were calculated using Cohen's d analysis.

Cohen's d is a statistical method for evaluating the effect of change when comparing factors tested before and after therapy. The value calculated indicates the number of standard deviations change.

Cohen's d determines the magnitude of the effect of the treatment. According to the description of Cohen's d, magnitudes and effect sizes can vary. Effect sizes less than .20 are considered to be insignificant factors. Effect sizes greater than .20 are predominantly used when studying positive improvement as a result of therapy. Effect sizes from .21 to .49 reveal a small change while effect sizes from .50 to .79 reveal a medium change. Large effect sizes are identified for values from .80 and higher. Table 3 presents the results of the Cohen's d effect size measures.

Table 3. Results of Cohen's d effect size statistical analysis comparing results post-treatment vs. pre-treatment for each measure having significant t-test findings.

APD Test	Measure	Cohen's d	Effect
Speech in Quiet	Right Ear	0.385	Small
	Left Ear	0.447	Small
Speech in Noise	Right Ear	0.598	Medium
Quiet/Noise	Right Ear	-0.456	Small
SSW Test	RNC	-0.868	Large
	RC	-0.821	Large
	LC	-0.812	Large
	LNC	-0.662	Medium
	Total NOE	-0.886	Large
	DOM	-0.564	Medium
Phonemic Synthesis	Quantitative	1.107	Very Large
Test	Qualitative	1.097	Very Large
Phoneme Recognition Test		-1.669	Very Large
Word Association Test		-1.717	Very Large

As stated earlier, only measures that revealed significant findings or trends were subjected to the Cohen's d effect size analyses. Three measures (Speech in Quiet for both ears and Quiet/Noise Difference for the Right Ear) revealed a small effect size. Medium effect sizes were identified for three other measures (Speech in Noise Right Ear, and SSW LNC, and DOM). All other effect sizes revealed large changes with the Phonemic Synthesis measures and the Phoneme Recognition and Word Association results revealing very large effect sizes greater than 1.00.

Results for the Buffalo Model Questionnaire

In addition to the above quantitative analysis of change after therapy, results from the Buffalo Model Questionnaire (BMQ) were used to look at changes reported by parents. Table 4 presents the summary data from the pre-therapy and post-therapy BMQ results.

Table 4. Descriptive data (ranges, means, and standard deviations (SD)) for the pre-treatment and post-treatment Buffalo Model Questionnaire (BMQ) results for the 20 participants used in the present study.

Area	When Tested	Range	Mean	SD
Decoding	Pre-Treatment	2 – 8	4.7	1.66
	Post-Treatment	0 – 8	3.5	2.11
Tolerance	Pre-Treatment	0 – 4	2.4	1.10
	Post-Treatment	0 – 4	1.85	1.18
Short-Term Memory	Pre-Treatment	0 – 6	3.2	1.79
	Post-Treatment	0 – 5	2.35	1.73
Integration	Pre-Treatment	0 – 4	1.2	0.9
	Post-Treatment	0 – 4	1.40	1.12
Organization	Pre-Treatment	0 – 3	1.5	1.36
	Post-Treatment	0 – 3	1.1	1.25
Other	Pre-Treatment	0 – 11	6.0	3.51
	Post-Treatment	0 – 11	4.8	3.14
Total	Pre-Treatment	6 – 29	19.0	14.45
	Post-Treatment	4 – 29	7.17	6.68

Review of this table indicates that the mean scores after therapy were different from the initial scores. In order to determine whether these differences were significant another series of paired sample t-tests were calculated. Table 5 presents the results from these analyses.

Table 5. Results of paired sample t-tests for each of the BMQ areas post-treatment vs. pre-treatment.

Area	t	df	p
Decoding	3.387	19	0.003*
Tolerance	1.718	19	0.102**
Short-Term Memory	2.904	19	0.009*
Integration	1.241	19	0.230
Organization	2.027	19	0.057**
Other	3.335	19	0.003*
Total	4.344	19	0.000*

*significant at p<0.05 **trend at p<0.10 but >0.05

Results for the seven paired sample t-tests indicated significant (p>0.05) differences for 4 comparisons. The greatest change was for the TOTAL score difference (t=4.344, df = 19, p=0.000). The specific categories identified having significant improvements included: DEC (t=3.387, df=19, p=0.003), STM (t=2.904, df=19, p=0.009), and OTHER (t=3.335, df=19, p=0.003). Two other categories (TOL: t=1.718, df=19, p=0.102; ORG: t=2.027, df=19, p=0.057) revealed a trend towards significance, with one category (TOL), very close to revealing a significant difference. BMQ findings indicate a decrease in observed weaknesses in auditory processing and listening skills as a result of APD therapy provided. Thus on the whole, parents identified significantly fewer concerns for auditory processing problems after therapy.

DISCUSSION AND CONCLUSIONS

Results of the present investigation support the hypothesis that therapy for auditory processing can and will make significant improvements in children's auditory processing abilities. Of the 17 measures of auditory processing investigated in this study, 12 revealed significant differences after the specific therapies used. In addition to these 12 significant findings, two other measures revealed a trend towards significance.

Thus, future research might look into the effects of longer therapy or different therapy focusing on the measures in which trends were found (Speech recognition in Quiet for each ear). Interestingly, basic speech understanding (in quiet) is usually not used as a measure to evaluate APD; rather it is used as a baseline measure to indicate the child's ability to recognize and repeat words heard at a comfortable listening level with no interference (i.e., noise) or distortion of the message. Possibly a significant finding might also have been found in the present study if children with low scores (i.e., below age level norms) on speech understanding in quiet were not included as subjects. Future research can be performed looking more closely at these measures and therapy for speech understanding in quiet.

It could be possible that lack of consistent and focused therapy in the specific areas that did not show a significant change were prominent factors. For example, the SIR scores may have improved more with therapy focusing on improving dichotic skills. Of the 20 subjects only 5 received Dichotic Offset Training to improve dichotic listening skills (therapy recommended by Jack Katz in which 10 items of each offset measure for right ear first presentation followed by left ear first presentation is provided. Each therapy session includes a total of 20 items for 1 offset measure. Beginning at 500 millisecond offset difference decreasing to 0 millisecond offset difference). Also, there was no formal therapy for speech in quiet. Providing speech in quiet listening therapy specifically may have improved the ability to decode monosyllabic words in quiet. Of the 14 measures that revealed significant differences or trends, a majority of the measures resulted in good effect sizes following therapy for auditory processing deficits. For 11 measures, the effect sizes revealed medium or better results. Of these 11 measures, 4 had large effect sizes and 4 additional measures revealed very large effect sizes. Thus, large and very large effect sizes were found for 8 of the 11 or for two-thirds (67%) of the measures of auditory processing.

Results from the present study refute the claim that suggests that there is insufficient data to conclude that treatments for auditory processing disorders really make a significant change in children's auditory processing abilities (DeBonis, 2015). Two-thirds of the measures used in the present study revealed significant improvements in auditory processing abilities following therapy. Thus, there is evidence that therapy can significantly improve auditory processing abilities in school-aged children.

In addition to these quantitative analyses, a qualitative analysis was conducted on the input from the Buffalo Model Questionnaire. Improvements in test scores also seemed to impact a variety of communication and academic skills. Parents completed the Questionnaire both pre and post therapy. Results revealed that parents identified fewer concerns for listening and APD problems for their children following therapy. More than 50% of the factors analyzed showed significant changes with two additional areas showing a trend towards significance. Typically, parents reported noticeable improvements in listening, auditory processing, learning, academic performance, and social communication interactions.

Following auditory processing therapy, often children were referred to a Speech-Language Pathologist, Reading Specialist (e.g., Orton Gillingham approach), Occupational Therapist, and for Visual Processing Therapy to improve other areas of weakness (Speech-Language; Reading; Sensory-Integration, Visual Processing). Some of these professionals who were familiar with these children pre-therapy and had initially recommended evaluation and therapy to improve auditory processing noticed improvements in the ease of listening and focusing skills post-auditory processing therapy when the children resumed specific interventions. The professionals often remarked that therapy for auditory processing skills had facilitated improved listening skills which helped the children progress more rapidly in the therapy being provided by them.

The objective of this present study was to provide empirical evidence supporting the use of auditory processing therapies to improve auditory processing skills in children. The outcomes from the present study revealed that the greatest improvements (i.e., very large effect sizes) were found for measures of auditory phonological processing. Large improvements were also seen in some areas of dichotic listening (SSW measures). Further research can provide even greater evidence to support which therapies to use with specific types of APD.

A limitation of the present study is that the evaluation of auditory processing and the therapies used were those specific to the Buffalo Model. Not all professionals hold to this model. Thus, further research needs to look at improvements in auditory processing when other therapies are used. Additionally, the therapist providing therapy for the children in the present study made the determination regarding what therapies to provide and when to stop each of the therapies based on the decision that the children had reached their goals. Thus, the present study did not incorporate the same amount of and types of therapy for each subject. Further research is needed in which the same exact therapies are provided to all subjects for the same length of time.

Another limitation of the present study is that there was no control group. This is because the study was retrospective in nature and not a standard experimental research study. Since this was an initial investigation to see what changes occur in individual subjects when they undergo treatments associated with the Buffalo Model, it was decided that looking at absolute change in raw score performance would be used. Now that there is evidence that significant changes can occur in the overwhelming number of measures of auditory processing used in the present study, future research can compare the pre- versus post- treatment scores on the norm-referenced tests used to see if significant changes occurred based on these results. Another approach could be to perform a standard experimental study in which a control group of children with APD who did not receive therapy would be compared with a group that did receive therapy to see what changes in performance on the APD tests occur and determine if the two groups differ. However, the present study was conducted as an initial look at changes in auditory processing abilities for a group of children who received specific therapy and evaluation based on the Buffalo Model of auditory processing. The results are felt to provide strong support that therapy for auditory processing makes significant changes in the children undergoing such therapy.

Another limitation of the present study is that the children in the study had a wide age range from 5 years to 15 years. It is possible that changes pre- versus post- could be thought to be due to the older age groups performing better than the younger groups, or vice versa, and, thus, balancing out the change. This is possible, but, one control for this was that paired sample t-tests were used comparing the pre- versus post- test findings for all subjects. Thus, the difference between the post-therapy and pre-therapy test performances was calculated and t-tests were run on the difference values obtained. These t-test findings led to the results and conclusions drawn from the analyses of the test data. Additionally, the individual responses from parents on the BMQ led to themes as to what changes parents noted in their individual child. Thus, future research could look at changes specific to the age of the subjects to see if therapy for auditory processing makes significantly greater changes for specific age groups compared. Additionally, the specific themes identified on the BMQ can be analyzed in future research.

Future research can also evaluate changes that auditory processing therapies might have on factors related to, but not specific with, auditory processing. The present investigation looked at changes on auditory processing measures, but children are often referred for auditory processing evaluations and therapy because of learning problems in school, such as problems with reading, spelling, and understanding lessons presented in class. Parent input on the BMQ indicated observed improvements in their children that relate to academic and learning factors. Thus, there is a need to look further into specific changes in school related skills following APD therapy (such as changes in the measures of academic performance in children such as grades, classroom performance, formal academic achievement tests, etc.).

References

Ackie D (2013). Dear Ackie on What Age? *SSW Reports*, 35(1), 5.

American Academy of Audiology (2010). Practice Guidelines for the Diagnosis, Treatment, and Management of Children and Adults with Central Auditory Processing Disorder (CAPD). Available on-line at: http://audiology-web.s3.amazonaws.com/migrated/CAPD%20Guidelines%208-2010.pdf_539952af956c79.73897613.pdf

American Speech-Language-Hearing Association (ASHA) (2005a). (Central) Auditory Processing Disorders [Technical Report]. Available from: www.asha.org/policy

American Speech-Language-Hearing Association (2005b). (Central) Auditory Processing Disorders – The Role of the Audiologist [Position Statement]. Available on-line from: www.asha.org/policy.

Bellis TJ (2011). Assessment and Management of Central Auditory Processing Disorders in the Educational Setting: From Science to Practice, Second Edition. *San Diego: Plural Publishing*.

Brander S, et al. (2004). Testing Younger Children, *SSW Reports, 26*(2), 7-12.

DeBonis DA (2015). It is time to rethink central auditory processing disorder protocols for school aged children. *American Journal of Audiology, 24*, 124-136.

Edell H, Lucker JR, Alderman L (2008). Don't You Get It? Living with Auditory Learning Disabilities. *Wood Dale, IL: Stoelting Co.*

Fey ME, Richard GJ, Geffner D, Kamhi AG, Medwetsky L, Paul D, Ross-Swain D, Wallach GP, Frymark T, Schooling T (2011). Auditory processing disorder and auditory/language interventions: An evidence-based systematic review. *Language, Speech, and Hearing Services in Schools, 42*, 246-264.

Geffner D (2011). Auditory Skills Assessment. *SSW Reports, 32*(3), 9-12.

Geffner D, Ross-Swain, D (eds.) (2012). Auditory Processing Disorders: Assessment, Management, and Treatment, Second Edition. *San Diego: Plural Publishing*.

Katz J (2005). At What Age?: Moral and Ethical Questions. *SSW Reports, 27*(3), 13-15.

Katz J (2007). APD Evaluation to Therapy: The Buffalo Model. *Audiology OnLine*. Available on-line at: http://www.audiologyonline.com/articles/apd-evaluation-to-therapy-buffalo-945

Katz J (2009). Therapy for Auditory Processing Disorders: Simple Effective Procedures. *Prairie Village*, Kan. Print.

Katz J, Zalewski T (2011). Katz, Jack. Buffalo Model Questionnaire with Manual [Auditory Processing Disorders Checklist]. *Educational Audiology Association, Pittsburgh PA*. http://edaud.org/product/buffalo-model-questionnaire-with-manual/

Katz J, Fletcher C (2004). Central Test Battery Kit [Buffalo Model for Auditory Processing Disorders Test Battery]. *Precision Acoustics, Inc., Vancouver, WA*. http://precisionacoustics.org/

Katz J (2015). Integration Signs-New Addition-Further Support. *SSW Reports, 37*(2), 1-7.

Keith W, Purdy S, Toth A, Russell E, Young, C, Wojciechowski I, Coutts J, Tyler J (2014). Balancing diagnostic considerations and the benefits of early intervention in the Management of auditory processing disorder: A case study report. *New Zealand Audiology Society Bulletin, 24*(2), 11- 22.

Lucker JR (2005a). At what age depends on your approach. *SSW Reports, 27*(4), 19-20.

Lucker JR (2005b). What do APD tests, in children below 7 years, tell us? *SSW Reports, 27*(4), 20-24.

Lucker JR (2015a). How young is too young to evaluate children for auditory processing disorders? *Canadian Audiologist, 2* (5).

Lucker JR (2015b). Auditory processing abilities in children: When to test? *Audiology Today, 27* (1), 24–30.

Moore DR (2006). Auditory processing disorder (APD): Definition, diagnosis, neural basis, and intervention. *Audiological Medicine, 4* (1), 4-11.

Musiek F, Shinn J, Hare C (2002). Plasticity, Auditory Training, and Auditory Processing Disorders. *Seminars in Hearing, 23* (4), 263-276.

Tillery KL (2005). Five year olds – CAP Test Battery. SSW Reports, 27(3), 15-16.

White-Schwoch T, Woodruff CK, Thompson EC, Anderson S, Nicol T, Bradlow AR, Zecker SG, Kraus N (2015). Auditory processing in noise: A preschool biomarker for literacy. *PLoS Biology, 13*(7), e1002196.

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Children's Auditory Recognition With Digital Stimuli

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The goal of this investigation was to design a new, age-appropriate, tablet-based word-recognition test, which consists of six lists of 20 digitally-recorded words each with corresponding picture slides. Prior to the study, the suitability of the stimuli was verified (i.e., content validity) by presenting the test vocabulary and photographs to five 3- to 5-year-old children. After the stimuli were deemed appropriate, the test-retest reliability, list equivalency, and convergent validity of the test were determined with 3- to 6-year-old children with normal hearing or hearing loss. Prior to administering the new test, each participant completed a hearing screening and receptive vocabulary test to rule out hearing loss and language delay, respectively. In the children with normal hearing, all lists on the test were completed in two test sessions to assess test-retest reliability and to examine list equivalency. For all participants, average performance on one list of the new test was compared to performance on the revised Word Intelligibility by Picture Identification (WIPI). Results of the study suggested good test-retest reliability and list equivalency of the CARDS for four-, five-, and six-year-old children. List equivalency was also confirmed for a group of 13 children with hearing loss ranging in age from three to six years. However, the three-year-old children showed an effect of test session, with better performance in Session 2, and significantly poorer performance on List 6 relative to all other lists. Convergent validity was not confirmed for the three- and four-year-olds with normal hearing or for the group of 13 children with hearing loss in this study, with significantly better performance on the CARDS than the WIPI for all groups except the five-to-six-year olds with normal hearing. Further testing with children who have normal hearing or hearing loss will need to be conducted to reexamine convergent validity, collect normative data, examine unaided versus aided performance, and evaluate differences across varying severities of hearing loss and between children using hearing aids and cochlear implants.

Introduction

The American Academy of Audiology (AAA) Audiologic Guidelines for the Assessment of Hearing in Infants and Young Children (2012) state that the gold standard of pediatric assessment should include an evaluation of ear-specific hearing thresholds and, when age appropriate, speech recognition measures at supra-threshold levels. Prior to assessing speech recognition, the child will need to master lower-level auditory skills including detection, defined as the awareness of a sound in his or her environment, and discrimination, defined as the ability to detect the difference or similarity between two sounds (Erber, 1982). Speech recognition in a quiet sound booth provides a standardized indicator of performance in a well-controlled acoustic environment (i.e., best case scenario). In younger children, ages two to five years, closed-set picture-pointing tasks may be used to determine supra-threshold speech recognition abilities. Closed-set speech recognition tests, such as the Word Intelligibility by Picture Identification (WIPI) and Northwestern University Children's Recognition of Speech (NU-CHIPS) tests, are widely known and used in audiological assessments of young children (Elliot & Katz, 1980; Cienkowski, Ross, & Lerman, 2009; Ross & Lerman, 1970). These closed-set tests consist of four lists of 25 to 50 words each which are depicted on picture plates containing four to six picture choices. Children are asked to point to the picture corresponding to the spoken word presented via monitored live voice (MLV) or recorded presentation. Both of these tests are valuable for speech recognition testing, especially in young children with expressive language delays or articulation disorders. However, the pictures used in these tests consist of paper-based line drawings and simple representations of the test stimuli rather than more realistic depictions of the stimuli. In fact, the original WIPI was found to contain several confounding picture choices and "pictures unfamiliar to children" (Cienkowski et al., 2009; Stewart, 2003, Dengerink & Bean, 1988).

Importance of Speech Recognition Testing

In addition to routine audiological assessments, the AAA guidelines for assessing hearing in children (2012) also state that assessment of speech recognition at supra-threshold levels is critical for formulating recommendations regarding amplification, aural habilitation, and educational strategies. Speech-recognition assessment is particularly important because, generally, the primary goal of amplification is to restore audibility of the speech signal to facilitate development of speech, language, and communication (Bagatto, Scollie, Hyde, & Seewald, 2010; Seewald, Moodie, Scollie, & Bagatto, 2005). Therefore, quantifying audibility is essential to ensure that children have sufficient access to the acoustic cues that facilitate speech and language development (McCreery & Stelmachowicz, 2011). Following a fitting of a hearing aid using objective verification measures including real ear to coupler difference and real-ear aided response (REAR) probe microphone measurements, speech recognition measures may be used to validate appropriate outcomes in children (AAA Clinical Practice Guidelines: Pediatric Amplification, 2013). When a child with hearing loss is evaluated for the potential benefit of amplification, speech recognition may be conducted at soft (e.g., 40 dB HL), conversational (e.g., 55 dB HL), and loud intensity levels (e.g., 80 dB HL) to assess audibility and comfort across a range of loudness levels in an ideal acoustic environment (i.e., sound booth). For children who have developed some speech and language, speech-recognition scores may also be used to determine cochlear implant candidacy. Following the receipt of a hearing aid or cochlear implant, the same three input intensities may be utilized to behaviorally verify the adequacy of programming. This same speech recognition testing may be conducted at follow-up appointments to monitor progress and to plan habilitative and educational goals and objectives. Finally, speech-recognition measures and outcomes may be used as a counseling tool for parents and/or caregivers. When adequate audibility is not achieved for soft speech in an unaided condition, low percent-correct scores provide concrete evidence to parents that intervention is necessary. Similarly, when adequate audibility is not achieved for conversational speech in an aided condition, poor speech-recognition scores provide evidence that further technology, such as a cochlear implant and frequency modulation (FM)/digital remote-microphone technology, may be necessary.

Study Rationale

Given the importance of supra-threshold speech-recognition testing and limitations of existing closed-set word-recognition tests for young children, a new word-recognition test consisting of simple stimuli and digital photographs was developed for computerized administration on an electronic tablet. Although one existing test, the WIPI, was updated in 2009 to include more relevant vocabulary and new artist drawings (Cienkowski et al., 2009), the presentation of this test via paper format and use of drawings still present limitations when compared to a computerized format and digital pictures. The investigators hypothesized that the computerized format and digital photographs of people, places, objects, and actions may be more relevant, recognizable, and universal to children when compared to existing test stimuli. Many young and school-aged children have access to or own digital hand-held devices and use these devices on a daily basis, making a tablet-based test format more familiar than a paper booklet to most children (Henry J. Kaiser Family Foundation, 2010). Also, the tablet, unlike a paper booklet, is portable and allows for storage of more than one test, resource, or game for children within one device. Tablet-based presentation allows for easy navigation and does not require flipping through pages of pictures during testing. The primary goal of this study was to construct an age-appropriate, supra-threshold tablet-based word-recognition test for children ages three to six years. Secondary goals were to examine aided performance of children with varying degrees of hearing loss in sound-field to examine list equivalency and to determine whether the new test may be feasible for use as a validation measure following a hearing aid or cochlear implant fitting.

Methods

Participants

The methods and procedures for this study were approved by the Institutional Review Boards at the University of North Texas (UNT) and the University of Washington (UW). Participants included a total of 57 children ranging in age from three to six years, and parental consent was obtained from all parents of the children prior to their participation in the study. Forty-three of these children had normal-hearing sensitivity bilaterally, defined as threshold responses of less than or equal to 20 dB HL on a pure-tone hearing test ranging at octave frequencies from 250 to 8000 Hz. Within the group of children with normal hearing, 14 were 3-years old, 14 were 4-years old, and 15 were 5- and 6-years old. All children with normal hearing were tested at UNT and UW. The remaining 14 children had bilateral sensorineural hearing loss with severities ranging from mild to severe and were tested at UNT, UW, or Hearts for Hearing in Oklahoma City, Oklahoma. All children with hearing impairment were fit using a standard hearing aid fitting protocol utilizing Desired Sensation Level (DSL) v5 prescriptive targets (Scollie et al., 2005; Seewald et al., 2005) and real-ear verification measures. Additional information about the children with hearing loss is provided in Table 1. Test stimuli were calibrated with a Type 1 sound-level meter (Larson-Davis, 824). An electronic version of the Peabody Picture Vocabulary Test, Fourth Edition (PPVT-4; Dunn & Dunn, 2012) was administered with a laptop computer.

Table 1. Demographic Information for Participants with Hearing Loss

Subject	Age	Aided PTA	Unaided	Description	Device
1	6;1	B: 17 dB	R:48 dB L:18 dB	R: Atresia L: sloping HL	R: Phonak Nios S H20 III L: Cochlear BAHA BP100 (Soft band)
2	5;3	B: 20 dB	R: 43 dB L: 38 dB	R: Moderate rising to normal L: Moderate rising to normal	Bilateral Phonak Nios S H20 III
3	6;2	R: 28 dB L: n/a	R: 95+ dB L: 12 dB	R: profound L: normal hearing	R: BAHA 5 Attract L: none
4	3;11	B: 32 dB	R: 78 dB L: 82 dB	Bilateral severe sloping to profound	R: Phonak Naida Q50 SP L: Cochlear Nucleus 6
5	3;4	R: n/a L: 33 dB	R: 67 dB L: 75 dB	R: flat moderately-severe L: flat severe	Bilateral Phonak Nios S H20 III
6	5;5	n/a	R: 52 dB L: 47 dB	Bilateral moderate flat	Bilateral Phonak Nios S H20 III
7	5;5	R: 27 dB L: 32 dB	R: 60 dB L: 57 dB	Bilateral moderate sloping to severe	Bilateral Phonak Sky Q50 M13
8	6;3	B: 15 dB	R: 8 dB L: 12 dB	Bilateral precipitous, normal to severe at 4kHz	Bilateral Phonak Sky Q50 M13
9	6;6	R: 28 dB L: 23 dB	R: 70 dB L: 95+ dB	R: moderate sloping to severe L: profound	R: Phonak Naida Q90 UP L: Cochlear Nucleus 6
10	4;1	R: 18 dB L: 23 dB	R: 95+ dB L: 95+ dB	Bilateral profound	Bilateral Cochlear Nucleus 6
11	4;7	R: 27 dB L: 23 dB	R: 95+ dB L: 95+ dB	Bilateral profound	Bilateral Cochlear Nucleus 6
12	3:8	B: 27 dB	R: 52 dB L: 53 dB	R: Mild sloping to moderately-severe at 4000 Hz L: Mild sloping to moderate at 2000 Hz	Bilateral Phonak Sky Q Q50 M13
13	4:0	R: 52 dB L: 53 dB	B: 27 dB	Bilateral mild sloping to moderate	Bilateral Phonak Nios S H20 III
14	6:8	B: 17 dB	R: 48 dB L: 50 dB	R: Moderate rising to normal at 6000 Hz L: Moderate rising to normal at 8000 Hz	Bilateral Phonak Sky Q50 M13

Note. R= right; L=left; B=binaural; n/a=not available.

Test Stimuli

The new word-recognition test, which will be referred to as the Children's Auditory Recognition with Digital Stimuli (CARDS) test, consisted of six lists of 20 words each. The 120 CARDS stimuli consisted of digital photographs arranged on picture plates and digitally-recorded monosyllabic words. The process of validating the stimuli is provided in the results section.

Digital Recordings

The pictured target words were recorded by a female talker, and the acoustic editing software, Cool Edit Pro Version 2 (2003) was used to equalize the root-mean-square intensity of each word. The phonemic distribution of the words across the six lists is provided in Table 2. The procedures used to determine phonemic balance of the text lists were modeled from those used in the development of the Hearing in Noise Test (HINT; Nilsson, Soli, & Sullivan, 1994). First, the target phoneme count was calculated, which is defined as the difference between the target phoneme count across the six lists divided by the total number of lists (6). Second, a difference score was calculated between the target phoneme count and the obtained (actual) phoneme count. The distribution of these differences is displayed in Figure 1 where a deviation of zero represents perfect phonetic balance. Finally, the percentage of the difference scores that were within + 1 phoneme were tabulated. A difference of + 1 phoneme was present in 63% of the difference scores. As a result, phonetic balance was achieved, for the most part, and was similar to the phonetic balance reported for the HINT, which had + 1 phoneme for 68% of difference scores. The equivalency of the test lists (i.e., equal difficulty) was determined in the study design. The stimuli were recorded to compact disc and were presented to the participant at 40 dB SL relative to his or her pure-tone average at 500, 1000, and 2000 Hz (aided PTA for children with hearing loss). In addition, one randomly-selected list was presented at 50 dB HL to examine performance for a fixed intensity representing conversational speech.

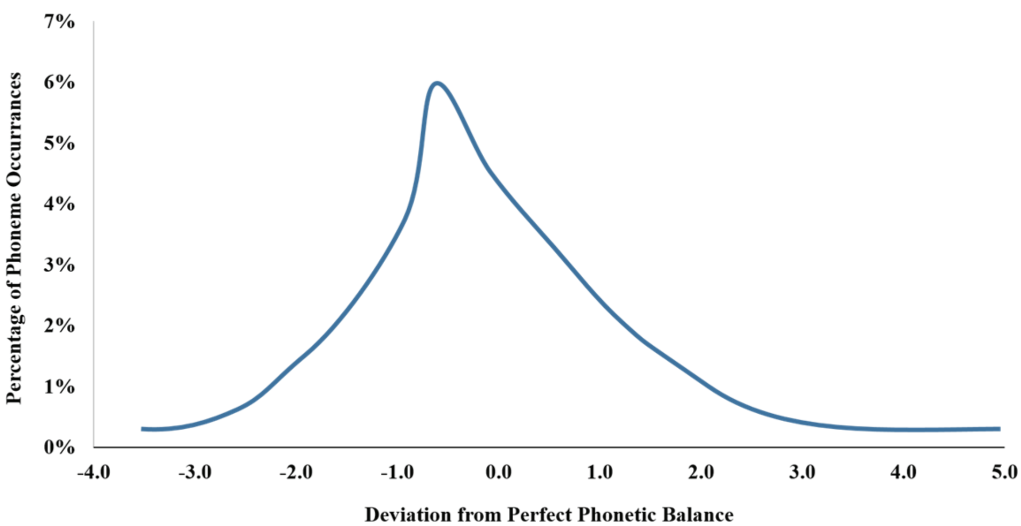

Figure 1. Deviation of difference scores for all 120 words in the six word lists.

Table 2. Phoneme Distribution for 120 Words in the Six Lists.

Consonant Distribution							
/p/	**4.1%**	/k/	7.6%	/s/	7.3%	/ʧ/	0.5%
/b/	**4.6%**	/g/	2.5%	/z/	1.0%	/ʤ/	0.8%
/t/	**5.8%**	/f/	2.3%	/ʃ/	1.5%	/m/	3.3%
/d/	**5.1%**	/θ/	1.3%	/h/	1.8%	/n/	5.1%
/ŋ/	**0.5%**	/l/	4.8%	/w/	2.5%	/r/	6.8%
Vowel Distribution							
/i/	**2.8%**	/æ/	3.8%	/ʊ/	0.5%	/ər/	0.3%
/ɪ/	**1.8%**	/ɑ/	5.1%	/u/	2.0%	/aɪ/	2.5%
/e/	**1.0%**	/ɔ/	1.0%	/ʌ/	3.3%	/aʊ/	1.0%
/ɛ/	**2.3%**	/o/	2.5%	/ɜr/	0.8%	/ɔi/	0.3%

Note. Percentages represent how often the phoneme occurred relative to the total number phonemes.

Other Test Measures

In addition to the CARDS lists, children completed one list of the Word Intelligibility by Picture Identification test (WIPI; Cienkowski et al., 2009) at 40 dB SL relative to his or her pure-tone average at 500, 1000, and 2000 Hz (aided PTA for the children with hearing loss) and the PPVT-4 (Dunn & Dunn, 2012) outside of the double-walled sound booth with the examiner sitting beside the child. The PPVT-4 was used to confirm every child in the study had appropriate receptive-vocabulary levels based his or her chronological age because poor receptive vocabulary could have impacted speech recognition performance on the CARDS. According to the testing, all children had age-appropriate receptive vocabulary levels.

Study Design and Procedures

The 43 children with normal hearing sensitivity were tested in two test sessions with a one- to three-week gap between test sessions. The 14 children with hearing loss were only tested in one test session. Two types of reliability were assessed in this study by calculating: (1) test-retest reliability, or the consistency of the scores from one session to another, and (2) internal consistency reliability or test list equivalency (Trochim, 2005). In addition, content validity was determined prior to the study when determining appropriate vocabulary and recognizable pictures in five, three-to six-year-old children (i.e., common vocabulary and pictures screened with pilot data). Finally, convergent validity was assessed with a comparison between scores on the CARDS test list and the WIPI test list in 41 of the 43 children with normal hearing and 13 of the 14 children with hearing loss.

Session 1

After study personnel explained study procedures and obtained parental consent in Session 1, parents were asked to complete a case history form for their child. The case history was used to rule out recurrent otitis media or surgeries in the children with normal hearing and to obtain more detailed hearing history and device information from the children with hearing loss.

Following completion of the paperwork, the examiner conducted the pure-tone hearing test or previous tests were obtained from the parent for some of the children with hearing loss who received an evaluation within the past six months. After the hearing test, the PPVT-4 was administered via laptop computer. Next, each list of the CARDS, in pseudo-randomized order (i.e., no repeated lists), was presented at 40 dB SL using the iPad and compact disc player, along with an additional list presented at 50 dB HL.

For children with normal hearing, only one ear was tested with an insert earphone to avoid ear effects in this initial assessment of the stimuli. This procedure was adapted from the WIPI procedures (Cienkowski et al., 2009). The test ear was counterbalanced across participants and the stimulus intensity for the test ear was determined by calculating the child's pure tone average (PTA) at 500, 1000, and 2000 Hz. Children with hearing loss were tested in their normal aided condition (Table 1) in the sound field with the loudspeaker at 0 degrees azimuth in order to examine the utility of CARDS for supra-threshold speech recognition assessment following a hearing aid fitting or cochlear implant activation. The stimulus intensity for the sound-field testing was determined by calculating the child's better-ear aided PTA at 500, 1000, and 2000 Hz, and testing was presented at 40 dB SL. If the child was not aided, the better unaided threshold was used (Participant #6). For both groups of children, the examiner recorded correct responses during testing and a percent-correct score was calculated for each list of 20 words. Following this testing, children completed one list of the WIPI.

Forty-one children with normal hearing and 13 children with hearing loss completed List 1 of the WIPI at 40 dB SL to examine convergent validity. Additionally, 35 children with normal hearing and 11 children with hearing loss also completed List 1 of the CARDS at 50 dB HL in order to provide normative data on expected performance at a level corresponding to normal conversational speech in an ideal acoustic environment (i.e., sound booth). The investigators expected similar performance between the 40 dB SL and 50 dB HL conditions given that both should provide adequate audibility.

Session 2

In Session 2, the children with normal hearing sensitivity completed a re-screen of hearing from 250 to 8000 Hz to verify no change in thresholds. Following the screening, all six lists of the CARDS were repeated in a pseudo-randomized order.

Results

Effects of Age, List, & Test Session

Average word-recognition scores from the three groups of children with normal hearing across the six lists are shown in Figure 2, and average performance across the lists and test sessions are shown in Figure 3. Because of the performance of the children at or close to ceiling (i.e., 100% correct), percent-correct scores were converted to rationalized arcsine units (RAU) prior to statistical analysis of all data (Studebaker, McDaniel, & Sherbecoe, 1995).

Two types of reliability, test-retest reliability and internal consistency reliability (list equivalency) were examined with parametric statistics. More specifically, a three-factor repeated measures analysis of variance (RM ANOVA) was conducted with the independent variables of age (3, 4, and 5-6), test list (1-6) and test session (1, 2). According to this analysis, there was a significant main effect of age, $F(2,516) = 17.9$, $p < 0.001$, a significant main effect of test list, $F(5,516) = 9.9$, $p < 0.001$, and a significant main effect of test session, $F(1,516) = 19.5$, $p < 0.001$. There were no significant interaction effects between age and session, $F(2,516) = 1.5$, $p < 0.23$, age and list, $F(10,516) = 1.3$, $p < 0.21$, or list and session, $F(5,516) = 1.3$, $p < 0.29$. Post-hoc analyses were conducted with the Tukey-Kramer Multiple Comparisons test to more closely examine the significant main effects. For the main effect of age, the two older age groups had significantly better average scores than the three-year olds (both $p < .05$). For the main effect of test list, List 6 yielded significantly lower average scores than Lists 1, 2, 3, and 5 (all p < .05), and List 4 resulted in significantly lower average scores than Lists 1 and 2 (both p < .05). No other significant differences were found. When examining the post-hoc analysis on test session, average scores in Session 2 were significantly better (p < .05) than those in Session 1. Given the significantly poorer performance of the three-year-old children, additional analyses were conducted to more closely examine the effect of age on the results. A post-hoc analysis for age by session suggested that only the average scores of the three-year-olds differed significantly between the two test sessions (p < .05). Similarly, an analysis of age by test list suggested that only the three-year-old children showed significant performance differences across the test lists with List 6 yielding worse scores than Lists 1, 3, and 4 (all p < .05).

To further examine test re-test reliability for the four-, five-, and six-year olds, the average score across the six lists was determined for each participant with normal hearing in Session 1 and Session 2. A Pearson's Product Moment Correlation was then calculated using the average scores for each participant in the two separate sessions. The correlation coefficient between the scores obtained in Session 1 and Session 2 was 0.71, which confirms moderately high test-retest for this word-recognition test.

List equivalency was also examined for the 14 children with hearing loss who ranged in age from three to six years. Individual scores of the 14 children with hearing loss ranged from 80-100% across lists (M=97%; SD=5). As a result, these data were also transformed to RAU to allow for statistical analysis. Given the effect of age for the children with normal hearing, a one-factor analysis of covariance (ANCOVA) was performed to control for the effect of age. According to this analysis, there was no significant main effect of test list, F (5,84) = 17.3, p = 0.20. To account for the repeated measures aspect of the design, a RM ANOVA was also conducted and yielded the same results (i.e., no significant main effect of list; F [5,84] = 1.62, p = 0.17).

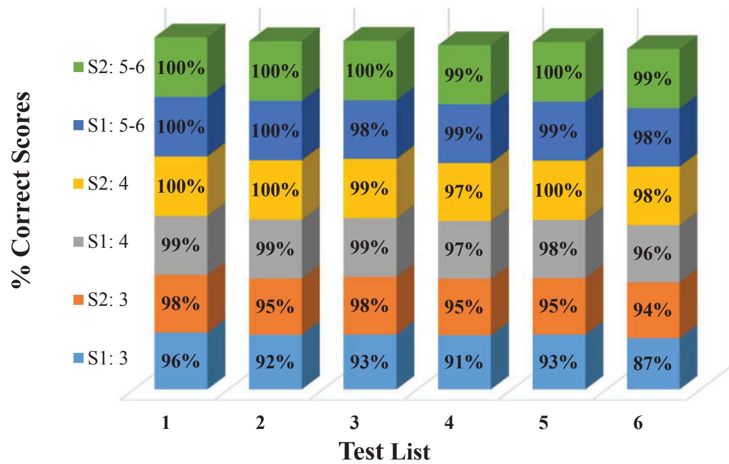

Figure 2. Average percent correct performance on the CARDS for each age group with normal hearing by session and word list.

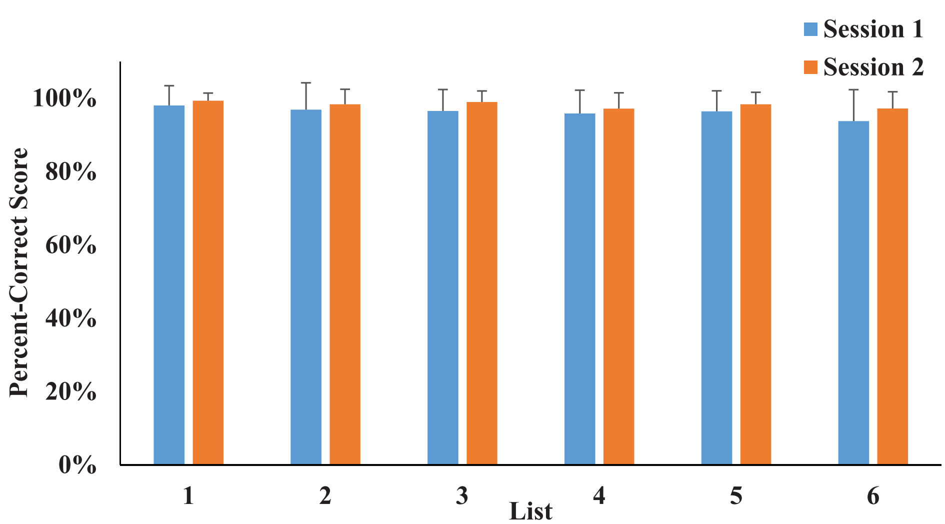

Figure 3. Average speech-recognition scores from children with normal hearing across session and CARDS word list.

Validity of the Word-Recognition Test

Content and convergent validity were examined in this study. Content validity was confirmed prior to the study through a series of steps to ensure appropriate test material for three-to-six-year-old children. First, four examiners determined and documented approximately 400 frequently occurring vocabulary words in children's environments through daily interactions with pre-school aged children over a period of four weeks.

Second, these 400 words were discussed by four examiners, who had experience working with children (i.e., pediatric audiologist; speech assistant; 2 graduate assistants with pediatric experience), in order to select the most appropriate stimuli for the test. Stimuli had to meet three criteria for further consideration: (1) only nouns and verbs were considered, (2) only monosyllabic words were considered, and (3) only words that could be depicted easily in photographs were included. Using these criteria, 150 words remained in the stimulus set.

Third, the examiners digitally photographed the 150 words. For all words, multiple photographs were taken to allow for selection of the clearest and most recognizable photograph with the best angle. The photographs were taken in everyday environments at home, at the park, and at school.

Fourth, the same four examiners reviewed all photographs taken for the 150 words and agreed collectively on which photograph best depicted the word, keeping in mind the age group for which the test was designed. At this stage, the examiners reduced the number of stimuli to include only the most clearly depicted 120 words.

Fifth, using Microsoft PowerPoint, 120 digital picture plates were created. On each plate, a photograph for the target word was shown along with five photographs for non-target words, which were randomly selected from the pool of remaining photographs. The 120 picture plates were divided equally into six separate digital folders containing 20 picture plates each (i.e., 6 lists of 20 words each), which were then uploaded to an Apple iPad. Two sample picture plates are shown in Figure 4and the six word lists are provided in Table 3.

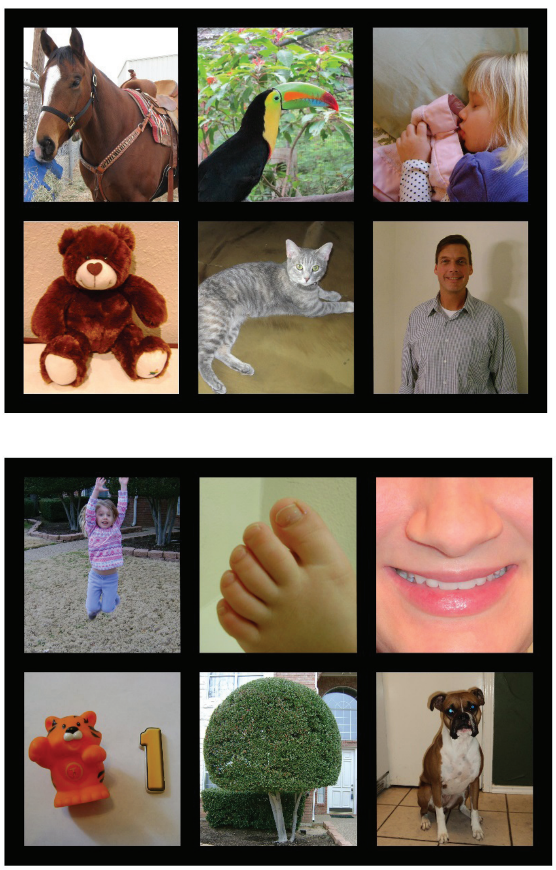

Figure 4. Two picture plates from the new word-recognition test.

Table 3. Word Lists 1 Through 6.

List 1	List 2	List 3	List 4	List 5	List 6
Bird	Three	Rocks	Mouth	Dress	Orange
Boat	Fan	Fish	Bed	Stairs	Sleep
Book	Dad	Cat	Pool	Clock	Sheep
Car	Girl	Blocks	Duck	Pie	Tie
Food	Boy	Black	Mouse	Cold	Walk
Hat	Hair	Two	Bat	Heart	Pants
Juice	Corn	Nap	Plate	Knife	Sad
Nose	Key	Brush	Bowl	Truck	Red
Doll	Paint	Teeth	Run	Snow	Pig
Mom	Eggs	Foot	Bear	Desk	Smile
Sand	Sky	Milk	Watch	Kick	Ball
Sun	Door	Star	Stop	Swing	Soap
Bug	Horse	Eat	Box	Wheel	Fork
Dog	Plane	Toes	Can	Goats	One
Phone	Green	Cup	Arm	Draw	Eye
Fire	Bath	Man	Hug	Drink	Cow
Sock	Hand	Light	Blue	Grass	Cake
Swim	Mop	Boot	Tree	Slide	Spoon
Drum	Frog	Sick	Shirt	Bike	Shoe
House	Thumb	Chair	Jump	Wash	Ear

Sixth, pilot data were then collected from five, three- to five-year old children (two, 3-yr olds; one, 4-yr old; two, 5-yr olds) with normal hearing sensitivity (< 20 dB HL from 250-8000 Hz), as determined by a hearing screening and no history of otitis media, ear surgeries, or speech-language disorders, as reported by parents on a case history form. During testing, an examiner was seated next to a child in a quiet room; the examiner presented each word via live voice with no visual cues. Following the auditory stimulus, the child was asked point to the photograph on an Apple iPad that best depicted the word that was heard. This process was repeated for all 120 picture plates. Given that all five children identified the 120 stimuli and picture plates with 100% accuracy, the stimuli were deemed appropriate and valid for use in the present study.

To evaluate convergent validity, or similarity of the CARDS to an existing word-recognition test, 41 of the children with normal hearing completed List 1 of the WIPI. These data are shown in Figure 5 The children's WIPI scores were compared to scores obtained with a list on the CARDS by calculating a correlation coefficient. The correlation coefficient was .33, which suggests a weak to moderate relationship between the two tests. Additionally, a two-factor RM ANOVA was conducted with the independent variables of age and test. The analysis yielded a significant main effect of age, $F(2,82) = 10.6$, $p = 0.0002$, and a significant main effect of test, $F(1,82) = 48.6$, $p < 0.0001$. Post-hoc analysis with the suggested that average performance between the CARDS and WIPI was similar for the five-to-six-year-olds, but significantly different for the three- and four-year olds. Although this analysis did not confirm a strong correlation (i.e., high convergent validity) and the same performance between the two tests, it did confirm that the CARDS will produce scores that are equal to or higher than scores obtained on the WIPI. Similar to the children with normal hearing, correlation coefficient was calculated and a two-factor RM ANOVA was conducted for 13 children with hearing loss. A weak to negligible correlation coefficient of -.09 was calculated, which may be related to the small sample size. Also, the RM ANOVA for the children with hearing loss showed no significant main effect of age, $F(2,26) = 4.0$, $p = 0.052$, and a significant main effect of test, $F(1,26) = 35.9$, $p = 0.0001$. A post-hoc analysis suggested better performance on the CARDS ($p < .05$) than the WIPI. Potential reasons for the performance discrepancy will be outlined in the discussion section.

When examining the results in the 50 dB HL CARDS test condition, average performance was 98% (SD=2.8; Range=90-100%) for the 35 children with normal hearing and 98% (SD=2.5; Range=95-100%) for the 11 children with hearing loss. The implications of these results will be explored in the discussion section.

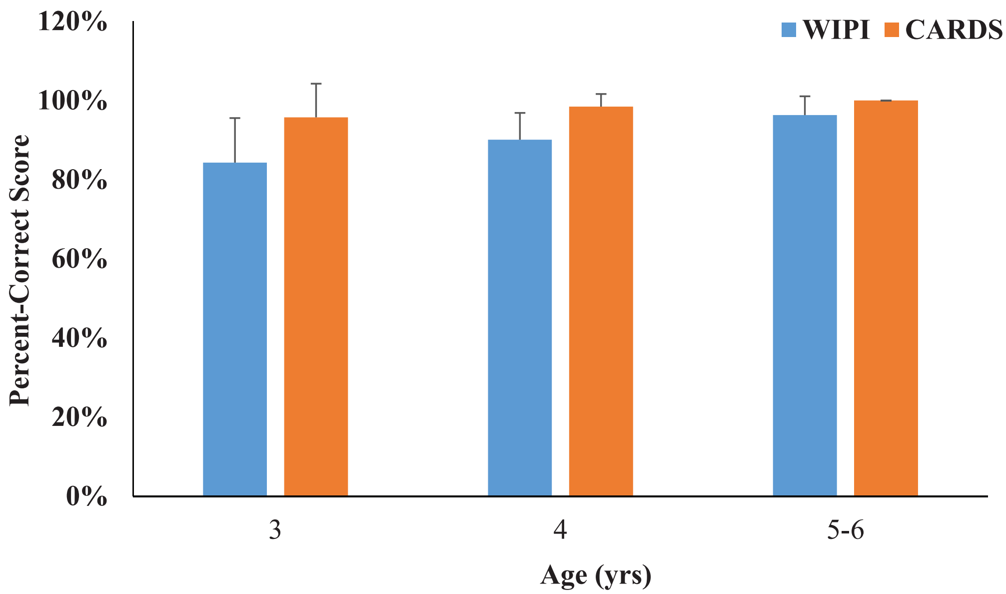

Figure 5. Average percent correct performance for one list of the WIPI and List 1 of the CARDS for 41 children with normal hearing. Note. Vertical lines represent one standard deviation

Discussion

On average, test-retest reliability and list equivalency of the CARDS were confirmed for the four-, five-, and six-year-old children. However, the three-year-old children showed an effect of test session, with better performance in Session 2, and significant worse performance on List 6 relative to all other lists. Because the average performance of the three-year-olds in Session 2 was slightly higher than what was obtained in Session 1, there was a likely a learning effect present, which may be related to the brief, one to three-week period between test sessions. As a result, if this test were used with three-year-olds in clinical practice, the authors of this study recommend completing a practice list prior to the test list at each appointment. Additionally, given the poorer performance of the three-year-olds on List 6, that list should not be used with this age group. List equivalency was confirmed for a group of 13 children with hearing loss ranging in age from three to six years.

Necessary steps were taken prior to the study to document content, and a comparison of performance on the CARDS and the WIPI was conducted to examine convergent validity. However, convergent validity was not confirmed for the three- and four-year-olds with normal hearing or for the group of 13 children with hearing loss in this study because performance on the CARDS was significantly better than performance on the WIPI. However, average performance of the five-to-six-year olds with normal hearing was similar on the CARDS and WIPI. Again, it is possible that learning effects were involved in the differences for the younger age groups. The order of the test lists on the CARDS was pseudo-randomized and, as a result, many children completed one or more test lists of the CARDS before List 1, which was used for the comparison to the WIPI. Conversely, there was no practice list(s) for the WIPI.

It is important to note that a 40 dB SL presentation level is not sensitive to performance differences in children with normal hearing or the sample of children with hearing in the present study who had, for the most part, good aided thresholds (Table 1). The present investigation is only the first step in the development of this test and was necessary to examine reliability and validity when stimuli were equally audible to all participants. The next step in the development of the CARDS would be to collect normative data on Lists 1-4 from a large sample of children with normal hearing and also with hearing impairment. Future research should examine the concurrent validity of the CARDS (i.e., the measure should distinguish between groups that should be different) by comparing performance of a group of children with normal hearing to a group of children with more severe degrees of hearing loss than those in the present study (Trochim, 2005). Additional research may also assess two-year old children in the closed-set format or evaluate performance in an open-set condition in young and older children with and without hearing loss. Although concurrent validity could have been shown in the 50 dB HL condition, there was highly similar performance between the normal hearing and hearing loss groups in the present study. First, for many of the children with normal hearing, 40 dB SL was 50 dB HL; therefore, limited additional information was gained from the extra condition at 50 dB HL for this group. Second, while the children with hearing loss all had aided thresholds (PTA) higher than 10 dB HL, they still achieved excellent performance in the 50 dB HL condition likely due to the fairly good aided thresholds (i.e., normal to mild hearing loss range). Different results might have been obtained if the children with hearing loss were tested in a unilateral condition or in the unaided condition. At the same time, the use of an insert earphone in one ear of normal hearing participants and use of sound field speakers for the aided/implanted children with hearing loss confirms that both presentation modes are feasible. Additional demographic information about the children with hearing loss, such as length of amplification/cochlear implant use and the quality of the fitting, would have been helpful for examining results from the children in this study. However, given their excellent performance at 40 dB SL relative to their aided PTA, these children appeared to have adequate recognition abilities with their hearing aids or cochlear implants. Future research should examine performance of children with hearing loss at soft (e.g., 40 dB HL), conversational (e.g., 55 dB HL), and loud intensity levels (e.g., 80 dB HL) because audibility and comfort across a range of loudness levels is important for optimal hearing aid fittings. Additionally, future investigations may determine the reliability and validity of the CARDS when presented in background noise.

When conducting this test with children who have hearing loss, it is important to consider whether the 40 dB SL presentation level is appropriate (Hornsby & Mueller, 2013). In cases where the child has a precipitously sloping hearing loss, it may be more appropriate to present the stimuli at 40 dB SL relative to the child's high-frequency PTA (average of 1000, 2000, and 4000 Hz). However, if 40 dB SL relative to high-frequency PTA exceeds the child's uncomfortable loudness level, the audiologist may consider using a fixed 80 dB HL presentation level. Of course, use of an 80 dB HL presentation level represents louder speech and will not simulate soft or conversational speech levels. It is also important to note that a 40 dB SL presentation level may be uncomfortably loud for some children with hearing loss, particularly relative to an unaided PTA. If this occurs, the examiner will need to present the CARDS stimuli at the child's most comfortable listening level.

One unexpected finding in this investigation was the significantly higher average scores on the tested list of the CARDS relative to the average scores on List 1 of the WIPI. As stated above, this could be due to a learning effect, or it is possible that the higher CARDS test scores may be related to the use of digital photographs instead of line drawings. As mentioned in the introduction section, closed-set speech recognition tests, such as the WIPI and the NU-CHIPS, are an important part of the audiological test battery. However, if a child does not recognize the picture as matching the verbal stimulus, the validity of the response may be questionable (Dengerink & Bean, 1988). For example, in a previous study of the NU-CHIPS, the picture tongue elicited labels of hat, God, and other body parts (Dengerink & Bean, 1988). This specific item was missed because the picture did not represent a recognizable item to the children. By using digital photographs on the CARDS, a child may be more likely to recognize the picture. As a result, the CARDS was developed to eliminate unfamiliarity with line drawings, as well as provide auditory and digital stimuli more relevant to modern children's lexicon. Research by Dengerink and Bean (1988) also show that test subjects found the common pictures of the WIPI to be more identifiable than the common pictures on the NU-CHIPS. More specifically, colored pictures were more readily identifiable than the black and white line drawings. It may be inferred from the results in the present study that photographs, which are more realistic than colored sketches or black and white line drawings, would also be more recognizable for children. At the same time, these differences could also be due to different vocabulary used for the CARDS and WIPI. The exact reason for the discrepancy between tests cannot be confirmed at this time.

Additionally, the use of a tablet-designed test allows the examiner to use the CARDS test program on multiple platforms, including but not limited to computers, Apple iPads, and various other tablets. The examiner also has the ability to upload various other programs onto a specific device, such as games to reengage the child during testing, counseling tools (e.g., digital pictures of ear anatomy), or auditory training applications. Furthermore, as technology advances, it is possible that various other audiological test materials will be provided in this format, condensing the testing material needed into one portable device. From the anecdotal experience of the examiners, the tablet-based platform for testing is also more engaging for children who are familiar with tablets and often possess positive associations with tablet-like applications.

In summary, the results of this investigation suggest that four lists of the CARDS may be used as a reliable measure (good test-retest and list equivalency) of closed-set word recognition in children 4 to 6 years of age with normal hearing. A group of children with hearing loss also showed list equivalency. The authors of this study believe that learning effects impacted performance for three-year-olds with normal hearing on the CARDS, but Lists 1-5 may be used clinically after a practice list is utilized at each appointment. Content validity was documented; however convergent validity (i.e., CARDS vs. WIPI) could not be confirmed for most children, with the exception of the five-year-olds with normal hearing. Additional research is necessary with a larger sample size and a range of hearing losses. At this time, the test may be used to examine supra-threshold or multi-level word-recognition performance during a general audiological assessment, to examine audibility of speech following a hearing aid fitting or cochlear implant programming, and to plan habilitative intervention.

References

American Academy of Audiology Clinical Practice Guidelines. (2012). *Audiologic guidelines for the assessment of hearing in young infants and children* [Guidelines].

American Academy of Audiology Clinical Practice Guidelines. (2013). *Pediatric amplification* [Guidelines].

Bagatto, M., Scollie, S., Hyde, M., & Seewald, R. (2010). Protocol for the provision of amplification within the Ontario infant hearing program. *International Journal of Audiology, 49*(Suppl. 1), S70-S79.

Cool Edit Pro. (Version 2)(2003). Phoenix, AZ: Syntrillium Software Corporation.

Cienkowski, K., Ross, M., & Lerman, J. (2009). The Word Intelligibility by Picture Identification (WIPI) test revisited. *Journal of Educational Audiology, 15*, 39-43.

Dengerink, J. & Bean, R. (1988). Spontaneous labeling of pictures on the WIPI and NU-CHIPS by 5-year-olds. *Language, Speech, and Hearing Services in Schools, 19*, 144-152.

Dunn, L. M. & Dunn, D. M. (2007). *PPVT-4: Peabody Picture Vocabulary Test*. Minneapolis, MN: Pearson Assessments.

Elliott, L.L. & Katz, D. (1980). Development of a new children's test of speech discrimination (Technical Manual). St. Louis, MO: Auditec.

Erber, N. (1982) Auditory Training. Washington DC: Alexander Graham Bell Association.

Henry J. Kaiser Family Foundation Generation M2: Media in the Lives of 8- to 18-Year Olds. (2010). Menlo Park, CA.

Hornsby, B., & Mueller, G. (2013). Monosyllabic word testing: Five simple steps to improve accuracy and efficiency. Retrieved from Audiology Online: http://www.audiologyonline.com/articles/word-recognition-testing-puzzling-disconnect-11978.

McCreery, R. & Stelmachowicz, P. (2011). Audibility-based predictions of speech recognition for children and adults with normal hearing. *Journal of the Acoustical Society of America, 130*, 4070-4081.

Nilsson, M., Soli, S., & Sullivan, J. (1994). Development of the Hearing in Noise Test for the measurement of speech reception thresholds in quiet and in noise. *Journal of the Acoustical Society of America, 95*(2), 1085-1099.

Ross, M., Lerman, J. (1970). A picture identification test for hearing-impaired children. *Journal of Speech, Language, and Hearing Research, 13*, 44-53.

Scollie, S., Seewald, R., Cornelisse, L., Moodie, S., Bagatto, M., Laurnagaray, D., … & Pumford, J. (2005). The Desired Sensation Level multistage input/output algorithm. *Trends in Amplification, 9*(4), 159–197.

Seewald, R., Moodie, S., Scollie, S., & Bagatto, M. (2005). The Desired Sensation Level method for pediatric hearing instrument fitting: Historical perspective and current issues. *Trends in Amplification. 9*, 145-157.

Stewart, B. (2003). The Word Intelligibility by Picture Identification Test: A two-part study of familiarity and use. *Journal of Educational Audiology, 11*, 39-48.

Studebaker, G. A., McDaniel, D. M., & Sherbecoe, R. L. (1995). Evaluating relative speech recognition performance using the proficiency factor and rationalized arcsine differences. *Journal of the American Academy of Audiology, 6*(2), 173-182.

Trochim, W.M. (2005). *Research Methods: The Concise Knowledge Base*. Cincinnati, OH: Atomic Dog Publishers.

Functional Listening Evaluation (FLE): Speech Material Effects in Children With Normal Hearing

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Functional Listening Evaluation (FLE) performance was determined for 31 typically-developing children with normal hearing (7 to 10 years of age). Investigators sought to provide comparison data to help audiologists using the FLE to justify recommendations of hearing assistance technology and/or other accommodations for special school-age populations with normal hearing. The effect of speech materials (including live-voice versus recorded presentation mode) and scoring strategy was evaluated. Each child was tested in the auditory-only conditions of the FLE (Close/Quiet, Close/Noise, Far/Quiet, Far/Noise) using three different sets of speech stimuli: Recorded FLE using [HINT-C] Sentences (RS), HINT-C sentences presented via monitored live voice (LS), and Children's Nonsense Phrases presented via monitored live voice (LNP). Mean word-level scores collapsed across listening conditions were above 97 percent for all three speech materials. LS yielded significantly higher mean performance than either RS or LNP, with no significant difference between RS and LNP means. Sentence- or phrase-level scores showed greater variability. Variability of individual scores was highest in the Far/Noise condition of the FLE. RS scores showed the highest variability among the three speech materials. Word-level scoring is recommended when conducting the FLE using any of these speech materials. In light of the high word-level scores overall for this sample, even relatively small reductions in scores could be clinically significant for 7- to 10-year-olds with normal hearing and special listening needs.

Introduction

The Functional Listening Evaluation (FLE; Johnson, 2013) is a measure of a child's ability to understand speech in a typical classroom. It was originally designed by educational audiologists to determine the effects of noise and distance on speech recognition for children with hearing impairment under conditions simulating each child's customary school listening environment. The results of the FLE, as part of a comprehensive evaluation of classroom listening needs, can be used to justify the recommendation of hearing assistance technology (HAT) for a particular child (AAA, 2011; Johnson, 2012a). In recent years, the use of classroom HAT has expanded to include children with typical hearing who may need a more favorable listening environment to learn (e.g., children with language/learning disabilities or attention deficits, dyslexia, those learning English as a second language) (see Schafer et al., 2014 for a review). Little research is available on the performance of children with normal hearing (with or without risk factors) on assessments such as the FLE which are commonly used with the hearing-impaired population; this information is needed to establish what FLE results would identify children who are likely to benefit from classroom HAT.

The extent to which school-age children exhibit reduced speech recognition in the classroom varies depending on numerous factors, including level of extraneous classroom noise relative to the teacher's voice (the signal-to-noise ratio, SNR), location of the child relative to the teacher, amount of reverberation (measured in reverberation time, RT), and difficulty of the speech task. Lower signal-to-noise ratios, greater distance between the teacher and child, longer reverberation times, and listening to speech with reduced syntactic or semantic cues would all be associated with poorer classroom speech recognition. Even typically-developing children with normal hearing have been shown to have difficulty under adverse listening conditions in either actual or simulated classroom environments (Bradley & Sato, 2008; Iglehart, 2016; Lewis, Hoover, Choi, & Stelmachowicz, 2010; Neuman, Wróblewski, Hajicek, & Rubinstein, 2010; Ruscetta, Arjmand, & Pratt, 2005; Valente, Plevinsky, Franco, Heinrichs-Graham, & Lewis, 2012; Wolfe et al., 2013; Wróblewski, Lewis, Valente, & Stelmachowicz, 2012).

The FLE is a flexible clinical protocol that guides professionals in the systematic evaluation of a child's speech recognition abilities across differing listening conditions by varying the presence of noise (Quiet versus Noise), speaker-to-listener distance (Close versus Far), and access to visual speech cues (Auditory-Visual versus Auditory only). The unaided FLE can be used as a pre-intervention measure to evaluate educational needs for children with listening difficulties; the FLE can also be administered with HAT to demonstrate benefit. Though a selection of speech materials is recommended in the FLE guidelines, the choice of speech stimulus is left to the examiner based on the age, developmental level, and other abilities of the child. The summary form includes a scorebox into which scores are entered, then automatically placed into an interpretation matrix where averaged scores from particular conditions can be compared to estimate the impact that noise, distance, and/or lack of access to visual cues have on speech recognition in the classroom (Johnson, 2013).

The FLE is administered in the child's classroom or a comparable environment, providing a more authentic representation of the child's daily receptive communication abilities than speech recognition testing performed in a sound booth.

Though originally developed for children with hearing loss, Dodd-Murphy and Ritter (2012) suggested the FLE could be useful in determining classroom listening needs of children at risk for academic delays due to factors other than hearing loss; these researchers administered the FLE to normal-hearing children with language and reading impairments, recommending the use of nonsense phrases to increase sensitivity. Normative data for the FLE would be invaluable to educational speech-language pathologists, audiologists, and to other professionals who assess classroom listening performance to provide evidence for educational need of HAT. The FLE provides quantifiable behavioral data that may carry greater weight when meeting eligibility standards or requesting special service provision from a school district.

Besides providing comparison data for evaluating children with normal hearing, the authors were interested in exploring the FLE performance of typically-developing children on multiple speech materials. Multi-word materials are more similar to the running speech that students listen to in the classroom, and each item is long enough in duration to evaluate the effects of reverberation, which is important for determining the need for HAT. The Recorded FLE Using Sentences (Johnson & Anderson, 2013) was recently made available online. The original version of the FLE specified the presentation of materials by monitored live voice, and instructions for live-voice presentation remain in the latest version. Monitored live voice presentation has been shown to increase both mean performance (Uhler, Biever, & Gifford, 2016) and the variability of scores in speech recognition tasks (Brandy, 1966). The use of live voice presentation in audiological speech recognition assessment has been criticized for decreasing its reliability and complicating both the intra- and inter-individual comparison of recognition scores (Hillock-Dunn, 2015); however, educational audiologists may continue to use live-voice presentation as part of the FLE protocol because of ease of administration and/or a sense that live speech has ecological validity in the school setting. Therefore, the current study compared FLE results for the Recorded FLE with live-voice presentation from the same set of sentence lists.

In addition, simple meaningful sentences had been found to be relatively easy for elementary-school-aged children with reading impairments to identify even in noise and with distance; nonsense phrases were suggested as an alternative because they were considered to offer a more difficult task because of the reduced linguistic content (Dodd-Murphy & Ritter, 2012, 2013). Other researchers have shown larger differences between the perception in noise of sentence and nonsense materials in children within the age group of interest. Ruscetta et al. (2005) found that children with and without unilateral hearing loss had significantly lower scores on the Nonsense Syllable Test (Edgerton & Danhauer, 1979) than on the HINT-C sentences (Nilsson, Soli, & Sullivan, 1994) while listening in the sound field in the presence of competing multi-talker babble. Lewis and colleagues (2010) showed a similar trend for 7-year-olds with normal hearing on a recording of nonsense syllables compared to the Bamford-Kowal-Bench sentences (BKB; Bench, Kowal, & Bamford, 1979) across a range of SNRs. Stelmachowicz et al. (2000) showed a small but consistent effect of semantic context in simple sentence recognition for both adults and children with normal hearing that was most evident under the poorest acoustic conditions. Because the Children's Nonsense Phrases (Johnson, 2012b) had been recommended specifically for use with the FLE as more challenging than meaningful sentences for children with minimal or unilateral losses (Johnson & Anderson, 2013), the current study compared FLE results for meaningful sentences and nonsense phrases.

Finally, Dodd-Murphy & Ritter (2012) showed that sentence-level scoring increased the variability and the sensitivity of the FLE to classroom listening difficulties exhibited by typically-hearing children with language and reading impairments. The current study therefore explored the effects of two scoring strategies: word-level and sentence- level.

The current study is the first that documents the FLE performance of children with normal hearing who are typically developing. The study sought to evaluate the following hypotheses: 1) children with typical hearing and development will show near-ideal speech recognition performance on the FLE using simple, meaningful sentences; 2) children with typical hearing and development will produce higher scores and increased variability on live-voice presentation of the FLE when compared to the recorded FLE; 3) children with typical hearing and development will show greater difficulty on the FLE using Children's Nonsense Phrases than on the FLE using meaningful sentences; and 4) sentence-level scoring will generate lower scores and increased variability when compared to word-level scoring on the FLE.

Methods

Participants

Upon Institutional Review Board approval, participants were recruited from a local elementary school. Recruitment activities included an explanation of study objectives and procedures to the principal of the school and the distribution of flyers stating the general purpose of the study, the participation criteria, and contact information.

In order to participate in this study, the children were required to meet the following criteria: 1) have an age between 7 years and 10 years, 11 months, 2) have English as their first language, 3) have no history of special educational services at school or private therapy, no history of developmental delay, and no history of hearing loss. Informed parental consent was required. Each child also signed to indicate assent at the time of testing and received a payment in cash upon completion of the testing.

Data were collected for 31 children with a mean age of 8 years, 11 months. One child over the age of 11 was also tested, but data from that session were not included in the analyses. The participants included 19 male and 12 female students. All participants passed a pure-tone hearing screening at 20 dB HL at 1000, 2000, and 4000 Hz in each ear using a portable audiometer (Maico MA40).

Materials

Three different sets of speech stimuli, all recommended in the FLE instructions, were used to determine scores under the four auditory-only FLE listening conditions. Auditory-visual conditions were not administered to reduce both test time and the likelihood of participant fatigue. The three speech materials were, in order of presentation: 1) the Recorded FLE Using Sentences [RS] (Johnson & Anderson, 2013); 2) HINT-C sentences presented via monitored live voice [LS]; and 3) Children's Nonsense Phrases presented via monitored live voice [LNP] (Johnson, 2012b). The Recorded FLE consists of a custom recording of a female speaker presenting Hearing in Noise Test for Children sentences (HINT-C; Nilsson et al., 1994). The HINT-C sentence materials, based on the original Bamford-Kowal-Bench sentences (Bench et al., 1979), have eight different but equivalent lists of ten simple sentences; each sentence contains five target words, allowing for the option of word-level or sentence-level scoring. For consistency, the examiners also read from the HINT-C sentences in the live voice presentations of meaningful sentences, using the four lists that were not used for the Recorded FLE. In addition, the mp3 file of ten minutes of continuous classroom noise included with the Recorded FLE was used for all live-voice conditions presented with noise. The Children's Nonsense Phrases, available with the FLE protocol, have eight lists of twenty phrases each and can be scored at either the word or phrase level (Johnson, 2013). The first four lists of the Children's Nonsense Phrases were used in the current study.

Procedure

All testing was conducted in an unoccupied room on site at the elementary school from which participants were recruited. Three undergraduate researchers (senior Communication Sciences & Disorders majors) administered the FLE. The first two authors trained the student examiners and periodically supervised the testing. Children for whom parental permission was received were tested individually during scheduled school days, with two examiners working together at one time. During each session, one examiner served as the speaker for the live-voice presentations, while the other examiner marked and scored the child's responses. The examiners alternated roles for each successive child they tested on a particular day.

The most recent version of the FLE was used; the set-up and test process are described in detail in a document available at this link: http://adevantage.com/uploads/FLE_2013v2a-saveable_autocalculable.pdf. Each participant was asked to repeat sentences or phrases under four different listening conditions presented in the following sequence: Close/Quiet, Close/Noise, Far/Noise, Far/Quiet for each of the three speech materials (see Materials above for descriptions). All of the live-voice conditions used were 'auditory only'; that is, the view of the examiner's face was prevented using a dark screen (loudspeaker cover material held in place by an embroidery hoop), so that visual cues were not available to the child, but undistorted auditory information was available. Each child sat in a desk and wore a lapel microphone connected to a digital recorder; a sound file of the entire test session was saved for each participant. Instructions were given before the beginning of testing with each speech material. Test items were only presented once, and children were instructed to repeat the entire sentence or phrase exactly as it was spoken.

All stimuli for the recorded FLE were played on a laptop computer set on top of a table located with the speaker three feet from the child (Close conditions). The laptop loudspeaker volume was adjusted while playing practice sentences without noise until speech was measured at 65 dB SPL at the child's near ear using a sound level meter application on an ipad or iphone (used SPL Meter for ipad (designer Adam Smith); 711RA RMS SPL Meter, A weighting, slow setting). This volume was then held constant for all four listening conditions. In the Far conditions, the computer was moved to a cabinet located at a distance of 15 feet from the child. During the conditions with noise, the designated Recorded FLE files played sentences mixed with classroom noise at a signal-to-noise ratio of + 5 dB.

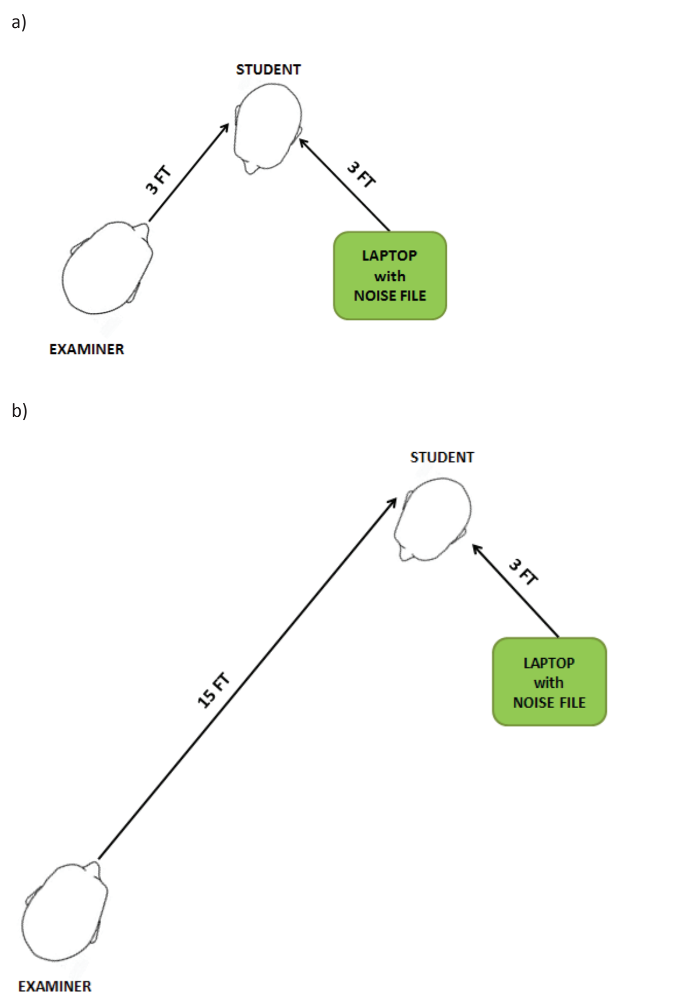


Figure 1. FLE set up for live-voice conditions: a) close condition; b) far condition

For all live-voice conditions with noise, a continuous digital recording of classroom noise was played on the laptop computer on a table set at approximately a 45 degree angle at three feet away from the child's desk. Prior to presentation of the live-voice HINT-C sentences and Children's Nonsense Phrases, the level of the computer speaker was readjusted so that the classroom noise was measured at 60 dB SPL at the child's near ear. The examiner presenting the sentences would then stand three feet away from the child and adjust his or her voice till the level of the practice sentences averaged 65 dB SPL at the child's near ear (see Figure 1 for the FLE set-up for the live-voice testing). At the same time, the research partner would use a second ipad or iphone with the same sound level meter application to determine the approximate dB SPL of the examiner's voice at a distance of one foot from his or her mouth. Then, for all subsequent conditions, the examiner presenting the sentences or nonsense phrases kept his or her voice level as constant as possible using an ipad or iphone located one foot from his or her mouth. The sound level meter applications on the two ipads and one iphone used in the study had been verified to measure dB SPL within one dB of each other. One ipad with the sound level meter device had previously been verified with a type I sound level meter to have accurate dBA SPL measurement above 30 dBA SPL. As with the recorded FLE, the Far conditions were presented (this time by the examiner) from a distance of 15 feet away from the child, shown in Figure 1b.

Analysis

Both the key word level and the sentence/phrase level were analyzed. Scores were computed for each participant based on the percentage of target words and on the percentage of whole sentences or phrases that were correctly identified for each condition, generating a total of 24 scores for the twelve lists. All participants were clearly intelligible. One child had a consistent articulatory problem with /r/; this child's articulation errors were treated so as not to influence the scoring. For example, if the child said /ʃɑp/ for 'sharp', the word was counted correct. If any child repeated the words out of order, the phrase or sentence was counted wrong, but the words were counted as correct. For the HINT-C sentences, the scoring forms indicated that certain words were interchangeable; when scoring sentences, use of either word would be counted as correct. For example, if the recorded voice said 'the' where the form listed 'a/the', the scorer would count the sentence as correct if the child repeated all other words exactly and said 'a' instead of 'the'. Phrases or sentences were considered incorrect if a child inserted a word that wasn't present in the original but otherwise said each word correctly (in that case, words would have been counted as correct). Finally, expanding a contraction (e.g., saying 'she is' instead of 'she's') rendered a sentence or phrase incorrect. When calculating percentage scores, any decimals were rounded to the tenths place.

Mean speech recognition scores for the sample were determined for each FLE listening condition and mean scores overall using the three speech materials were compared statistically. In every comparison involving the Children's Nonsense Phrases (both word and sentence/phrase level score), arcsine transformations of all scores were compared due to the variations in the number of items between the HINT-C sentence lists and the nonsense phrase lists.

The FLE includes an interpretation matrix which analyzes the effects of noise and distance on the child's speech recognition ability. Individual noise and distance effects were determined by calculating the difference between each child's average scores for quiet versus noise conditions and for close versus far conditions, respectively. Mean noise and distance effects were also determined for the sample for each stimulus type. Inter-rater reliability of scoring was also measured by having an experienced graduate student in speech-language pathology listen to approximately half of the recorded sessions and assign both word and sentence level scores for each condition. These scores were then compared to the scores of the original examiners for the same children.

Results

Inter-rater Reliability of Scoring

The speech recognition scores determined by an independent rater were highly correlated with the scores computed by the original examiners. Spearman correlations were similar for both word and sentence level scoring ($r = .775$, $p < .01$, and $r = .771$, $p < .01$, respectively). All data in the current report represent the original scoring.

Percent Correct Word Recognition Scores

Participants showed high word-level scores across speech materials and listening conditions. Mean word recognition scores for the four listening conditions by the three speech materials are shown in Table 1. Mean key-word scores collapsed across listening conditions were above 97 percent for all three speech materials, as indicated in Table 2. Individual scores ranged from 86 to 100 percent. There were only six scores (from six different participants) below 90% on the recorded FLE (RS) in one of the Far conditions; all other scores (366 of 372) were at or above 90%. Because scores were high and similar across listening conditions, group means showed little to no noise or distance effect. Mean noise effects ranged from 0.45% (LS) to 1.3% (RS), while distance effects ranged from 0.1% (LS) to 2.3% (RS).

Table 1

Means/Standard Deviations for Percentages Correct for Listening Condition by Speech Material for Word-Level and Sentence-Level Scoring Strategies

	Listening condition			
	Close/Quiet	Close/Noise	Far/Quiet	Far/Noise
Word level				
Speech material				
LS	99.16/1.34	99.15/0.85	99.87/0.50	98.65/1.82
RS	98.84/1.13	98.71/2.22	97.74/3.45	95.16/4.58
LNP	99.20/1.29	98.28/1.86	97.21/2.50	96.84/2.66
Sentence level				
Speech material				
LS	95.81/6.72	97.74/4.25	99.35/2.50	93.55/8.39
RS	94.84/5.08	95.16/6.26	93.87/8.82	83.87/13.83
LNP	97.26/4.05	92.58/6.69	89.68/8.65	89.35/8.54

Note. LS = Live Voice Sentences; RS = Recorded Sentences; LNP = Live Voice Nonsense Phrases.

Table 2

Means/Standard Deviations for Percentages Correct by Scoring Strategy and Speech Material

	Word level	Sentence level
Speech material		
LS	99.31/1.3	96.61/6.23
RS	97.61/3.43	91.64/10.18
LNP	97.88/2.32	92.22/7.82
Overall	98.27/2.61	93.59/8.49

Note. LS = Live Voice Sentences; RS = Recorded Sentences; LNP = Live Voice Nonsense Phrases.

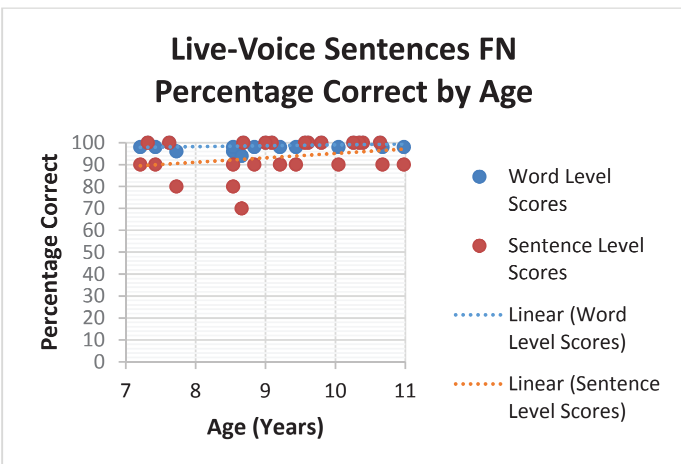
A repeated measures ANOVA showed a significant main effect of the speech material used on the mean word recognition score for all listening conditions, $F(2,246) = 27.88$, $p<.01$. Post hoc pairwise comparisons using the Bonferroni correction revealed that the mean score for the sentences presented by live voice (LS) was significantly higher than the mean score for the recorded FLE (RS) ($p < .01$) and that the LS mean was also significantly higher than the mean for the live-voice nonsense phrases (LNP) ($p < .01$). There was no significant difference between means for RS and LNP ($p >.05$).

Variability

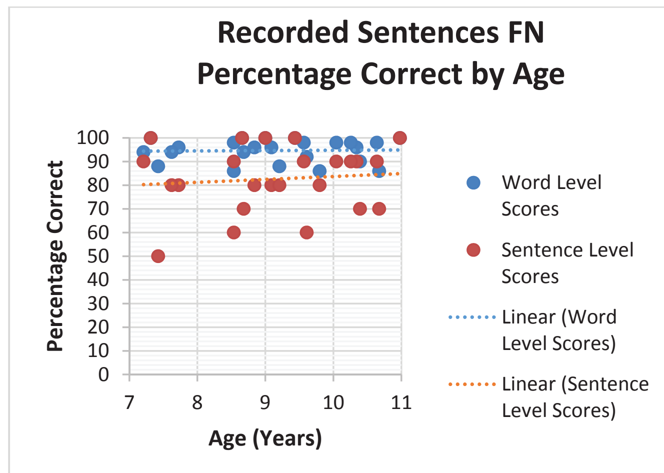
Overall, scores at the word level showed much less variability than scores at the sentence level. Though mean scores for sentence or phrase level scoring were above 90% (i.e., less than 10% reduction relative to key word scoring) for all three speech materials, individual scores ranged from 50 to 100 percent. Each of the speech materials yielded individual scores less than 90% (a total of 54 scores from 24 different participants).

For both word level and sentence level analyses, variability in scores was greatest for recorded sentences (RS) and least for live-voice sentences (LS), indicated by the standard deviations in Table 1. For all three speech materials, the highest variability of both word and sentence level scores was demonstrated in the Far/Noise listening condition. Figure 2 displays scatterplots of individual scores in the Far/Noise condition by age for each of the three speech materials. These graphs illustrate the much higher variability for sentence or phrase level scoring than for key word scoring and the tighter distribution of scores for the live-voice sentences (LS) when compared with either the recorded sentences (RS) or the live-voice nonsense phrases (LNP).

a.



b.



c.

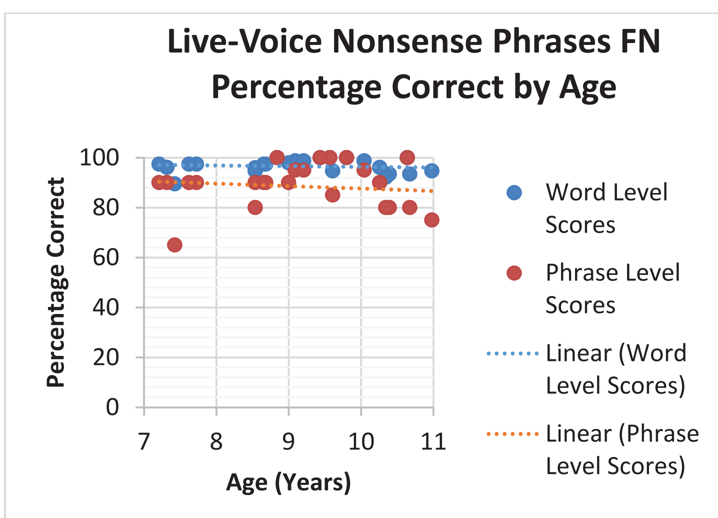


Figure 2. Individual scores by age for the FLE Far/Noise condition for the three speech stimulus types. Dashed lines indicate a line of best fit for each set of scores.

Discussion

The current study is the first that documents the FLE performance of children with normal hearing who are typically developing. We sought to provide comparison data to help educational audiologists using the FLE to justify recommendations of classroom HAT and/or other accommodations for special school-age populations with normal hearing. Establishing criteria that indicate reduced access to speech for auditory learning is particularly important when evaluating children with normal hearing sensitivity because they usually are not expected to need auditory-based interventions. We also intended to demonstrate how choice of speech material may affect FLE performance. To that end, we compared FLE scores in auditory-only conditions using three types of materials in a group of children between 7 and 10 years of age. Though monosyllabic word lists can be used for the FLE, phrase or sentence level materials are more similar to the speech children listen for in classroom settings, and their longer duration may allow a more valid measure of classroom reverberation effects on speech recognition.

Consequently, we chose to conduct the FLE with phrase and sentence materials. The Recorded FLE using Sentences (RS condition: Johnson & Anderson, 2013), recently made available online, has been presented as a convenient way to administer the FLE. Our study compared the recorded version to live-voice presentation of the same sentences (LS). In addition, the same group of children were administered the FLE using the Children's Nonsense Phrases presented by live voice (LNP) to assess whether recognition scores would be reduced with less linguistically predictable material.

Word-level scores were high across the materials and listening conditions when conducting the FLE using either HINT-C sentences (RS or LS) or Children's Nonsense Phrases (LNP), as shown in Tables 1 and 2. Overall mean scores for each type of speech stimulus were above 97 percent. Only six participants scored below 90% in any condition; in all six cases, scores of 86 or 88% were only observed for the Recorded FLE in one of the Far conditions. Otherwise, all scores were at or above 90%. This high level of word recognition performance is consistent with results from Dodd-Murphy and Ritter (2012), who investigated the FLE in elementary school age children with language and reading impairments and typical hearing. Using the BKB-SAE sentences (Bench et al., 1979; Kenworthy, Klee, & Tharpe, 1990) presented via monitored live voice with recorded multi-talker babble as competing noise, we found that means ranged from 96.3 to 98.1 percent in the auditory-only conditions for a sub-group of the sample who were rated by parents to have no significant auditory problems.

The live voice FLE (LS and LNP) presentations in this study were set up to approximate a +5 dB SNR in the Close/Noise conditions and as low as -5 dB SNR in the Far/Noise conditions. Studies from researchers associated with Boys Town National Research Hospital used fixed level SNRs under headphones or in the sound field to study speech recognition of children using recorded versions of the BKB sentences. Lewis and co-workers (Lewis et al., 2010) showed mean scores above 90 percent in a group of 7-year-olds on the BKB-SAEs mixed with speech shaped noise at a +5 dB signal-to-noise ratio under headphones even when scoring sentences correctly only if all three key words were accurate. Another group investigated reverberation effects on key word recognition masked by speech spectrum-shaped noise that was either stationary (i.e., constant in amplitude) or amplitude-modulated in children aged 7 to 14 years old across SNRs from -10 to +10 dB (Wróblewski et al., 2012). The 65 dB SPL speech signal was mixed with noise and with simulated reverberation effects and presented through earphones. Ceiling effects were demonstrated for all participants at +5 and +10 dB SNRs in all conditions, consistent with the results of the current study in the Close/Noise conditions. In the two-meter reverberant condition at -5 dB SNR with the modulated masker (conditions closest to the Far/Noise conditions in the FLE), mean speech recognition score for 7- to 8-year-olds dropped below 80 % and the mean for 9- to 10-year-olds decreased below 90%, though means for 9- to 10-year-olds were not significantly different from that of adults in the same condition (Wróblewski et al., 2012). In comparison, participants in the current study continued to score above 95% on the average; live voice conditions allowed for spatial separation of the speech and the noise, whereas the Wróblewski et al. investigation used a less advantageous spatial orientation of co-located speech and noise. This, however, does not explain why scores on the Recorded FLE remained high in the current group of children. The characteristics of the classroom noise for the Recorded FLE were not specified; however, perceptually, the intensity level of the noise (real talkers interacting in a classroom) varied frequently and to a significant extent, which likely allowed the children opportunities to receive speech cues in the gaps, resulting in improved recognition performance (Griffin, 2015; Stuart, 2005, 2008). Reverberation in the room used in this study may also have been less pronounced, though reverberation time was not measured. The acoustic treatments in Wróblewski et al. simulated reverberation effects at 2 meters (about 6.5 feet) or at 6 meters (almost 20 feet), both distances longer than used in this study.

Wolfe et al. (2013) used key word scoring of recorded HINT-C sentences to evaluate children with normal hearing in a classroom at a variety of fixed SNRs using recorded 4-classroom noise. As expected, children showed near-ideal word recognition in quiet. Mean word recognition dropped slightly below 90% at +4 dB SNR (condition most similar to FLE Close/Noise), with relatively high variability. As SNR dropped to -1 and -6 dB, normal-hearing scores decreased to about 60% and below 20%, respectively. The better performance at negative SNRs shown by the children in the present study is likely related to both the differences in the acoustic properties of the noise and the number of noise sources. Wolfe et al. used four loudspeakers in the corners of the room to present the noise, while the FLE uses only one noise source.

It is more difficult to compare the current study results with those of previous investigations using adaptive or quasi-adaptive procedures; however, in two reports, authors estimated performance functions by SNR or calculated the SNR that would be associated with 95% performance for participant groups, enabling us to evaluate similarities in our findings (Iglehart, 2016; Neuman et al., 2010). Speech recognition scores in noise from the current study were generally higher than predicted by Neuman and colleagues, particularly for the least advantageous FLE condition (Far/Noise, approximating -5 dB SNR). Neuman et al. (2010) used the BKB-SIN with multi-talker babble serving as competition to determine the combined effects of noise and reverberation on speech recognition in 6 to 12-year-old children and adults. As with Wróblewski et al. (2012), speech and noise were co-located and presented binaurally under headphones at several different RTs. The stimuli were designed to simulate the acoustic experience for a child sitting in the back of the classroom at 5.5 m (over 18 feet) from a teacher who is producing a speech level of 70 dB SPL. SNR thresholds for BKB sentences associated with both 50% and 95% performance were calculated. In a graph estimating the performance by SNR function for selected participant groups (Figure 3, p. 342), 9-year-olds' performance was predicted to be within the 65 to 75% range for a SNR of +6 (most similar to conditions for the FLE Close/Noise conditions) while at -6 dB SNR, 9-year-olds' performance was predicted to show floor effects even in the lowest reverberation condition. Eight-year-olds required +11 to +12 dB SNR for 95% performance, while our sample of 7- to-10-year-olds showed mean performance greater than 95% even in a negative SNR.

Performance of children at +5 dB SNR in the current study was more similar to results from Iglehart (2016), who measured speech recognition in actual school classrooms under a variety of SNR and RT conditions using an adapted BKB-SIN procedure for a group of 20-23 children with typical hearing ranging from 5.2 to 16.6 years of age (M=11.1). Iglehart reported mean performance of nearly 95% at +6 dB SNR under both 0.3 and 0.6 RT conditions, comparable to mean scores of 98 to 99% of the present participants in the FLE Close/Noise condition (see Table 1). Iglehart found mean scores for the -6 dB SNR conditions below 30%, though the variability was quite high; while the least advantageous condition of the FLE (Far/Noise) in this study yielded mean scores above 95% for all three speech materials, with relatively low variability. Children in the Iglehart study listened in the sound field, facing the speech signal, with four loudspeakers in the corners of the room generating the four-talker babble from the recorded BKB-SIN. Differences in the acoustic properties of the noise and the number of noise sources probably explain the better performance by children in the current study.

The Recorded FLE Using Sentences (Johnson & Anderson, 2013) is presented as a convenient and standardized alternative to the commonly used live-voice FLE. In this study, live-voice presentation of HINT-C sentences (LS) yielded scores that were slightly but significantly higher than those for the Recorded FLE (RS). Surprisingly, the live-voice presentation of HINT-C sentences produced much lower variability than the Recorded FLE, regardless of whether word or sentence/phrase level scoring was employed. Even with three different speakers in this study, two female and one male, the FLE (LS) using live-voice meaningful sentences showed the highest means and lowest standard deviations of the three types of speech materials, as shown in Table 1. Uhler et al. (2016) reported word/sentence recognition scores with lower standard deviation values for live-voice than for recorded presentation in the sound field in children with hearing impairment in the best aided condition for each child. We chose to present the Recorded FLE using the digitized sound files with the speech and noise pre-mixed because it was the most expedient arrangement and did not require the use of a separate device to present the noise (all sentence lists are also provided in quiet so the examiner may separate the speech and noise sources spatially). Having the speech and noise coming from the same source may have increased the difficulty of the Recorded FLE task for the children based on reported spatial release from masking advantages in children (Cameron, Dillon, & Newall, 2006; Griffin, 2015; Johnstone & Litovsky, 2006). Additionally, the examiners commented that the 5-second interval between sentences on the recording may have introduced variability because some children may have needed more time to respond. The examiner could have monitored the timing, pausing when necessary; however, this reduces the 'press and play' convenience of the recorded test. In this case, then, the greater variability generated by the recorded test is likely related to the difficulty of the task.

The Children's Nonsense Phrases lists are available online and recommended for use with the FLE protocol, particularly for young children with mild/unilateral loss or children with normal hearing who may require classroom listening assessment. There are eight lists, an advantage in the FLE protocol; however, there is little published information about their development, particularly the equivalency of the lists in intelligibility. Children in this study produced significantly lower mean scores on the FLE conditions on Children's Nonsense Phrases (LNP) than on HINT-C sentences (LS) when both were presented via live voice. Though the mean score for nonsense phrases was statistically lower than the mean for simple sentences, the effect size was small, consistent with the findings of Stelmachowicz et al. (2000), who reported average context effects of less than ten percent for 8- and 10-year-old children. Children's Nonsense Phrases items consist of short word sequences without syntactic context, but children would still be able to take advantage of phonotactic probability cues using their experience of phoneme combinations that occur in English (McCreery & Stelmachowicz, 2011). A nonsense syllable task might be more difficult and provide greater contrasts between listening conditions or individuals.

While sentence-level scoring is considered more rigorous, in the current study, using a sentence/phrase scoring strategy yielded scores that were too variable to provide normative reference data. Variability was highest in the Far/Noise condition regardless of the speech material. Figure 2 consists of scatterplots of individual speech recognition scores by age in the Far/Noise condition with scoring strategy as the parameter for each speech material. The recorded version of the FLE (RS) generated higher variability than either of the live voice conditions (LS, LNP) regardless of scoring strategy. The figure illustrates the reduced variability in scores when word-level scoring is used. One advantage of word-level scoring for sentence or phrase materials is that it increases the number of items, which decreases variability. Thus, when administering the FLE using the materials tested in this study, word-level scoring is recommended over sentence-level scoring.

The FLE was designed to compare speech recognition across a variety of conditions simulating realistic classroom listening demands for an individual child, rather than to measure the child's performance relative to normative data. School age children with special listening needs who have normal or near normal hearing, though, may show relatively subtle listening deficits even when they may benefit from HAT or classroom accommodations. This population offers a particular challenge to audiologists for clinical decision-making and providing evidence of educational need. Based on the current results, relatively small differences in scores could be clinically significant for children with typical hearing, indicating difficulties with noise or distance that are outside of normal limits. This pattern was most evident using key word scoring of the live-voice HINT-C sentences (LS), where the noise effect (.45%) and the distance effect (.1%) were practically non-existent when comparing mean data. Therefore, a child showing a noise or distance effect of greater than 5% on the FLE potentially could be at risk for listening difficulties that would reduce her access to spoken language in the classroom.

Certainly, the FLE would be used as only one part of a comprehensive evaluation of classroom listening. Schafer et al. (2014) proposed components and a process for assessing the need for remote-microphone HAT for children with typical hearing who show atypical auditory processing relative to peers. The FLE can provide information useful for the classroom acoustics and observation components of the recommended process. Its interpretation matrix is a useful visual aid in making decisions about classroom placements or communication strategies, counseling children and families, and educating teachers (Gustafson, Hicks, & Lau, 2016). Speech recognition in noise measures are also an important part of this process. Though Schafer et al. (2014) favor the use of the BKB-SIN for this purpose for school age children (see also Schafer, 2010 for a detailed review of specific tests), it is unclear how predictive the SNR threshold it generates is of supra-threshold sentence recognition performance in children across the range of SNRs in typical classroom settings, and it is not appropriate for children younger than elementary school age. Many educational audiologists have had extensive experience with the FLE and value its flexibility. For those professionals who regularly use the FLE as part of their practice, this study has documented that for elementary-school-aged children with normal hearing, word-level scoring generated less variability for sentence recognition, and that the recorded FLE using the current parameters yielded slightly reduced scores when compared to a live voice presentation of sentences from the same set of lists. Knowing that children with normal hearing and typical development have uniformly high scores on the FLE helps strengthen rationales for the provision of HAT and/or other accommodations for 7- to 10-year olds with normal hearing and relatively poor auditory function in the classroom.

References

American Academy of Audiology (2011, April). *Clinical practice guidelines: Remote microphone hearing assistance technologies for children and youth from birth to 21 years (Includes Supplement A).* Retrieved from http://audiology-web.s3.amazonaws.com/migrated/HAT_Guidelines_Supplement_A.pdf_53996ef7758497.54419000.pdf

Bench, J., Kowal, A., & Bamford, J. (1979). The BKB (Bamford-Kowal-Bench) Sentence Lists for Partially-Hearing Children. *British Journal of Audiology, 13*(3), 108-112.

Bradley, J. S. & Sato, H. (2008). The intelligibility of speech in elementary school classrooms. *Journal of the Acoustical Society of America, 123*(4), 2078-2086.

Brandy, W. T. (1966). Reliability of voice tests of speech discrimination. *Journal of Speech, Language, and Hearing Research, 9*(3), 461-465.

Cameron, S., Dillon, H., & Newall, P. (2006). The listening in spatialized noise test: Normative data for children. *International Journal of Audiology, 45*, 99-108.

Dodd-Murphy, J. & Ritter, M. (2012). Functional Listening Evaluation performance in children with reading difficulties. *Journal of Educational Audiology, 18*, 61-73.

Dodd-Murphy, J. & Ritter, M. (2013). Interpretation of Functional Listening Evaluation results of normal-hearing children with reading difficulties. *Journal of Educational Audiology, 19*, 80-85.

Edgerton, B. J., & Danhauer, J. L. (1979). *Clinical implications of speech discrimination testing using nonsense stimuli*. Baltimore, MD: University Park Press.

Griffin, A. M. (2015). Recognition and comprehension of speech in noise in school-aged children with unilateral hearing loss. Retrieved from http://scholarworks.umass.edu/dissertations_2 (Paper 358)

Gustafson, T. J. S., Hicks, C. B., & Lau, M. (2016). The Functional Listening Evaluation: Exploring how audiologists implement the FLE for classroom enhancement. Retrieved from http://speech-language-pathology-audiology.advanceweb.com/Features/Articles/The-Functional-Listening-Evaluation.aspx

Hillock-Dunn, A. (2015, September). 20Q: Pediatric speech recognition measures – What's now and what's next. Retrieved from http://www.audiologyonline.com/articles/20q-pediatric-speech-recognition-measures-15296

Iglehart, F. (2016). Speech perception in classroom acoustics by children with cochlear implants and with typical hearing. *American Journal of Audiology*, 1–10.

Johnson, C. D. (2012a). Classroom listening assessment: Strategies for speech-language pathologists. *Seminars in Speech and Language, 33*(4), 322-339.

Johnson, C. D. (2012b). Common Children's Phrases and Nonsense Phrases. Available from www.ADEvantage.com

Johnson, C. D. (2013). Functional Listening Evaluation. (Revised, based on C. D. Johnson & P. Von Almen, 1993). Retrieved from http://adevantage.com/uploads/FLE_2013v2a-saveable_autocalculable.pdf

Johnson, C. D. & Anderson, K. L. (2013). The Recorded FLE with Sentences. Retrieved from http://successforkidswithhearingloss.com/fle-recorded

Johnstone, P.M., & Litovsky, R.Y. (2006). Effect of masker type and age on speech intelligibility and spatial release from masking in children and adults. *Journal of the Acoustical Society of America, 120*(4), 2177-2189.

Kenworthy, O.T., Klee, T., & Tharpe, A.M. (1990). Speech recognition ability of children with unilateral sensorineural hearing loss as a function of amplification, speech stimuli and listening condition. *Ear and Hearing, 11*(4), 264-270.

Lewis, D., Hoover, B., Choi, S., & Stelmachowicz, P. (2010). Relationship between speech perception in noise and phonological awareness skills for children with normal hearing. *Ear and Hearing, 31*(6), 761-768.

McCreery, R. W., & Stelmachowicz, P. G. (2011). Audibility-based predictions of speech recognition for children and adults with normal hearing. *The Journal of the Acoustical Society of America, 130*(6), 4070-4081.

Neuman, A. C., Wróblewski, M., Hajicek, J., & Rubinstein, A. (2010). Combined effects of noise and reverberation on speech recognition performance of normal-hearing children and adults. *Ear and Hearing, 31*(3), 336-344.

Nilsson, M., Soli, S. D., & Sullivan, J. A. (1994). Development of the Hearing in Noise Test for the measurement of speech reception thresholds in quiet and in noise. *The Journal of the Acoustical Society of America, 95*(2), 1085-1099.

Ruscetta, M. N., Arjmand, E. M., & Pratt, S. R. (2005). Speech recognition abilities in noise for children with severe-to-profound unilateral hearing impairment. *International Journal of Pediatric Otorhinolaryngology, 69*(6), 771-779.

Schafer, E. (2010). Speech perception in noise measures for children: A critical review and case studies. *Journal of Educational Audiology, 16*, 4-15.

Schafer, E. C., Anderson, C., Dyson, J., Wright, S., Sanders, K., & Bryant, D. (2014). A critical review of remote-microphone technology for children with normal hearing and auditory differences. *Journal of Educational Audiology, 20*, 3-13.

Stelmachowicz, P. G., Hoover, B. M., Lewis, D. E., Kortekaas, R. W. L., & Pittman, A. L. (2000). The relation between stimulus context, speech audibility, and perception for normal-hearing and hearing-impaired children. *Journal of Speech, Language, and Hearing Research, 43*, 902-914.

Stuart, A. (2005). Development of auditory temporal resolution in school-age children revealed by word recognition in continuous and interrupted noise. *Ear and Hearing, 26*, 78-88.

Stuart, A. (2008). Reception thresholds for sentences in quiet, continuous noise, and interrupted noise in school-age children. *Journal of the American Academy of Audiology, 19*, 135-146.

Uhler, K., Biever, A., & Gifford, R. H. (2016). Method of speech stimulus presentation impacts pediatric speech recognition: Monitored live voice versus recorded speech. *Otology & Neurotology, 37*(2), e70-e74.

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

Wolfe, J., Morais, M., Neumann, S., Schafer, E., Mülder, H. E., Wells, N., … Hudson, M. (2013). Evaluation of speech recognition with personal FM and classroom audio distribution systems. *Journal of Educational Audiology, 19*, 65-79.

Wróblewski, M., Lewis, D. E., Valente, D. L., & Stelmachowicz, P. G. (2012). Effects of reverberation on speech recognition in stationary and modulated noise by school-aged children and young adults. *Ear and Hearing, 33*(6), 731.

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Head Start Hearing Screening Protocols in Connecticut: A Survey

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For several years, the University of Connecticut Speech and Hearing Clinic provided hearing screening services to one of the large, diverse Head Start programs in the state. Through ongoing efforts to determine the most efficient, cost effective, and reliable screening process using existing evidence for best practices in screening hearing in preschoolers, the question of how the other Head Start programs in the state were conducting screening arose. The researchers designed and disseminated a survey of Head Start programs to each of the 22 health managers that manage the 114 service locations in Connecticut. The results of that survey revealed several areas of concern regarding hearing screenings. Head Start health managers used a wide variety of types of equipment, protocols for screening, and personnel to conduct the screening. Screening processes were seldom adapted to children with disability or who spoke a foreign language. Training for persons who conduct the screenings also varied widely in type and frequency. Health managers and similar gatekeepers for the screening process struggled with determining whether a referral was more appropriate for an audiologist or the pediatrician. They defaulted in almost every instance to the pediatrician even if middle ear function was intact. Respondents reported high interest in more education on conducting the screening, use and care of equipment, and interpretation of results. They also requested more access to pediatric audiologists in the community that could provide testing and screening resources to the program.

Introduction

The Head Start program is a federally funded program designed to promote the school readiness of children ages birth to five from low-income families. Target areas of readiness include cognitive, social, and emotional development (U.S. Department of Health and Human Services, 2015a). In order to minimize the impact of controllable factors in development, overall health is also an important target area for Head Start programs. Amongst the many regulations for promotion of health and safety are mandates for completion of developmental, sensory, and behavioral screenings. These must occur within the first 45 calendar days of a child's first day in the program. Specifically noted in the regulation for Head Start screening (45 CFR 1304.20; 1308.60; U.S. Department of Health and Human Services, 2015b), is the demand that all screening be "linguistically and age appropriate" and "to the greatest extent possible, these screening procedures must be sensitive to the child's cultural background". In addition, the agencies must obtain direct guidance from a mental health or child development professional on how to use the findings to address identified needs.

Hearing screening is a mandated component because the early childhood and the preschool years are critical for speech, language and cognitive development. Research consistently demonstrates that undetected childhood hearing loss, late identification of hearing loss, and lack of early intervention, are likely to result in delayed speech, language, and literacy development (Delage, Tuller, 2007; Kiese-Himmel, Reeh, 2006; McGuckian, Henry, 2007; Moller, 2000; Sininger, Grimes, Christensen, 2010; Yoshinagao-Itano et al., 1998). Even a unilateral hearing loss can result in a delay in a child's speech and language development, poor academic achievement, and increased social and emotional dysfunction (Bess, Dodd-Murphy & Parker, 1998; Khairi et al., 2010; Lieu, 2013).

Newborn hearing screenings are effective at identifying children born with hearing loss. In 2012, the Centers for Disease Control (CDC) identified one to four per 1000 infants as having a hearing loss through the United States hearing screening programs (CDC, 2012). However, the prevalence of hearing loss continues to increase as children develop. Research suggests that up to 14% of school-age children (approximately 7 million) have some degree of hearing loss (Niskar et al., 1998; White, Forsman, Eichwald, & Munoz, 2010). Screening in the birth-to-three and preschool years allows capture of children not previously identified with late-onset, progressive, or adventitious hearing loss. These losses may be associated with diseases or traumatic events occurring in early childhood such as meningitis or head trauma. Middle ear disorders also occur frequently in the early childhood years. Otitis media is the most common cause of conductive hearing loss in early childhood. In one study, 75% of children experienced at least one case of otitis media with effusion by age three (NIDCD, 2002).

In order to meet the demand for this important screening and minimize the risks of undetected hearing loss, various groups established protocols for the timing and nature of screening in early childhood. The American Academy of Pediatrics (AAP) and Bright Futures published recommendations which guided well-child screenings and recommended hearing screenings at 4, 5, 6, 8, and 10 years of age (AAP, 2014). The timing or occurrence of screening was, therefore, clear. The manner of screening, however, was more variable as there were a variety of screening protocols for ages seven months to five years of age. Head Start standards did not indicate a particular hearing screening protocol (Eiserman et al., 2007).

Several organizations published recommended practices for hearing screenings including the National Center for Hearing Assessment and Management (NCHAM, 2014) Early Childhood Hearing Outreach (ECHO) Initiative, the American Speech-Language-Hearing Association (ASHA, n.d.), and the American Academy of Audiology (AAA, 2011). NCHAM ECHO recommendations supported the use of otoacoustic emission (OAE) screenings for all children birth-to-three years of age and for children older than three that were unable to follow instructions or complete a behavioral screening task. Pure tone screenings were recommended for populations age three (chronologically and developmentally) or older (AAA, 2011; ASHA, n.d.; NCHAM, 2014). Both AAA and ASHA suggest conducting pure tone screenings at 20 dB HL for 1000, 2000 and 4000 Hz. ASHA (n.d.) screening recommendations included the use of play audiometry as more appropriate for children age two to four. ASHA (n.d.) also stated, "the use of OAE technology may be appropriate for screening children who are difficult to test using pure-tone audiometry." AAA (2011) and ASHA (n.d.) promoted the involvement of a pediatric audiologist in the selection of equipment and development of OAE protocols. In addition, both the ASHA and AAA papers discussed the use of tympanometry during screenings. AAA (2011) indicated that tympanometry should be utilized as a second-stage screening for toddler, preschool, kindergarten and 1st grade populations due to high risk of middle ear effusion in these groups. These recommended practices provided guidance in development of protocols. However, ASHA (n.d.) recognized that available technology, the population screened, and staffing/audiology resources influence protocol development.

The UCONN Speech and Hearing Clinic provided screening assistance to some Head Start programs in Connecticut. Annual review of the UCONN screening protocol and a request from one Head Start program to expand services to additional student populations resulted in awareness of the variability of protocols in use by the Head Start programs in Connecticut. In addition, contact with the State Early Hearing Detection and Intervention task force revealed a need to identify current screening methods and plan activities to enhance screening, surveillance, and service delivery. A need for data related to the tools, techniques, reporting, and referral processes was clear. Therefore, the purpose of this study was to collect data, through a survey, focusing on current methods of hearing screening in Connecticut Head Start agencies. The results of the survey would serve as a starting point for assisting the state of Connecticut in promoting the use of best practice in hearing screening in early childhood.

Method

Survey

Researchers developed an online survey instrument to collect data to answer the question of methodology of hearing screening in Connecticut Head Start agencies. Questions targeted health managers, or the person in a program that was responsible for the coordination and/or delivery/execution of the required screenings. Questions were designed by the authors in conjunction with a representative from the Early Hearing Detection and Intervention, Family Health Section of the Connecticut Department of Public Health. The demographic section included questions on the nature of adaptations made to screening for various sub populations (i.e. language and disability). The 34 survey questions were divided into seven categories: Program and Student Demographics, Protocols, Equipment, Referral Process, Screening Personnel, Personnel Training, and Requested Needs. Questions were predominantly multiple choice with some yes/no and open-ended questions (see Appendix A for survey questions). Twenty-two of the 34 questions required completion. The introductory letter provided instructions for the survey and an estimate of the time needed to complete it (approximately 15 minutes). At most, there were five questions per page. Question logic employed in the first question confirmed the respondents desire to participate. If the answer was yes, participants entered the survey and if the answer was no, they exited the survey. Question logic employed later in the survey determined if every child underwent the same screening process. For this question, if the participant responded "no," they answered an additional question regarding the screening protocol choice.

Participants

At the time of this study, Head Start in Connecticut was comprised of 118 locations under the jurisdiction of 26 agencies. The 2013 population estimate for Connecticut was 3,596,080 persons, of whom 5.3% were under the age of five (U.S. Census Bureau, 2014). The state of Connecticut encompassed both highly urban regions (Bridgeport, Hartford, Stamford), smaller cities and suburbs (Willimantic, New Britain, Bristol), and rural areas (Pomfret, Dayville, Morris). It was also a highly diverse population where 14.2% of households were Hispanic or Latino alone, 11.2% were Black or African American alone, and 4.2% were Asian alone. Approximately 2% of households represented two or more races (U.S. Census Bureau, 2014), and 21.2% of households containing children who were five years old or older spoke a language other than English. The percentage of persons living below the poverty level between 2008 and 2012 was 10% (U.S. Census Bureau, 2014).

The Connecticut Head Start Program indicated that there were 118 Head Start locations operating in the state and suggested using the Head Start website for individual contact information (Head Start, 2012). Utilizing the Connecticut Head Start website, 114 of the 118 Head Start locations were identified. Of these 114 Head Start locations, the same directors and health managers managed multiple locations. As a result, for all 114 locations there were 22 health managers in charge of coordinating health-screening activities. These individuals received the survey. One of the health managers identified and contacted was affiliated with an agency that contracted UCONN to complete the hearing screenings at their facilities.

Procedure

An e-mail introduced the survey to the 22 health managers and invited them to participate. A University of Connecticut graduate assistant confirmed the e-mail addresses for the most appropriate recipient per program by phone call prior to sending the e-mail. The letter described participation in the survey to the managers as voluntary and anonymous. An embedded link in the e-mail led directly to the survey. The tool used to conduct the survey, surveymonkey.com, was set to prevent tracking or storage of IP addresses, therefore, protecting the anonymity of responders. The e-mail was sent three times within two months to increase participation and allow completion over time for programs that needed to gather data in order to respond. Due to the anonymity of the survey, the University of Connecticut Institutional Review Board (IRB) deemed the study unnecessary for full IRB approval.

Results

Demographics

Twenty-two invitations resulted in 16 responses. This yielded a 73% response rate as each survey response represented a health manager that was responsible for multiple locations. Twelve respondents managed one to five Head Start locations, two respondents managed six to ten locations, one respondent managed 16-20 and one respondent managed for more than 20 locations. Figure 1 shows the percentage of respondents from each of the counties in Connecticut. Responses represented all of the counties in Connecticut except Middlesex County. New Haven County had the highest number of children represented in their responses. The approximate number of children served by the health managers totaled 4,000. The average number of children screened, which may have been comprised of one or more locations, was 250 children per health manager. Numbers ranged from 30 to 765 children.

Across all health managers, 72% of children served spoke English as their primary language. Other common languages spoken in the home were Spanish (33%), Polish (1%), Arabic (3%), and Chinese (1%). Figure 2 demonstrates that there was variability in the percentage of children speaking each primary language across health managers, with four respondents who indicated more than 50% of their children spoke Spanish as their primary language. Respondents five and fourteen did not provide answers to this question. Health managers reported from five to 30% of children had a disability. Health managers listed the disabilities present in their locations. The most common was speech/language delay. Seventy-seven percent of health managers cited this as their most typical disability. Also listed were developmental delay (62% of respondents) and autism/autism spectrum disorder (31% of respondents).

Screening Protocol and Equipment

The heath managers described the method of hearing screening used in their facilities. OAE was used by 75% of respondents, audiometry by 50%, and 25% used physician report. Questionnaire, tympanometry, and newborn screening results were also sources of screening information. Only 11 health managers answered the question about first method of screening. OAE screenings were used first by four respondents while three respondents used pure tone audiometry as a first method. Four participants used reports from physicians, newborn screening results, or teacher/parent ratings as the first method of screening.

Eight health managers reported a second type of screening. Three used OAE screening as their second method, one used pure tone audiometry, one used tympanometry, and three used reports/questionnaires. Four health managers reported a third option if necessary which was one of the following: OAE screening, tympanometry, and report/questionnaire. One health manager indicated that the fourth option was OAE. No respondent used otoscopy. It should be noted that some individuals indicated they had access to tympanometry and otoscopy at times, but did not use them in their protocol.

While all health managers screened within the federally mandated 45 days from admission, the surveyors asked for any other times when screenings might also be necessary. Nine health managers reported screening at teacher request and nine screened at parent's request. Four indicated they screened annually. It was not clear if annual screening referred to the annual mandatory screening for new students or repeat screening for students still in the program after one year. One individual screened every six months and, once again, it was not clear who received the screening.

Eighty-eight participants indicated that children of all ages underwent the same screening process. Of the two respondents who modified the protocol, one used OAE for children below three years of age and pure tone screening for children over three years of age. The second individual used OAE for Head Start children and observation for Early Head Start children.

Specific questions focused on whether protocols were modified due to disability or language barriers. Four individuals used assistance from a Speech-Language Pathologist, paraprofessional, teacher, or family member in these cases. Two respondents modified the way in which the child responded to the test. he modifications were picture pointing for pure tone screening and completion of OAE screening during naptime. One individual requested a physician evaluation if a child could not be tested, and one person requested nursing assistance from a neighboring health manager.

Location of screenings, regardless of the protocol, was variable. Some health managers screened in multiple environments. Fifty percent of health managers described locations specific to their setting including "the quietest place available," which may have been an office, an unused classroom, or other room. Forty-four percent indicated use of the nurse's office, 25% used a special hearing screening room, and 19% screened in the child's home.

For equipment maintenance, all but one health manager indicated regular calibration by the manufacturer or private technician. Ten participants reported that calibration occurred annually and three were unsure how often calibration occurred.

Screening Personnel and Training

Various individuals were responsible for completing the screenings. Seven of 16 health managers used a nurse as the primary screener. Four respondents indicated the primary screener was the family service coordinator. Four health managers indicated they conducted screenings. A contracted service completed the screening for one respondent. Eight health managers reported that the individuals completing the screening had 10 years or less experience in conducting screenings. Two reported screeners had more than 10 years of experience and four reported the experience of their professionals as "varied". Health managers reported using additional individuals to assist in completing screenings and some of those positions included teachers, volunteer medical assistants, interpreters, family advocates, home visitors, health program aides, partnership managers, and parents.

When it came to training the individuals who conducted screenings, again, a variety of methods were employed. Most respondents reported using more than one method of training. Half of the respondents used a written protocol and the other half used demonstration by an equipment provider. Six used demonstration by facility personnel and six used discussion of the procedure with facility personnel. Five individuals used an outside contractor. Respondents did not report qualifications of the outside contractors. Four individuals indicated that training occurred annually, and one individual indicated that training occurred at the onset of the screening cycle. The remainder of the health managers either did not conduct repeat training or did it "as needed", which was not defined. Figure 3 is a breakdown of the number of programs that had multiple training methods available for screening staff. This figure illustrates the lack of consistency in training screeners across health managers.

Referral Process

Eleven health managers defined the need for referral as a failed second screening in at least one ear. Additionally, two health managers referred following the first screening if a child failed in one ear. Six respondents indicated referrals made when there was a failure to complete the screen. The majority of health managers reported multiple triggers for referring for outside evaluations. Health managers and nurses were the primary persons responsible for making referrals. Three individuals had the family advocate/service worker make the decision to refer. Five health managers used the "failed" or "refer" readout from OAE or tympanometry exclusively to refer. Seven indicated that they did not necessarily refer based on the equipment readout alone. The survey questions did not require further clarification.

The most common referral destination was the pediatrician, regardless of the nature of the test result. Figure 4 shows that few referrals are made directly to a hearing professional, either the audiologist or otolaryngologist. In the state of Connecticut, children covered by the Husky or state Medicaid system are required to have referrals to specialists from their primary physician. Therefore, a visit to the pediatrician was a necessary first step to a visit with an audiologist or otolaryngologist. One health manager gave the parents a general referral so they could decide themselves. Once the referral was made it fell most frequently to the family advocate/social worker to track the outcome. Follow-up occurred anywhere from two weeks to 60 days, although over half of the health managers did not report a timeline for follow-up.

Program Needs

The respondents indicated the primary educational and training needs related to hearing screenings within their programs. The number one overwhelming response was a need for pediatric audiology resources. In a follow-up question, only three out of the 16 health managers indicated access to a pediatric audiologist for assistance in developing or reviewing the hearing screening protocols and referral processes. Eleven respondents wanted referral locations for comprehensive hearing testing. Half of the health managers requested additional training on conducting hearing screenings and making follow-up recommendations. Two respondents wrote additional comments: "Staff to conduct screening as it is very labor intensive. As a manager, my services are needed elsewhere," and "a review for experienced staff would still be good; a way to help with training of new staff when we have them."

A final question encouraged respondents to provide additional information at the completion of the survey. One health manager referred to the protracted nature of the screening process with two fail/refers needed, then a trip to the pediatrician, followed by rescreen, followed by referral to an ENT physician/Audiologist, followed by an ENT physician/Audiology report and recommendations. Another person indicated a need for pediatricians to support the hearing concern referral. Many times, the response back was "no concern at this time." One additional health manager responded with a need for recommendations on tools and resources available for Early Head Start populations.

Discussion

The survey yielded a high return rate from Head Start agencies. The demographic questions indicated that responses represented a diverse group of Head Start programs that ranged in size, primary language spoken by enrolled children, and number of children enrolled with disabilities.

All health managers that responded comply with the federally mandated screening standard. Various personnel roles were primary hearing screeners including the health manager, the nurse, and the family service coordinator. Many individuals also indicated the use of additional personnel or family members to assist during the screening process. The training provided to these roles was extremely diverse, likely due to the variety of methods and protocols in place. More notable was the lack of consistency of initial or repeat training. Methods of training included written protocols, vendor demonstrations, or current user training to the next user. Regular training is necessary to maintain competence for the primary screener and insure that they are providing correct training to those in supporting roles or to new staff. Regular training can also trigger processes for calibration and preventive maintenance for equipment used.

ASHA (n.d.) indicated, "personnel may include an audiologist, SLP, nurse or other trained lay or volunteer screener." The American Academy of Audiology Task Force on Early Childhood Hearing (2014) stated in their description of screening standards for newborns: "A formal training program for support personnel should be in place under the direction of the supervising audiologist who should conduct the training. Specific competency-based training through formal instruction and supervised practice should be included. Instruction in all assigned responsibilities and clear definition of limits in the role and function of support personnel should be included. Personnel should complete a recertification of proficiency every two years, as a minimum, with ongoing assessment and re-training as needed." The key in both of these statements is the need for training for screening personnel. The researchers noted from the results that no health manager had regular communication with a pediatric audiologist for guidance or training. Access to an audiologist is critical for application of the American Academy of Audiology or American Speech-Language-Hearing Association recommendations.

The survey identified large variability in screenings protocols, with pure tone screening and OAE screening as the primary methods of obtaining results. According to the ASHA Guidelines for Childhood Hearing Screening (n.d.), an acceptable modification or alternative procedure for screening when a child cannot condition to pure tone screening would be OAE. In an evidenced-based systematic literature review on the accuracy of hearing screening instruments, Prieve and colleagues (2015) reported that both pure tone and OAE screening methods can be used to screen hearing loss in preschool and school age populations. In their review of 18 studies, only two studies directly compared both screening tools in the same sample. Results from those studies suggested that pure tone screenings were more effective in identifying hearing loss in the school age population than OAE screenings. As a result, pure tone screenings are the preferred tool for school age children. However, Harlor and Bower (2009) described OAEs as a test that "allows for individual ear assessment, can be performed quickly at any age, and does not depend on whether the child is asleep or awake". These factors may be more important in a preschool population in comparison to a school age population.

Health managers reported that within each program, there was often one primary hearing screening method in use. This method, however, was not consistently adaptable to disability, language or culture. Therefore, despite high numbers of disability and language difference reported by some programs, there was minimal adaptation of screening procedures.

One of the predominant findings regarding the methods employed in screening was the lack of otoscopy and/or tympanometry. While not demanded by Head Start standards, by not using these tools, the opportunity for misidentification or cause of screening failure may exist. Further support for the use of these tools is the high incidence of middle ear pathology previously discussed. Lack of these procedures may lead to inappropriate referrals, excessive re-screening, overuse of resources, and excessive time invested in the screening process. An example would be a child sent to a pediatrician for a middle ear evaluation when excess cerumen or a pressure equalization tube disrupted the test results. A few programs indicated the use of tympanometry during their screening procedure. It is unknown if the screener was familiar with the difference in screening for middle ear dysfunction versus hearing sensitivity. Due to increased risk of middle ear dysfunction and to assist the screener in determining audiological or medical referral, both ASHA (n.d.) and AAA (2011) recommended adding tympanometry screening to the protocol for younger children. Differentiating the purpose of screening is crucial to the interpretation of results and timely and accurate referrals.

Programs also reported reliance on physician report in certain circumstances to meet the screening standard. For example, if the physician's physical report clearly stated a hearing screening result within the previous six months, that result could be accepted and the screening deferred. The survey did not address questions that would elicit descriptions of the type of screening completed by the physician. It is unknown if those were OAE, pure tone audiometry, tympanometry, otoscopy, or behavioral report.

In the programs that reported use of parent or teacher report to meet the screening standard, the survey did not detail the nature of the questions asked or what format the screening was conducted. It is unclear if the checklists or questionnaires were solicited by the program or if they were used as a screening tool only when triggered by the parent or teacher themselves. Subjective questionnaires may have poor sensitivity to differentiate between children with and without hearing loss, especially those with mild hearing loss, or otitis media (Gomes & Lichtig, 2005; Olusanya, 2001). One study demonstrated that parent hearing ratings do not accurately predict hearing levels or changes in hearing in children with otitis media (Rosenfeld et al., 1998).

Review of the data clearly indicated that the standard referral destination was the pediatrician. This was true regardless of the trigger for referral. A failed tympanogram suggesting middle ear pathology was appropriately sent to the pediatrician. A failed OAE screening indicating questionable hearing sensitivity with a typical tympanometry and/or otoscopy result may be better referred to the audiologist. In reference to an example presented earlier, otoscopy that revealed a pressure equalization tube in the ear canal along with a failed tympanogram result may be best sent to the ENT when the child is followed by that professional. The previously noted comments regarding access to a pediatric audiologist and adequate training in the interpretation of results are implicated in this area as well. In fact, when asked to list program needs, survey respondents identified more input and assistance in determining referrals as areas of need. They also noted that a list of area pediatric audiologists to answer questions or accept referrals would be very beneficial.

Conclusions

Connecticut Head Start agencies clearly followed the hearing screening mandate and providers were conscientious in attending to the screening needs of the children in their care. While there were protocols for screening in place, they represented a wide range of approaches and variability in the data and its use for determining referrals. Interestingly, OAE screening was present in many locations as a primary or secondary tool despite inconsistent guidelines from professional organizations. There was also a misconception among health managers that a paper based screening tool met the Head Start standards for sensory screening of vision and hearing (US Department of Health and Human Services, 2015b). Some respondents reported using paper tools to meet the screening criteria.

It was quite evident that there was a need for a statewide standard in Connecticut for Head Start hearing screening. Standard protocols could lead to improved training consistency, allocation of training resources in the most cost effective manner across programs, and results that have predictable interpretation and referral. A consistent protocol in the Head Start population may lead to an improved statewide process for hearing screening in other early childhood agencies and programs such as Early Head Start, Birth to Three services, and Medical Home programs. Researchers identified an overwhelming need for access to pediatric audiology resources. This presents an opportunity for state advocacy groups and supportive agencies such as the university community to establish strong partnerships and mutually beneficial relationships that support these needs.

Future studies might further explore the sensitivity and specificity of OAE screening versus pure tone screening of hearing sensitivity and middle ear function in the Head Start preschool population. Other studies might determine best practices for including tympanometry in hearing screening protocols for preschool populations when otitis media may be more prevalent. Time and efficiency studies in the delivery of various protocols would be of benefit in establishing cost effective practice. Outcome research is necessary regarding the effect of standardized training on referral rates and efficiency of hearing screening protocols. This body of research is essential to establish a standard protocol for the earliest possible identification of children with hearing loss. Head Start programs, along with other early childhood service agencies, whose constituents have reduced access to the medical community, make this endeavor even more imperative.

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References

American Academy of Audiology [AAA]. (2011). *Childhood Hearing Screening [Clinical Practice Guidelines]*. Retrieved from http://audiology-web.s3.amazonaws.com/migrated/ChildhoodScreeningGuidelines.pdf_5399751c9ec216.42663963.pdf

American Academy of Audiology Task Force on Early Identification of Hearing Loss. (2014). *Considerations for the use of support personnel for newborn hearing screening*. Retrieved from http://www.audiology.org/publications-resources/document-library/considerations-use-support-personnel-newborn-hearing

American Academy of Pediatrics. (2014). *Recommendations for Preventive Pediatric Health Care*. Retrieved from http://www.aap.org/en-us/professional-resources/practice-support/Periodicity/Periodicity%20Schedule_FINAL.pdf.

American Speech-Language-Hearing Association [ASHA]. (n.d.). *Childhood Hearing Screening. [Practice Portal]* Retrieved February 28, 2016, from http://www.asha.org/PRPSpecificTopic.aspx?folderid=8589935406&section=Key_Issues

Bess, F. H., Dodd-Murphy, J., & Parker, R. A. (1998). Children with minimal sensorineural hearing loss: prevalence, educational performance, and functional status. *Ear & Hearing, 19*(5), 339-354.

Centers for Disease Control and Prevention. (2012). Summary of 2009 National CDC EHDI Data. Retrieved from http://www.cdc.gov/ncbddd/hearingloss/2009-data/2009_ehdi_hsfs_summary_508_ok.pdf

Delage, H. & Tuller, L. (2007). Lanugage development and mild-to-moderate hearing loss: Does language normalize with age? *Journal of Speech, Language, & Hearing Research, 50*, 1300-1313.

Eiserman, W. D., Shisler, L., Foust, T., Buhrmann, J., Winston, R., & White, K. R. (2007). Screening for hearing loss in early childhood programs. *Early Childhood Research Quarterly, 22*(1), 105-117.

Gomes, M. & Lichtig, I. (2005). Evaluation of the use of a questionnaire by non-specialists to detect hearing loss in preschool Brazilian children. *International Journal of Rehabilitation Research, 28*(2), 171-174.

Harlor, A.D.B & Bower, C. (2009). Hearing assessment in infants and children: Recommendations beyond neonatal screening. *Pediatrics, 111*(2), 436.

Head Start. (2012). *Head Start Locator*. Retrieved from http://eclkc.ohs.acf.hhs.gov/hslc/HeadStartOffices#map-home

Khairi, M. D., Daud, M., Noor, R. M., Rahman, N. A., Sidek, D. S., & Mohamad, A. (2010). The effect of mild hearing loss on academic performance in primary school children. *International Journal of Pediatric Otorhinolaryngology, 74*(1), 67-70.

Kiese-Himmel, C., & Reeh, M. (2006). Assessment of expressive vocabulary outcomes in hearing-impaired children with hearing aids: Do bilaterally hearing-impaired children catch up? The *Journal of Laryngology & Otology, 120*, 619-626.

National Center for Hearing Assessment and Management [NCHAM]. (2016). Early childhood screening & follow-up. Retrieved from http://www.infanthearing.org/earlychildhood/

Lieu, J. E. C. (2013). Unilateral hearing loss in children: speech-language and school performance. *B-ENT, Suppl 21*, 107–115.

McGuckian, M. & Henry, A. (2007). The grammatical morpheme deficit in moderate hearing impairment. *International Journal of Language & Communication Disorders, 42*(S1), 17-36.

Niskar, A. S., Kieszak, S. M., Holmes, A., Esteban, E., Rubin, C., & Brody, D. J. (1998). Prevalence of hearing loss among children 6 to 19 years of age: The Third National Health and Nutrition Examination Survey. *The Journal of the American Medical Association, 279*(14), 1071-1075.

Olusanya, B. (2001). Early detection of hearing impairment in a developing country: What options? *Audiology, 40*, 141–7.

Prieve, B.A., Schooling, T., Venediktov, R., & Franceschini, N. (2015). An evidenced-based systemic review on the diagnostic accuracy of hearing screening instruments for pre-school- and school-age children. *American Journal of Audiology, 24*, 250-267.

Rosenfeld, R. M., Goldsmith, A. J., & Madell, J. R. (1998). How accurate is parent rating of hearing for children with otitis media? *Archives of Otolaryngology–Head & Neck Surgery, 124*(9), 989-992.

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

U.S. Department of Health and Human Services Administration for Children and Families Office of Head Start. (2015a). Retrieved from http://www.acf.hhs.gov/programs/ohs/about

U.S. Department of Health and Human Services Administration for Children and Families Office of Head Start. (2015b). *Head Start Program Performance Standards* (45 CFR 1304.20; 1308.60). Retrieved from http://eclkc.ohs.acf.hhs.gov/hslc/standards/hspps

U.S. Census Bureau. (2014). *State and County Quick Facts*. Retrieved from quick-facts.census.gov

White, K. R., Forsman, I., Eichwald, J., & Munoz, K. (2010). The evolution of early hearing detection and intervention programs in the United States. *Seminars in Perinatology, 34*(2), 170-179.

Noise Pollution (Noise-Scape) Among School Children

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Students' daily noise exposure presents an underlying threat in many classrooms that undermines student engagement, access to curriculum, and other important indicators of achievement. Students with and without hearing loss are at risk. Educational audiologists are uniquely positioned to promote awareness and work collaboratively to improve student outcomes.

Introduction

The 2015 reauthorization of the Elementary and Secondary Education Act of 1965 (Pub. L. 114-95, S.114, Stat. 1177), otherwise known as the Every Student Succeeds Act, and the 2004 reauthorization of the Individuals with Disabilities Education Act (20 U.S.C. 1400 et seq.) are designed to ensure that all students achieve their maximum potential. Thus, promoting student access to and improving student engagement and achievement in the education curriculum is of paramount concern for all educators. However, noise presents an underlying threat in many classrooms that undermines student engagement and access to the curriculum (Crandell & Smaldino, 2000; Flexer, 1999; Klatte, Hellbruck, Seidel, & Leistner, 2010; Nelson, Smaldino, Erler, & Garstecki, 2007-2008; Schafer, Bryant, Sanders, Baldus, Lewis, Traber, et al., 2013). Further, there is increasing evidence that students' daily exposure to low and moderate noise in and out of school negatively impacts their ability to learn (Bess, Gustafson, & Hornsby, 2014; Klatte et al., 2010), and "may evoke substantial impairments in performance because their cognitive functions are less automatized and thus more prone to disruption" (Klatte, Bergstrom, & Lachmann, 2013).

For example, Klatte and her colleagues provide evidence that students' chronic exposure to noise, across the day, can be viewed as their daily "noise-scape." Albeit limited, there is emerging research linking poorer student outcomes to some daily noise-scapes. The poorer outcomes include both academic achievement and educational performance, as well as general well-being for those with normal hearing and hearing loss (Crandell & Smaldino, 2000; Flexer, 1999; Klatte et al., 2010; Nelson et al., 2007-2008; Schafer et al., 2013). Yet, few educators receive training in noise-related concerns and promoting auditory access within their classrooms (Squires, Pakulski, Diehm & Glassman, 2016), and as a result, may not recognize the profound impact of their students' daily noise-scape. The aim of this article is to examine variations in students' noise-scape, the effects it may have on readiness and ability to learn in a typical classroom, and to discuss strategies for monitoring and reducing the negative impact of noise.

Despite the profound impact noise may have on both students and teachers, it often goes unnoticed or ignored. A student's daily noise-scape may be made up of sounds that range from moderately loud to harmful. The sounds may occur at school, in recreational contexts, and in and around the home (American Speech Language Hearing Association [ASHA], 2015; Bittel, Freeman, & Kemker, 2008; Fligor, 2009; Klatte, et al., 2010). Further, there is "second-hand" noise that arises from car stereos, traffic, yard work equipment, and many other sources (United States Environmental Protection Agency, n.d.) that adds to the daily noise-scape. Examples of typical noise-scapes encountered during common daily experiences among students are provided in Table 1. Albeit limited, there is convincing evidence of the detrimental effects of the daily noise-scape of many students, including chronic exposure to moderate noise (Occupational Safety and Health Administration [OSHA], 2014).

Table 1. Intensity and Permissible Exposure Time of Common Noise Sources Among Students

Sound source/experience	dBA*	Maximum permissible exposure time+
Computer	37-45	Unlimited
Typical conversation	50-65	Unlimited
Laser printer	58-65	Unlimited
Video/electronic games in the home	68-76	Unlimited
Household appliances	40-103	Unlimited ranging to 7.5 minutes
Personal listening device (iPod, Mp3) – *varies by earphones and volume level*	45-110	Unlimited ranging to < 2 minutes
Telephone	60-75	Unlimited
Alarm clock	60-80	Unlimited
Television	70-90	Unlimited ranging to 2 hours
Squeeze toy	81-97	Unlimited ranging to 30 minutes
Train/Subway	75-102	Unlimited ranging to 5 minutes
Indoor sports facility	77-112	Unlimited ranging to 1 minute
Recreational vehicles (e.g., snowmobile, motorcycle)	90-120	2 hours ranging to not permissible
Lawn equipment: mower, leaf blower, weed trimmer	95-115	1 hour ranging to 30 seconds
Restaurant	105-112	5 minutes ranging to 1 minute
School Dance	100	15 minutes
Busy Video Arcade	110	~1 minute
Concerts (e.g., Band, Rock, Symphony)	110-120	~1 minute ranging to not permissible
Stadium Football Game	117	Not permissible
Car Stereo (factory installed; at full volume)	125	Not permissible
Bicycle Horn	143	Not permissible
Firecracker	150	Not permissible
Cap gun	156	Not permissible
Balloon Pop	157	Not permissible
Fireworks (3 feet away)	162	Not permissible
Shotgun	170	Not permissible

*The dBA scale represents relative loudness of sounds as perceived by the human ear by reducing low frequencies with a correction factor. Sound level data were primarily adapted from the Center for Hearing and Communication online: http://chchearing.org/noise/common-environmental-noise-levels/

+ Represents permissible exposure before possible damage can occur for continuous time weighted average noise. Adapted from Dangerous Decibels online: http://dangerousdecibels.org/education/information-center/decibel-exposure-time-guidelines/

While people generally consider harmful noise as the extremely loud sounds that can cause immediate hearing loss, research indicates that chronic noise exposure even at moderate levels can also result in irreversible damage (OSHA, 2014). Specifically, psychological and physiological effects of chronic noise exposure, which can impact health, brain development, and learning, have been demonstrated. Moreover, chronic noise exposure is now considered a topic for action among children (World Health Organization [WHO], 2010) because of its adverse effects on cognition, attention, reading acquisition, and memory, as well as other physiological and psychological mechanisms (Flexer, 1999; Haines, Stansfeld, Berglund, & Head, 2001a; Haines, Stansfeld, Soames, Berglund, & Head, 2001b; Klatte et al., 2010; WHO, 2004). Nevertheless, an increasing number of school children routinely experience chronic overexposure to noise (Klatte et al., 2010; Lercher, Evans, & Meis, 2003).

The unfavorable academic, psychological and physiological outcomes associated with chronic noise exposure are often overlooked by parents and educators. Possible reasons for this oversight include: a) negative consequences of noise overexposure are not widely recognized; b) symptoms may be subtle, and vary widely, and c) students may compensate, at least initially. Further, more commonly recognized student concerns, such as attention deficit disorder or behavior problems, may be blamed. Even if noise-scape is suspected, some parents and educators may consider the effects of chronic noise exposure to be unavoidable.

Student Noise-Scapes

Classroom Noise

Noise at school, in and around the classroom, is insidious, and difficult for educators to quantify and control (Squires et al., 2016). Consequently, it poses a serious threat in many classrooms, and it negatively impacts teachers and their students' ability to listen and learn, whether the student has normal hearing or hearing loss (Crandell & Smaldino, 2000; Flexer, 1999; Klatte, Hellbruck, Seidel, & Leistner, 2010; Mealings, Demuth, Buchholz, & Dillon, 2015; Mealings, Dillon, Buchholz, & Demuth, 2015; Nelson et al., 2007-2008). Classroom acoustics are influenced by several factors including ambient background noise, speech-to-noise ratio at the student's position, and reflected or reverberated sounds (Crandell & Smaldino, 2000; Flexer, 1999; Knecht, Nelson, Whitelaw, & Feth, 2002). Background noise includes undesirable sounds that affects the targeted sound (Nelson et al., 2007-2008) which, in the classroom, can include noise generated from electronic equipment, heating and cooling systems, and shuffling papers and chairs along with noise generated by the students (Crandell & Smaldino, 2000; Flexer, 1999; Nelson et al., 2007-2008; Yang & Bradley, 2009). Though the acoustics of classrooms throughout the day are highly variable, poor classroom acoustics, overall, in the U.S. and other countries are well documented (Blair & Larsen, 2011; Crandell & Smaldino, 2000; Nelson et al., 2007-2008). Furthermore, there is significant research on the detrimental effects of noise and sound reverberation on all students, with and without hearing loss (Bess, Gustafson, & Hornsby, 2014; Klatte & Hellbruck, 2010; Klatte et al., 2010; Mealings, Deluth et al., 2015; Mealings, Dillon et al., 2015; Schafer et al., 2013; Sullivan, Thibodeau, & Assmann, 2012).

To address this issue, the American National Standards Institute (ANSI) established acceptable criteria for classroom noise levels, and in 2015, the International Code Council (ICC) added an amendment to include the ANSI standards to the International Building Code A117.1 building standards. However, this legislation allows for voluntary compliance on previously constructed school buildings. Despite these standards, researchers continue to find that neither new nor old general education classrooms are in compliance with the ANSI classroom background noise standard, and that larger, open-concept classrooms are particularly troublesome (Crandell & Smalldino, 2000; Nelson et al., 2007-2008). Common causes of unfavorable noise levels include hard reflective surfaces (such as drywall and cinderblocks walls, vinyl or cement floors, multiple windows without coverings), unattached desks with movable chairs, and electronic equipment such as projects or multiple computers as well as HVAC systems.

The use of classroom amplification systems can improve select student outcomes by increasing the intensity of the desirable signal over the noise, but may do so at the expense of increasing the overall noise-scape (Anderson, Pakulski, & Alo, 2014; Crandell, Smaldino, & Flexer, 1995; Rosenberg, Blake-Rahter, Heavner, Alllen, Redmond et al., 1999; Squires et al., 2016). In a series of small scale studies, researchers noted that when teachers and their students utilized a classroom amplification system, aimed at improving the signal-to-noise ratio, they often found it necessary to do so at high intensity levels to off-set the classroom noise level, which further contributed to the overall noise-scape of the classroom (Andersen, Pakulski & Alo, 2014; Squires et al., 2016). In a related study, Blair & Larsen (2011) reported the actual signal-to-noise levels of classroom amplification systems ranged greatly from +5 to +23 dB across grades in an elementary building while classes were in session, and also found that teachers are willing to increase sound levels in an effort to be heard by their students. Thus, while a positive signal-to-noise ratio is generally considered to be an indicator of a favorable listening environment, in many cases the increased intensity levels of voices through classroom amplification systems in order to be heard above the noise, may also contribute to an unsafe daily noise-scape.

In addition to added and competing noise with a classroom, educational shifts toward open-concept classrooms (Nelson et al., 2007-2008), and a more student-driven, collaborative learning environment (Wolf, 2012) perpetuate the concept of the "café effect" (Klatte & Hellbruck, 2010). Klatte and Hellbruck (2010) describe the "café effect" as an increase of noise due to reverberation (i.e., a manifestation of the Lombard effect in social situations): "When separate groups of students are working in the room, each group competes with the reverberant noise from other groups (p. 2)." Though not conclusive, small-scale studies have found that the type of overlapping vocalizations present in the café effect can be seen in larger general education and smaller intervention or resource classrooms, and may be worsened with the use of classroom amplification systems (Anderson, Pakulski & Alo, 2014; Squires et al., 2016). This poses an additional concern for students who work with a paraprofessional or educational interpreter in the general education classroom, who may be subject to overlapping instruction as well (Anderson, Pakulski & Alo, 2014).

Sports and Recreational Noise

Outside of school, students also experience chronic overexposure to noise that contributes to their daily noise-scape from toy play, recreation activities, and sporting events both as participants and spectators (ASHA, 2015). According to the Sight and Hearing Association (2015), which publishes a list of toys that exceed safe sound levels annually, many common toys pose a noise danger including toy guns, musical instruments, talking dolls and stuffed animals, and vehicles with horns and sirens. Recreational and sporting events also pose a threat, and contribute to the daily noise-scape. Crowd noise, air horns, and music played prior to events or during down time have the potential to exceed recommended safe listening standards. Peak noise levels during sporting events have been recorded well beyond safe listening levels. In addition to game time exposure, student athletes also attend practices where the same or additional (other sports or teams practicing) noise may be present. In fact, after documenting the noise levels of collegiate basketball games, England and Larsen (2014) suggested that spectators be warned of the dangers of being exposed to extreme noise, especially if experiencing chronic exposure throughout the day prior to the sporting event. Other common examples of recreational noise that may exceed safe sound levels include arcade games, personal listening devices such as iPads and phones (Portnuff, Fligor, & Arehart, 2011), motor sports such as snowmobiling, motorcycling, and car races (Rose, Ebert, Prazma, et al., 2008), concerts, and cheering crowds (Engard, Sandfort, Gotshall, & Brazile, 2010; Serra, Biassoni, Richter, Minoldo, Franco, et al., 2005). Table 1 includes a list of noise levels of common recreation and sporting events and current standards for permissible exposure. It should be noted that these time limits are based upon the notion of a single high-intensity exposure and do not reflect growing concern of chronic exposure to low and moderate sounds.

Environmental Noise and Noise In and Around the Home

Environmental noise exposure and its adverse effects have long been well-documented among adults. More recently, researchers have turned their attention to students and reported on the impact of noise from traffic, trains/subways, and airports (e.g., Klatte et al., 2007; van Kempen, van Kamp, Lebret, Lammers, Emmen et al., 2010). However, much less is known about the daily noise-scape of the home because it is not easy to quantify, as it is so variable. Considering the decibel levels of everyday sounds within and around the home as reported in Table 1, it is likely that students have substantial noise exposure of at least a moderate intensity level, and possibly more throughout their day. Considering the cumulative nature of noise exposure, each and every occurrence of moderate and high intensity noise can create a significant impact. In other words, noise dose never decreases over time, but individuals do vary in their susceptibility to noise damage. As explained by Johnson (n.d.), “While sound levels may go up and down over time, noise dose only increases or plateaus over time. This is because you can’t remove the exposure once it has occurred, much the same way you can’t undo sun exposure after the fact (p.8).”

Impact of Daily Noise-Scape

Noise and Health

While there are no standards for acceptable daily noise-scapes regarding students, emerging research and anecdotal reports provide clear linkages between chronic noise exposure and physical and psychological health, which ultimately impacts general well-being. For example, both students with normal hearing and hearing loss report high levels of fatigue, stress and annoyance from the demands of speech processing in noisy conditions (Bess, Gustafson, & Hornsby, 2014; Hornsby, Werfel, Camarata & Bess, 2014; Mealings, Dillon, et al., 2015). Further, there is sufficient evidence to link noise exposure among students with endocrine secretion changes, negative effects on cognition that may impact long-term memory, higher-level thinking skills such as reasoning and the ability to absorb details and understand messages, as well as general well being (Bess, Gustafson, & Hornsby, 2014; Blair & Larsen, 2011; Hornsby et al., 2014; Klatte, Bergstrom, & Lachmann, 2013; Stansfield & Clark, 2015). Albeit limited, there is also growing evidence for an association with increased hyperactivity symptoms as well as potential changes in cardiovascular functioning (Stansfield & Clark, 2015).

Impact of Noise on Classroom Learning

In addition to health concerns, robust evidence exists linking noise with students’ ability to access and engage in the education curriculum, ultimately impacting their achievement. Both students with normal hearing and hearing loss with undesirable noise-scapes perform more poorly on tasks of academic learning, classroom performance, and reading that ultimately impact standardized academic test scores (Bess, Gustafson, & Hornsby, 2014; Blair & Larsen, 2011; Hornsby et al., 2014; Klatte, Bergstrom, & Lachmann, 2013; Stansfield & Clark, 2015). This research is based upon several well-established premises about learning: (a) most classroom instruction is delivered orally, and thus, facilitating listening is a necessity for successful learning (Flexer & Rollow, 2009), (b) optimal acoustical conditions for instruction are essential to learning facilitation (Crandell & Smaldino, 2000; Flexer, 1999; Larson & Blair, 2008), (c) children are more negatively affected by poor signal-to-noise ratio because their communication and listening skills are not fully developed until adulthood (Klatte et al., 2010; Shield & Dockrell, 2008; Talarico, Abdilla, Aliferis, Balazic, Glapakis et al., 2007; Yang & Bradley, 2009), and (d) those skills are more likely to be compromised when hearing loss exists (Daud, Noor, Rahman, Sidek, & Mohamad, 2010; Lieu, Tye-Murray, Karzon, & Piccirillo, 2010; McFadden & Pittman, 2008). Highlights of this work are summarized in Table 2.

Table 2. Evidence of Academic Concerns Linked with Unfavorable Noise-Scapes
Compromised oral language comprehension and reading acquisition (Haines et al., 2001a and 2001b; Schafer et al., 2013) and difficulty categorizing speech sounds (Klatte et al., 2007)
Poorer scores on standardized tests of literacy, mathematics, and science (Shield & Dockrell, 2008)
Decreased intelligibility of speech (Crandell & Smaldino, 2000; Yang & Bradley, 2009), and poorer performance on phonological discrimination tasks (Klatte et al., 2005)
Negative effects on cognition including short- and long-term memory (Klatte et al., 2010), intentional, incidental, and recognition memory (Lercher et al., 2003), and disrupted memory for nonwords (Klatte et al., 2007)
Increased levels of fatigue, stress and annoyance (Bess et al., 2014; Klatte & Hellbrück, 2010; Klatte et al., 2010; Mealings, Dillon et al., 2015)
More difficulty communicating with teachers and peers (Klatte et al., 2010; Mealings, Dillon et al., 2015)

Noise Induced Hearing Loss

Although daily noise doses may not reach intensity levels commonly associated with noise induced hearing loss (NIHL), there is evidence that chronic exposure to moderate levels may cause permanent damage to the sensory cells of the ear (Johnson, n.d.). Further, the increasing use of personal electronic devices may leave some children exposed to harmful levels of noise (Stansfield & Clark, 2015). In fact, research suggests that as many as one in 5 US adolescents aged 12 to 19 years have minimal or mild hearing loss (Shargorodsky, Curhan, Curhan, & Eavey, 2010). Urban minority youth are especially at risk, and represent an under-reported and under-studied group (Henderson, Testa, & Hartnick, 2011; Mehra, Eavey, & Keamy, 2009).

Regardless of the causation factors, when hearing loss is present, it may result in additional problems in listening, language acquisition, and learning. According to the American Speech-Language-Hearing Association (n.d.a), there are four major ways in which a permanent hearing loss affects students: (a) it causes delay in the development of receptive and expressive communication skills (speech and language); (b) the resultant language deficit causes learning problems that lead to reduced academic achievement; (c) communication difficulties often lead to social isolation and poor self-concept; and (d) it may impact vocational choices. When hearing loss is coupled with an unfavorable daily noise-scape, the potential for serious academic and social concerns that jeopardize quality of life are exacerbated (Bess, Gustafson, & Hornsby, 2014; Hornsby et al., 2014; Kochkin, Luxford, Northern, Mason, & Tharpe, 2007; McFadden & Pittman, 2008). This is especially true for minimal and mild hearing losses that may go undetected or untreated.

Despite students' daily noise-scape, educators need their students to be prepared to learn, and to be able to effectively listen, process, and comprehend complex messages in order to achieve academic success (Schafer et al., 2013). Thus, educational audiologists are well-positioned to support educators in recognizing unfavorable noise-scapes, signs and symptoms of chronic noise exposure as well as hearing loss, and reducing students' daily noise dose and overall classroom noise levels. Given the limited background of most educators on these topics, it is important to recognize the best ways to collaborate and support students.

COLLABORATION AMONG PROFESSIONALS

As described, a classroom's acoustic environment has the potential to significantly impact both students and teachers (Klatte, Meis, Sukowski, & Schick, 2007; Mealings, Demuth et al., 2015; Mealings, Dillion et al., 2015). Within classrooms, instruction is generally provided to students through spoken language, and students spend as much as 75% of their time in school engaged in listening activities (Flexer & Rollow, 2009). Because most classroom instruction is conveyed from teachers to students through spoken language, classroom noise is an important issue that must been adequately addressed (Bess, Gustafson, & Hornsby, 2014; Schafer et al., 2013).

As explained by the American Speech-Language-Hearing Association (n.d.b), “audiologists, acoustical consultants, speech-language pathologists (SLPs), classroom teachers, and administrators can and should work closely together in order to improve acoustic conditions in schools.” As this important issue receives more attention, educational audiologists (EAs) will have an increasingly important role in identifying and managing issues related to hearing and classroom acoustics (Bess, Gustafson, & Hornsby, 2014). Part of this role includes working collaboratively with teachers and other professionals to identify classroom noise sources that have a negative impact on teachers and students, especially those with hearing loss. Educational audiologists are equipped with the knowledge and skills necessary to lead a team of professionals in accomplishing this multi-step task. However, because EAs are not often available in a classroom, or even a building, on a daily basis, teachers, speech-language pathologists (SLPs), and other professionals are also responsible, thus necessitating a teaming approach.

Teaming in educational settings is supported by both legislation (the Individuals with Disabilities Act Amendments [IDEA] of 1997 [PL 105-17]) and research (Sheldon & Rush, 2013). The concept of a trans-disciplinary teaming model was first introduced into the literature by Haynes (1976). Trans-disciplinary teaming can be defined as a group of professionals who work collaboratively, sharing responsibilities in evaluation, planning, and implementing services (Meyers, Meyers, Graybill, Proctor, & Huddleston, 2012). One of the six stages of trans-disciplinary teaming involves a process of role enrichment in which team members develop an understanding of terminology and core practices of other disciplines represented on the team through team meetings, colleague coaching, and the sharing of information and resources (Meyers, Meyers, Graybill, Proctor, & Huddleston, 2012).

Educational audiologists can use a collaborative teaming approach to provide role enrichment to educators, SLPs, and other professionals on topics related to classroom noise, noise-scape and hearing loss. To accomplish this, EAs may assist teachers and SLPs in identifying sources of classroom noise that have a negative impact on student success. This may include identifying and considering the following factors that can contribute to unfavorable classroom acoustics: surfaces that increase reverberation times, sources of background noise (e.g., HVAC systems, shuffling chairs, traffic noise), sources of the “café effect,” and poor signal-to-noise ratio.

Another important topic that EAs can discuss with educators, SLPs and other professionals is the impact that classroom noise has on the academic success and general well-being of students with and without hearing loss. While many educators are familiar with hearing loss, there is growing concern about the combined effects of poor acoustics and minimal hearing loss (MHL), which is on the rise among school students. Goldberg and McCormick Richburg (2004) reported anecdotal evidence of frequent misperceptions about MHL among professionals and the corresponding need to “educate parents and professionals who work with students with [minimal] hearing loss, including teachers, administrators, audiologists, SLPs, and school nurses (p. 159).” Goldberg & McCormick Richburg (2004) documented common misperceptions:

(1) “Minimal hearing loss (MHL) does not exist. In essence, these students have hearing within normal limits

(2) Students with MHL will be identified through school hearing screenings

(3) If students with MHL pass the hearing screening, they should have no difficulties learning in the classroom

(4) Preferential seating is a sufficient recommendation or modification for students with MHL

(5) Hearing conservation programs are not needed in school settings (p.153-158).”

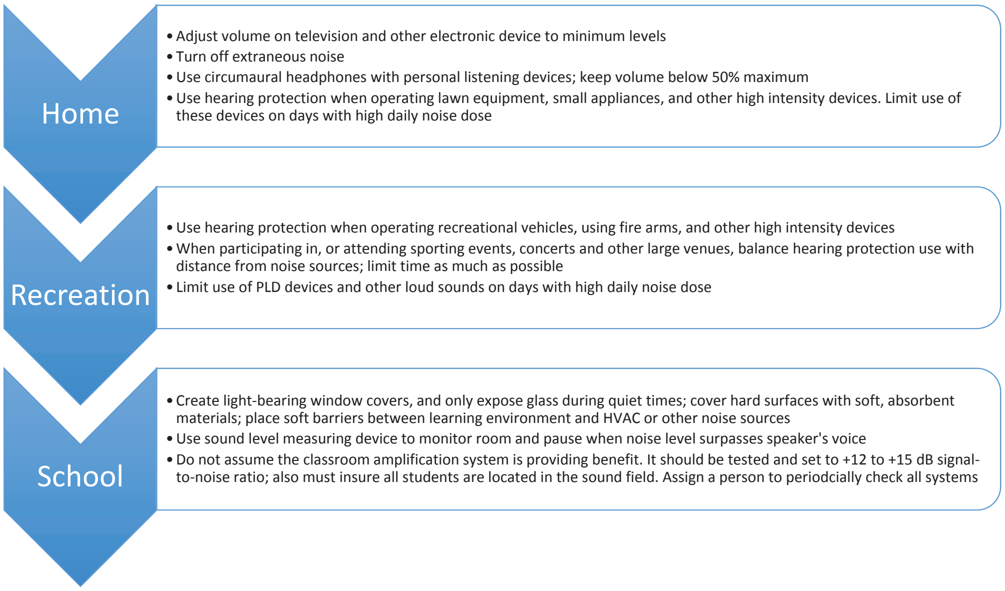
In a follow-up study, McCormick Richburg and Goldberg (2006) surveyed teachers’ perceptions about MHL with respect to the five myths previously stated. The authors concluded that school personnel play an important role in identifying and addressing the needs of students with MHL. Moreover, through collaboration, team members can contribute accurate information and provide effective intervention for students with MHL.

Educational audiologists can help teachers identify students who demonstrate signs of unfavorable noise-scapes as well as MHL, and can support teachers in implementing strategies in the classroom that accommodate the educational needs of their students. This can be accomplished with tools that explain the negative impact of unmanaged classroom acoustics on student performance, outline the relationship between various severities and types of hearing problems and the corresponding impact on students’ listening and learning needs, and provide teachers with clear instructions on how to use and troubleshoot classroom soundfield devices as well as personal hearing technology.

RESOURCES FOR EDUCATORS AND RELATED PERSONNEL

In the absence of comprehensive guidelines for educators and parents to create safe and comfortable daily noise-scapes for their students, EAs can make a profound impact by promoting awareness and developing training materials for teachers, administrators, SLPs and related professionals, along with providing direct services. Hearing health and noise education are underdeveloped in most curriculums, but with support of the EA, can be implemented in simple steps by all educators (Thompson, Pakulski, Kleinfelder, Price & Mondelli, 2013). While the EA should address each classroom individually, there are general ways in which educators and students can be taught to monitor and improve the daily noise-scape; these are highlighted in Figure 1.

Figure 1. Solutions for Educators and their Students to Improve Daily the Noise-Scape



A second, but equally important issue is training educators and parents to recognize the signs and symptoms of acute and chronic over exposure to noise, as well as the often subtle signs of hearing loss. It is important to promote awareness among educators and related professionals of the significant impact a hearing loss in childhood may have, even if it is considered a minimal or mild loss. Identifying and intervening early will help students achieve their maximum potential.

Fortunately, there are many available resources that EAs can use as guides when working with classroom teachers and students who may have unfavorable daily noise-scapes, or be at risk or have hearing loss. These tools include checklists of important considerations that should be made when developing educational programs. In addition to national organization websites, one of the more comprehensive resources, developed by Karen Anderson, can be found online: http://successforkidswithhearingloss.com/

CONCLUSION

Noise-scapes develop from all areas of life: classroom noise, indoor sports and recreational noise, and home and environmental noise. The level and intensity of these noise sources vary from person to person based on exposure, and individual susceptibility also varies. Nevertheless, action should be taken to reduce the daily noise dose of students, particularly when it may permanently damage hearing, and when it interferes with physical and psychological health and development, and academic learning. Much like sun exposure, it may contribute to permanent and irreversible damage.

It is important to remember that classroom noise is inescapable for students. They have no options for choosing an alternate setting, nor do they have the autonomy to reduce their risk. Increasing the signal-to-noise ratio by amplifying the primary speaker, often the teacher, has resulted in an increase in some academic outcomes for students. However, the increased ambient noise and additional reverberation can be distracting for some students. Further, it may contribute to the “café effect.” Similarly, students already receiving assistance from paraprofessionals may have the additional difficulty of differentiating from two primary speakers (teacher and para) through the competing ambient noise.

Recreational and sporting events can also contribute to the daily noise-scape and impact student learning and achievement. Variances in the home exposure could include but are not limited to: television volume and duration of viewing time, computer sound output, personal listening device use, neighborhood, ventilation (heating and cooling), and proximity to traffic or industrial areas. Yet, educators do not have control over their students’ listening experiences outside of school. Nevertheless, they have the opportunity to incorporate hearing and noise health into the curriculum and their daily activities to promote awareness and self-improvement. The educational audiologist is uniquely positioned to team with the educators and related professionals to bring about change.

References

American Speech-Language-Hearing Association (n.d.a). Effects of hearing loss on development. Available online: http://www.asha.org/public/hearing/Effects-of-Hearing-Loss-on-Development/

American Speech Language Hearing Association (n.d.b) Classroom Acoustics. Retrieved from: http://www.asha.org/PRPSpecificTopic.aspx?folderid=8589935320&section=Key_Issues

American Speech Language Hearing Association (2015). Home, community, and recreational noise. *Audiology Information Series*. Available online: http://www.asha.org/uploadedFiles/AIS-Home-Community-Recreational-Noise.pdf#search=%22sound%22

Anderson, K., Pakulski, L.A., & Alo, S. (2014, November). Language-learning environment of elementary students: A case study. Poster presented at The American Speech-Language-Hearing Association Annual Convention, Orlando, FL.

Bess, F.H., Gustafson, S.J., & Hornsby, B.W.Y. (2014). How Hard Can It Be To Listen? Fatigue in Students With Hearing Loss. *Journal of Educational, Pediatric & (Re)Habilitative Audiology, 20*, 34-47.

Bittel, S.N., Freeman, B.A., & Kemker, B.E. (2008). Investigation of toy-noise exposure in children. *Seminars in Hearing, 29*(1),10-18.

Blair, J.C., & Larsen, J.B. (2011). The Importance of Appropriate Adjustments to Classroom Amplification: A One School, One Classroom Case Study. *Journal of Educational Audiology, 17*, 94-98.

Crandell, C., & Smaldino, J. (2000). Classroom acoustics for children with normal hearing and with hearing impairment. *Language, Speech, and Hearing Services in Schools, 31*(4), 362-370.

Crandell, C., Smaldino, J., & Flexer, C. (1995). *Sound-field FM amplification: Theory and practical applications*. Independence, KY: Singular.

Dangerous Decibels. (n.d.). Decibel exposure guidelines: how loud is too loud? Dangerous Decibels. Retrieved from http://www.dangerousdecibels.org/education/information-center/decibel-exposure-time-guidelines/.

Daud, M.K., Noor, R.M., Rahman, N.A., Sidek, D.S., & Mohamad, A. (2010). The effect of mild hearing loss on academic performance in primary school children. *International Journal of Pediatric Otorhinolaryngology, 74*, 67-70.

Engard D.J., Sandfort D.R., Gotshall R.W. & Brazile W.J. (2010). Noise exposure, characterization, and comparison of three football stadiums. *J Occup Environ Hyg, 7*, 616-621.

Flexer, C.A. (1999). *Facilitating hearing and listening in young children, 2nd ed.* San Diego: Cengage.

Flexer, C.A., & Rollow, J. (2009). Classroom acoustics accessibility: A brain based perspective. *Volta Voices, 16*, 16-18.

Fligor B. (2009). Risk for noise-induced hearing loss from use of portable media players: A summary of evidence through 2008. *Perspectives on Audiology, 5*,10-20.

Goldberg, L., & McCormick Richburg, C. (2004). Minimal hearing impairment: major myths with more than minimal implications. *Communication Disorders Quarterly, 25*(3), 152-160.

Haines, M.M., Stansfeld, S.A., Soames Job, R.F., Berglund, B., & Head, J. (2001a). Chronic aircraft noise exposure, stress response, mental health and cognitive performance in school children. *Psychological Medicine, 31*(2), 265-277.

Haines, M.M., Stansfeld, S.A., Soames Job, R.F., Berglund, B., & Head, J. (2001b). A follow-up study of effects of chronic aircraft noise exposure on child stress responses and cognition. *International Journal of Epidemiology, 30*, 839-845.

Haynes, U. (1976). Staff development handbook: A resource for the transdisciplinary process. New York: United Cerebral Palsy Association of America.

Hornsby, B. W., Werfel, K., Camarata, S., & Bess, F. H. (2014). Subjective fatigue in children with hearing loss: some preliminary findings. *American Journal of Audiology, 23*, 129-134. doi: 10.1044/1059-0889(2013/13-0017)

Johnson, P.T. (n.d.). Noise exposure explanation of OSHA and NIOSH safe-exposure limits and importance of noise dosimetry. Available online: http://www.etymotic.com/downloads/dl/file/id/47/product/77/noise_exposure_explanation_of_osha_and_niosh_safe_exposure_limits_and_the_importance_of_noise_dosimetry.pdf

Klatte, M., Bergstrom, K., & Lachmann, T. (2013). Does noise affect learning? A short review on noise effects on cognitive performance in children. *Frontiers in Psychology, 30*. Available online: http://dx.doi.org/10.3389/fpsyg.2013.00578

Klatte, M., & Hellbruck, J. (2010). *Effects of classroom acoustics on performance and well-being in elementary school children: A field study*. Paper presented at the Proceedings of the 39th International Congress on Noise Control Engineering, Internoise 2010, Lisbon. Available online: https://www.sowi.uni-kl.de/fileadmin/frueh/publications/Klatte_Hellbrueck_2010.pdf

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

Klatte, M., Meis, M., Sukowski, H., & Schick, A. (2007). Effects of irrelevant speech and traffic noise on speech perception and cognitive performance in elementary school children. *Noise Health, 9*(36), 64-74.

Kochkin, S., Luxford, W., Northern, J., Mason, P., & Tharpe, A.M. (2007). MarkeTrak VII: are 1 million dependents with hearing loss in America being left behind? *Hearing Review, 14*(10), 10-36.

Larsen, J. B., & Blair, J. C. (2008). The effect of classroom amplification on the signal-to-noise ratio in classrooms while class is in session. *Language, Speech, and Hearing Services in Schools, 39*, 451-460.

Lercher, P., Evans, G.W., & Meis, M. (2003). Ambient noise and cognitive processes among primary school children. *Environment and Behavior, 35*, 725-735.

Lieu, J.E., Tye-Murray, N., Karzon, R.K., & Piccirillo, J.F. (2010). Unilateral hearing loss is associated with worse speech-language scores in children. *Pediatrics, 125*, 1348-1355.

McCormick Richburg, C., & Goldberg, L.R. (2006). Teachers' perceptions about minimal hearing loss: A role for educational audiologists. *Communication Disorders Quarterly, 27*(1), 4-19.

McFadden, B., & Pittman, A. (2008). Effect of minimal hearing loss on children's ability to multitask in quiet and in noise. *Language, speech, and hearing services in schools, 39*, 342-351.

Mealings, K.T., Demuth, K., Buchholz, J.M., & Dillon, H. (2015). An Assessment of Open Plan and Enclosed Classroom Listening Environments for Young Students: Part 1 – Students's Question. *Journal of Educational, Pediatric & (Re)Habilitative Audiology, 21*, 1-19. Available online http://www.edaud.org/journal/2015/3-article-15.pdf

Mealings, K.T., Dillon, H., Buchholz, J.M., & Demuth, K. (2015). An Assessment of Open Plan and Enclosed Classroom Listening Environments for Young Students: Part 2 – Teacher's Questionnaires. *Journal of Educational, Pediatric & (Re) Habilitative Audiology, 21*, 1-15. Available online: http://www.edaud.org/journal/2015/4-article-15.pdf

Meyers, A.B., Meyers, J., Graybill, E.C., Proctor, S.L., & Huddleston, L. (2012). Ecological approaches to organizational consultation and systems change in educational settings. *Journal of Educational and Psychological Consultation, (22)*, 106-124.

Occupational Safety and Health Administration [OSHA], 2014. Technical manual. Available online: https://www.osha.gov/dts/osta/otm/otm_extended_toc.html

Portnuff C.D., Fligor B.J. & Arehart K.H. (2011). Teenage use of portable listening devices: a hazard to hearing? *J. Am. Acad. Audiol.*, 22, 663-677.

Rose AS, Ebert CS, Prazma J, et al. Noise exposure levels in stock car auto racing. *Ear Nose Throat J.* 2008;87(12):689-92.)

Rosenberg, G.G., Blake-Rahter, P., Heavner, J., Allen, L., Redmond, B.M., Phillips, J., & Stigers, K. (1999). A three-year FM sound field classroom amplification study. *Journal of Educational Audiology, 7*, 8-28.

Schafer, E.C., Bryant, D., Sanders, K., Baldus, N., Lewis, N., Traber, J., Layden, P., Amin, A., & Algier, K. (2013). Listening Comprehension in Background Noise in Students with Normal Hearing. *Journal of Educational Audiology, 19*, 58-64.

Serra M.R., Biassoni E.C., Richter U., Minoldo G., Franco G., et al. 2005. Recreational noise exposure and its effects on the hearing of adolescents. Part I: an interdisciplinary long-term study. *Int. J. Audiol.*, 44, 65-73.

Shargorodsky, J., Curhan, S.G., Curhan, G.C., & Eavey, R. (2010). Change in Prevalence of Hearing Loss in US Adolescents. *Journal of the American Medical Association, 304*(7), 772-778.

Shelden, M. L., & Rush, D. D. (2013). *The early intervention teaming handbook: The primary service provider approach.* Baltimore: Paul H. Brookes Pub.

Shield, B. M., & Dockrell, J. E. (2008). The effects of environmental and classroom noise on the academic attainments of primary school children. *Journal of the Acoustical Society of America, 123*, 133-144.

Sight and Hearing Association (2015). 2015 Noisy toys list. Available online: http://www.sightandhearing.org/Services/NoisyToysList©.aspx

Squires, E., Pakulski, L.A., Diehm, E., & Glassman, J. (2016). Measuring classroom acoustics. Manuscript submitted for publication.

Stansfeld, S. & Clark, C. Curr Envir Health Rpt (2015) 2: 171. doi:10.1007/s40572-015-0044-1

Talarico, M., Abdilla, G., Aliferis, M., Balazic, I., Glapakis, I., Stefanakis, T., ... Paolini, A.G. (2007). Effect of age and cognition on childhood speech in noise perception abilities. *Audiology and Neurotology, 12*, 13-29.

Thompson, A., Pakulski, L.A., & Kleinfelder, J.A., Price, J., & Mondelli, J. (2013). Health teachers' perceptions and teaching practices regarding hearing conservation, *American Journal of Health Education, 44*, 335-342.

van Kempen, E., van Kamp, I., Lebret, E., Lammers, J., Emmen, H., & Stansfeld, S. (2010). Neurobehavioral effects of transportation noise in primary schoolchildren: A cross-sectional study. *Environmental Health,9*, 25.

Wolf, M.A. (2012). *Culture shift: Teaching in a learner-centered environment powered by digital learning*. Alliance for Excellent Education. Retrieved from http://all4ed.org/wpcontent/uploads/2013/10/CultureShift.pdf

World Health Organization (2004). Retrieved from *Training for health care providers: Children and noise.* www.who.int/ceh/capacity/noise.pdf

World Health Organization, United Nations Environment Programme. (2010). *Healthy environments for healthy children: key messages for action.* Retrieved from http://www.who.int/ceh/publications/hehc_booklet/en/

Yang, W., & Bradley, J.S. (2009). Effects of room acoustics on the intelligibility of speech in classrooms for young children. *Journal of the Acoustical Society of America, 125*, 922-933.

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The Effect of Age of Cochlear Implantation on Speech Intelligibility to Others

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Cochlear implantation is a common surgical procedure for children with profound hearing loss who receive minimal or no benefit from traditional hearing aids. Cochlear implants bypass the damaged portion of the inner ear by providing direct electrical stimulation to the auditory nerve. This electrical stimulation attempts to simulate hearing and is highly successful in many children. However, previous research suggests that most children will need to be implanted at an early age to allow for normal auditory processing of speech signals; normal auditory processing of signals is vital in producing intelligible speech. The goal of the present systematic review is to examine the effect of age at implantation on speech intelligibility, which is defined as the comprehensibility of speech to an outside listener. Providing cumulative evidence that age at implantation significantly impacts speech intelligibility will provide further support for early intervention and implantation in children with profound hearing loss.

Introduction

Speech Intelligibility and Hearing Loss

Speech intelligibility refers to the amount by which a speaker's message is recognized by the listener (Chin et al., 2003), and when impaired, negatively impacts communication (Svirsky et al., 2007, Habib et al. 2010; Van Lierde et al., 2005). Normal or near-normal hearing in at least one ear is required to facilitate typical development of oral language and speech production in children. As a result, if spoken language is inaudible to a child due to bilateral hearing loss, it will be difficult or impossible for the child to develop intelligible speech (Khwaileh & Flipsen, 2010). Access to linguistic input is required for an individual to develop the phonological representations that make up the roots of spoken word production (Ambrose et al. 2014). It is important to note that, according to a published study of 74 children as well as a critical review of five peer-reviewed, published studies, even a unilateral hearing loss may negatively affect language development relative to peers with normal hearing (Jośe, Mondelli, Feniman, & Lopes-Herrera, 2014; Lieu, Tye-Murray, Karzon, Piccirillo, 2010)

Optimal hearing is critical for speech and language development as well as speech intelligibility for at least two primary reasons. First, if the speech frequencies are inaudible (i.e., 250-6000 Hz), children will either be unaware of environmental speech or will receive a degraded and inconsistent signal due to the sensorineural hearing loss, which most often occurs in the high-frequency region where most consonants reside. Second, hearing and adequate audibility are necessary to self-monitor speech production.

When considering the impact of hearing on speech and language, typically developing children with normal hearing are 50 to 75% understandable at three years old and 100% understandable at five years old (Peña-Brooks & Hegde, 2015). Conversely, at four to five years old, a child with profound hearing loss and no amplification will have the vocabulary of only a few single words. According to Peng et al. (2004), the average speech intelligibility in profoundly hearing-impaired individuals without cochlear implants is 20%. Without cochlear implantation or traditional amplification that provides adequate audibility, children with profound hearing losses will have speech that is characterized by articulation, voice, speech, prosody and resonance problems as well as developmental delays in form (phonology, syntax, morphology), content (vocabulary and semantics), and use (pragmatics) of language (Northern & Downs, 2002; Schow & Nerbonne, 2013). These children will also exhibit disordered production of consonants and vowels, speech breathing, resonance and the production of suprasegmental features (Schow & Nerbonne, 2013; Van Lierde et al., 2005). Also, as a consequence of absent auditory feedback, many children with severe-to-profound hearing impairments will have deviant nasal resonance and a slow speaking rate (Baudonck et al., 2015). To develop intelligible speech, children must be able to regulate their rate of speech and exhibit concise placement or manner of the articulators. Manner of articulation is defined as the interaction and configuration of the articulators (tongue, lips, and palate) during speech. In addition to speech and language issues, children who do not utilize spoken language may exhibit difficulty with literacy and reading. The ability to express or comprehend written language strongly correlates to comprehension of oral language (Northern & Downs, 2002). Therefore, children who are born with severe-to-profound hearing loss will likely experience greater challenges while learning how to write and read when compared to normal-hearing peers (Svirsky et al., 2007). Some of these difficulties may relate to inadequate development of phonological awareness (rhyming, alliteration, etc.) in children with hearing loss, which is an important precursor to reading ability (Schow & Nerbonne, 2013).

When considering speech intelligibility of children who use hearing technology, a child with a severe-to-profound hearing loss that utilizes hearing aids will have significantly poorer speech production and intelligibility than a child with a cochlear implant (Van Lierde et al., 2005; Sininger et al., 2014). Children with a cochlear implant will have 80 to 90% intelligible speech after 8 to 10 years of implant experience (Tobey et al., 2011). Cochlear implants aid in the production of spoken language in both children and adults with severe-to-profound hearing impairments. When the cochlear implant is in use, hearing thresholds are often in the near normal-to-normal range in the speech frequencies (Wolfe & Schafer, 2015). Speech intelligibility is one effective way to quantify the benefit of cochlear implants on the production of speech because it addresses the communicative properties of language (Chin et al., 2012). The goal of human communication is to make oneself understood and the inability to develop intelligible speech can lead to a communication disability (Khwaileh & Flipsen, 2010).

Although the benefits of cochlear implants are well-documented for children with severe-to-profound hearing loss (Svirsky et al. 2007; Geers et al., 2010; Sininger et al., 2010), there are several criteria a child must meet before being eligible to receive an implant. The United States Food and Drug Administration (FDA) publishes guidelines on who can receive a cochlear implant and at what age implantation can occur (Cochlear Implant Eligibility, n.d.). For example, before a child is implanted, he or she is recommended to use a hearing aid for a trial period of three to six months, experience limited progress with appropriately fit hearing aids, and poor speech perception (Geers et al., 2010). Additionally, the FDA recommends children to be at least 12 months old before receiving a cochlear implant (Habib et al., 2010). Due to these stipulations, the majority of children do not receive cochlear implants until after their first birthday. Normal-hearing, typically-developing children speak their first word at 12 months, while children with hearing impairment usually do not receive an implant to begin language development until 12 months (Cochlear Implant Eligibility, n.d.). Hearing impairments can be identified with newborn hearing tests at birth, but children are not implanted until after 12 months of age unless the implantation is completed off-label. Implantation after 12 months precludes normal speech and language development because hearing is critical to language development and a recipient does not hear until implant activation. Speech and language development begins in infancy, and according to Ambrose et al. (2014), normal-hearing children typically experience rapid development of their speech sound systems just prior to their second birthday. Hence, earlier implantation will provide access to speech sounds required for the development of speech intelligibility. According to Geers et al. (2010), congenitally deaf children implanted at the youngest possible age are more likely to develop age-appropriate language and reading skills than children who receive implants at 4 to 5 years old. Geers et al. (2010) also states that children whose profound hearing loss occurred shortly after birth exhibited higher long-term communication outcomes if they received a cochlear implant shortly after the development of their hearing loss. Therefore, the age of implantation is a crucial predictor of speech development, which continues to develop through early childhood (Schow & Nerbonne, 2013; Chin et al., 2003; Peng et al., 2004; Connor et al., 2014). In addition to the initial gains made in language and speech immediately after cochlear implantation, additional improvements continue for 10 to 15 years post implantation (Beer et al. 2014). According to Tobey et al. (2011), speech intelligibility continues to improve from elementary school through adolescence.

Importance of Speech Intelligibility

Adequate development of speech intelligibility is important for at least four reasons: integration into society, access to mainstream education, quality of life, and psychosocial development. Intelligibility affects societal interactions because the majority of people communicate with oral speech, and, therefore, intelligible speech is required in order to interact with the world (Svirsky et al. 2007). A major factor affecting how well an individual with cochlear implants will integrate into society is related to meeting intelligibility expectations of his or her communication partner, which the communication partner bases on experience speaking with other individuals of similar age with normal hearing (Chin et al., 2003). To make oneself understood by others is imperative to human interaction, and the failure to develop completely intelligible speech may result in difficulties (Flispen & Colvard, 2005). Additionally, it is important that children with hearing loss are able to communicate with children of their own age because peer relationships are models for self-identity and proper behavior (Northern & Downs, 2002; Theunissen et al., 2014).

Second, speech intelligibility is important for full integration into mainstream classrooms, a goal of many parents of children with hearing loss and cochlear implants (Schow & Nerbonne, 2013). Improved technology, refined rehabilitation, and the ability to implant at an earlier age have resulted in pressure to place children with cochlear implants into mainstream educational settings (Chin et al., 2003). Although some children who use manual communication systems (e.g., American Sign Language) can be successful in general education or mainstreamed classrooms, most of these classrooms require high levels of oral-aural communication and depend on speech and auditory skills (Habib et al., 2010). Mainstreaming aims to provide the hearing-impaired child with the least restrictive educational environment, which provides the best access to academic, emotional, and social support (Schow & Nerbonne, 2013). In addition, mainstream, general-education classrooms will allow children with cochlear implants to interact with normal-hearing peers of the same age, which will foster the adequate development of social skills. Cochlear implantation by the age of three can promote spoken language and integration into a mainstream academic classroom (Ertmer, 2007). However, children with profound, unaided hearing losses may only acquire speech and language through rigorous special education classes or through the use a qualified sign language interpreter, which may not be available in a child's home school.

The third reason that speech intelligibility is important is that it will likely affect the child's quality of life for families that choose spoken language as the child's primary mode of communication (Langereis & Vermeulen, 2015). Based on previous research, both speech and severe hearing impairments negatively impact the health-related quality of life of parents of children with these disabilities as compared to parents of children with typical functioning (Aras et al., 2014). However, according to a study including 161 parents, a higher quality of life is found for children with hearing loss after cochlear implantation (Yorgun et al., 2015). More specifically, the majority of parents reported that articulation improved after implantation (77%), children could converse without visual cues (80%), and self-confidence and independence increased (both 85%). In social situations, parents reported that 90% of children were more talkative and conversational, 86% were more sociable in family gatherings, and 88% made friends more easily.

Many children, who receive cochlear implants at an early age and enter Kindergarten at five-years old, will be able to understand others without lip reading, sign language or other visual cues (Schow & Nerbonne, 2013; Yorgun et al., 2015). The ability to hear and acquire speech and language allows a child to develop the ability to think independently, develop self-control and self-direction, and maintain healthy relationships with others. As reported in the aforementioned quality-of-life research (Yorgun et al., 2015), cochlear implantation gives a school-age child with profound hearing loss the ability to socialize with other individuals more frequently. This allows the child to develop appropriate interpersonal skills needed to transition into functional settings, such as employment and post-secondary education (Schow & Nerbonne, 2013). Additionally, children with hearing impairments are usually born into normal-hearing families who want the children to participate in the family community (Tobey et al., 2011).

Finally, the adequate development of psychosocial skills is affected by a child's speech intelligibility, particularly for children with hearing loss who are educated in general education classrooms. Adequate self-esteem is necessary for the development of healthy psychosocial skills, allowing children to adjust to stress and burdens (Theunissen et al., 2014). Self-esteem is one's general appraisal of the self, including feelings of self-worth. The way an individual feels about his or her self affects friendships, academic careers and successes. It is important to have a sufficient level of self-esteem because individuals with higher levels of self-esteem are better adjusted to handle stressful life events, while those with lower levels of self-esteem feel greater amounts of loneliness, peer rejection and psychopathology. Individuals with hearing impairments encounter difficulties regarding self-esteem because they face speech and language delays, problems with communication and less or no access to the sound-dominated world. Cochlear implantation allows a child to develop the language and communication skills required to connect with peers and create solid social networks (Theunissen et al., 2014).

An individual describes, interprets and understands his or her emotions through language. Children with profound hearing loss may have restricted experience with self-expression and a delay in the understanding of their own emotions (Schow & Nerbonne, 2013). They do not have the opportunity to listen to adults and other children verbally manage their feelings about experiences and situations. Children with profound hearing losses are not as accurate in recognizing the emotional states of others compared to their normal hearing. They also have less understanding of emotional vocabulary (Schow & Nerbonne, 2013). According to Chin et al. (2012), prosody is important for the accurate transmission of meaning and is, thus, important for adequate speech intelligibility. Chin et al. (2012) also reports that the control over prosodic aspects, such as intonation and stress, could be problematic because these constructs align with multiple physical parameters (duration, intensity, etc.). In addition, children with profound hearing losses may develop a poor self-concept due to negative reactions to their communication difficulties. They may feel less socially accepted and have lower self-esteem than their normal hearing peers (Theunissen et al., 2014). A delay in language and speech acquisition can negatively affect the development of self-identity (Schow & Nerbonne, 2013; Theunissen et al., 2014).

Rationale for Critical Review

Given the importance of speech intelligibility for societal integration, unrestricted educational success, quality of life, and psychosocial function, an investigation into the demographic characteristics that affect speech intelligibility of children with cochlear implants was conducted. To achieve this goal, a systematic review was performed on peer-reviewed research pertaining to factors influencing speech intelligibility of children with cochlear implants. Systematic reviews and meta-analyses provide the highest level of evidence in the professions of audiology and speech-language pathology because they summarize data from multiple studies over a given time period. These comprehensive reviews also facilitate evidence-based practice and, in some cases, may be used to facilitate changes in insurance coverage for medical devices, such as cochlear implants. The primary hypothesis of this systematic review was that the age at implantation would be the strongest predictor of speech intelligibility, thus providing additional support for the early intervention and implantation of cochlear implants during the critical period of speech, language and auditory development. This hypothesis was derived from research on central auditory development in cochlear implants users showing that stimulation must be presented to a human sensory system within a small window (sensitive period) during development, before 3.5 years, for this sensory system to develop adequately (Sharma et al., 2002). This sensitive period is a time when the central auditory pathways are maximally plastic and ready for development driven by stimulation (Sharma et al., 2009). Furthermore, according to Tobey et al. (2011), diminished or absent auditory input during the formative years may result in poor speech and expressive communication abilities. Therefore, the primary focus of this investigation was the effect of age at implantation on the perceived speech intelligibility of children with cochlear implants.

METHODS

The systematic review was performed using the methods detailed in the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA; The PRISMA Group, 2009) guidelines, which provides evidence-based step-by-step guidelines for reporting in systematic reviews and meta-analyses. The PRISMA guidelines provided a 32-item checklist for the necessary components of a successful systematic review.

Article searches were conducted in March 2015, and no additional searches were conducted past March 26, 2015. Articles were found through the following databases: PubMed, ProQuest, ASHA, Theime Medical Publishers, and Gale Group Database using the key words: cochlear implants, speech intelligibility, and children. With the exception of review articles, all studies met the following inclusion criteria: (1) children in experimental studies had at least 6 months of cochlear implant experience; (2) peer-reviewed and published in a scholarly journal after the year 2000; (3) the research was performed in English and in a primarily English-speaking country. Implant use for at least 6 months was required in the selection criteria to include children who were implanted at an older age (> 3 years) and to ensure that children would have stable implant programming (Wolfe & Schafer, 2015). All study designs were included in the systematic review. Initially, approximately 20 studies were identified. The abstracts of these 20 studies were reviewed to see if they met the inclusion criteria. As described in the results section, 13 studies met the inclusion criteria for the review.

General Description of Studies

The 13 studies identified for the systematic review were published between 2004 and 2014. Eleven of the studies included experimental designs, while two studies (Dowell et al., 2011 and Flipsen, 2008) were review articles summarizing the effect of cochlear implantation on speech intelligibility. Seven of the eleven experimental studies shown in Table 1 used the Beginner's Intelligibility Test (BIT; Osberger, Robbins, Todd, & Riley, 1994) as the method of determining speech intelligibility. The four remaining studies used various measures listed in Table 1.

Table 1. Description of Experimental Studies

Author/Year	# Of Subjects	Ages of Subjects at Implantation	Test
Beer, 2014	42	8.28 - 47.70 months	BIT, PPVT-3
Chin, 2003	49	17 - 70 months	BIT
Chin, 2012	15	8.27 - 40.44 months	BIT, PUP
Connor, 2006	100	12 - 120 months	PPVT-3, AAPS, GFTA
Ertmer, 2007	6	10 - 36 months	BIT
Flipsen, 2006	6	20 - 36 months	PPVT-3, II-Original, II-AN
Habib, 2010	37	8 - 40 months	BIT
Khwaileh, 2010	17	14 - 100 months	BIT, CSIM
Montag, 2014	63	27.9 - 47.7 months	MSIT
Peng, 2004	24	30.9 - 132.5 months	SLST
Svirsky, 2007	67	20.14 - 83.17 months	BIT, MS

Note. BIT = Beginner's Intelligibility Test, MS = Monson's Sentences, PPVT-3 = Peabody Picture Vocabulary Test 3, PUP = Prosodic Utterance Test, AAPS = Arizona Articulation Proficiency Scale, MSIT = McGarr Sentence Intelligibility Test, GFTA = Goldman-Fristoe Test of Articulation, SLST = Short-Long Sentence Test, CSIM = Children's Speech Intelligibility Measure, II-Original = Intelligibility Index Original, II-AN = Intelligibility Index Age-Normalized

Most of the studies in Table 1 utilized a cross-sectional group design; however, five studies involved single-subject designs (Ertmer, 2007; Flipsen & Colvard, 2006; Khwaileh & Flipsen, 2010; Peng et al., 2004; Svirsky et al. 2007). Two studies used longitudinal designs (Ertmer, 2007; Connor et al., 2006). More specifically, Ertmer (2007) conducted a longitudinal study and used the BIT to assess the same group of six participants at 24, 30 and 36 months after the participants received cochlear implants. Similarly, Connor et al. (2006) used a longitudinal study to test participants on several measures after they had 12 months, 24 months and 36 months of implant experience.

As shown in Table 1, the number of subjects in each study ranged from 6 to 100. All of the experimental studies, excluding Flipsen & Colvard (2006) and Peng et al. (2004), used three unfamiliar normal hearing listeners to judge the speech intelligibility of the participants. The unfamiliar listeners used by nine of the eleven experimental studies were chosen by set of study-specific criteria. According to the guidelines set by the BIT, the criteria for a listener judge is: (1) age between 18-40 years, (2) normal speech and hearing, (3) English as native language, (4) minimal or no experience with the speech of an individual with a hearing impairment. The implanted child eliciting the sentences during the BIT is recorded and played for each judge twice. The judges record what they believe the child is saying, and a score is given based on the match between the judge's responses and the target sentences (Osberger et al., 1994). The conversational speech samples recorded by Flipsen & Colvard (2006) were transcribed by a trained graduate student clinician who completed a phonetics course as an undergraduate student. The graduate student transcribed several conversational samples of delayed speech that had been previously transcribed by a clinician with over 20 years of experience in phonology. Peng et al. (2004) used a write-down method to judge intelligibility. For the write down method, each judge would listen to the sentence twice, write down the recorded sentence, and, then, rate the sentence on a 5-point rating scale. A rating of one indicated that the sentence was not intelligible at all, and a rating of five indicated that the sentence was completely intelligible. The majority of the studies included participants who were implanted before the age of three, while certain studies, listed in Table 2, included both participants who were implanted before and after the age of three.

Table 2. Summary of Results

Author, Year	Ages	Results	Description
Beer, 2014	Age < 3	PPVT-3 & BIT highly correlated	Preschool speech/language development is predictive of long-term speech intelligibility
Chin, 2003	Age < 3	r = 0.710 correlation BIT & age	Correlation between BIT & chronological age
Chin, 2012	Age < 3	84% SI of declarative sentences	Declarative Sentences are best for determining SI
Connor, 2006	Age < 3, Age > 3	Children implanted before 2.5 yrs (group A1) had high SI %	Earlier age of implantation is more beneficial than longer length of use
Ertmer, 2007	Age < 3	Mean SI scores increased 28-62% during third year of CI use	5/6 made greater progress in the 3rd year of CI use
Flipsen, 2006	Age < 3	SI from II-Original 85.7(7.9) SI from II-AN 87.7(7.1)	Age can be used to measure the SI of children implanted before age 3
Habib, 2010	Age < 3	SI ≥ 50%	Children who receive CI's before 2 have high SI rates by 6
Khwaileh, 2010	Age < 3, Age > 3	< 3 SI 72.11(17.79) > 3 SI 41.88(25)	SI and age of implantation are correlated, but not with chronological age
Montag, 2014	Age < 3	89.7 % had intelligible speech	Individual factors that affect NH children also affect children w/ CI's
Peng, 2004	Age < 3, Age > 3	Recognition = 68% correct, Intelligibility = 71.54%	Implanted at younger age resulted in better speech intelligibility
Svirsky, 2007	Age < 3, Age > 3	SI ≥ 90%	CI implantation before the age of 2 may have better SI than later implantation

Note:
BIT = Beginner's Intelligibility Test, CI = cochlear implant, SI = speech intelligibility

RESULTS

Primary Factors Influencing Performance

Upon examining results across the 11 experimental studies (Tables 1 and 2), performance was significantly influenced by three primary factors: (1) age at implantation, (2) chronological age, and (3) implant experience.

Factor 1: Age at Implantation

First, results of all but one study supported the hypothesis that speech intelligibility levels would be higher with earlier implantation. For example, Connor et al. (2006) investigated the correlation of speech intelligibility with the age at implantation in a study with 100 participants who received implants between the ages of 12 months and 10 years. The participants were divided into four subgroups based on age (group A1 = 1 to 2.5 years, group A2 = 2.6 to 3.5 years, group B = 3.6 to 7 years, and group C = 7.1 to 10 years). The participants were assessed with numerous speech and language measures, listed in Table 1, before and after cochlear implantation. These measures included the Peabody Picture Vocabulary Test 3 (PPVT-3, Dunn & Dunn, 1981), a receptive vocabulary test, and the Goldman-Fristoe Test of Articulation (GFTA, Goldman & Fristoe, 1969) or Arizona Articulation Proficiency Scale (AAPFS, Fudala, 1974), tests of consonant production accuracy (SPEECH). According to the GFTA and AAPFS, group A1 had significantly better consonant production accuracy when compared to the other three groups and was predicted to continue to surpass the other groups as they age.

Similar to the previous study, Svirksy et al. (2007) reported a relationship between *the age of implantation* and intelligibility in children with three to six years of implant experience, who attained intelligibility scores ranging from 78 to 94% when rated with the BIT. In another similar study, Habib et al. (2010) found that children tested past the age of 5.5 years old, who received cochlear implants sometime between 8 to 24 months of age, had an average intelligibility score of 93%, compared to only 80% for the children who were implanted at the age of 35 to 40 months. The researchers in the Habib et al. (2010) study found that all children who were implanted between the ages of 8 to 24 months achieved speech intelligibility ratings of 80% or higher after the age 5.5 years. Children implanted from 25 to 35 months averaged 15 to 18% lower than the group of children that were implanted at 8 to 24 months old. However, there were no differences in speech intelligibility scores of children who were implanted at 8 to 12 months and children implanted at 13 to 24 months. Furthermore, the authors also reported that 3 of their 37 participants, who were implanted before the age of three, had higher speech intelligibility scores than their normal hearing peers. Svirsky et al. (2007) and Habib et al. (2010) used identical methodology when conducting their studies, but Svirsky reported different findings. Two of the three participants that surpassed their normal-hearing peers in the Habib et al. (2010) study were implanted before the age of two. In comparison, 14 of the participants tested by Svirsky et al. were implanted before the age of 24 months, but none surpassed their normal-hearing peers. These two studies highlight the inherent variability associated with performance outcomes in children with cochlear implants.

The importance of speech intelligibility as it relates to overall communicative success is emphasized in Beer et al. (2014), where the authors stated that the speech intelligibility rating (determined by the BIT) in preschool were found to predict long-term speech intelligibility and language capabilities. The investigators reported a correlation between receptive language and speech intelligibility; the preschool BIT administered to the participants accounted for 34 to 39% of the variance in the long-term performance on the Peabody Picture Vocabulary Test-4 (PPVT-4; Dunn and Dunn, 1997, 2007), a receptive vocabulary test, and Clinical Evaluation of Language Fundamentals (CELF-Core; Semel et al., 2003) receptive language scores.

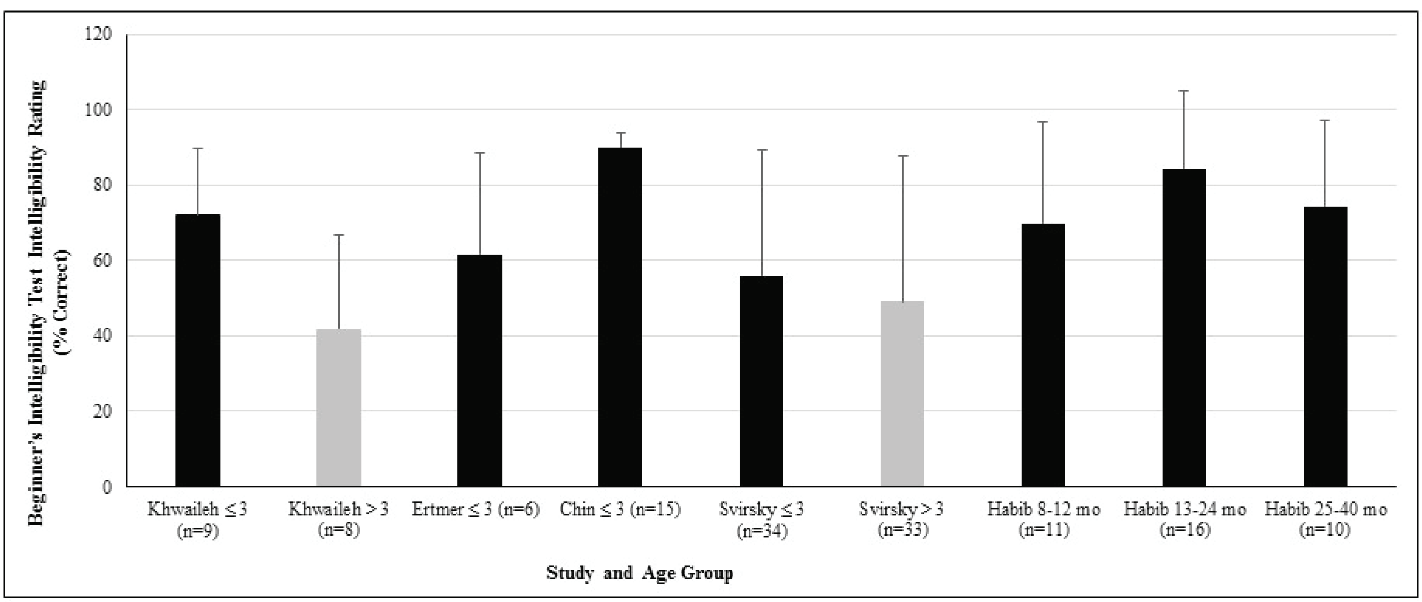

Figure 1. Average speech intelligibility ratings from the experimental studies providing average or raw data. Note. Vertical lines represent one standard deviation; number provided after primarily study author represents the age at cochlea implantation..

When examining results across the studies that investigated the effect of age at implantation on speech intelligibility, the results seen in Figure 1 support the hypothesis that children who are implanted before the age of three have higher intelligibility scores than children who are implanted after three. However, it is important to note the large variability across studies and even within studies. Therefore, it is difficult to make very strong conclusions with the data currently published in the field.

Factor 2: Chronological Age

The second major factor, *chronological age* at the time of testing, is also highly correlated with speech intelligibility ratings. More specifically, Beer et al. (2014), Connor et al. (2006), Chin et al. (2003) and Chin et al. (2012) stated that there was a significant correlation between chronological age at testing and speech intelligibility. For example, Chin et al. (2012) reported a significant correlation between the BIT score and chronological age (r = .71). Similarly, Chin et al. (2003) found a significant correlation between intelligibility scores and chronological age (r = .60). Flipsen & Colvard (2006) found multiple factors to be significantly correlated with speech intelligibility, but chronological age was the strongest factor (r = .64-.66). It is important to note that Flipsen & Colvard (2006) only tested children who received cochlear implants before the age of three. Therefore, Flipsen & Colvard (2006) believe that chronological age should be used to set expectations for levels of speech intelligibility in children who receive cochlear implants before the age of three.

Conversely, Khwaileh & Flipsen (2010) stated that speech intelligibility scores were not significantly correlated with *chronological age* (Pearson correlation r = .28-.42). The investigators administered three intelligibility tests, listed in Table 1, to a group of 17 participants who were all implanted before the age of eight. Results across the test measures showed the highest scores were reported on the Children's Speech Intelligibility Measure, scored by multiple-choice (CSIM-MC; Wilcox and Morris, 1999) test. The CSIM-T, scored by transcription (Wilcox and Morris, 1999) yielded scores that were strongly correlated to scores on the CSIM-MC (r = .85). The third measure, the BIT, resulted in higher scores than the scores than the CSIM-T, but these scores were lower than the scores on the CSIM-MC. The BIT and CSIM-MC scores were correlated (r =.89), and the BIT scores were also correlated with the CSIM-T scores (r = .78).

In the Kwaileh & Flipsen (2010) study, some children that were similar in age had drastically different BIT scores. For example, Participants #1 and #2, who only differed in age by six months at the time of testing, performed differently on the BIT measure. Participant #1 had a score of 12 on the BIT, while Participant #2 had a score of 74. Similarly, Participants #9 and #15, who were both 118 months at the time of testing had varying intelligibility scores. Participant #9 had a score of 85 on the BIT, while Participant #15 had a score of 73, thus supporting the authors' conclusion that chronological age is not correlated with intelligibility.

Factor 3: Implant Experience

In the Khwaileh & Flipsen (2010) study, *implant experience*, the third major factor identified in this systematic review, was the only factor significantly correlated with speech intelligibility (r = .58-.67). More specifically, intelligibility scores at both single and sentence levels were correlated with implant experience. As mentioned in the previous section, chronological age did not appear to correlate strongly with speech intelligibility, possibly because of the narrow range of chronological ages (4 to 11 years). However, the length of implant experience in this study ranges from 12 months to 94 months, allowing for a broader distribution of data points.

Other Factors Influencing Performance

In addition to age at implantation, chronological age, and implant experience, there are additional factors that could affect the speech intelligibility ratings identified in the aforementioned studies. Some of these factors may include the sample size, study design, the time each participant spent in speech therapy, the intelligibility tests proctored, and the individual differences of each participant.

First, it is important to note that the sample size and the study design used in each study could have influenced the intelligibility scores of the participants and the variability associated with the findings. For example, Chin et al. (2003) included 15 participants with cochlear implants and only 10 participants with normal-hearing, resulting in unequal experimental and control groups. Additionally, a smaller sample size results in greater variability. As stated previously, the sample sizes of the studies included in this systematic review ranged from 6 to 100 participants.

The study design used within each study may also impact results. In several studies, a within-subjects group design was used, and as a result, no control group was used to compare the scores of the children with cochlear implants.

Second, the time the participants spent in speech therapy could have affected the scores on the speech intelligibility tests. If a participant spent more time in speech-language therapy, or was introduced to speech-language therapy at an earlier age than the other participants were, their intelligibility ratings could have been skewed positively. A gender effect could have been present in several studies, potentially skewing data. For example, Khwaileh & Flipsen (2010) conducted a study with 17 participants. Four of those participants were male, and 13 were female. This unequal distribution of male and female participants could have resulted in a gender effect. However, these factors were not explicitly addressed in the studies used in this systematic review and cannot be used to explain the variability of intelligibility scores at this time.

Third, the types of intelligibility rating tests proctored and the judges could have affected the results presented by each study. The majority of the studies included used the BIT as the main measure of obtaining speech intelligibility ratings, but other methods, such as the Intelligibility Index and GFTA were also used. As stated previously, the BIT is an objective test to measure the intelligibility of a child's speech. Using the BIT, an audio recording of a child eliciting 10 sentences is played to a panel of unfamiliar listeners. The listeners write what they believe the child has said the percentage of words understood correctly is calculated. The majority of the studies used three normal-hearing, adult listeners as judges of the participants' speech intelligibility levels through a rating system. Other studies used a write-down method to calculate intelligibility ratings. In the write-down method, judges wrote what they heard the participants say, and those results were contrasted with the correct sentences. Peng et al. (2004) used the write-down method with the Short-Long Sentence Test (SLST), which is a component of the procedure used in the Iowa Children's Cochlear Implant Project. In this study, the children were recorded modeling 14 sentences. The recordings were transcribed by 72 adult listeners recruited from the University of Iowa campus. According to Peng et. al (2004), the rating scale is more efficient because it takes less time to calculate a speech intelligibility score, but the write-down method allows for analysis of specific error patterns.

Although not a factor, it is important to consider the individual differences of each child with a cochlear implant, which makes it difficult to clearly examine all factors. Children develop language at different rates and individual differences can account for differences in the time it takes for a child to learn language. For example, Svirsky et al. (2007) reported that in a group of children implanted before the age of two, several participants reached 95% intelligibility after a few years of device use, while other participants did not. As a result, large sample sizes are necessary when examining any factor related to performance.

DISCUSSION

Age at Implantation

The primary purpose of this systematic review was to examine if children who receive cochlear implants before the age of three years will have higher levels of speech intelligibility than children who receive implants after the age of three years. The majority of the studies included in this systematic review supported the idea that earlier implantation results in higher levels of speech intelligibility, thus providing more support to early intervention and implantation. More specifically, the age at implantation proved the most important factor influencing a child's speech intelligibility; five studies concluded that the age of implantation directly influences the speech intelligibility of a child (Flipsen & Colvard, 2006; Connor et al., 2006; Beer et al., 2014; Montag et al., 2014; Ertmer, 2007). The data in Figure 1 clearly illustrate the high levels of speech intelligibility obtained with the implant. However, four studies included limited data on children who were implanted past the age of three years old.

According to Connor et al. (2006), children who received cochlear implants at a younger age demonstrated stronger outcomes at any given age than their same-age peers who received cochlear implants at an older age. These stronger outcomes were related to the amount of implant experience; children who received the implant at a younger age had more implant experience. Connor et al. (2006) observed a length-of-use effect; children who had earlier access to spoken language and sound had higher rates of vocabulary and speech-production accuracy. Similarly, Montag et al. (2014) suggests that implanting children as young as possible optimizes adequate language development. Montag et al. (2014) determined the age at implantation to be a significant factor influencing the overall speech intelligibility of a child. The investigators also stressed the importance of maximizing the quantity of spoken language in which a child is exposed after receiving the implant. A combination of early implantation and a large amount of verbal interaction experience will provide a child with the best outcome for speech intelligibility. Age at implantation and exposure to spoken language were significant predictors of future language capabilities. Additionally, Beer et al. (2014) observed that the age at implantation and the onset of deafness were the only two variables that had a significant impact on the ability to predict preschool speech intelligibility and later speech and language outcomes.

The Existence of a Sensitive Period

While the majority of the studies included in this systematic review supported the implantation of children before three years of age, five studies (Connor et al., 2006; Habib et al., 2010; Flipsen & Colvard, 2006; Svirsky et al., 2007; Ertmer, 2007) also discussed the existence of a sensitive period for cochlear implantation. When children received implants before 2.5 years old, a sensitive period of speech and language growth was observed.

First, Connor et al. (2006) observed significant growth immediately after implantation in children who received the implant before the age of 30 months. Children who were implanted at 1 to 2.5 years of age demonstrated an early surge of consonant-production accuracy that continued for about two years before slowing to rate similar to the children who were implanted at 2.6 to 3.5 years of age or 3.6 to 7 years of age. Children who were implanted before 2.5 years of age had faster rates of vocabulary and consonant production accuracy than the other groups included in this study.

Second, Habib et al. (2010) stressed implanting children with cochlear implants before their second birthday. This study was significant because the investigators explored the differences between children who were implanted between 8 and 24 months of age and children implanted at 25 to 35 months of age. While the purpose of this systematic review was to compare speech intelligibility in children implanted before and after three years of age, this article provided insight into the potential benefit of implanting children earlier than 12 months of age, which is the earliest age recommended for implantation by the FDA. As stated in the results section, the groups of children implanted at 8 to 12 months and 13 to 24 months had slightly higher speech intelligibility ratings when compared to the children implanted after 24 months. However, when comparing the children who were implanted at 8 to 23 months to those who were implanted at 13 to 24 months, there were no evident differences in speech intelligibility between the two groups. The data found by Habib et al. (2010) does not support a large difference in speech intelligibility between the two earlier-implanted groups. Further research will need to be conducted to provide stronger support for earlier implantation.

Third, Flipsen & Colvard (2006) also support the existence of a sensitive period. The researchers state that intelligible speech emerges quickly in children who are implanted before the age of three years old. All six children included in the Flipsen & Colvard (2006) study were implanted before the age of 36 months; the earliest a child was implanted was at 20 months, and the latest at 36 months. For a child who is implanted by 3 years old, intelligible speech emerges rapidly in the first two years of implant experience.

Neurological Plasticity

In addition, the existence of a sensitive period suggests the existence of plasticity in the neurological systems of young children. According to Connor et al. (2006), the sensitive period suggests a high level of plasticity in the neurological systems fostering vocabulary development, especially those systems associated with the auditory pathways. Connor et al. (2006) also suggests that the window for speech-production accuracy seems to be even wider than the window for vocabulary production. At birth, the typically developing human cochlea is mature, but auditory neural development continues in the brainstem in very early childhood and in the cerebral cortex until late childhood. Adequate development of the auditory system is dependent on stimulation from a diverse auditory environment of relevant sounds (Sininger et al., 2014). According to Sharma et al. (2002), the auditory system is maximally plastic around 3.5 years of age, and cochlear implantation by this age produces the best results in regards to the adequate development of the auditory system. Auditory deprivation for more than seven years considerably alters the development of the auditory system (Sharma et al, 2002). The results obtained by Connor et al. (2006) and Sininger et al. (2014) align with the research on neuroplasticity conducted by Sharma et al. (2002) and Sharma et al. (2009), mentioned previously in the introduction.

Therefore, it is important for a child with severe-to-profound hearing loss to receive cochlear implants before the age of three years old, at the latest, in order to take advantage of the plasticity of the auditory and speech-production systems. Development of intelligible spoken communication is dependent on the ability of the auditory channel to receive and transmit information to the central nervous system during the early stages of development (Sininger et al., 2010). In addition, given the importance of the age at implantation, the FDA age criterion may need to be reevaluated to consider implantation before 12 months of age.

Peak of Speech Intelligibility Development

Additionally, several studies (Chin et al. 2003; Connor et al., 2006; Peng et al., 2014) discussed the existence of a plateau in speech intelligibility development in children with cochlear implants. Chin et al. (2003) stated that children with cochlear implants do not reach a plateau for speech intelligibility, unlike other children with normal hearing, who reach their peak levels of speech intelligibility at four years old. In the Chin et al. (2003) study, children with cochlear implants did not experience plateaus in their intelligibility scores, indicating that children with cochlear implants may continue to increase their speech intelligibility accuracy with age. Similarly, Peng et al. (2014) recorded a continuation in the development of accurate speech intelligibility even after a child has 5-6 years of cochlear implant experience. In the Connor et al. (2006) study, data expressed a lasting rate of speech intelligibility development after implantation for children who received cochlear implants before the age of seven years. It is likely that a plateau does occur at some age or duration of implant use; however, it was not captured in the studies included in this review.

Limitations

Originally, the articles included in this systematic review were to be a part of a meta-analysis. However, numerous studies did not include mean intelligibility scores or standard deviations, which are required for a meta-analysis. This systematic review included a limited number of studies, and only four studies included data on children implanted past the age of three. Additionally, numerous studies used only a few subjects in their experimental design, which could limit the results of this systematic review. It is also important to note that only one study provided CI aided thresholds (Ertmer, 2007). Audibility across the frequency range, and particularly in the speech frequencies, is important for speech intelligibility because it would experience with speech sounds and the ability to monitor (i.e., auditory feedback) his or her own voice while speaking. It would be helpful for future research to see how aided thresholds correlate to speech intelligibility. Furthermore, many of the studies did not specifically state whether children were using unilateral, bilateral, or bimodal arrangements (cochlear implant + hearing aid). There is certainly the possibility that children with binaural hearing (i.e., bilateral or bimodal) could have better speech intelligibility; however, future research will need to test this hypothesis.

Conclusions

The majority of these studies support the hypothesis that a child will have greater speech intelligibility the earlier they are implanted. In addition, several studies indicated implant experience and chronological age contribute positively to speech intelligibility.

References

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

Aras, I., Stevanović, R., Vlahović, S., Stevanović, S., Kolarić, B., Kondić, B. (2014). Health related quality of life in parents of children with speech and hearing impairment. *International Journal of Pediatric Otorhinolaryngology*, *78*(2), 323-329.

Baudonck, N., Lierde, K., D'Haeseleer, E., & Dhooge, I. (2014). Nasalance and nasality in children with cochlear implants and children with hearing aids. *International Journal of Pediatric Otorhinolaryngology, 79*(4), 541-545.

Beer, J., Kronenberger, W. G., Castellanos, I., Colson, B. G., Henning, S. C., & Pisoni, D. B. (2014). Executive functioning skills in preschool-age children with cochlear implants. *Journal of Speech, Language, and Hearing Research, 57*(4), 1521+.

Chin, S. B., Tsai, P. L., & Gao, S. (2003). Connected speech intelligibility of children with cochlear implants and children with normal hearing. *American Journal of Speech-Language Pathology/American Speech-Language-Hearing Association, 12*(4), 440-451.

Chin, S., Bergeson, T., & Phan, J. (2012). Speech intelligibility and prosody production in children with cochlear implants. *Journal of Communication Disorders, 45*(5), 355-366

Cochlear Implants for Sensorineural Hearing Loss from MED-EL. ("Cochlear Implant Eligibility", n.d.). Retrieved April 11, 2016, from http://www.medel.com/us/candidacy-cochlear-implants/

Connor, C. M., Craig, H. K., Raudenbush, S. W., Heavner, K., & Zwolan, T. A. (2006). The age at which young deaf children receive cochlear implants and their vocabulary and speech-production growth: is there an added value for early implantation? *Ear and Hearing, 27*(6), 628-644.

Dowell, R., Galvin, K., Dettman, S., Leigh, J., Hughes, K., & Hoesel, R. (2011). Bilateral cochlear implants in children. *Seminars in Hearing, 32*(1), 053-072.

Ertmer, D. (2007). Speech intelligibility in young cochlear implant recipients: Gains during year three. *The Volta Review, 107*(2), 85-99,

Flipsen, P. (2008). Intelligibility of spontaneous conversational speech produced by children with cochlear implants: a review. *International Journal of Pediatric Otorhinolaryngology, 72*(5), 559-564.

Flipsen, P., & Colvard, L. G. (2006). Intelligibility of conversational speech produced by children with cochlear implants. *Journal of Communication Disorders, 39*(2), 93-108.

Fudula, J. B. (1974). *Arizona Articulation Proficiency Scale: Revised*. Los Angeles: Western Psychological Services.

Geers, A., Strube, M., Tobey, E., Pisoni, D., & Moog, J. (2010). Epilogue: factors contributing to long-term outcomes of cochlear implantation in early childhood. *Ear and Hearing, 32*(1), 84S-92S.

Goldman, R. & Fristoe, M. (1969). *Goldman-Fristoe Test of Articulation*. Circle Pines MN: American Guidance Service, Inc.

Habib, M. G., Waltzman, S. B., Tajudeen, B., & Svirsky, M. A. (2010). Speech production intelligibility of early implanted pediatric cochlear implant users. *International Journal of Pediatric Otorhinolaryngology, 74*(8), 855-859.

Jośe, M. R., Mondelli, M. F., Feniman, M. R. & Lopes-Herrera, S. A. (2014). Language disorders in children with unilateral hearing loss: a systematic review. *International Archives of Otolaryngology, 18*(2), 198-203.

Khwaileh, F., & Flipsen, P. (2010). Single word and sentence intelligibility in children with cochlear implants. *Clinical Linguistics & Phonetics, 24*(9), 722-733.

Langereis, M., & Vermeulen, A. (2015). School performance and wellbeing of children with CI in different communicative–educational environments. *International Journal of Pediatric Otorhinolaryngology, 79*(6), 834-839.

Lieu, J. E., Tye-Murray, N., Karzon, R. K., Piccirillo, J. F. (2010). Unilateral hearing loss is associated with worse speech-language scores in children. *Pediatrics, 125*(6), e1348-55.

Montag, J. L., AuBuchon, A. M., Pisoni, D. B., & Kronenberger, W. G. (2014). Speech intelligibility in deaf children after long-term cochlear implant use. *Journal of Speech, Language, and Hearing Research, 57*(6), 2332-2343.

Northern, J., & Downs, M. (2002). *Hearing in Children* (Fifth ed.). Philadelphia, Pennsylvania: Lippincott Williams & Wilkins.

Osberger MJ, Robbins AM, Todd SL, Riley AI. (1994). Speech intelligibility of children with cochlear implants. *Volta Review*, *96*, 169-180.

Peña-Brooks, A., & Hegde, M. (2015). *Assessment and Treatment of Speech Sound Disorders in Children: A Dual-Level Text* (Third ed.). Austin, Texas: Pro Ed.

Peng, S., Spencer, L. J., & Tomblin, J. B. (2004). Speech intelligibility of pediatric cochlear implant recipients with 7 years of device experience. *Journal of Speech, Language, and Hearing Research: JSLHR, 47*(6), 1227-1236.

Schow, R. & Nerbonne, M. (Eds.). (2013). *Introduction to Audiological Rehabilitation* (Sixth ed.). Boston: Pearson Education, Inc.

Sharma, A., Dorman, M., & Spahr, A. (2002). A sensitive period for the development of the central auditory system in children with cochlear implants: implications for age of implantation. *Ear and Hearing, 23*(6), 532-539.

Sharma, A., Nash, A. A., & Dorman, M. (2009). Cortical development, plasticity and re-organization in children with cochlear implants. *Journal of Communication Disorders, 42*(4), 272–279.

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

Svirsky, M., Chin, S., & Jester, A. (2007). The effects of age at implantation on speech intelligibility in pediatric cochlear implant users: clinical outcomes and sensitive periods. *Audiological Medicine, 5*(4), 293-306.

Theunissen, S., Rieffe, C., Netten, A., Briaire, J., Soede, W., Kouwenberg, M., & Frijns, J. (2014). Self-esteem in hearing-impaired children: the influence of communication, education, and audiological characteristics. *PLoS ONE, 9*(4).

Tobey, E., Geers, A., Sundarrajan, M., & Shin, S. (2011). factors influencing speech production in elementary and high school-aged cochlear implant users. *Ear and Hearing, 32*(1), 27S – 38S.

Van Lierde, K., Vinck, B., Baudonck, N., Vel, E., & Dhooge, I. (2005). Comparison of the overall intelligibility, articulation, resonance, and voice characteristics between children using cochlear implants and those using bilateral hearing aids: a pilot study. *International Journal of Audiology, 44*(8), 452-465.

Wolfe, J. & Schafer, E. C. (2015). Programming Cochlear Implants, Second Edition. San Diego, CA: Plural Publishing Inc.

Yorgun, M., Sürmelioğlu, Ö., Tuncer, Ü., Tarkan, Ö., Özdemir, S., Çekiç, E., Çetik, F., & Kıroğlu, M. (2015). Quality of life in pediatric cochlear implantations. *International Journal of Advanced Otology, 11*(3), 218-221

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