Published in final edited form as:
Ear Hear. 2013 September ; 34(5): 575–584. doi:10.1097/AUD.0b013e3182857742.

Influence of hearing loss on children's identification of spondee words in a speech-shaped noise or a two-talker masker

Lori J. Leibold, Ph.D.[1], **Andrea Hillock-Dunn, Au.D., Ph.D.**[1], **Nicole Duncan, Au.D.**[1], **Patricia A. Roush, Au.D.**[2], and **Emily Buss, Ph.D.**[2]

[1]Department of Allied Health Sciences, The University of North Carolina at Chapel Hill, School of Medicine, Chapel Hill, North Carolina

[2]Department of Otolaryngology/Head and Neck Surgery, The University of North Carolina at Chapel Hill, School of Medicine, Chapel Hill, North Carolina

Abstract

This study compared spondee identification performance in presence of speech-shaped noise or two competing talkers across children with hearing loss and age-matched children with normal hearing. The results showed a greater masking effect for children with hearing loss compared to children with normal hearing for both masker conditions. However, the magnitude of this group difference was significantly larger for the two-talker compared to the speech-shaped noise masker. These results support the hypothesis that hearing loss influences children's perceptual processing abilities.

INTRODUCTION

The developing child must learn about important sounds such as speech in natural acoustic environments. These environments often contain multiple sources of competing sounds. For example, spoken instruction in the classroom co-occurs with noise produced by other sources. This noise can be comprised of the steady-state hum of a ventilation system and/or it might contain more complex waveforms such as speech produced by classmates. It has been well documented that these environments offer a greater challenge for children than for adults. For example, preschoolers and school-aged children require a more advantageous signal-to-noise ratio (SNR) than adults to recognize speech in the presence of competing background sounds (e.g., Nittrouer & Boothroyd 1990; Hall et al. 2002) or in reverberation (e.g., Neuman & Hochberg 1983; Neuman et al. 2010).

Children with hearing loss have greater difficulty recognizing speech in these situations when compared to age-matched peers with normal hearing (e.g., Finitzo-Hieber & Tillman 1978; Crandell 1993; Gravel et al. 1999; Hicks & Tharpe 2002; Rance et al. 2007). For example, Rance et al. (2007) compared spondee identification thresholds in the presence of speech-shaped noise between children with sensorineural hearing loss (6–13 years) and children with normal hearing (5–12 years). An adaptive, forced-choice task was used to estimate the SNR needed to achieve 79.4% correct identification performance. The group average SNR for children with normal hearing was −11.5 dB, compared to −5.4 dB for

Name and Address for Correspondence: Lori J. Leibold, Department of Allied Health Sciences, The University of North Carolina at Chapel Hill, School of Medicine, 3122 Bondurant Hall, CB #7190, Chapel Hill, NC 27599-7190, Phone: 919-966-8546, Fax: 919-966-0100, leibold@med.unc.edu.

<u>Conflicts of Interest</u>
For the remaining authors, no conflicts of interest were declared.

children with hearing loss. Thus, children with hearing loss required an additional 6 dB SNR to perform as well as their peers with normal hearing.

The mechanisms responsible for the increased challenges experienced by children with hearing loss in the presence of competing sounds have not been identified. At least a portion of these difficulties can be attributed to damage to the cochlea and/or other structures in the peripheral auditory system. In the classroom example provided in the opening paragraph, the ability to hear and follow the teacher's spoken instruction depends upon an adequate sensory representation of the spectral, temporal, and intensity properties of the overlapping mixture of sounds that originated from the teacher and all active sources of noise in the environment. Peripheral hearing loss reduces the fidelity with which that stimulus is represented in the auditory system. There is support in the literature for the idea that reduced audibility contributes to the increased speech perception difficulties experienced by children with hearing loss in quiet (e.g., Boothroyd 1984; Scollie 2008). In a study involving more than 100 children with hearing loss (11–18 years), Boothroyd (1984) observed a strong relation between children's pure tone average threshold and their open-set phoneme recognition scores in quiet. Specifically, recognition scores decreased as degree of hearing loss increased.

In addition to decreased audibility, the ability to discriminate supra-threshold sounds is likely compromised for children with moderate and greater hearing loss (e.g., Moore 1996). For example, hearing impairment associated with loss of outer hair cells is believed to increase the width of auditory filters (e.g., Moore 1998). A wider-than-normal auditory filter might result in spectral smearing of auditory features and a reduced effective SNR in the presence of background noise. Even with early and appropriate intervention, the quality of the acoustic signal thus remains degraded for many children with hearing loss.

It is becoming evident that delayed or altered perceptual processes operating within the central auditory system also contribute to the increased vulnerability to competing background sounds experienced by children with hearing loss (e.g., Stelmachowicz 2004; Moeller et al. 2007a; reviewed by Eisenberg et al. 2012). These processes include the ability to parse acoustic waveforms and assign them to the appropriate source (auditory scene analysis), as well as the ability to select the appropriate auditory object for further processing, while discounting information that is irrelevant to the task (selective attention). One line of evidence supporting the idea that hearing loss influences the development of perceptual processing comes from studies that have examined the relation between degree of hearing loss and masked speech perception (e.g., Rance et al. 2007; Gravel et al. 1999; Hicks & Tharpe 2002; Sininger et al. 2010). Although hearing loss severity has been shown to predict speech perception outcomes in quiet (e.g., Boothroyd 1984), a similar relation has not consistently been observed in multi-talker babble (Gravel et al. 1999; Hicks & Tharpe 2002), or in a single stream of competing speech (Sininger et al. 2010). These findings suggest that, although audibility is strongly associated with degree of hearing loss, audibility alone is not a sufficient predictor of performance in more complex maskers.

One possible explanation for lack of association between measures of audibility and measures of complex auditory skills is that hearing loss, even when it is appropriately managed, can reduce both the quality and quantity of children's speech and language experiences (e.g., Carney & Moeller 1998; Stelmachowicz 2004; Moeller et al. 2007a). For example, the identification and management of hearing loss during infancy have been linked to improvements in communication outcomes (e.g., Yoshinaga-Itano et al. 1998; Moeller 2000; Sininger et al. 2010; reviewed by Moeller 2011). Nonetheless, delays in language development continue to be reported for children with hearing loss compared to their peers with normal hearing (e.g., Moeller et al. 2007a; 2007b).

Although there is converging evidence supporting the hypothesis that congenital deafness alters the development of the cortical auditory system (reviewed by Moore & Linthecum 2007; Eggermont and Moore 2012), little is known about the maturation of perceptual processing skills in children with less severe hearing loss. The gap in the knowledge base reflects, in part, difficulties associated with determining the relative contributions of peripheral and perceptual factors for children with varying degrees of hearing loss. A promising approach that has been applied to the study of children with normal hearing is to compare speech recognition scores between maskers that differ in their potential to produce 'informational masking'. In this context, informational masking generally refers to masking produced even though the peripheral auditory system provides the brain with an adequate representation of the spectral and temporal properties of the target and masker speech. More specifically, it has been suggested that maskers made up of two or three competing talkers are easily confused with the target speech tokens. Originally called 'perceptual masking' by Carhart et al. (1969), this target-masker similarly reduces the listener's ability to perceptually segregate the target speech from the competing speech masker and/or selectively attend to the target speech while disregarding the irrelevant masker streams (e.g., Brungart 2001; Hall et al. 2002, Freyman et al. 2004).

Studies of speech-on-speech informational masking involving children with normal hearing have shown that the ability to use the information provided by the sensory system requires experience with sound spanning a period of almost two decades (reviewed by Leibold 2012). Preschoolers and young school-aged children require a more advantageous signal-to-noise ratio (SNR) than adults to achieve similar performance on speech recognition tests in the presence of noise maskers, but adult-like estimates have been reported for most children older than 7–8 years of age (e.g., Elliott et al. 1979; Nittrouer & Boothroyd 1990; Nishi et al. 2010; but see McCreery & Stelmachowicz 2011). In contrast, child-adult differences have been observed as late as adolescence for measures of speech recognition in the presence of one or two competing talkers (e.g., Hall et al. 2002; Wightman & Kistler 2005; Bonino et al. 2012). For example, Bonino et al. (2012) examined age-related changes in the ability to recognize monosyllabic words in the presence of a speech-shaped noise or a two-talker speech masker. Open-set word recognition was assessed in two groups of children (5–7 and 8–10 years) and a group of adults. Consistent with previous studies (e.g., Nishi et al. 2010), mature performance with a competing noise masker was observed for 8- to 10-year-olds, but not for 5- to 7-year-olds. However, word recognition scores with the two-talker speech masker were significantly poorer for both groups of children compared to adults. Children older than 10 years of age were not tested by Bonino et al. (2012), but Wightman and colleagues reported age effects for speech recognition in a single stream of competing speech for children as old as 16 years (e.g., Wightman & Kistler 2005).

The purpose of the present study was to evaluate the influence of hearing loss on children's speech perception abilities in the presence of competing noise or speech. To accomplish this goal, estimates of the SNR required for 70.7% correct identification of spondee words embedded in a background of speech-shaped noise or two competing talkers were compared across children with hearing loss and children with normal hearing. Based on results from previous studies (e.g., Finitzo-Hieber & Tillman 1978; Crandell 1993; Rance et al. 2007), it was expected that children with hearing loss would require a more advantageous SNR than children with normal hearing to achieve the same level of performance in the speech-shaped noise masker. This result would be consistent with the idea that hearing loss has a negative effect on peripheral auditory processing of supra-threshold stimuli, such as reduced frequency resolution. In contrast to the speech-shaped noise masker, the two-talker masker was expected to interfere with the target spondees at both peripheral and central stages within the auditory system. Thus, it was hypothesized that a larger difference between the two groups of children would be observed in the two-talker compared to the speech-shaped noise masker. This finding would be consistent with the idea that hearing loss early in life influences perceptual processing, such as those related to the segregation and selection of target from background speech.

MATERIALS AND METHODS

Listeners

Seventeen children with hearing loss participated in this study (6 males, 11 females). The degree of hearing loss spanned from moderate to severe across subjects. Listeners ranged in age from 9 yr 3 mo to 17 yr 1 mo (mean = 12 yr 2 mo). Criteria for inclusion were: 1) bilateral, sensorineural hearing loss; 2) consistent use of binaural behind-the-ear (BTE) hearing aids; 3) use of English as the native language; 4) receptive and expressive language skills sufficient to participate in the speech identification task; 5) negative history of unresolved or recurring conductive or middle ear issues; 6) negative history of neurological problems including auditory neuropathy spectrum disorder; and 7) negative history of learning problems, cognitive problems, or developmental delays. Demographic information for individual listeners is shown in Table 1. Pure-tone thresholds for the better ear of each child with hearing loss are provided in Table 2.

Listeners with hearing loss were recruited from active cases followed through the Pediatric Audiology Clinic of the University of North Carolina, Chapel Hill, NC. Children who met the study criteria were identified, and parents of these children were contacted via email or telephone regarding their interest in participating in the study.

A group of 10 children with normal hearing was also assessed. These listeners were age-matched within six months to the 10 youngest children with hearing loss. All listeners with normal hearing were native English speakers and were required to pass a hearing screening prior to testing (i.e., thresholds less than or equal to 20 dB HL for octave frequencies between 250 and 8000 Hz; ANSI 2004). The 10 youngest children with hearing loss ranged in age from 9 yr 3 mo to 11 yr 2 mo (mean = 10 yr 4 mo). The group of age-matched children with normal hearing ranged in age from 9 yr 3 mo to 11 yr 11 mo (mean = 10 yr 6 mo). The older children with hearing loss ranged in age from 13 yr 2 mo to 17 yr 1 mo (mean = 14 yr 11 mo). Age-matched 13- to 17-year-olds with normal hearing were not included in the present study due to ceiling effects observed in earlier pilot testing. Although an adaptive procedure was used, the average root-mean-square (rms) level of stimulus presentation was not allowed to exceed 81 dB SPL.

Hearing aid fitting and verification

Consistent with the larger clinical population from which the children with hearing loss were recruited, all listeners with hearing loss were consistent users of binaural BTE hearing aids with active nonlinear frequency-compression (NLFC) processing. NLFC is a frequency-lowering algorithm that is gaining widespread use in the pediatric population. The goal of NLFC is to improve access to high-frequency sounds without introducing overlap of sounds from different frequency regions. Table 1 displays the type of hearing aids worn by each listener, along with the duration of both hearing aid use and NLFC processing use. All but two children were fitted with amplification within 3 months of identification of their hearing loss. The two exceptions include HL3, who was fitted 7 months following identification, and HL17, who was fitted 22 months following identification.

One benefit of the recruitment approach used in this study is that the same hearing aid fitting and verification procedures were followed for all listeners with hearing loss. Hearing aid fitting and verification was performed by the child's clinical audiologist in the UNC Pediatric Audiology Clinic using the Audioscan Verifit. A full description of the clinical verification procedures used to ensure appropriate gain and NLFC settings is provided by Glista and Scollie (2009). Briefly, a standard speech passage was used to verify gain targets for soft, average, and loud inputs (55, 65, and 75 dB SPL, respectively) with NLFC processing deactivated. These targets were based on each child's audiometric thresholds and individual real-ear-to-coupler differences (RECDs) using the Desired Sensation Level [i/o] v5.0 method (Scollie et al. 2005). Next, the child's audiologist ensured that both gain and maximum output levels of the hearing aid matched the prescribed targets through the use of simulated real ear probe microphone measurements. Finally, NLFC was activated and adjustments were made to the hearing aids to optimize the audibility of the filtered speech bands of the Audioscan Verifit centered at 3150, 4000, 5000, and 6300 Hz. Hearing aid functioning was verified in the laboratory immediately prior to testing with a listening check and electroacoustic analysis (i.e., standard speech passage at 65 dB SPL) at user settings using the Verifit.

Stimuli

Based on Hall et al. (2002), the target tokens were 25 spondee words that could be unambiguously represented by pictures (airplane, armchair, baseball, bathtub, birthday, bluebird, cowboy, cupcake, doormat, flashlight, football, hotdog, ice-cream, mailman, mousetrap, mushroom, playground, popcorn, sailboat, seesaw, shoelace, sidewalk, snowman, toothbrush, and toothpaste). The words were recorded in isolation from an adult female speaker in a sound-treated booth (IAC) using a condenser microphone (AKG-C1000S) mounted approximately six inches from the speaker's mouth. Productions were amplified (TDT MA3) and digitized at a resolution of 32 bits and a sampling rate of 44.1 kHz (CARDDELUXE). Token durations ranged from 845 to 1412 ms (mean = 1126 ms). Prior to the experiment, the 25 spondee tokens were scaled to have equal total rms levels and resampled at a rate of 24.414 kHz using MATLAB.

The masker was either two-talker speech or speech-shaped noise, presented continuously throughout testing. The two-talker masker consisted of recordings of two female talkers, each reading unrelated passages from children's books. The individual masker streams were manually edited to remove silent pauses greater than 300 ms, resulting in samples that were 3.1 and 3.5 min in duration. A 60-minute ‘seamless’ stream was created for each sample by repeating it without discontinuity. The two individual streams were then balanced for overall rms level, mixed, and digitized using a sampling rate of 24.414 kHz and a resolution of 32 bits. The speech-shaped noise masker was created based on the spectral envelope of the two-talker masker by first calculating the magnitude spectrum based on a 95.1-sec sample of the two-talker masker. Next, a Gaussian noise of equal duration was transformed into the frequency domain, multiplied by the spectral envelope, and the result was transformed back into the time domain. This procedure generated a 95.1-sec sample of noise that could be repeated without discontinuities.

Custom software (MATLAB) was used to control the selection and presentation of stimuli. The spondee tokens and the masker were mixed (TDT SM3), amplified (Techtron 5507), sent to a headphone buffer (TDT HB6), and presented using a loudspeaker (Monitor Audio, Monitor 4). During testing, the listener was positioned 1m from the loudspeaker in the sound field of a 7×7 foot, double-walled sound-treated booth. The height and position of the listener's chair was adjusted so that the stimuli would be presented at approximately 0° azimuth and 0° elevation.

Procedure

Listeners were tested while seated in the sound booth. Children with hearing loss wore their personal hearing aids at their regular settings during testing. Automatic and advanced features of the hearing aid were deactivated during testing, including both directional microphone and digital noise reduction processing. The sole exception was feedback cancellation, which was not disabled if it was activated by the child's audiologist. Prior to testing, each listener completed a familiarization phase in quiet, in which they listened to and identified each of the pictured spondees presented on a laminated board. Listeners from all three groups (9- to 11-year-olds with hearing loss, 13- to 17-year olds with hearing loss, and 9- to 11-year-olds with normal hearing) completed this familiarization phase with ease.

Listeners completed separate testing conditions in the presence of each masker. Following Hall et al. (2002), an adaptive, 4-alternative, forced-choice (4AFC) spondee identification task was used. Listeners held a 7-inch, touchscreen monitor (MIMO) during testing. On each trial, one of the 25 spondee words was randomly selected as the target. Four different pictures were displayed on the monitor approximately 20-msec before the selected target spondee was presented. Each picture was randomly assigned to appear in one quadrant of the monitor. One of the four pictures corresponded to the target spondee. The other three pictures were drawn without replacement from the 24 remaining possibilities. Listeners indicated their responses by touching the corresponding image on the touchscreen monitor. After each response, visual feedback was provided on the monitor by displaying the appropriate picture flashing in isolation.

The average rms level of each target spondee was fixed at 65 dB SPL, corresponding to the average level of speech used to verify the children's hearing aids. The level of the masker was changed adaptively, but was not allowed to exceed 81 dB SPL. A 2-up, 1-down rule (Levitt 1971) was followed to obtain an estimate of the SNR required to achieve 70.7% spondee identification. The starting level for the masker was approximately 10 dB below the expected threshold for each masker condition, adjusted for individual listeners. An initial step size of 4 dB was reduced to 2 dB after the first two reversals. Runs were stopped after eight reversals, and the average of the masker level at the final six reversals was used to compute the average SNR at threshold. At least two runs were completed for each masker condition. A third run was obtained if the first two estimates differed by 5 dB or more. A third estimate was obtained for three children with hearing loss (HL7, HL13, and HL15) and three children with normal hearing (NH6, NH7, and NH 11) in the two-talker masker condition. For those children requiring an additional run, the final thresholds reported below correspond to the average of the two runs with the most similar threshold estimates. A third estimate of threshold was not required for any of the children in the speech-shaped noise masker. Testing order for the masker conditions was counterbalanced across blocks of testing.

RESULTS

Figure 1 presents the SNR estimates at threshold for each masker condition. The black circles show the group average SNRs for the 10 youngest children with hearing loss, the shaded triangles rectangles show the group average SNRs for the 7 older children with hearing loss, and the open squares show the group average SNRs for the 10 children with normal hearing who were aged matched to the 10 younger children with hearing loss. Error bars represent ± one standard deviation. Results for the speech-shaped noise masker are plotted to the left, and results for the two-talker masker are plotted to the right. Lower SNRs indicate better performance in the masker than higher SNRs.

Both groups of children with hearing loss performed more poorly than children with normal hearing in each masker condition, but the magnitude of this group difference appears to be larger for the two-talker compared to the noise masker. For the speech-shaped noise condition, a difference of 2.7 dB in average SNR was observed across the two age-matched groups of children, with average estimates of −8.3 dB (range = −10.2 to −6.8 dB) for children with normal hearing and −5.6 dB (range = −7.8 to −3.2 dB) for 9- to 11-year-old children with hearing loss. For the two-talker speech condition, a difference of 8.1 dB in average SNR was observed across the younger children with hearing loss and their age-matched peers with normal hearing. The average SNR for children with normal hearing in the two-talker masker was −8.0 dB (range = −15.7 to −0.7 dB), similar the average SNR for the same children tested in the noise masker. In contrast, the average SNR for the 10 younger children with hearing loss was 0.1 dB (range = −2.5 to 2.0 dB).

The 13- to 17-year-old children with hearing loss appeared to perform more poorly in the speech-shaped noise masker compared to the younger children with hearing loss. The average SNR required for 70.7% correct identification performance in the speech-shaped noise masker was −5.6 dB (range = −7.8 to −3.2 dB) for the 10 younger children with hearing loss, compared to an average SNR of −3.6 dB (range = −7.8 to −1.3) for the 7 older children with hearing loss. Similar performance was observed across the two age groups of children with hearing loss in the two-talker speech masker. Average SNR estimates were 0.1 dB (range = −2.5 to 2.0) for the subset of 10 younger children, and 0.1 dB (range = −3.3 to 3.0) for the subset of 7 older children with hearing loss.

A two-way mixed analysis of variance (ANOVA) was conducted to test the statistical reliability of the trends in the SNR at threshold observed in Figure 1. This analysis included the within-subjects factor of Masker (speech-shaped noise and two-talker speech) and the between-subjects factor of Group (9- to 11-year-olds with hearing loss, 13- to 17-year-olds with hearing loss, and 9- to 11-year-olds with normal hearing). Mauchly's test of sphericity was not statistically significant. The analysis revealed a significant main effect of Masker [$F(1,24) = 13.4$; $p = 0.001$; $\eta_p^2 = 0.36$], a significant main effect of Group [$F(1,24) = 24.3$; $p < 0.001$; $\eta_p^2 = 0.67$], and a significant interaction between these two factors [$F(1,24) = 3.6$; $p = 0.04$; $\eta_p^2 = 0.23$]. A visual inspection of the Masker x Group interaction suggested that differences in SNRs between the speech-shaped noise and two-talker speech masker were not equivalent across the three listener groups. This interaction was examined further by performing a paired samples *t*-test (with Bonferroni correction) for each group of children. This analysis revealed significantly greater masking for the two-talker masker than for the noise masker for both younger ($t_9 = 8.14$, $p < 0.0001$) and older ($t_6 = 3.7$, $p = 0.01$) children with hearing loss. In contrast, no significant difference between masker conditions was observed for children with normal hearing ($t_9 = 0.14$, $p = 0.9$).

Figures 2 and 3 show SNRs for individual listeners tested in the speech-shaped noise and two-talker speech maskers, respectively. Data for individual listeners are plotted as a function of age. Black filled circles indicate performance for the 10 youngest children with hearing loss. Grey filled triangles indicate performance for the 7 oldest children with hearing loss. Open squares indicate performance for the children with normal hearing. The effects observed in the individual data are in general agreement with those in the group data. As shown in Figure 2, most children with normal hearing performed better in the presence of the noise compared to children with hearing loss. However, SNRs for four of the children with hearing loss (HL3, HL6, HL8, and HL14) were within the range of performance observed for children with normal hearing. As shown in Figure 3, SNRs for six children with normal hearing in the two-talker masker condition were −5 dB or lower, with estimates for the remaining four children with normal hearing ranging from −2.8 to −0.7 dB. In contrast, none of the SNRs for children with hearing loss were lower than −3 dB in the presence of the two-talker masker.

Considerable between-subjects variability was observed for all three groups of children. Younger and older children with hearing loss and children with normal hearing were about equally variable in the speech-shaped noise masker. In addition, there was no apparent difference in variability between the two masker conditions for either group of children with hearing loss. In contrast, children with normal hearing were more variable in the two-talker speech than in the speech-shaped noise masker. This is evident in the error bars displayed in Figure 1, which are 2.5 times as large for children with normal hearing in the two-talker condition than in any of the other datasets.

The influence of degree of hearing loss on the data obtained from all 17 children with hearing loss is considered next. Figure 4 shows the relation between the pure-tone average (PTA) thresholds (500, 1000, and 2000 Hz) in the better ear and the SNR estimates for the noise (top panel) and two-talker (bottom panel) maskers. For the noise masker, a significant correlation ($p < 0.05$) of $r = 0.53$ was observed between the PTA thresholds and SNR estimates. The line in the top panel represents the best linear least squares fit to the data. This correlation was positive, indicating that the SNR required for 70.7% correct spondee identification performance increased as degree of hearing loss increased. In contrast, no significant correlation was observed between PTA thresholds and SNR estimates for the two-talker masker ($p = 0.42$). A similar pattern of results was obtained comparing the high-frequency PTA (2000, 4000, and 8000 Hz).

DISCUSSION

The present results support the hypothesis that hearing loss influences children's perceptual processing abilities. Children with hearing loss required a more advantageous SNR than children with normal hearing to achieve similar performance in the presence of either speech-shaped noise or a two-talker speech masker. However, the between-groups difference was larger for the two-talker masker. The a priori expectation was that the two-talker masker would interfere with the target speech via both peripheral (energetic) and perceptual (informational) masking, whereas the speech-shaped noise masker would produce primarily peripheral effects.

Effect of hearing loss on children's performance in speech-shaped noise

For the speech-shaped noise masker, children with normal hearing had an average SNR advantage of 3.5 dB over the combined group of 17 children with hearing loss. Moreover, children's three-frequency PTA was significantly correlated with their spondee identification performance. This significant association is consistent with the idea that the amount of masking produced by the speech-shaped noise masker reflects, at least in part, deficits in peripheral processing. Overall, the present results are in agreement with previous studies showing poorer speech recognition in noise or multi-talker babble for children with sensorineural hearing loss compared to age-matched children with normal hearing (e.g., Finitzo-Hieber & Tillman 1978; Crandell 1993; Gravel et al. 1999; Hicks & Tharpe 2002; Rance et al. 2007). However, the average difference of 3.5 dB observed here is smaller than the 6.1 dB difference observed between children with normal hearing and children with sensorineural hearing loss by Rance et al. (2007). Despite using a similar 4AFC spondee identification task, differences in stimulus levels, presentation mode, and adaptive rules complicate efforts to determine the basis for the smaller SNR difference observed across groups in the present study compared to Rance et al. (2007). In that study, target spondees were presented via insert phones at a fixed level presentation level, and the masker level was varied to estimate the SNR corresponding to 79.4% correct identification. For children with either normal hearing or relatively moderate hearing loss (PTA < 50 dB HL), target spondees were presented at 70 dB SPL. For children with more severe hearing loss, the fixed presentation level was increased up to a maximum of 105 dB SPL. In contrast to Rance et al. (2007), target spondees in the present study were presented to all participants at a fixed level of 65 dB SPL; masker level was adapted to obtain an estimate of 70.7% correct spondee identification; and children with hearing loss wore their personal hearing aids during testing.

Effect of hearing loss on children's performance in two-talker speech

The most compelling result of the present study was the increased performance gap between children with hearing loss and their peers with normal hearing in the presence of the two-talker masker. Recall that children with hearing loss required an average increase in SNR of 3.5 dB to perform as well as children with normal hearing in the speech-shaped noise masker. This average disadvantage increased to 8.1 dB for the same group of 17 children in the two-talker speech masker. Moreover, this disadvantage was similar across younger (9–11 years) and older (13–17 years) children with hearing loss. The additional difficulties experienced by children with hearing loss in the two-talker masker suggest that traditional measures of speech perception obtained in quiet, in noise, or in multi-talker babble might *underestimate* the difficulties experienced by children with hearing loss when they are attempting to understand speech in the presence of a two or three competing talkers. Additional research involving a wide variety of target speech, masker combinations, and testing paradigms is needed to fully describe and quantify the specific deficits experienced by children with hearing loss in the presence of speech maskers comprised of a small number of talkers.

Effects of hearing loss on children's ability to segregate and select auditory sources

The present results provide support for the hypothesis that hearing loss interferes with perceptual processing abilities related to the segregation and selection of target from background speech. The lack of a significant correlation between performance in the two-talker masker and the three-frequency PTA is consistent with this interpretation. Previous investigators have suggested that the quality and/or quantity of auditory experiences may be reduced for children with sensorineural hearing loss compared to children with normal hearing (e.g., Carney & Moeller 1998; Stelmachowicz et al. 2004; Moeller et al. 2007a). Thus, it may take longer for children with hearing loss to accumulate the same number of auditory experiences as children with normal hearing. As a result, children with hearing loss may pass more slowly through the same stages of perceptual development than their peers with normal hearing. Alternatively, this process may be fundamentally altered in children who have had diminished or degraded access to sound. For example, a reduced ability to segregate sounds might limit how well individuals with hearing loss benefit from the improved SNR at the "dips" of a modulated noise masker (e.g., Oxenham 2008). Similar to many naturally-occurring sounds, the two-talker masker used in the current study varied in amplitude across time. In a recent study, Hall et al. (2012) compared masked speech reception thresholds between children with hearing loss and children with normal hearing in either a temporally-modulated or a steady-state noise masker. The amount of masking release for temporal modulation was smaller for children with hearing loss compared to their peers with normal hearing. Similarly, several laboratories have demonstrated a smaller benefit of temporal modulation for adults with hearing loss compared to adults with normal hearing (e.g., Festen & Plomp 1990; Peters et al. 1998; Bernstein & Grant 2009).

Possible effects of hearing aid processing

It is possible that the use of fast-acting, wide-dynamic-range compression (WDRC) amplification influenced the performance of children with hearing loss to a greater extent in the two-talker compared to the noise masker. The purpose of WDRC is to maximize audibility for listeners with hearing loss by compressing the dynamic range of speech into the dynamic range of the hearing-aid user. This compression is accomplished by providing more gain for low-level than for high-level input sounds. Whereas WDRC has been shown to improve speech recognition in quiet for both adults (e.g., Jenstad & Souza 2005) and children (e.g., Marriage & Moore 2003) with hearing loss, mounting evidence suggests that WDRC may decrease adults' speech recognition in the presence of competing sounds (e.g., Souza et al. 2006). The detrimental effects of WDRC appear to be more pronounced for fluctuating backgrounds, perhaps due to distortions in temporal envelope cues (e.g., Stone & Moore 2004) and/or because it introduces additional informational masking (e.g., Shen & Lentz 2010). Previous studies on speech recognition in modulated noise with adults have shown greater detrimental effects of WDRC in listeners with greater hearing loss (Olsen et al. 2004).

The failure to find a significant correlation between the three-frequency PTA and performance in the two-talker masker undermines the possibility that WDRC played a dominant role in the particularly large effect of hearing loss observed for children with hearing loss in the two-talker masker. Since WDRC would be more pronounced in cases where greater gain was required, a detrimental effect of WDRC on performance in the two-talker masker should be associated with a negative correlation between PTA and threshold SNR. In addition, follow-up testing was completed to evaluate the potential influence of amplitude modulation in the poor performance observed for hearing-impaired children tested in the two-talker masker. Two children with hearing loss (HL6 and HL8) returned to the lab for an additional assessment. Each child repeated the spondee identification task in a baseline of the speech-shaped noise as well as in a noise that was temporally modulated to match the envelope of the two-talker speech masker. Briefly, the two-talker masker was first rectified, and then low-pass filtered at 50 Hz with a 4th order Butterworth filter. The resulting envelope was multiplied by the speech-shaped noise. For HL6, the original SNR estimates required to achieve criterion performance were −7.8 dB for the speech-shaped noise condition and 0.2 dB for the two-talker condition. In the follow-up testing, the SNR estimate in the speech-shaped noise was −7.0 dB, compared with −9.0 dB in the temporally-modulated noise. A similar pattern of results was observed for HL8. The original SNR estimates were −7.8 and −1.3 dB for the speech-shaped noise and two-talker conditions, respectively. In the second testing session, this child required an SNR of −6.3 dB in the speech-shaped noise masker and −8.0 dB SNR to achieve the same criterion level of performance in the modulated noise. These limited data suggest that, although children with hearing loss may benefit less from the provision of masker fluctuations than children with normal hearing, this explanation is unlikely to account for the pronounced difficulties observed in the two-talker masker for children with hearing loss tested in the present study. Future studies are needed to evaluate the influence of hearing loss on children's ability to benefit from temporal modulations, and on the potential effects of WDRC processing in dynamic acoustic environments.

In addition to WDRC, another factor that affected the stimulus heard by the children with hearing loss was NLFC. It is unlikely that the frequency-compression algorithm (NLFC) employed in the children's personal hearing aids is responsible for their increased difficulties in the two-talker compared to the speech-shaped noise masker. The primary goal of NLFC is to compress high-frequency information into lower frequency regions. While this strategy appears to improve speech recognition in quiet for many children with hearing loss (e.g., Glista et al. 2009; Wolfe et al. 2010), it is possible that NLFC could negatively influence speech recognition in fluctuating maskers by reducing the perceptual distinctiveness of spectral features that aid in the separation of target and background speech. However, supplemental data collected from two additional children with hearing loss are inconsistent with the idea that the pronounced masking effects observed in the two-talker masker were the result of active NLFC processing. These two children (8 yr 7 mo and 10 yr 7 mo) met all of the study criteria, but were fitted with hearing aids that did not have active NLFC processing. For the speech-shaped noise masker, the SNR estimates were −0.3 dB for the 8-year-old and −6.2 dB for the 10-year-old. For the two-talker masker, the corresponding SNR estimates were 1.2 and −0.2 dB. Recall that SNR estimates for all 17 children with hearing loss (with active NLFC processing) ranged from −7.8 to −1.3 dB in the speech-shaped noise masker, and from −3.3 to 3.0 dB in the two-talker masker.

Potential Implications

The current findings have clinical implications. A primary goal for the pediatric audiologist is to narrow the functional performance gap between children with hearing loss and their peers with normal hearing. It is becoming increasingly evident, however, that conventional audiometric measures are poor predictors of the difficulties children with hearing loss experience in natural acoustic environments. The present data indicate the need to incorporate clinical tools that are not solely dependent on audibility in order to provide valuable information about the perceptual strategies children with hearing loss rely on in complex acoustic environments.

An important issue to highlight is that children with normal hearing are more susceptible to masking than adults for speech maskers comprised of 1–2 talkers (e.g., Hall et al. 2002; Bonino et al. 2012; Leibold et al. 2011). For example, Hall et al. (2002) compared spondee identification thresholds across children (5–10 years) and adults with normal hearing in the presence of a continuous two-talker or a speech-shaped noise masker. The child-adult difference in average threshold was about 4 dB for the two-talker condition, compared to about 2 dB for the speech-shaped noise condition. Similar child-adult differences have been observed in two-talker maskers for monosyllabic word recognition (Bonino et al. 2012), and consonant identification (Leibold et al. 2011). In addition to age effects, adults with hearing loss appear to have more difficulty understanding speech in the presence of speech maskers compared to adults with normal hearing (e.g., Hornsby et al. 2006; Helfer & Freyman 2008). These results suggest that both children with normal hearing and adults with hearing loss are at a disadvantage relative to adults with normal hearing in real-life environments where they must rely on the ability to process important sounds in the presence of competing streams of speech. Further study is warranted to determine the magnitude of child-adult differences in listeners with hearing loss.

Despite the growing interest in the development of more realistic measures of complex listening skills for children with hearing loss, many unresolved questions remain. For example, few normative data are available for rigorous measures of complex auditory perception. Moreover, the available research data indicate age-related changes in these abilities throughout childhood. Thus, it is not clear what is ‘within normal limits’ for most measures of complex listening. What is clear, however, is that hearing loss in children can be more detrimental when target speech is presented in a complex than in a steady state masker. Future research should examine whether the findings reported here generalize to the larger, more diverse population of children and adolescents with hearing loss. The feasibility of incorporating laboratory measures of complex listening ability into clinical assessments should also be evaluated, as well as the validity of these measures in predicting functional listening abilities of hearing impaired listeners in natural listening environments.

Acknowledgments

Source of Funding

Patricia Roush is a member of the Pediatric Advisory Board for Phonak AG.

This work was supported by the March of Dimes Foundation (#5-FY10-28) and by the National Institute of Deafness and Other Communication Disorders (R01 DC011038). We are grateful to the members of the Human Auditory Development Laboratory for their assistance with data collection. Crystal Taylor, Ryan McCreery and Patricia Stelmachowicz provided helpful comments on earlier versions of this manuscript.

References

ANSI. Methods for Manual Pure-tone Threshold Audiometry. ANSI S3.21–2004. New York, NY: American National Standards Institute; 2004.

Bernstein JG, Grant KW. Auditory and auditory-visual intelligibility of speech in fluctuating maskers for normal-hearing and hearing-impaired listeners. J Acoust Soc Am. 2009; 125:3358–3372. [PubMed: 19425676]

Bonino AY, Leibold LJ, Buss E. Release from perceptual masking in children and adults: benefit of a carrier phrase. Ear Hear. 201210.1097/AUD.0b013e31825e2841

Boothroyd A. Auditory perception of speech contrasts by subjects with sensorineural hearing loss. J Speech Hear Res. 1984; 27:134–144. [PubMed: 6716999]

Brungart DS. Informational and energetic masking effects in the perception of two simultaneous talkers. J Acoust Soc Am. 2001; 109:1101–1109. [PubMed: 11303924]

Carhart R, Tillman TW, Greetis ES. Perceptual masking in multiple sound backgrounds. J Acoust Soc Am. 1969; 45:694–703. [PubMed: 5776931]

Carney AE, Moeller MP. Treatment efficacy: hearing loss in children. J Speech Lang Hear Res. 1998; 41:S61–S84. [PubMed: 9493747]

Crandell CC. Speech recognition in noise by children with minimal degrees of sensorineural hearing loss. Ear Hear. 1993; 14:210–216. [PubMed: 8344478]

Eggermont, JJ.; Moore, JK. Morphological and functional development of the auditory nervous system. In: Werner, LA.; Fay, RR.; Popper, AN., editors. Human Auditory Development. New York, NY: Springer; 2012. p. 61-106.

Eisenberg, LS.; Johnson, KC.; Ambrose, SE., et al. Atypical auditory development and effects of experience. In: Werner, LA.; Fay, RR.; Popper, AN., editors. Human Auditory Development. New York, NY: Springer; 2012. p. 255-278.

Elliott LL, Connors S, Kille E, et al. Children's understanding of monosyllabic nouns in quiet and noise. J Acoust Soc Am. 1979; 66:12–21. [PubMed: 489827]

Festen JM, Plomp R. Effects of fluctuating noise and interfering speech on the speech-reception threshold for impaired and normal hearing. J Acoust Soc Am. 1990; 88:1725–1736. [PubMed: 2262629]

Finitzo-Hieber T, Tillman T. Room acoustic effects on monosyllabic word discrimination ability for normal and hearing-impaired children. J Speech Hear Res. 1978; 21:440–458. [PubMed: 713515]

Freyman RL, Balakrishnan U, Helfer KS. Effect of number of masking talkers and auditory priming on informational masking in speech recognition. The J Acoust Soc Am. 2004; 115:2246–2256.

Glista, D.; Scollie, S. [Accessed April 22, 2012] Modified verification approaches for frequency lowering devices. Audiology Online #2301. 2009. from: http://www.audiologyonline.com/Articles/article_detail.asp?article_id=2301

Glista D, Scollie S, Bagatto M, et al. Evaluation of nonlinear frequency compression: clinical outcomes. Int J Audiol. 2009; 48:632–644. [PubMed: 19504379]

Gravel JS, Fausel N, Liskow C, et al. Children's speech recognition in noise using omni-directional and dual-microphone hearing aid technology. Ear Hear. 1999; 20:1–11. [PubMed: 10037061]

Hall JW, Buss E, Grose JH, et al. Effects of age and hearing impairment on the ability to benefit from temporal and spectral modulation. Ear Hear. 2012; 33:340–348. [PubMed: 22237164]

Hall JW, Grose JH, Buss E, et al. Spondee recognition in a two-talker masker and a speech-shaped noise masker in adults and children. Ear Hear. 2002; 23:159–165. [PubMed: 11951851]

Helfer KS, Freyman RL. Aging and speech-on-speech masking. Ear Hear. 2008; 29:87–98. [PubMed: 18091104]

Hicks CB, Tharpe AM. Listening effort and fatigue in school-age children with and without hearing loss. J Speech Lang Hear Res. 2002; 45:573–584. [PubMed: 12069009]

Hornsby BWY, Ricketts TA, Johnson EE. The effects of speech and speechlike maskers on unaided and aided speech recognition in persons with hearing loss. J Am Acad Audiol. 2006; 17:432–447. [PubMed: 16869056]

Jenstad LM, Souza PE. Quantifying the effect of compression hearing aid release time on speech acoustics and intelligibility. J Speech Lang Hear Res. 2005; 48:651–667. [PubMed: 16197279]

Leibold, LJ. Development of Auditory Scene Analysis and Auditory Attention. In: Werner, LA.; Fay, RR.; Popper, AN., editors. Human Auditory Development. New York, NY: Springer; 2012. p. 137-162.

Leibold, LJ.; Hillock-Dunn, A.; Buss, E. Children's identification of consonants in a two-talker masker or speech-shaped noise. 2012 Meeting of the American Auditory Society; Scottsdale, AZ. 2011.

Levitt H. Transformed up-down methods in psychoacoustics. J Acoust Soc Am. 1971; 49:467–477. [PubMed: 5541744]

Marriage JE, Moore BCJ. New speech tests reveal benefit of wide-dynamic-range, fast-acting compression for consonant discrimination in children with moderate-to-profound hearing loss. Int J Audiol. 2003; 42:418–425. [PubMed: 14582638]

McCreery RW, Stelmachowicz PG. Audibility-based predictions of speech recognition for children and adults. J Acoust Soc Am. 2011; 130:4070–4081. [PubMed: 22225061]

Moeller MP. Early intervention and language development in children who are deaf and hard of hearing. Pediatrics. 2000; 106:1–9. [PubMed: 10878140]

Moeller MP. Language development: new insights and persistent puzzles. Semin Hear. 2011; 32:172–181.

Moeller MP, Hoover B, Putman C, et al. Vocalizations of Infants with Hearing Loss Compared with Infants with Normal Hearing: Part I - Phonetic Development. Ear Hear. 2007a; 28:605–627. [PubMed: 17804976]

Moeller MP, Hoover B, Putman C, et al. Vocalizations of Infants with Hearing Loss Compared with Infants with Normal Hearing: Part II - Transition to Words. Ear Hear. 2007b; 28:628–642. [PubMed: 17804977]

Moore BCJ. Perceptual consequences of cochlear hearing loss and their implications for the design of hearing aids. Ear Hear. 1996; 17:133–160. [PubMed: 8698160]

Moore, BCJ. Cochlear Hearing Loss. London, England: Whurr; 1998.

Moore JK, Linthecum FH. The human auditory system: a timeline of development. Int J Audiol. 2007; 46:460–478. [PubMed: 17828663]

Neuman AC, Hochberg I. Children's perception of speech in reverberation. J Acoust Soc Am. 1983; 73:2145–2149. [PubMed: 6875100]

Neuman AC, Wroblewski M, Hajicek J, et al. Combined effects of noise and reverberation on speech recognition performance of normal-hearing children and adults. Ear Hear. 2010; 31:336–344. [PubMed: 20215967]

Nishi K, Lewis DE, Hoover BM, et al. Children's recognition of American English consonants in noise. J Acoust Soc Am. 2010; 127:3177–3188. [PubMed: 21117766]

Nittrouer S, Boothroyd A. Context effects in phoneme and word recognition by young children and older adults. J Acoust Soc Am. 1990; 87:2705–2715. [PubMed: 2373804]

Olsen HL, Olofsson A, Hagerman B. The effect of presentation level and compression characteristics on sentence recognition in modulated noise. Int J Audiol. 2004; 43:283–294. [PubMed: 15357412]

Oxenham AJ. Pitch perception and auditory stream segregation: implications for hearing loss and cochlear implants. Trends Amplif. 2008; 12:316–331. [PubMed: 18974203]

Peters RW, Moore BC, Baer T. Speech reception thresholds in noise with and without spectral and temporal dips for hearing-impaired and normally hearing people. J Acoust Soc Am. 1998; 103:577–587. [PubMed: 9440343]

Rance G, Barker E, Mok M, et al. Speech perception in noise for children with auditory neuropathy/dys-synchrony type hearing loss. Ear Hear. 2007; 28:351–360. [PubMed: 17485984]

Scollie SD. Children's speech recognition scores: the speech intelligibility index and proficiency factors for age and hearing level. Ear Hear. 2008; 29:543–556. [PubMed: 18469717]

Scollie S, Seewald R, Cornelisse L, et al. The desired sensation level multistage input/output algorithm. Trends Amplif. 2005; 9:159–197. [PubMed: 16424945]

Shen Y, Lentz JJ. Effect of fast-acting compression on modulation detection interference for normal hearing and hearing impaired listeners. J Acoust Soc Am. 2010; 127:3654–3665. [PubMed: 20550264]

Sininger YS, Grimes A, Christensen E. Auditory development in early amplified children: factors influencing auditory-based communication outcomes in children with hearing loss. Ear Hear. 2010; 31:166–185. [PubMed: 20081537]

Souza PE, Jenstad LM, Boike KT. Measuring the acoustic effects of compression amplification on speech in noise. J Acoust Soc Am. 2006; 119:41–44. [PubMed: 16454262]

Stelmachowicz PG, Pittman AL, Hoover BM, et al. The importance of high-frequency audibility in the speech and language development of children with hearing loss. Arch Otolaryngol Head Neck Surg. 2004; 130:556–562. [PubMed: 15148176]

Stelmachowicz, PG. Pediatric amplification: Past, present and future. In: Bamford, J.; Seewald, R., editors. A Sound Foundation through Early Amplification. Staefa, Switzerland: Phonak AG; 2004. p. 27-40.

Stone MA, Moore BCJ. Side effects of fast-acting, dynamic range compression that affect intelligibility in a competing speech task. J Acoust Soc Am. 2004; 116:2311–2323. [PubMed: 15532662]

Wightman FL, Kistler DJ. Informational masking of speech in children: Effects of ipsilateral and contralateral distracters. J Acoust Soc Am. 2005; 118:3164–3176. [PubMed: 16334898]

Wolfe J, John A, Schafer E, et al. Evaluation of nonlinear frequency compression for school-age children with moderate to moderately severe hearing loss. J Am Acad Audiol. 2010; 21:618–628. [PubMed: 21376003]

Yoshinago-Itano C, Sedley AL, Coulter DK, et al. Language of early- and later-identified children with hearing loss. Pediatrics. 1998; 5:1161–1171.

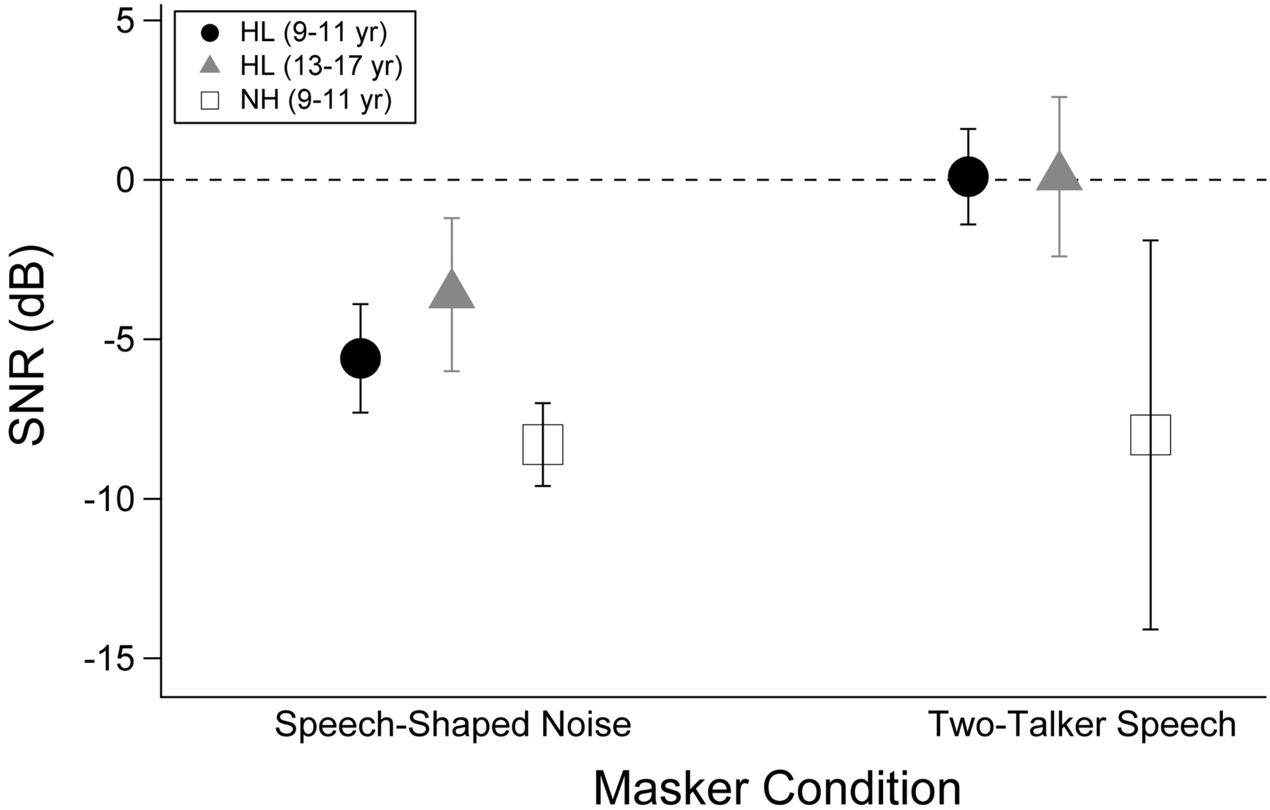

Figure 1.
Average SNRs at threshold across listeners (+/− 1 SD) are shown for each of the three groups (black circles for younger children with hearing loss, grey triangles for older children with hearing loss, and open squares for children with normal hearing). Data for the speech-shaped noise masker are presented to the left, and data for the two-talker speech masker are presented to the right. The dotted horizontal line indicates 0 dB SNR.

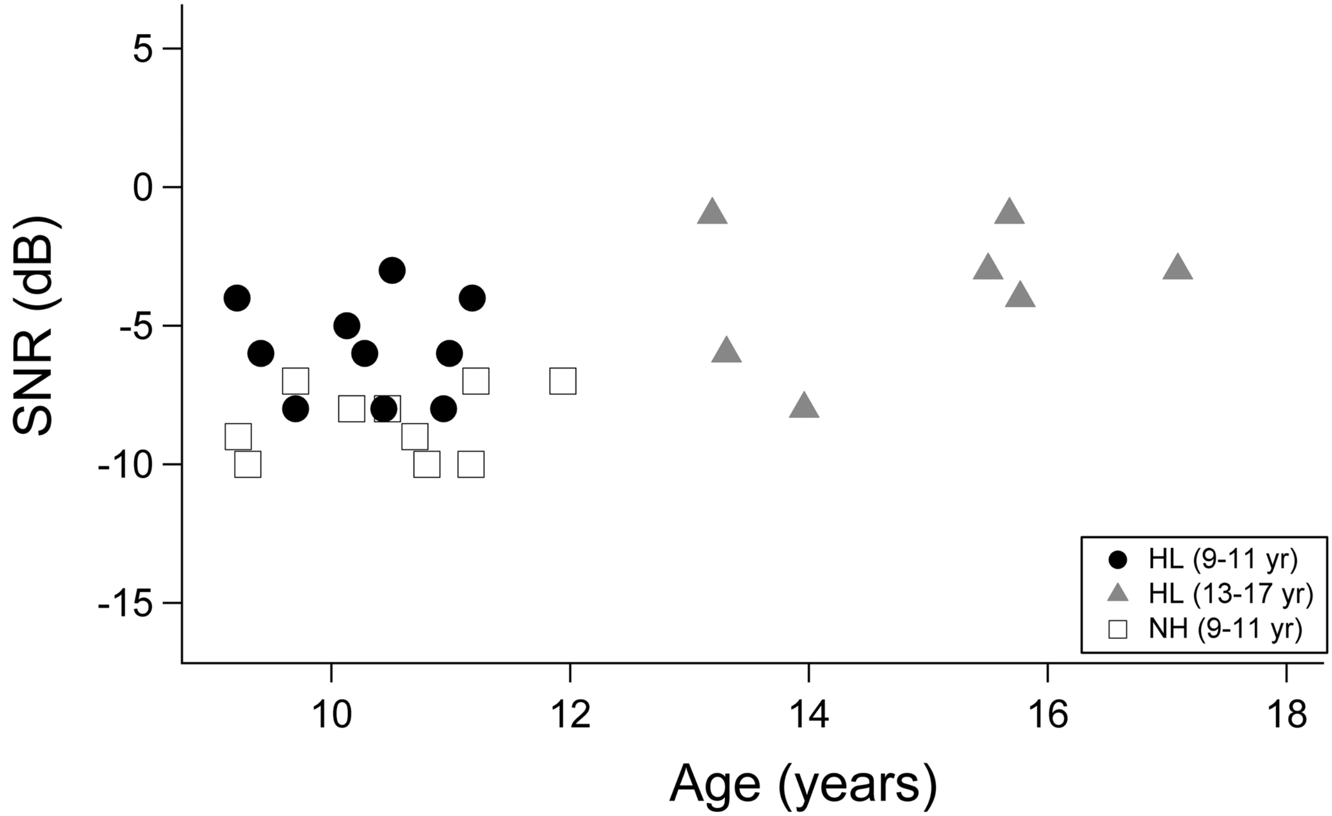

Figure 2.
Individual SNRs at threshold in the speech-shaped noise masker are plotted as a function of age. The black circles show SNRs for the 10 younger children with hearing loss, the grey triangles show SNRs for the 7 older children with hearing loss, and the open squares show SNRs for the 10 children with normal hearing.

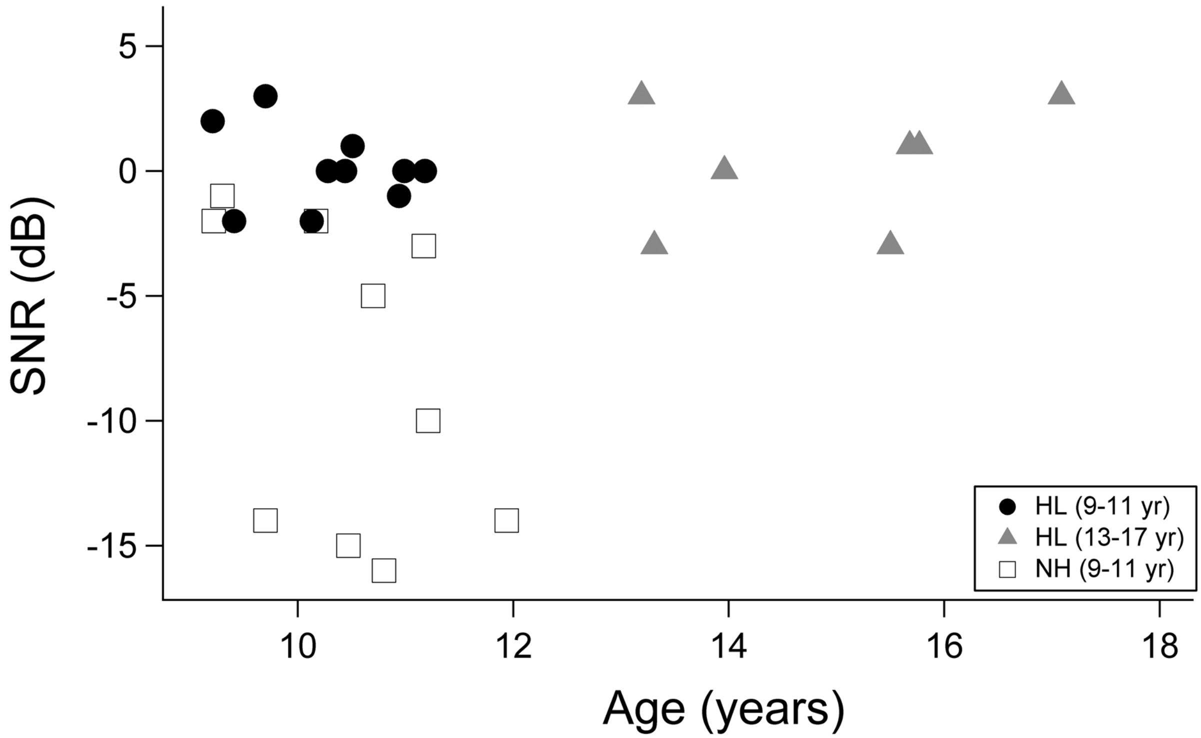

Figure 3.
Individual SNRs at threshold in the two-talker speech masker are plotted as a function of age. The black circles show SNRs for the 10 younger children with hearing loss, the grey triangles show SNRs for the 7 older children with hearing loss, and the open squares show SNRs for the 10 children with normal hearing.

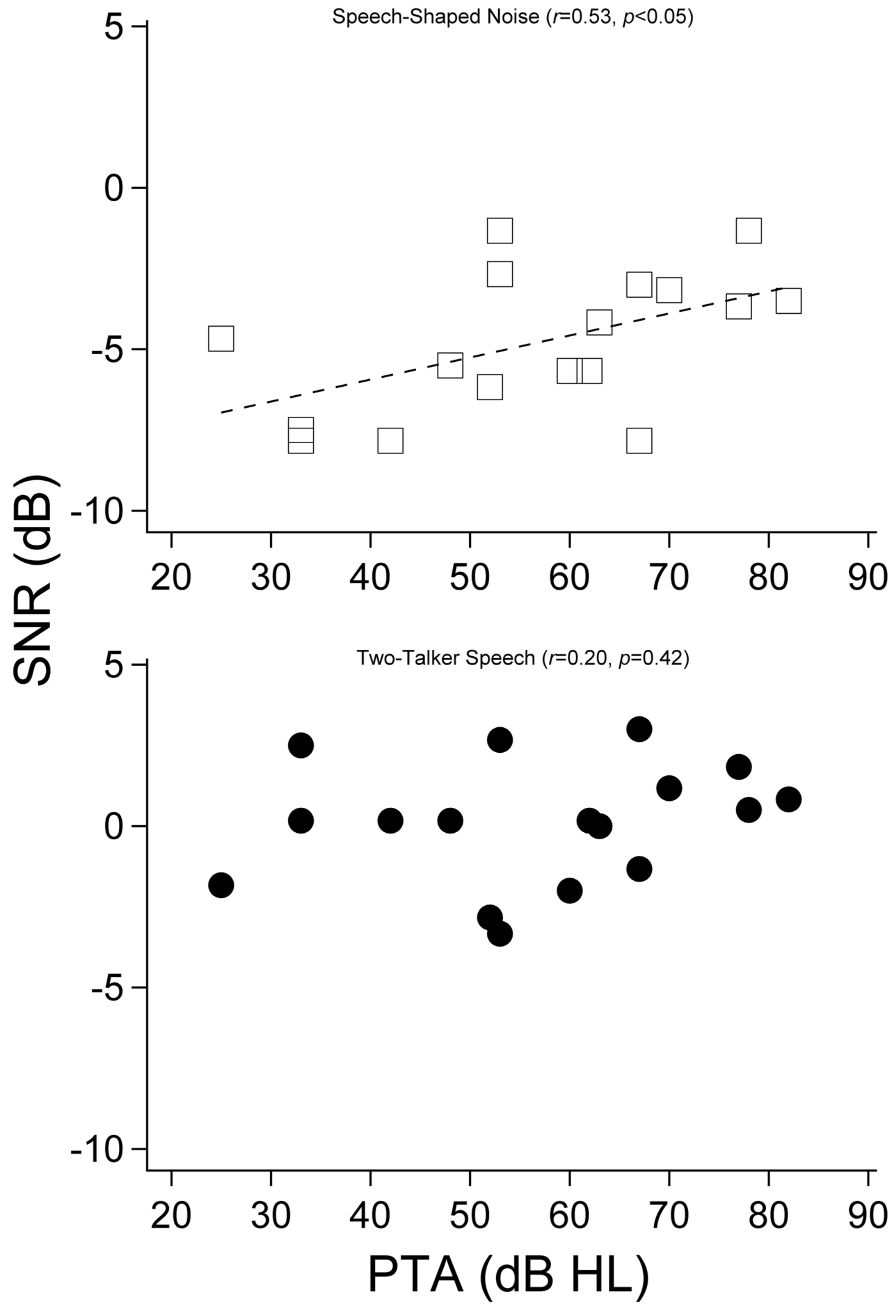

Figure 4.
Scatterplots of the three-frequency PTA as a function of the SNR at threshold are shown for the 17 children with hearing loss in the speech-shaped noise (top) and the two-talker masker (bottom). The correlation coefficient is provided for each linear regression.

NIH-PA Author Manuscript

NIH-PA Author Manuscript

TABLE 1

Demographic and hearing aid information for children with hearing loss (n=17).

Subject	Sex	Age at testing (yr:mo)	Age at first fitting (yr:mo)	Duration hearing aid use (yr:mo)	Amplification (Phonak)	Duration NLFC (yr:mo)
HL1	F	9:3	0:5	9:2	Exelia Art M	1:5
HL2	M	9:5	2:0	7:5	Naida V SP	1:9
HL3	F	9:8	4:2	5:7	Solana micro P	0:1
HL4	F	10:2	5:3	4:11	Exelia micro	0:9
HL5	M	10:3	0:2	10:1	Naida IX SP	2:5
HL6	F	10:5	0:4	10:1	Nios micro V	1:7
HL7	M	10:6	5:7	5:2	Naida V SP	2:0
HL8	M	10:11	0:3	10:8	Naida V SP	2:2
HL9	F	11:00	0:6	10:9	Naida IX SP	0:8
HL10	F	11:2	3:3	7:11	Nios micro V	1:11
HL11	F	13:2	4:3	8:11	Naida V SP	1:7
HL12	F	13:4	5:0	8:4	Exelia Art SP	0:7
HL13	F	14:0	4:1	9:10	Nios micro V	0:7
HL14	F	15:6	6:0	9:6	Naida V SP	2:1
HL15	M	15:8	3:0	12:8	Naida IX SP	3:0
HL16	M	15:9	2:1	12:11	Naida V SP	1:9
HL17	F	17:1	3:0	14:0	Naida V SP	2:4

TABLE 2

Pure-tone thresholds (dB HL) in the better ear are provided for individual children with hearing loss (n=17). The three-frequency pure-tone average (500, 1000, and 2000 Hz) for each child is shown in the far right column.

	Frequency (Hz)						
Subject	**250**	**500**	**1000**	**2000**	**4000**	**8000**	**3-freq PTA**
HL1	60	70	85	75	70	65	77
HL2	35	60	65	55	50	60	60
HL3	30	30	35	35	10	0	33
HL4	10	10	10	55	80	75	25
HL5	50	55	65	65	60	65	62
HL6	10	10	50	65	60	60	42
HL7	50	55	75	80	100	NR	70
HL8	55	65	65	70	70	65	67
HL9	35	40	55	50	50	65	48
HL10	10	25	60	105	110	NR	63
HL11	25	35	55	70	65	70	53
HL12	30	40	55	60	50	30	52
HL13	0	5	5	90	95	75	33
HL14	30	40	45	75	85	NR	53
HL15	40	65	80	90	90	NR	78
HL16	50	65	90	90	85	NR	82
HL17	15	20	75	105	105	95	67