# Speech Recognition in Noise by Children with Hearing Loss as a Function of Signal-to-Noise Ratio

**Jessica R. Sullivan, Ph.D.**
University of Washington, Seattle, WA

**Linda M. Thibodeau, Ph.D.**
University of Texas at Dallas, Richardson, TX

**Peter F. Assmann, Ph.D.**
University of Texas at Dallas, Richardson, TX

**As part of a larger study, the speech recognition in continuous and interrupted noise was measured for ten children with moderate-to-severe sensorineural hearing loss (HL), ages 6 to 16 years, at varying signal-to-noise ratios (SNRs). Children with bilateral amplification received 10 sentences at each of six SNRs with the 60 dBA noise at 180 degrees azimuth and the speech at 0 degrees azimuth. Sentences were randomly selected from a corpus of 1500 sentences taken from seven thematic categories. The continuous and interrupted speech-shaped noise was filtered to match the long-term average spectrum of the sentences. The average performance-intensity (PI) functions for the interrupted and continuous noise conditions were not significantly different. Children with HL received limited benefit from the interruptions in the noise and therefore might benefit from auditory training designed to take advantage of the silent intervals in noise. Based on the average PI function, an appropriate SNR to begin auditory training would be 6 dB.**

## Introduction

Even though the quality of hearing-assistive technology (HAT) has greatly improved access to auditory information, pediatric hearing aid users still have difficulty understanding speech in noise. While the advancements in HAT have been extremely successful in providing better access to auditory information in noisy environments, the devices cannot surpass the auditory capacity of the individual with hearing loss (HL). Auditory capacity refers to the ability to process auditory information in conjunction with cognitive resources with auditory sensitivity and resolution being key factors (Boothroyd, 1997). Thus, interventions, such as auditory training coupled with HAT, are important in providing children with HL a comprehensive aural habilitation plan. Recently, there is renewed interest in auditory training as a method to improve speech perception abilities, especially in noise. However, there is a paucity of research related to the effectiveness of auditory training in noise for children with HL. There is also a lack of appropriate intervention materials designed to improve speech recognition in noise for children with HL. Materials that are appropriate for children with normal hearing may not account for differences in the language and audibility levels of children with HL. Therefore, two issues should be addressed before implementing auditory training in noise. First, the vocabulary should be familiar and appropriate so there is no confound with the varying language levels of children with HL. Second, the noise level for auditory training should be equal in difficulty for interrupted and continuous noise conditions. In order to determine if auditory training in interrupted and continuous noise could be beneficial, it is necessary to develop a performance-intensity (PI) function for each noise type by children with HL.

Auditory training is an area of interest for researchers and clinicians who seek to improve the listening and communication skills of individuals with HL. Recently, computer-based auditory training (CBAT) programs have become a popular method to provide cost-effective and reliable intervention. The emergence of CBAT programs, such as Listening and Communication Enhancement (LACE), has provided some evidence in support of training in noise for adults with HL (Sweetow & Sabes, 2006). However, most commercially-available CBAT programs for children are designed to address remediation of language disorders (Clendon, Flynn, & Coombes, 2003; Hayes, Warrier, Nicol, Zecker, & Kraus, 2003; Pokorni, Worthington, & Jamison, 2004; Zwolan, Connor, & Kileny, 2000) and are not specifically designed to improve the hearing abilities of individuals with HL. Although some programs are promoted for pediatric hearing aid users, there is no evidence regarding their effectiveness. In three studies, children with cochlear implants improved in speech and language following CBAT training (Clendon, et al., 2003; Schopmeyer, Mellon, Dobaj, Grant, & Niparko, 2000; Zwolan, et al., 2000). Several studies indicated that frequent users of the CBAT programs receive more benefit (Pokorni, et al., 2004; Zwolan, et al., 2000). However, there has not been any clear evidence that one of the currently commercially-available programs is significantly more effective than the others. Several studies have indicated the quantity of time spent practicing skills using CBAT is associated with amount of benefit received from the program (Pokorni, et al., 2004; Zwolan, et al., 2000). Limitations in the CBAT literature are the small sample sizes, lack of follow-up assessments, and duration of training. While there is no evidence of CBAT in noise as an effective intervention to improve speech perception in noise for children with HL there is some evidence for adults with HL.

Speech recognition in noise is a complex process that is dependent on the detection of spectrotemporal cues in the target signal. Several researchers suggest that redundancy of the speech signal, along with contextual and indexical information, facilitates the understanding of speech in adverse listening conditions (Assmann & Summerfield, 2004; Cooke, 2003, 2006; Li & Loizou, 2007, 2009). Numerous studies indicate that glimpsing is one strategy by which speech in noise is understood (Assmann & Summerfield, 1994, 2004; Cooke, 2003, 2006; Culling & Darwin, 1993; Li & Loizou, 2007, 2009; Miller & Licklider, 1950). In the case of children and individuals with hearing impairment, researchers still have a limited understanding of which cues are most beneficial to perceive speech in noise. Evidence suggests that children with HL may utilize listening strategies to understand speech in noisy environments differently from peers with normal hearing and adults with HL (Eisenberg, Shannon, Martinez, Wygonski, & Boothroyd, 2000; Jerger, 2007; Stuart, 2005).

Several researchers believe that listening in interrupted noise may provide additional information on how individuals with and without hearing impairment understand speech in challenging environments (Bacon, Opie, & Montoya, 1998; Jin & Nelson, 2010; Miller & Licklider, 1950; Stuart & Phillips, 1996; Wilson et al., 2010). For example, previous research with adults and children with normal hearing indicates that speech recognition in interrupted noise may yield better thresholds than in continuous noise at the same signal-to-noise ratio (SNR) (Stuart, 2005; Stuart & Phillips, 1996). These results likely relate to the silent intervals in the interrupted noise, which allow listeners to access additional acoustic and linguistic cues that aid in speech understanding in noise. The perceptual advantage increases with age for children with normal hearing and does not reach adult-like levels until around age 11 years (Stuart, 2005). Currently, there is no information regarding the differential between speech recognition in interrupted and continuous noise for children with HL. It is possible that children with HL may follow the same developmental time course as their peers with normal hearing with a slight delay. Alternatively, the presence of hearing impairment may severely disrupt auditory development such that they do not experience any perceptual advantage in interrupted noise. Typically, adults with HL will experience a reduced release from masking compared to individuals with normal hearing in interrupted noise (Jin & Nelson, 2010; Stuart & Phillips, 1996; Wilson, et al., 2010). For the purpose of this study, release from masking refers to the difference between continuous and interrupted noise word recognition scores. Because of the paucity of information on the speech recognition in interrupted noise for children with HL, it is important to establish what perceptual advantage, if any, they receive. This is necessary to design auditory training programs in interrupted and continuous noise at comparable difficulty levels.

## Rationale

Auditory training in noise could be an effective method to enhance listening strategies, such as glimpsing, and to improve speech recognition in noise skills for children and adults with hearing impairment. Specifically, computer-based auditory training could provide a consistent and reliable method to provide delivery of services at home or school. Changes in auditory plasticity through auditory training are supported by perceptual learning and electrophysiology studies (Karni & Sagi, 1993; Kilgard & Merzenich, 1998; Kilgard, Vazquez, Engineer, & Pandya, 2007; Kraus et al., 1995; Recanzone, Schreiner, & Merzenich, 1993; Tremblay & Kraus, 2002; Tremblay, Kraus, Carrell, & McGee, 1997). Evidence also supports the use of noise in the training environment (Burk & Humes, 2007, 2008; Burk, Humes, Amos, & Strauser, 2006; Hayes, et al., 2003; Humes, Burk, Strauser, & Kinney, 2009; Kilgard, et al., 2007; Moucha, Pandya, Engineer, Rathbun, & Kilgard, 2005; Warrier, Johnson, Hayes, Nicol, & Kraus, 2004). Furthermore a well-developed auditory training in noise program could be beneficial in improving speech recognition abilities of children with hearing impairment because their daily lives are filled with noise, and additional hearing assistive devices (i.e. FM systems) are not always available. Therefore, auditory training methods that focus on developing skills to improve speech understanding in noise are vital. Currently, there is limited information regarding auditory training in noise for children with hearing impairment. Evidence suggests that interrupted noise may provide more opportunities than continuous noise to access spectrotemporal cues, which may lead to improved speech recognition in noise abilities over time.

The first step to developing this type of auditory-training program is to establish parameters for presentation level and step size. Determining the starting SNR level is important to ensure audibility and similar difficulty for interrupted and continuous noise, and the step size will determine appropriate changes of SNR for each noise condition. When these parameters are established, it will be possible to a PI function based on speech recognition in interrupted versus continuous noise at different SNRs by children with HL. These results would then be useful for developing pediatric auditory-training protocols for a larger investigation of the benefits of auditory training in noise in children with HL (Sullivan, Thibodeau, & Assmann, In Press). More specifically, the slopes of the PI functions in interrupted and continuous noise would be used to establish easy, medium, and difficult levels for systematic auditory training. As a result, the purpose of this study was to determine the PI functions for speech recognition in noise by children with moderate-to-severe, sensorineural HL in order to establish the parameters to be used in auditory training.

## Methods

### Participants

Ten children, ages 6 to 16 (mean age 9 years, 6 months), were recruited from school districts in Texas and Louisiana. All children had moderate-to-severe sensorineural HL with at least one year of experience with bilateral hearing aids. The configuration of HL was similar between ears and participants. The children were all native English speakers and had no history of neurological impairments and/or auditory neuropathy according to case history. Table 1 provides additional demographic information about the participants. No child was excluded based on gender, ethnic, or racial group. All of the participants were administered the OWLS: Listening Comprehension Scale and Oral Expression Scale to assess receptive and expressive language levels (Carrow-Woolfolk, 1996). All participants had language levels within 2 years of their chronological age at the time of testing. All testing was conducted with the child's personal hearing aids at user settings following a listening check and visual inspection to verify function. Digital hearing aids were worn by all participants during all testing.

### Speech stimuli

A young, native American-English speaking adult female with normal hearing recorded a corpus of 1500 sentences from which a random sample was selected to comprise six unique lists of 10 sentences. In order to reflect a typical classroom environment, we selected a female talker for the stimuli. Because vocabulary and language can be an issue for children with HL, we developed our stimuli to reflect common words that all children should be familiar with and to have enough material for auditory training. Each sentence began with a carrier phrase followed by an adjective, adjective, and a noun; or possessive noun, adjective, and noun (i.e., *He saw three green bears*). There were six themed categories of 216 sentences each, and one category with 125 sentences as shown in Table 2. The final three keywords of each sentence were monosyllabic to increase homogeneity of the stimuli within the category. As shown in Figure 1, the sentences were recorded in a double-walled Wenger sound-treated booth using a desktop microphone (Condenser Shure model SM94). A pre-amplifier was connected to the microphone, and the output was delivered to the amplifier module of the Tucker Davis Technologies (TDT) System 3. The signal from the TDT system was digitized at a sampling rate of 48,828 Hz by a computer using a MATLAB program. The talker was seated with the microphone approximately 8 inches from her mouth.

**Table 1.** Demographic Information

| Participant | Gender | Age | PTA-Left dBHL | PTA-Right dBHL |
|---|---|---|---|---|
| S1 | M | 6 | 76 | 63 |
| S2 | F | 7 | 82 | 83 |
| S3 | F | 7 | 57 | 55 |
| S4 | F | 8 | 55 | 50 |
| S4 | M | 8 | 55 | 57 |
| S5 | M | 9 | 43 | 48.3 |
| S6 | F | 10 | 73 | 70 |
| S8 | M | 10 | 43 | 38 |
| S9 | M | 15 | 56 | 45 |
| S10 | F | 16 | 45 | 38 |
| Mean | | | 59 | 55 |
| SD | | | 14.00 | 14.23 |

Note. PTA= Pure tone average, SD=Standard Deviation, M=Male, F=female.

**Table 2.** Template for Themed Categories and Sentence Totals

| Theme Categories | Total Number of Sentences | Template |
|---|---|---|
| Transportation | 216 | We saw *number + color + vehicle* |
| House | 125 | Her house has a + *adjective + color + object* |
| Food I | 216 | We ate *number + color + food* |
| Mall | 216 | Mother brought *proper name+ color + clothing* |
| Zoo | 216 | He saw + *numbers+ colors+ animals* |
| Food II | 216 | Grandmother gave *proper name + color + food* |
| Toys | 216 | I saw *proper name('s)+ number + toy* |

Each sentence was recorded with a relatively slow, clear speaking rate and was approximately 4 seconds in duration. Sentence prompts were presented at the top portion of the computer monitor every 4 seconds throughout each block. The lower portion of the computer screen displayed a VU meter to monitor vocal intensity during recording. The talker was instructed to monitor her speech and keep the marker in the middle of the scale. After the stimuli were edited for errors and extraneous noise, they were scaled to an equal RMS level.

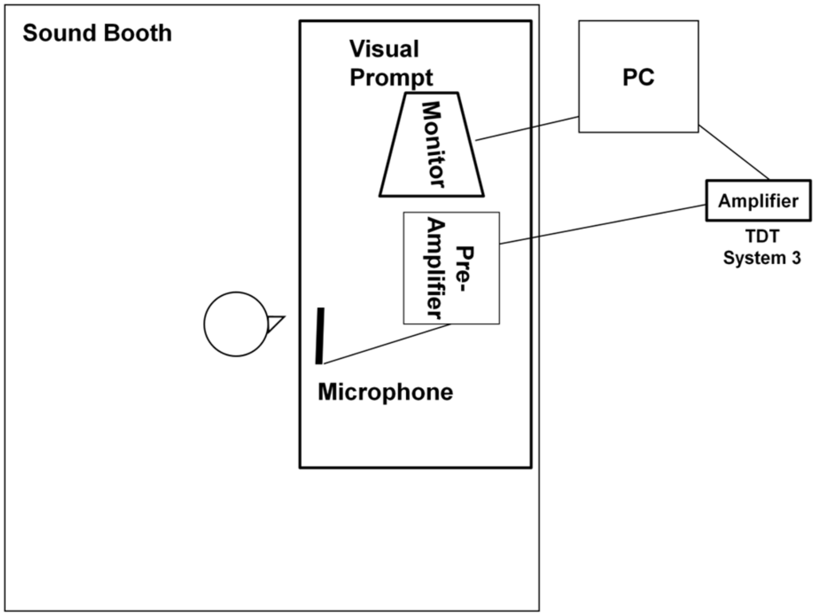

**Figure 1.** Arrangement for digital recording of speech stimuli.

### Noise Stimuli

Continuous speech-shaped noise was generated from random samples of digital speech and shaped according to the long-term average speech spectrum of the female talker. To create the interrupted noise, the continuous speech-shaped noise was interrupted randomly with 5 to 95 ms silent intervals and a duty cycle of .50 using a MATLAB program (Stuart, 2005, 2008; Stuart & Phillips, 1996). Random interruptions of 5 to 95 ms were used to provide an ecologically valid listening environment as the number and duration of interruptions varies in the real world.

### Mixing of Speech and Noise

The noise and speech were recorded on separate channels. The continuous speech-shaped noise was used to calibrate each speaker prior to testing. The RMS level of the noise was equivalent to the average RMS level of the sentences. The noise remained on between sentences and was fixed at 60 dBA as measured by a sound-level meter (Radio Shack Model 33-2055) at the location of the listener's head. The lists of sentences were scaled in 6-dB steps in MATLAB and then organized into six tracks at the following SNRs: -18, -12,-6, 0, 6, and 12 dB. Two compact discs with six tracks each were recorded for the interrupted and continuous noise conditions. For example, at -12 dB SNR, the noise remained at 60 dBA while speech was at 48 dBA.

### Equipment and Procedure for Performance-Intensity (PI) Function

For the PI function, children were tested in a quiet room at their school where the ambient noise ranged from 40 to 50 dBA as measured by a head-level sound level meter at their seat. A Sony CMT-BX20i 50w Micro Hi-Fi Shelf System with two detachable speakers was used to present the stimuli one meter from the child's seated position as shown in Figure 2. The speech was presented at 0 degrees azimuth while noise was presented at 180 degrees azimuth. A practice list was presented in quiet to familiarize the child with the vocabulary and procedure. One list of ten sentences was presented in interrupted and continuous noise at each of the following dB SNRs: -18,-12,-6, 0, 6, and 12. The sequence of SNR presentations was randomized across noise conditions, which were counterbalanced among participants. The child gave a verbal response, and the final three keywords were scored to yield a percent correct score for each SNR level.

## Results

### Individual Results

Figure 3 shows the individual word-recognition performance scores as a function of SNR in interrupted and continuous noise. In the interrupted condition only, three children were able to take advantage of the interruptions at -18 SNR with word recognition performance ranging from 10% to 40% compared to 0% to 3% performance in the continuous condition. The greatest variability for listening in the interrupted noise was at the -6 dB SNR (*M*= 32%, *SD*= 28), and the least variability was at the highest SNR, 12 dB (*M*= 92%, *SD*= 13). The SNR with the greatest variability for listening in the continuous noise was at 0 dB (*M*= 53%, *SD*= 35), and the SNR for the least variability was at -18 dB (*M*= .30%, *SD*=

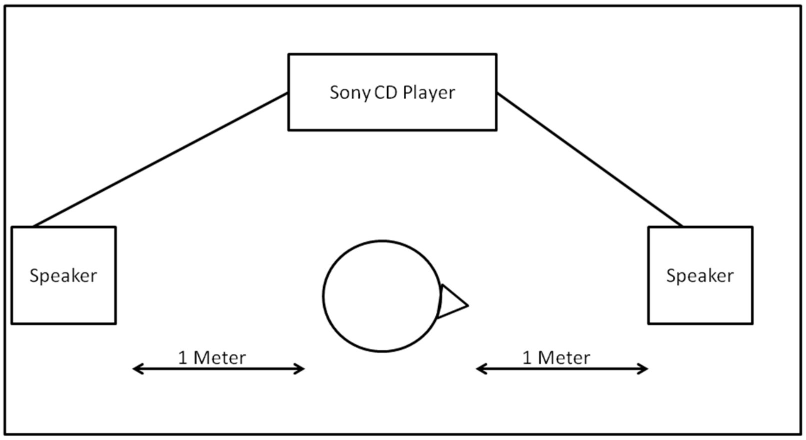

**Figure 2.** Arrangement for evaluating speech recognition in noise with children with hearing loss.

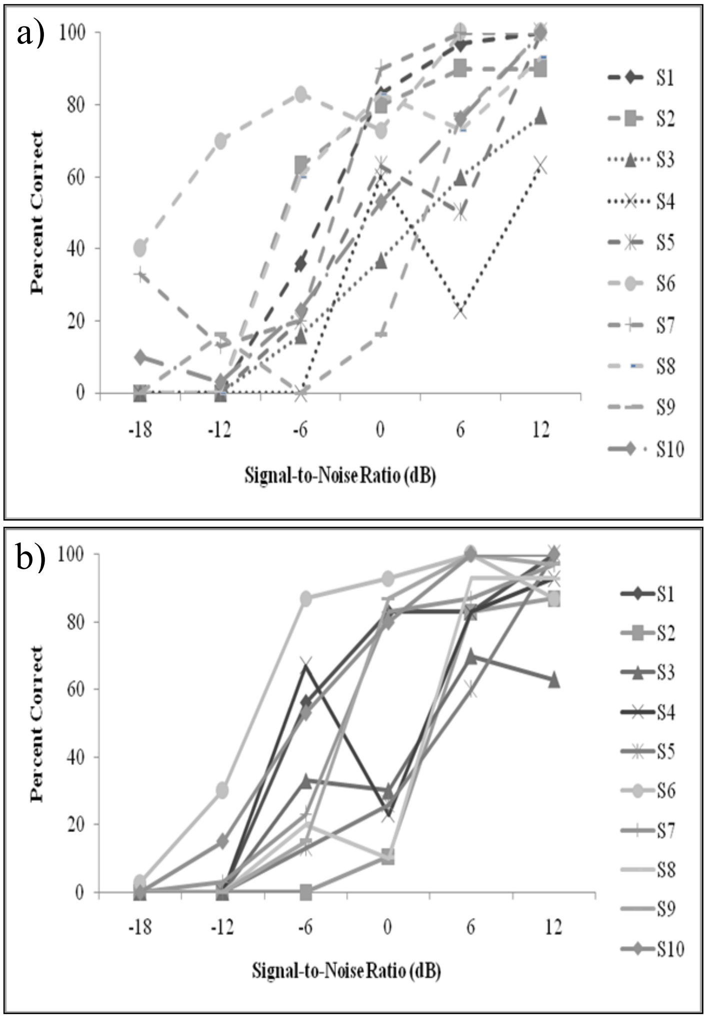

**Figure 3.** Individual word-recognition percent correct scores across signal-to-noise ratios plotted as a function of participant number for the a) interrupted noise condition and b) continuous noise condition. Some data points overlap.

.95). Participant S4, the youngest participant, demonstrated non-monotonic functions for both interrupted and continuous noise.

### Group Results

Figure 4 illustrates the mean performance-intensity (PI) function for 10 children with moderate-to-severe HL in interrupted and continuous noise. Percent correct scores for word recognition in interrupted and continuous noise were plotted as a function of SNR. Third-order polynomial regression lines were fit to determine the 80% word-recognition performance level in interrupted ($R^2$=.993) and continuous noise ($R^2$=.998).

### Determining Appropriate Performance Level

The PI function can be used to determine a starting level for auditory training for children with these stimuli. To start training at a relatively easy level, the 80% word-recognition performance level was selected. Using the corresponding equations shown in Figure 4, the 80% performance level for the interrupted noise was 6.73 dB SNR and for the continuous noise was 6.41 dB SNR. Because the levels were similar, the recommended initial training level is 6 dB SNR in both noise conditions for auditory training with these sentence stimuli.

### Discussion

The purpose of this study was to determine a PI function in interrupted and continuous noise for children with moderate-to-severe hearing impairment ages 6 to 16 years old that would guide the development of a larger computer-based auditory training program. Word-recognition performance in interrupted and continuous noise was evaluated at the following SNR: -18, -12, -6, 0, 6, and 12 dB. The release from masking, as shown in Figure 5, was calculated by subtracting word-recognition scores in interrupted noise from scores in continuous noise at the same SNR. The children with HL in this study demonstrated limited release from masking as shown in Figure 5. In the current study, the average release from masking was about 3% at 0 dB SNR on these open-set simple sentences for children with HL. While it is difficult to make a direct comparison between the current study and the findings of Stuart (2005), because differences in hearing status, age, stimuli type, and sample size, it is important to recognize that children with normal hearing demonstrate a release from masking when comparing performance in continuous and interrupted noise (Stuart, 2005). In addition, this release

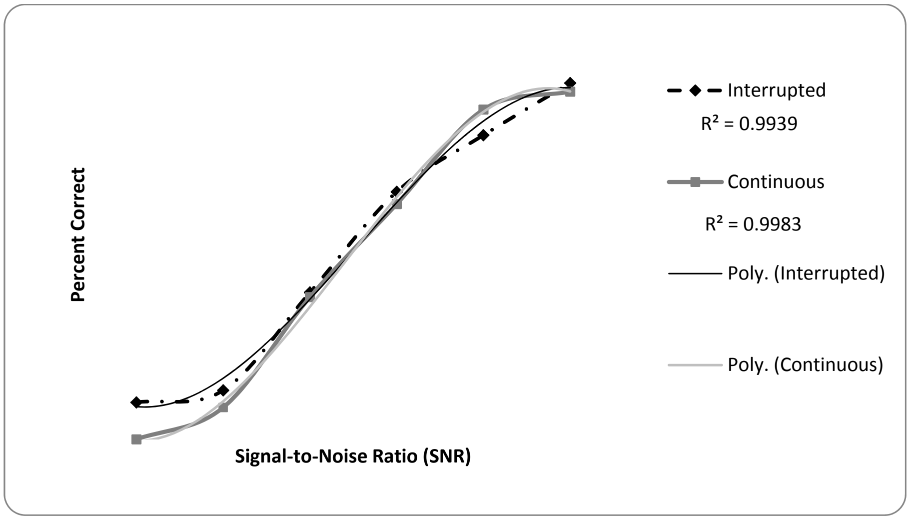

**Figure 4.** Mean performance-intensity functions in interrupted and continuous noise. Poly = 3rd order Polynomial regression line for the average interrupted and continuous conditions. Equation for the interrupted function $y = -1.339x^3 + 14.22x^2 - 26.34x + 21.46$; Equation for the continuous function $y = -1.626x^3 + 16.49x^2 - 28.46x + 13.23$.

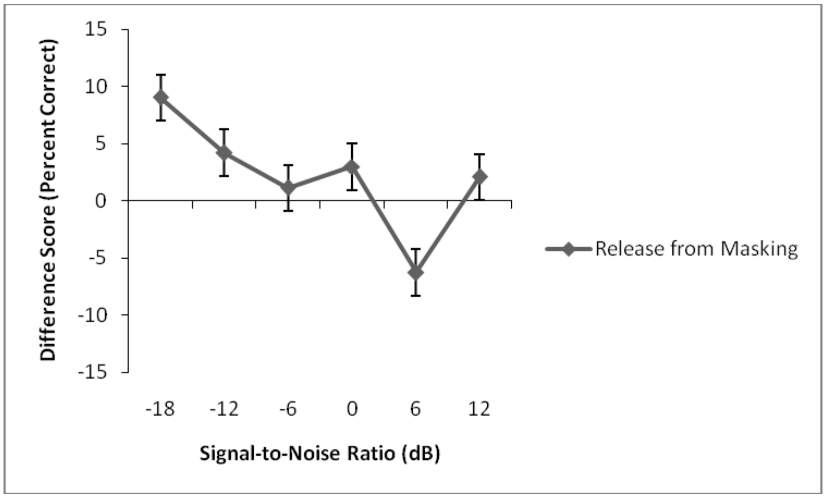

**Figure 5.** Mean release from masking (i.e. interrupted noise minus continuous noise score) as a function of signal-to-noise ratio. Error bars indicate standard errors.

from masking increases with age. According to Stuart (2005), children with normal hearing, ages 8 to 9 years old, experience about a 9% release from masking at 0 dB SNR on open-set word stimuli.

As expected, there was high variability associated with speech recognition in noise by children with hearing impairment (Finitzo-Hieber & Tillman, 1978). For example, Participant S4, the youngest participant, demonstrated inconsistent word-recognition performance across SNR conditions for both noise conditions. This is especially evident in the 6-dB SNR interrupted noise condition where S4 scored 23% while the mean word-recognition score was 75%. Overall, there was little difference between the slopes of the interrupted and continuous noise PI functions. However, the variability across participants suggests that further examination of the difference in speech recognition in interrupted and continuous noise for children with hearing impairment is needed. Therefore, research with a larger sample size is necessary before any conclusions can be reached regarding the amount of release from masking experienced by children with HL and the auditory perception processes involved in speech perception in noise. However, the parameters for the starting SNR level (6 dB) and adaptive-step size (6 dB) determined from this sample may be useful guides in the development of auditory training programs for children with HL.

## References

Assmann, P., & Summerfield, A. (1994). The contribution of waveform interactions to the perception of concurrent vowels. *Journal of the Acoustical Society of America, 95*(1), 471-484.

Assmann, P., & Summerfield, A. (2004). The Perception of Speech Under Adverse Listening Conditions. In S. Greenberg, W. A. Anisworth, A. N. Popper & R. R. Fay (Eds.), *Speech Processing in the Auditory System,* (Vol. 18): Springer-Verlang ,Berlin.

Bacon, S. P., Opie, J. M., & Montoya, D. Y. (1998). The effects of hearing loss and noise masking on the masking release for speech in temporally complex backgrounds. *Journal of Speech, Language, and Hearing Research, 41*(3), 549-563.

Boothroyd, A. (1997). Auditory capacity of hearing-impaired children using hearing aids and cochlear implants: issues of efficacy and assessment. *Scandinavian Audiology, Suppl, 46*, 17-25.

Burk, M. H., & Humes, L. E. (2007). Effects of training on speech recognition performance in noise using lexically hard words. *Journal of Speech Language, and Hearing Research, 50*(1), 25-40.

Burk, M. H., & Humes, L. E. (2008). Effects of long-term training on aided speech-recognition performance in noise in older adults. *Journal of Speech Language, and Hearing Research, 51*(3), 759-771.

Burk, M. H., Humes, L. E., Amos, N. E., & Strauser, L. E. (2006). Effect of training on word-recognition performance in noise for young normal-hearing and older hearing-impaired listeners. *Ear Hear, 27*(3), 263-278.

Carrow-Woolfolk, E. (1996). Oral and written language scales : OWLS Circle Pines, MN  American Guidance Service.

Clendon, S., Flynn, M. C., & Coombes, T. (2003). Facilitating speech and language development in children with cochlear implants using computer technology. *Cochlear Implants International, 4*(3), 119-136.

Cooke, M. (2003). Glimpsing Speech. *Journal of Phonetics, 31*, 579-578.

Cooke, M. (2006). A glimpsing model of speech perception in noise. *Journal of the Acoustical Society of America, 119*(3), 1562-1573.

Culling, J. F., & Darwin, C. J. (1993). Perceptual separation of simultaneous vowels: within and across-formant grouping by F0. *Journal of the Acoustical Society of America, 93*(6), 3454-3467.

Eisenberg, L. S., Shannon, R. V., Martinez, A. S., Wygonski, J., & Boothroyd, A. (2000). Speech recognition with reduced spectral cues as a function of age. *Journal of the Acoustical Society of America, 107*(5 Pt 1), 2704-2710.

Finitzo-Hieber, T., & Tillman, T. (1978). Room acoustics effects on monosyllabic word discrimination ability for normal and hearing impaired children. *Journal of Speech Language, and Hearing Research, 21*, 440-458.

Hayes, E. A., Warrier, C. M., Nicol, T. G., Zecker, S. G., & Kraus, N. (2003). Neural plasticity following auditory training in children with learning problems. *Clinical Neurophysiology, 114*(4), 673-684.

Humes, L. E., Burk, M. H., Strauser, L. E., & Kinney, D. L. (2009). Development and efficacy of a frequent-word auditory training protocol for older adults with impaired hearing. *Ear and Hearing, 30*(5), 613-627.

Jerger, S. (2007). Current state of knowledge: perceptual processing by children with hearing impairment. *Ear and Hearing, 28*(6), 754-765.

Jin, S. H., & Nelson, P. B. (2010). Interrupted speech perception: the effects of hearing sensitivity and frequency resolution. *Journal of the Acoustical Society of America, 128*(2), 881-889.

Karni, A., & Sagi, D. (1993). The time course of learning a visual skill. *Nature, 365*(6443), 250-252.

Kilgard, M. P., & Merzenich, M. M. (1998). Plasticity of temporal information processing in the primary auditory cortex. *Nature Neuroscience, 1*(8), 727-731.

Kilgard, M. P., Vazquez, J. L., Engineer, N. D., & Pandya, P. K. (2007). Experience dependent plasticity alters cortical synchronization. *Hearing Research*, 171-179.

Kraus, N., McGee, T., Carrell, T. D., King, C., Tremblay, K. L., & Nicol, T. (1995). Central Auditory System Plasticity Associated with Speech Discrimination. *Journal of Cognitive Neuroscience, 7*(1), 25-32.

Li, N., & Loizou, P. C. (2007). Factors influencing glimpsing of speech in noise. *Journal of the Acoustical Society of America, 122*(2), 1165-1172.

Li, N., & Loizou, P. C. (2009). Factors affecting masking release in cochlear-implant vocoded speech. *Journal of the Acoustical Society of America, 126*(1), 338-346.

Miller, G. A., & Licklider, J. (1950). The intelligibility of interrupted speech. *Journal of the Acoustical Society of America, 22*, 167-173.

Moucha, R., Panty, P. K., Engineer, N. D., Rathbun, D. L., & Kilgard, M. P. (2005). Background sounds contribute to spectrotemporal plasticity in primary auditory cortex. *Experimental Brain Research, 162*(4), 417-427.

Pokorni, J., Worthington, C., & Jamison, P. (2004). Phonological Awareness Intervention: Comparison of Fast ForWord, Earobics, and LiPS. *The Journal of Education Research, 97*(3), 147-157.

Recanzone, G. H., Schreiner, C. E., & Merzenich, M. M. (1993). Plasticity in the frequency representation of primary auditory cortex following discrimination training in adult owl monkeys. *Journal of Neuroscience, 13*(1), 87-103.

Schopmeyer, B., Mellon, N., Dobaj, H., Grant, G., & Niparko, J. K. (2000). Use of Fast ForWord to enhance language development in children with cochlear implants. *Annals of Otology, Rhinology, and Laryngology, Suppl, 185*, 95-98.

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*(1), 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*(2), 135-146; quiz 191-132.

Stuart, A., & Phillips, D. P. (1996). Word recognition in continuous and interrupted broadband noise by young normal-hearing, older normal-hearing, and presbyacusic listeners. *Ear and Hearing, 17*(6), 478-489.

Sullivan, J. R., Thibodeau, L., & Assmann, P. (In Press). Auditory Training in Interrupted Noise and Improvements in Speech Recognition In Noise For Children With Hearing Impairment. *J Acoust Soc Am.*

Sweetow, R. W., & Sabes, J. H. (2006). The need for and development of an adaptive Listening and Communication Enhancement (LACE) Program. *Journal of the American Academy of Audiology, 17*(8), 538-558.

Tremblay, K. L., & Kraus, N. (2002). Auditory training induces asymmetrical changes in cortical neural activity. *Journal of Speech, Language, and Hearing Research, 45*(3), 564-572.

Tremblay, K. L., Kraus, N., Carrell, T. D., & McGee, T. (1997). Central auditory system plasticity: generalization to novel stimuli following listening training. *Journal of the Acoustical Society of America, 102*(6), 3762-3773.

Warrier, C. M., Johnson, K. L., Hayes, E. A., Nicol, T., & Kraus, N. (2004). Learning impaired children exhibit timing deficits and training-related improvements in auditory cortical responses to speech in noise. *Expermental Brain Research, 157*(4), 431-441.

Wilson, R. H., McArdle, R., Betancourt, M. B., Herring, K., Lipton, T., & Chisolm, T. H. (2010). Word-recognition performance in interrupted noise by young listeners with normal hearing and older listeners with hearing loss. *Journal of the American Academy of Audiology, 21*(2), 90-109.

Zwolan, T., Connor, C., & Kileny, P. (2000). Evaluation of the Foundations in Speech Perception Software as a Hearing Rehabilitation Tool for Use at Home. *Journal of the Academy of Rehabilitative Academy, 33*, 39-51.