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Research Article

Pediatric Hearing Loss and Speech Recognition in Quiet and in Different Types of Background Noise

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Purpose: Speech recognition deteriorates with hearing loss, particularly in fluctuating background noise. This study examined how hearing loss affects speech recognition in different types of noise to clarify how characteristics of the noise interact with the benefits listeners receive when listening in fluctuating compared to steady-state noise.
Method: Speech reception thresholds were measured for a closed set of spondee words in children (ages 5–17 years) in quiet, speech-spectrum noise, 2-talker babble, and instrumental music. Twenty children with normal hearing and 43 children with hearing loss participated; children with hearing loss were subdivided into groups with cochlear implant (18 children) and hearing aid (25 children) groups. A cohort of adults with normal hearing was included for comparison.
Results: Hearing loss had a large effect on speech recognition for each condition, but the effect of hearing loss was largest in 2-talker babble and smallest in speech-spectrum noise. Children with normal hearing had better speech recognition in 2-talker babble than in speech-spectrum noise, whereas children with hearing loss had worse recognition in 2-talker babble than in speech-spectrum noise. Almost all subjects had better speech recognition in instrumental music compared to speech-spectrum noise, but with less of a difference observed for children with hearing loss.
Conclusions: Speech recognition is more sensitive to the effects of hearing loss when measured in fluctuating compared to steady-state noise. Speech recognition measured in fluctuating noise depends on an interaction of hearing loss with characteristics of the background noise; specifically, children with hearing loss were able to derive a substantial benefit for listening in fluctuating noise when measured in instrumental music compared to 2-talker babble.

Foundational work on speech recognition was conducted by French and Steinberg (1947), in which they investigated effects of speech intensity, background noise, filtering, and the overarching effects of hearing loss. The articulation index model that they developed, which models the intelligibility of speech as a weighted combination of signal-to-noise ratios in contiguous frequency bands, has been influential for the past 70 years. Around the same time as that development, pioneering work was conducted regarding how speech recognition is affected by interrupting either the target speech or the background noise in a fluctuating manner (Miller, 1947; Miller & Licklider, 1950).

Following those innovative studies, data emerged clarifying how hearing loss differentially affects speech recognition in fluctuating compared to steady-state noise (e.g., Carhart & Tillman, 1970; Jokinen, 1973; Lindeman, 1967; Palva, 1955). These studies demonstrated that the advantage that listeners with normal hearing have for listening in fluctuating compared to steady-state noise is dramatically reduced by hearing loss. Plomp (1978, 1986) provided a concise and influential model explaining these results in terms of audibility and distortion. Since the development of that model, numerous studies have demonstrated the detrimental effect of hearing loss on speech recognition in fluctuating compared to steady-state noise (e.g., Buss, Leibold, Porter, & Grose, 2017; Bronkhorst & Plomp, 1992; Eisenberg, Dirks, & Bell, 1995; Festen & Plomp, 1990; George, Festen, & Houtgast, 2006; Gustafsson & Arlinger, 1993; Hygge, Ronnberg, Larsby, & Arlinger, 1992; Jin, Nie, & Nelson, 2013; Nelson, Jin, Carney, & Nelson, 2003; Peters, Moore, & Baer, 1998; Snell, Mapes, Hickman, & Frisina, 2002; Stuart & Phillips, 1996; Takahashi & Bacon, 1992; Wagener & Brand, 2005).

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For hearing aid users, it has been shown that amplification does not restore the advantage for speech recognition in fluctuating noise (e.g., George et al., 2006). Bernstein and Grant (2009) argued that part of this loss derives from needing to test people with hearing loss using higher signal-to-noise ratios. For cochlear implant users, several articles have described some particularly dramatic results for speech recognition in fluctuating noise, with some individuals having "poorer" speech recognition in fluctuating noise (Fu & Nogaki, 2004; Kwon, Perry, Wilhelm, & Healy, 2012; Nelson & Jin, 2004; Nelson et al., 2003; Qin & Oxenham, 2003; Stickney, Zeng, Litovsky, & Assmann, 2004). Many of those studies were conducted using simulations of cochlear implant signal processing, however, and recent work has demonstrated a broad range of outcomes for actual cochlear implant users, with the average user receiving an advantage in fluctuating compared to steady-state noise (Goldsworthy, 2015; Goldsworthy, Delhorne, Braida, & Reed, 2013; Jin et al., 2013).

The preceding introduction summarizes some of the history regarding how hearing loss affects speech recognition in fluctuating compared to steady-state noise. In parallel with that literature, others have studied how speech recognition changes during development (e.g., Eisenberg, Shannon, Martinez, Wygonski, & Boothroyd, 2000; Leibold, Hillock-Dunn, Duncan, Roush, & Buss, 2013; Nishi, Lewis, Hoover, Choi, & Stelmachowicz, 2010). Numerous factors affecting speech recognition and potential differences between children and adults have been investigated, including spatial hearing (Johnstone & Litovsky, 2006), the presence or absence of a carrier phrase (Bonino, Leibold, & Buss, 2013; Lynn & Brotman, 1981), visual cues (Wightman, Kistler, & Brungart, 2006), speaking style of the target speech (Baker, Buss, Jacks, Taylor, & Leibold, 2014; Pittman & Wiley, 2001), and knowledge of the competing speech-language (Calandruccio, Leibold, & Buss, 2016).

Previous studies have provided evidence that differences between children and adults on speech recognition measures tend to be larger when measured in competing speech compared to steady-state noise (Buss et al., 2017; Corbin, Bonino, Buss, & Leibold, 2016; Hall, Grose, Buss, & Dev, 2002; Leibold & Buss, 2013). It has been suggested that a prolonged developmental trajectory for speech recognition in competing speech reflects maturation of central mechanisms for stream segregation and attention (Hall, Buss, Grose, & Roush, 2012; Leibold & Buss, 2013).

This study was designed to measure the effects of hearing loss on speech recognition in quiet and in different types of background noise. The noise types considered were steady-state speech-spectrum noise, two-talker babble, and instrumental music. The two fluctuating noises differ in many ways and serve to characterize speech recognition with speech and nonspeech maskers. Speech on speech masking depends on many factors, including linguistic content, voicing characteristics, and number of competitors (e.g., Brungart, 2001, 2006; Brungart, Simpson, Ericson, & Scott, 2001; Carhart, Tillman, & Greetis, 1969; Wightman & Kistler, 2005). The repeated pattern of the instrumental music likely makes it easier to segregate from the target speech, even for listeners with hearing loss. Consequently, we expect that people with hearing loss will be able to segregate the target speech from predictable background music and derive benefit compared to when listening in stationary noise.

Method

Participants

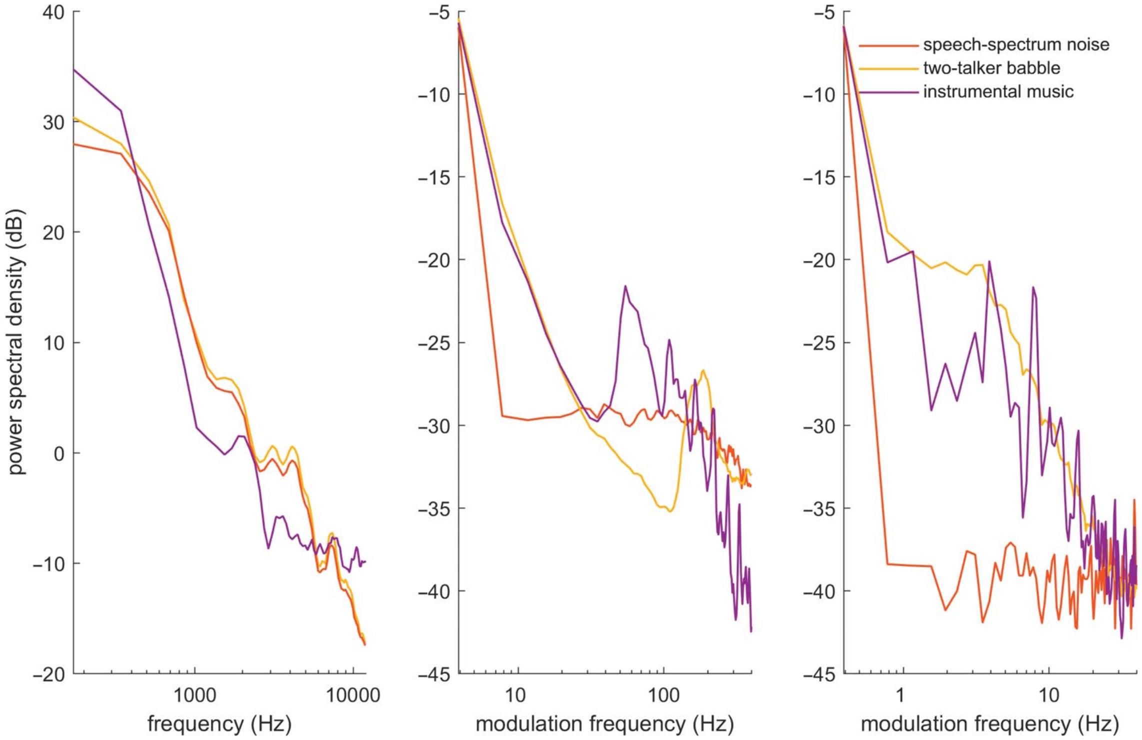
Sixty-three children between the ages of 5 and 17 years participated in this study. Participants included children with normal and impaired hearing. Normal hearing was defined as having pure-tone audiometric thresholds of 20 dB HL or better at octave frequencies between 125 and 8000 Hz and having no known history of hearing loss. Of the 63 children who participated, 20 had normal hearing and 43 had varying degrees of hearing loss. The children with hearing loss were divided into cochlear implant (18) and hearing aid (25) groups for analysis; bimodal users were classified within the cochlear implant group. Ten adults with normal hearing between the ages of 18 and 24 years also participated in this study. This research was approved by the University of Southern California Institutional Review Board.

Materials

Speech reception thresholds (SRTs) were measured in quiet and in noise using a picture-pointing word identification task with a set of 25 spondee words. This database of words and pictures is referred to as the Children's Realistic Intelligibility and Speech Perception database (Litovsky, 2005). SRTs were measured using an adaptive procedure, described below, in which the level of the target speech was adaptively varied. SRTs were measured in quiet, speech-spectrum noise, two-talker babble, and instrumental music. Sound was presented from a speaker 0.75 m directly in front of the listener. Speech-spectrum noise was synthesized by filtering white noise from a Gaussian distribution through a spectral shaping filter. The spectral shaping filter was the average of the log magnitude spectra of the two-talker babble, which was as described by Leibold and Buss (2013). The instrumental music masker was a 16-s loop of synthetic instruments made available by JewelBeat.com. This instrumental music was an easy-to-anticipate loop played in 4/4 time with a tempo of 60 beats per minute. This audio file is available from the authors at https://www.teamhearing.org/data/noise/calibrated/Exciting%20Ride.wav.

Power and modulation–power spectral densities for the three noise types are shown in Figure 1. Because the speech-spectrum noise was shaped using the power spectral estimate from the two-talker babble, those two noise types have similar profiles. The instrumental music was not explicitly shaped to have the same spectral profile and has a slightly different spectral profile with faster roll-off with increasing frequencies below 5000 Hz, but plateauing for higher frequencies compared to the other two noise types. The middle and right subplots of Figure 1 show the modulation

Figure 1. Power (left subplot) and modulation–power (middle and right subplots) analysis for the three types of background noise considered. Modulation–power spectra estimated from the Hilbert transform of the broadband signal. The right subplot is a higher resolution analysis of the modulation–power spectra presented in the middle subplot.



power spectrum for modulation frequencies between 0 and 400 Hz and with higher resolution between 0 and 40 Hz, respectively. The modulation spectrum for speech-spectrum noise is relatively flat. The modulation spectrum for two-talker babble has a prominent peak centered around 180 Hz corresponding to the fundamental frequencies of the two voices in the two-talker babble. The modulation spectrum of the instrumental music contains greater variation with multiple peaks for both the region typically corresponding to fundamental frequency (80–400 Hz), as well as for modulation rates between 1 and 20 Hz. These noise types were selected to study the effect of hearing loss in steady-state and fluctuating noise and how characteristics of fluctuating noise can affect the advantage that listeners receive when listening in fluctuating compared to steady-state noise.

Procedure

SRTs were measured using a picture-pointing word identification task using the Children's Realistic Intelligibility and Speech Perception spondee word database. In total, listeners participated in 12 measurement runs corresponding to three repetitions of the four conditions (quiet, speech-spectrum noise, two-talker babble, and instrumental music). Runs were conducted in a blocked format with a randomized condition order for each repetition. For measurements conducted in background noise, the noise was continuously presented at 64 dB SPL. The gain of the target speech was dynamically adjusted following subject responses according to an adaptive procedure. For each trial of a run, four words were randomly selected from the database, and the corresponding pictures were shown as alternatives in a graphical user interface. The target word was one of these alternatives, and the audio for the target was presented at an adaptively controlled level. The listener was instructed to press the corresponding picture of the spoken word.

For adaptive control of the target speech, the initial level was set to 70 dB SPL. After correct responses, the speech level was decreased by an amount referred to as the step size. The initial step size was 6 dB and was reduced by 1 dB after each reversal until obtaining a value of 1 dB at the fifth reversal. After incorrect responses, the target speech level was increased by three times the step size. The average of the last four reversals was taken as the SRT for the run. This adaptive rule converges to a 75% accuracy SRT (Kaernbach, 1991).

This procedure was implemented as a web application using HTML, JavaScript, and PHP programming languages. Mobile Safari implemented on an iPad was used as the browser. Sound was presented using a Bose SoundLink Bluetooth speaker. Procedures were conducted in a sound-attenuating audiometric booth. Children were tested with their personal hearing devices adjusted to their normal daily use settings.

Results

Figure 2 presents SRTs organized by subject groups as measured in quiet, speech-spectrum noise, two-talker babble, and instrumental music. Table 1 summarizes average SRTs for each group and condition. A repeated-measures analysis of variance was implemented using condition as a main factor and subject group as a random blocking factor. The effects of condition and group were significant ($p < .001$), as was the interaction between Condition × Group, $F(9, 276) = 169$, $p = .004$. Multiple-comparison analysis was completed using Tukey's honestly significant difference criterion. Across-group comparisons within a condition are labeled in Figure 2 for significance criteria of .05 (*), .01 (**), and .001 (***). Average SRTs for the speech-spectrum noise condition were not significantly different across groups, but with most of the other comparisons between children with and without hearing loss reaching significance at the .01 level.

The effect of hearing loss was estimated as the difference in SRTs between children with and without hearing loss (Cohen's *d*). The effect size comparing children with normal hearing to those in the cochlear implant group was highest, indicating better sensitivity for separating groups, for SRTs measured in two-talker babble. The effect sizes comparing children with normal hearing with those who use cochlear implants were 1.8, 1.0, 2.4, and 1.7 for SRTs measured in quiet, speech-spectrum noise, two-talker babble, and instrumental music, respectively. The narrow range of SRTs for the children who use cochlear implants contributes to the large effect size measured in two-talker babble. Similarly, effect sizes were calculated comparing children with normal hearing with those in the hearing aid group. The corresponding effect sizes were 1.0, 0.9, 1.2, and 1.2 for SRTs measured in quiet, speech-spectrum noise, two-talker babble, and instrumental music, respectively.

Confidence intervals were estimated to compare effect sizes (Fritz, Morris, & Richler, 2012; Hedges & Olkin, 1985). The very large effect size of 2.4 for the difference between SRTs measured in children with normal hearing and those who use cochlear implants when measured in two-talker babble was significantly larger than the same effect measured in speech-spectrum noise ($p < .05$). Estimated confidence intervals indicated 97% chance that the separation of SRTs between children with normal hearing and those who use cochlear implants were larger when testing in two-talker babble compared to speech-spectrum noise. No other comparison of effect sizes was significant at 95% confidence. Comparing children with normal hearing to those who use cochlear implants, the effect size was larger when measured in quiet ($d = 1.8$) compared to speech-spectrum noise ($d = 1.0$). Estimated confidence intervals indicate 86% chance that the effect size in quiet is larger than that in speech-spectrum noise.

Figure 3 presents SRTs measured in noise versus SRTs measured in quiet. Generally, the relationship between

Figure 2. Summary of speech reception thresholds in quiet and in the three background noise conditions examined. Plotted data points are averages across repetitions for each subject. The left axis of ordinate indicates the target speech level in dB SPL; for noise conditions, the background noise was continuously presented at 64 dB SPL, and the right axis of ordinate indicates the corresponding signal-to-noise ratio (SNR) for those conditions (e.g., 0 dB SNR corresponds to 64 dB SPL). On each box, the central mark indicates the median, the edges of the box indicate the 25th and 75th percentiles, the whiskers extend to the most extreme data points not considered outliers, and outliers are plotted individually.

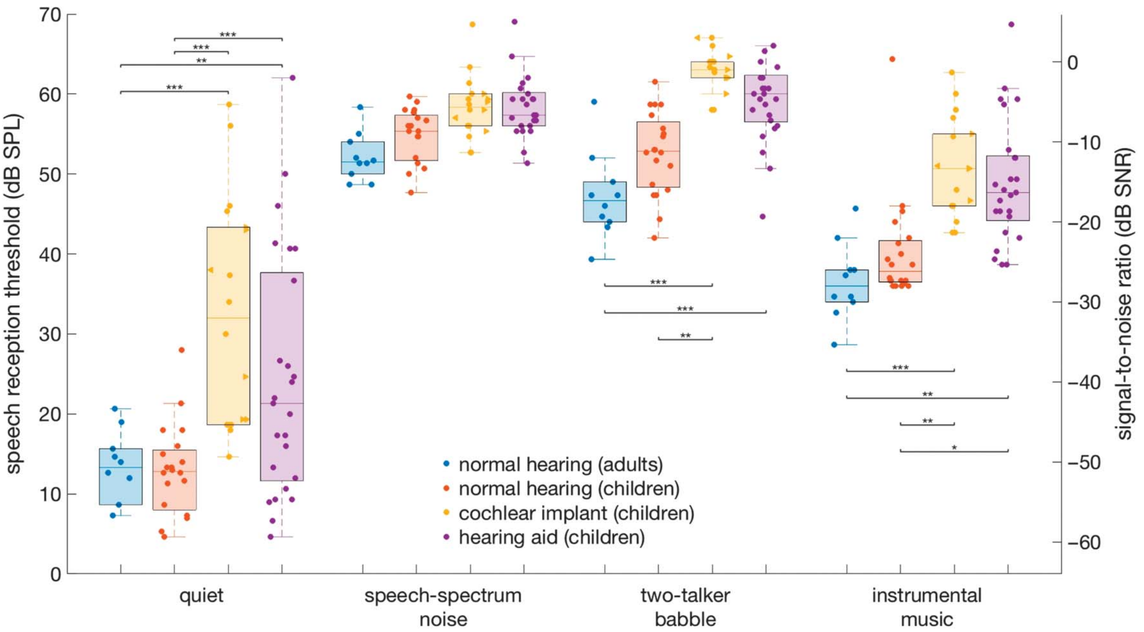


Table 1. Speech reception thresholds averaged across subject groups for each condition.

Group	Quiet	Speech-spectrum noise	Two-talker babble	Instrumental music
Normal hearing (adults)	12.0 (7.1)	52.1 (3.0)	47.2 (5.4)	36.6 (4.8)
Normal hearing (children)	12.2 (7.1)	54.7 (3.3)	52.6 (5.2)	40.2 (6.5)
Cochlear implant (children)	32.4 (14.1)	58.3 (3.8)	62.8 (2.8)	50.7 (6.0)
Hearing aid (children)	24.3 (15.2)	59.1 (5.7)	60.2 (7.2)	48.9 (7.7)

Note. Standard deviation of the mean is indicated in parentheses.

SRTs measured in noise and those measured in quiet was monotonically increasing with children who had elevated thresholds in quiet requiring more favorable speech levels when measured in noise. This relationship was modeled using linear regression fit to SRTs pooled across all subjects, children and adults. SRTs measured in speech-spectrum noise have a relatively narrow range of values (compared to SRTs measured in two-talker babble or instrumental music): Children with normal hearing typically had SRTs in the range of 50–60 dB SPL, whereas children with hearing loss had SRTs in the range of 50–65 dB SPL.

Figure 4 presents SRTs measured in the fluctuating noises versus SRTs measured in speech-spectrum noise. The left panel presents the comparison of SRTs measured in two-talker babble versus SRTs measured in speech-spectrum noise. For children with normal hearing, SRTs were generally lower when measured in two-talker babble compared to speech-spectrum noise. In contrast, for children with hearing loss, SRTs were generally higher when measured in two-talker babble compared to speech-spectrum noise. The right panel presents the comparison of SRTs measured in instrumental music versus SRTs measured in speech-spectrum noise. Almost all children obtained lower SRTs when measured in instrumental music compared to when measured in speech-spectrum noise, but the difference was larger for children with normal hearing.

Table 2 summarizes the average differences between SRTs measured in the two fluctuating noise conditions and those measured in speech-spectrum noise. This average difference between thresholds in instrumental music compared to speech-spectrum noise for children with normal hearing was 15.5 dB (±2.4), whereas the corresponding

Figure 3. Speech reception thresholds for each type of background noise plotted against speech reception thresholds in quiet. Plotted data points are averages across repetitions for each subject. The left axis of ordinate indicates the target speech level; for noise conditions, the right axis of ordinate indicates the corresponding signal-to-noise ratio (SNR). Intersecting ellipses are centered upon group means, and the major and minor axes of the ellipses indicate standard deviation and standard error, respectively. Averaged thresholds pooled across subject groups were modeled by linear regression; shaded region indicates ± RMS error.

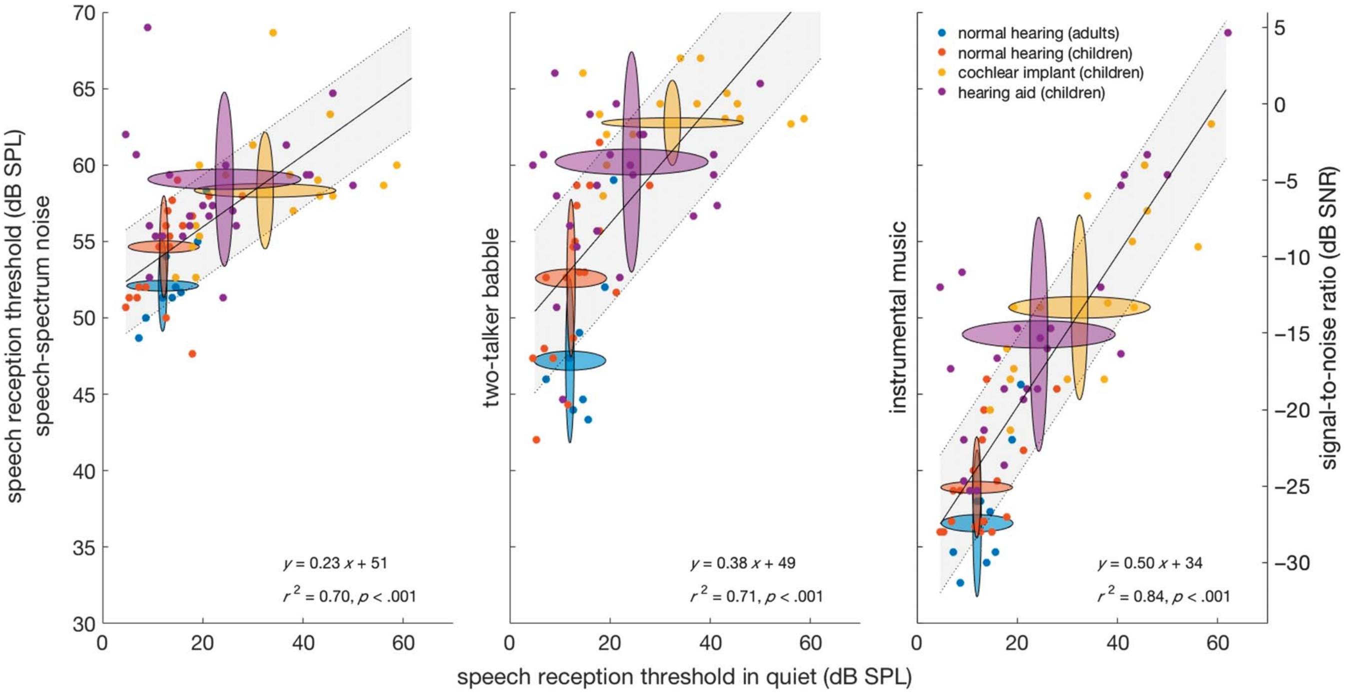
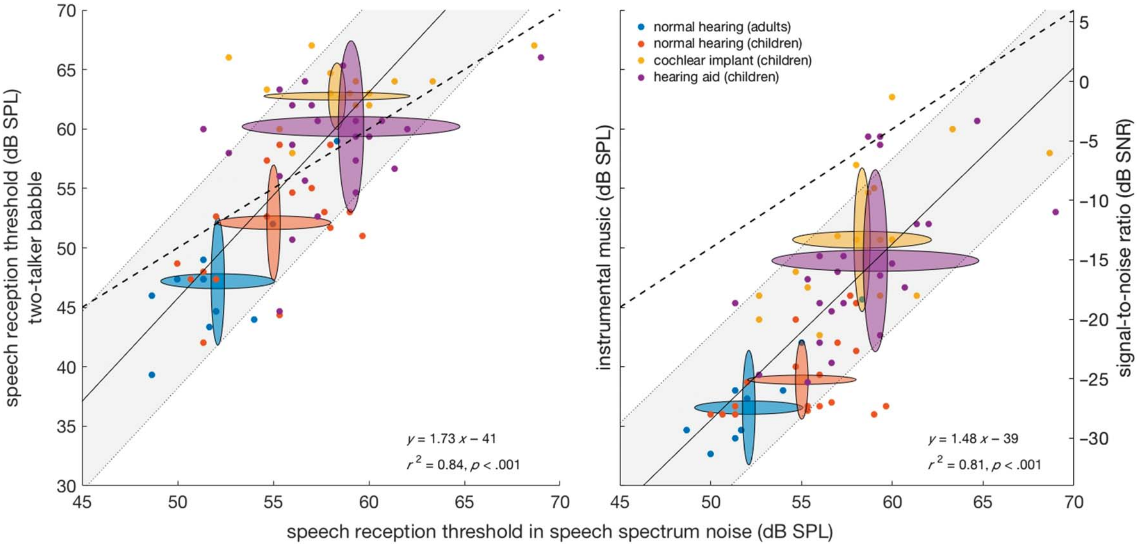


Figure 4. Speech reception thresholds for the two-talker babble and instrumental music conditions plotted against speech reception thresholds for speech-spectrum noise. Plotted data points are averages across repetitions for each subject. The left axis of ordinate indicates the target speech level; for noise conditions, the right axis of ordinate indicates the corresponding signal-to-noise ratio (SNR). Intersecting ellipses are centered upon group means, and the major and minor axes of the ellipses indicate standard deviation and standard error, respectively. The dashed line is a unity line indicating where performance for the two conditions would be the same; consequently, points falling beneath that line indicate lower thresholds for the fluctuating compared to steady-state noise conditions. Averaged thresholds pooled across subject groups were modeled by linear regression; shaded region indicates ± RMS error.



average difference was only 7.6 dB (±4.7) and 10.1 dB (±5.2) for the children in the cochlear implant and hearing aid groups, respectively. The children with the highest SRTs tended to have the smallest difference between instrumental music and speech-spectrum noise.

Figure 5 presents SRTs versus age at time of testing, and Table 3 provides the corresponding linear regression fits and statistics. SRTs generally improved with age for SRTs measured in quiet and in noise; however, age accounts for a small portion of the variability in measured SRTs. Using a liberal criterion for significance at the .1 level, age only accounts for a significant portion of the SRT variability for children with normal hearing when tested in quiet and two-talker babble and for children in the hearing aid group when tested in two-talker babble and instrumental music. Because age accounted for some of the variability in measured SRTs, we applied an age adjustment based on the analysis model and recalculated the analysis of variance to determine if the increased power changed the significance of any comparisons. The age adjustment did lower the error of the analysis of model by 10% but did not change the categorical significance for any of the comparisons.

Table 2. Average difference between speech reception thresholds measured in fluctuating and steady-state speech-spectrum noise.

Group	Two-talker babble	Instrumental music
Normal hearing (adults)	4.9 (3.6)	15.5 (2.4)
Normal hearing (children)	2.9 (4.1)	16.1 (3.5)
Cochlear implant (children)	−4.4 (3.5)	7.6 (4.7)
Hearing aid (children)	−1.1 (5.3)	10.1 (5.2)

Note. Standard deviation of the mean is indicated in parentheses.

Discussion

We studied pediatric hearing loss as it affects speech recognition in quiet and different types of background noise. The effect of hearing loss was large for all conditions, but largest when measured in two-talker babble and smallest when measured in speech-spectrum noise. The effect of hearing loss was significantly larger for children who use cochlear implants when measured in two-talker babble compared to speech-spectrum noise. These results support the argument that speech recognition is more sensitive to the effects of hearing loss when measured in competing speech compared to steady-state noise.

The two-talker babble used in this study was produced by two women reading passages from children's books (Leibold & Buss, 2013), whereas the target speech consisted of isolated words spoken by a man. The fundamental frequency differences between speech and competing speech facilitate stream segregation and speech recognition (Bressler, Masud, Bharadwaj, & Shinn-Cunningham, 2014). With hearing loss, speech recognition becomes particularly difficult in competing speech (Hossain & Goldsworthy, 2018). People who use cochlear implants have notably poor discrimination of voice fundamental frequency, which has

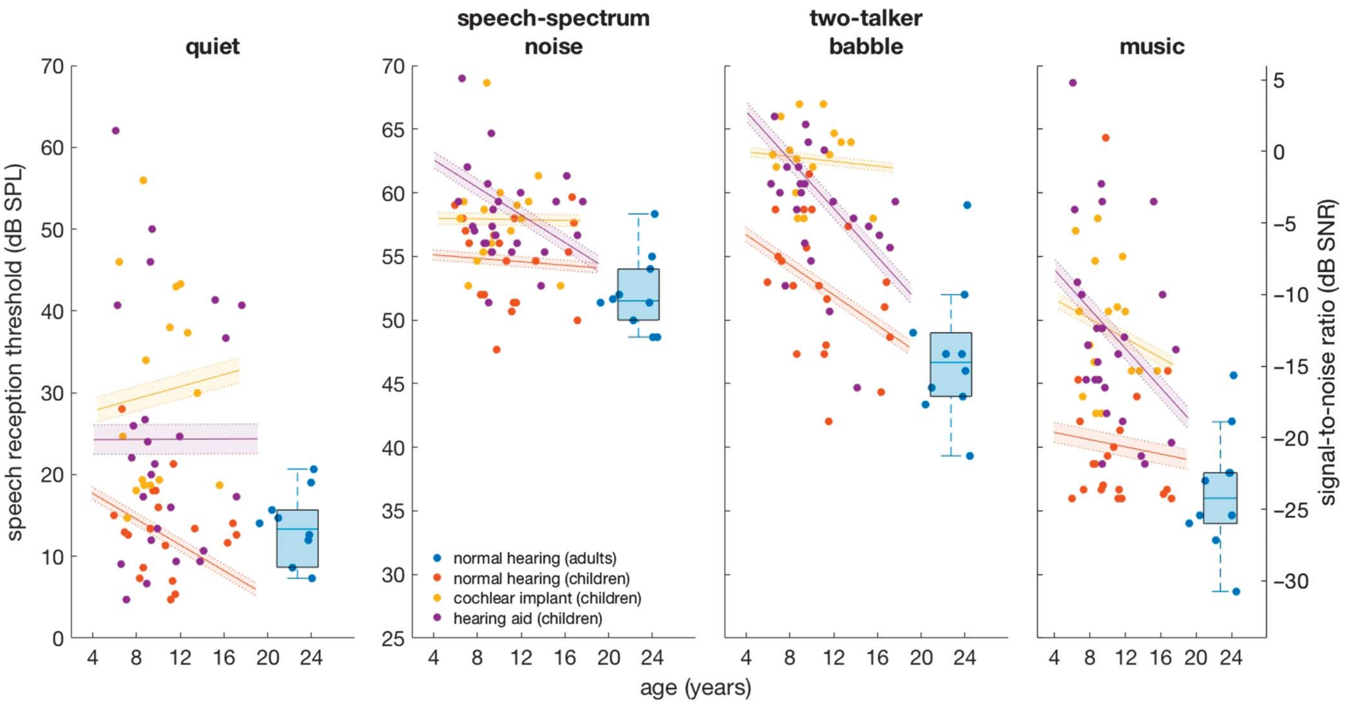


Figure 5. Measured speech reception thresholds averaged across repetitions for each participant plotted against their age. The left axis of ordinate indicates the target speech level; for noise conditions, the right axis of ordinate indicates the corresponding signal-to-noise ratio (SNR).

been shown to be correlated with speech recognition in background noise (Brown & Bacon, 2010; Goldsworthy, 2015; Zaltz, Goldsworthy, Kishon-Rabin, & Eisenberg, 2018). Poor voicing discrimination likely contributes to the consistently poor speech recognition observed in this study for children who use cochlear implants when measured in two-talker babble.

The instrumental music used here was quite different from the two-talker babble even though both were fluctuating noises. The instrumental music was a repetitive loop with a 1-Hz beat and a predictable rhythm (with strong 4- and 8-Hz components in the modulation spectrum). The acoustic differences between instrumental music and the target speech, as well as the predictability of this instrumental music, likely facilitate stream segregation in a way that is robust to hearing loss. That would explain why children with hearing loss had, on average, better speech recognition when measured in instrumental music compared to speech-spectrum noise.

Adults and children with normal hearing generally had better speech recognition measured in two-talker babble compared to speech-spectrum noise. Part of this advantage likely derives from an ability to use local spectrotemporal fluctuations to glimpse target speech (Brungart, 2006; Buss, Leibold, & Hall, 2016; Buss et al., 2017; Cooke, 2006; Hall et al., 2012; Howard-Jones & Rosen, 1993; Miller & Licklider, 1950; Stuart, 2008; Stuart, Givens, Walker, & Elangovan, 2006). With hearing loss, reduction of spectrotemporal resolution degrades the auditory representation used for such glimpsing (Bregman, 1990; Buss et al., 2017; Carhart et al., 1969; Leibold, 2017). In this study and in contrast with the children who had normal hearing, the children with hearing loss generally had worse speech recognition when measured in two-talker babble compared to when measured in speech-spectrum noise.

That children with hearing loss perform worse in two-talker babble compared to speech-spectrum noise

Table 3. Linear regression model fits and statistics for speech reception thresholds versus age (Figure 5) for each subject group and condition.

Group	Quiet	Speech-spectrum noise	Two-talker babble	Instrumental music
Normal hearing (children)	$y = -0.79x + 21$ $r^2 = .15, p = .089$	$y = -0.07x + 55$ $r^2 = .01, p = .76$	$y = -0.59x + 59$ $r^2 = .16, p = .079$	$y = -0.14x + 42$ $r^2 = .01, p = .75$
Cochlear implant (children)	$y = 0.37x + 26$ $r^2 = .01, p = .78$	$y = -0.01x + 58$ $r^2 = .00, p = .97$	$y = -0.09x + 64$ $r^2 = .01, p = .76$	$y = -0.38x + 53$ $r^2 = .04, p = .45$
Hearing aid (children)	$y = 0.01x + 24$ $r^2 = .00, p = .99$	$y = -0.54x + 65$ $r^2 = .10, p = .12$	$y = -0.95x + 70$ $r^2 = .2, p = .025$	$y = -0.77x + 57$ $r^2 = .12, p = .094$

supports the argument that hearing loss prevents them from using local spectrotemporal fluctuations in the noise. However, children with hearing loss had much better speech recognition when measured in instrumental music compared to speech-spectrum noise (see Figure 4, right). Although not as large as the advantage observed for adults or children with normal hearing, children with hearing loss typically had SRTs of 10–20 dB lower when measured in instrumental music compared to speech-shaped noise. Given the predictable pattern and nonspeech characteristics of the instrumental music, it is likely that people with hearing loss can use local fluctuations in the noise as long as the noise can be perceptually segregated from the target speech.

This study contributes to existing evidence indicating that people who use cochlear implant do receive an advantage when listening in fluctuating compared to steady-state noise (Goldsworthy, 2015; Goldsworthy et al., 2013; Jin et al., 2013). Early studies that indicated little to no advantage were often conducted with simulations of cochlear implant processing and at relatively high signal-to-noise ratios (Fu & Nogaki, 2004; Kwon et al., 2012; Nelson & Jin, 2004; Nelson et al., 2003; Qin & Oxenham, 2003; Stickney et al., 2004). As argued by Bernstein and Grant (2009), the fluctuating masker advantage is expected to be less for such higher signal-to-noise ratios.

Regarding the effect of age, SRTs generally improved with age for the conditions tested, but this effect explained only a small portion of the variability and was generally not significant (see Figure 5 and also Table 3). Taken by itself, the results of this study do not strongly characterize the effect of age but are in line with the research concerning the effect of age in listeners with normal hearing (Leibold, 2017). This study is consistent with previous studies indicating more pronounced differences between children and adults when measuring speech recognition in competing speech (Buss et al., 2017; Corbin et al., 2016; Hall et al., 2002; Leibold & Buss, 2013).

Precise characterization of the interaction of age and hearing loss would require a larger study that examines individual differences. Previous studies—requiring large number of participants—have considered age and individual differences; for instance, Niparko et al. (2010) examined language development following cochlear implantation and demonstrated the importance of residual hearing prior to cochlear implantation, higher ratings of parent–child interactions, and higher socioeconomic status as associated with greater rates of growth in language comprehension and expression. Previous studies have also provided influence models for how epigenetics can influence language development following cochlear implantation (Markman et al., 2011).

A limitation of this study is that it did not examine how spatial and/or visual cues are used by listeners to selectively attend to target speech (Bregman, 1990). Children with normal hearing use spatial cues to segregate spatially separated sounds; spatial hearing diminishes with hearing loss as does the weighting of stream segregation cues (Hossain & Goldsworthy, 2018; Litovsky, 2005). Visual cues also aid stream segregation, and there is some evidence that cochlear implant users emphasize visual cues more than listeners with normal hearing (Winn, Rhone, Chatterjee, & Idsardi, 2013). Consequently, speech recognition in many situations will depend on how well the listener integrates other cues beyond those considered in this study.

Conclusion

The effect of pediatric hearing loss on speech recognition was measured in quiet and different types of background noise. The effect of hearing loss on speech recognition was largest when measured in two-talker babble, suggesting speech recognition measured in competing speech is more sensitive to effects of hearing loss than similar measures in steady-state background noise. Children with hearing loss generally had their best speech recognition when measured in instrumental music and their worst when measured in two-talker babble. We interpret this result as evidence that people with hearing loss do derive an advantage in fluctuating compared to steady-state noise, but only insofar as they are able to segregate the noise from the target speech.

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