Listening Comprehension in Background Noise in Children with Normal Hearing

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

Introduction

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

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

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

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

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

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

Methods

Participants and Procedures

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

Test Stimuli & Equipment

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

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

Results & Discussion

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

Main Idea

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

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

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

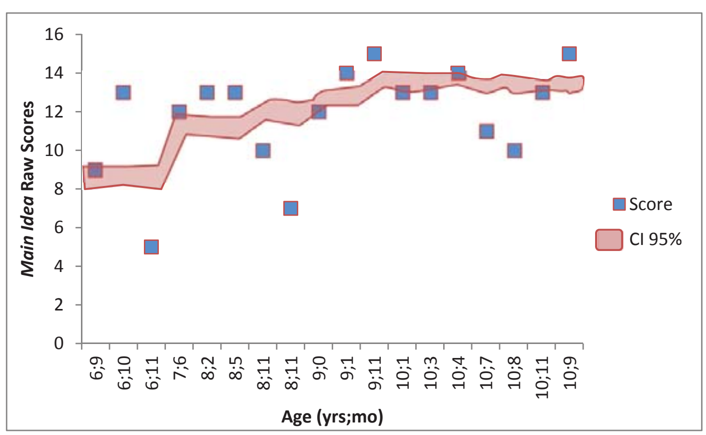

Figure 1. Raw scores from the participants and the 95% confidence intervals in the shaded region for performance in quiet from the test manual for the *main idea* subtest.

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

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

Details

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

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

Reasoning

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

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

Vocabulary

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

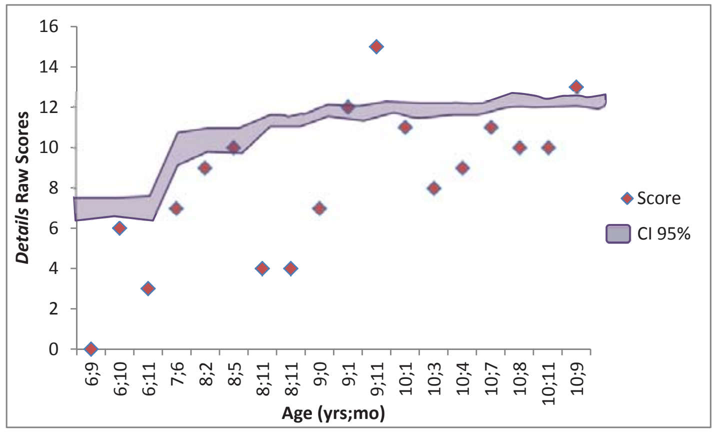

Figure 2. Raw scores from the participants and the 95% confidence intervals in the shaded region for performance in quiet from the test manual for the *details* subtest.

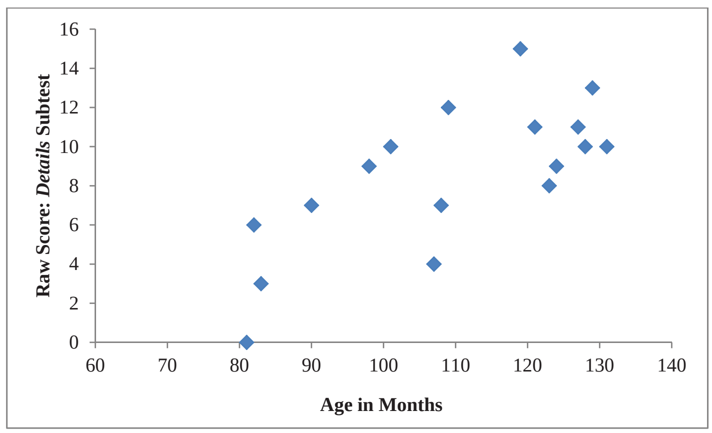

Figure 3. Scatter plot of age in months and raw scores in the *details* subtest.

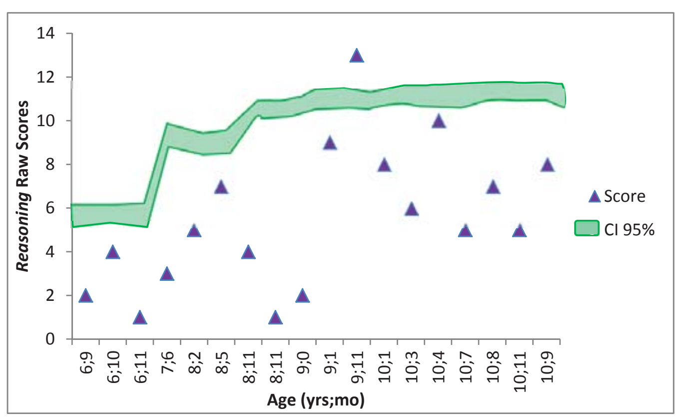

Figure 4. Raw scores from the participants and the 95% confidence intervals (vertical lines) for performance in quiet from the test manual for the *reasoning* subtest.

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

Understanding Messages

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

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

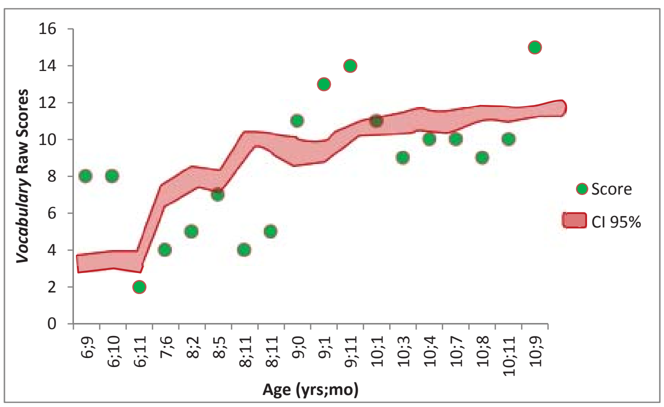

Figure 5. Raw scores from the participants and the 95% confidence intervals in the shaded region for performance in quiet from the test manual for the *vocabulary* subtest.

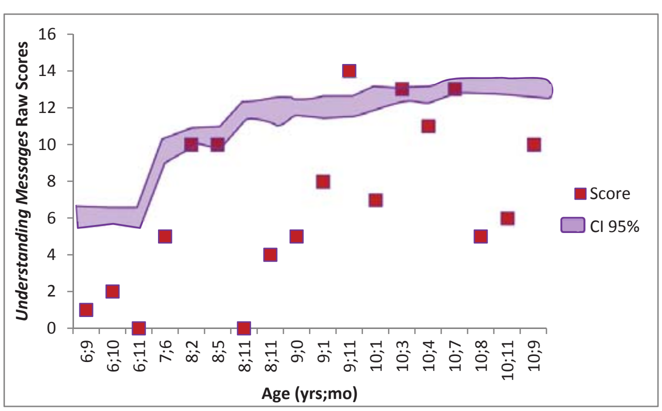

Figure 6. Raw scores from the participants and the 95% confidence intervals (vertical lines) for performance in quiet from the test manual for the *understanding messages* subtest.

Comparisons Across Subtests

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

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

Study Limitations

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

Conclusions

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

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References

American National Standards Institute. (2010). Acoustical performance criteria, design requirements, and guidelines for schools, Part 1: permanent schools (No. ANSI S12.60-2010). NY: Melville.

American Speech-Language-Hearing Association. (2005 Acoustics in educational settings: position statement.

Bowers, L., Huisingh, R., & LoGiudice, C. (2006). The Listening Comprehension Test 2. East Moline: LinguiSystems, Inc.

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

Erber, N. (1977). Evaluating speech perception ability in hearing impaired children. In F. H. Bess (Ed.), *Childhood deafness: Causation, Assessment, and Management*. New York: Grune & Stratton

Jamieson, D. G., Kranjc, G., Yu, K., & Hodgetts, W. E. (2004). Speech intelligibility of young school-aged children in the presence of real-life classroom noise. *Journal of the American Academy of Audiology, 15*, 508-517.

Knecht, H., Nelson, P., Whitelaw, G., & Feth, L. (2002). Background noise levels and reverberation times in unoccupied classrooms: predictions and measurements. *American Journal of Audiology*, 11(2), 65–71.

Lundsteen, S. W. (1979). *Listening: Its impact on reading* and *the other language arts (2nd ed.)*. Urbana, IL: NCTE/ERIC

Nelson, E. L., Smaldino, J., Erler, S., & Garstecki, D. (2007/2008). Background noise levels and reverberation times in old and new elementary school classrooms. *Journal of Educational Audiology, 14*, 16-22.

Neuman, A. C., Wroblewski, 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.

Pugh, K. C., Miura, C. A., & Asahara, L. L. Y. (2006). Noise levels among first, second, and third grade elementary school classrooms in Hawaii. *Journal of Educational Audiology, 13*, 32-38.

Sanders, D. A. (1965). Noise conditions in normal school classrooms. *Exceptional Children, 31*, 344-353.

Schafer, E. C., Beeler, S., Ramos, H., Morais, M., Monzingo, J., & Algier, K. (2012). Developmental effects and spatial hearing in young children with normal-hearing sensitivity. *Ear and Hearing, 33*(6), e32-43.

Schafer, E. C., & Thibodeau, L. M. (2006). Speech recognition in noise in children with bilateral cochlear implants while listening in bilateral, bimodal input, and FM-system arrangements. *American Journal of Audiology, 15*, 114-126.

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. *Journal of the Acoustical Society of America, 131*(1), 232.

Wolvin, A. D. (2009). Listening, Understanding, and Misunderstanding. In W. F. Eadie (Ed.), *21st Century Communication: A Reference Handbook* (137-147). Thousand Oaks, CA: SAGE Publications.

Wroblewski, M., Lewis, D. E., Valente, D. L., & Stelmachowicz, P. G. Effects of reverberation on speech recognition in stationary and modulated noise by school-aged children and young adults. *Ear and Hearing, 33*(6), 731-744.