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ORIGINAL ARTICLE

Impact of Noise on Sound Processing at Lower Auditory System: An Electrophysiological Study

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Abstract The importance of signal-to-noise ratio (SNR) is well documented in behavioral speech perception experiments and psychophysical measurements. Studies on ABR related to the encoding of signals in ipsilateral noise are very limited. The present study aimed to systematically investigate the effect of various SNRs on the latency and amplitude of ABR to a range of stimuli & to compare the latency and amplitude of ABR recorded in various ipsilateral SNRs in children and adults. We recorded auditory brain stem responses (ABR) in children and young adults for clicks, a speech token /da/ of 40 ms duration, and for a 1000 Hz tone burst in the presence of a broad band noise and quiet. There were four SNR conditions (+ 10 dB SNR, 0 dB SNR and -10 dB SNR), and the level of noise was varied, while the stimulus level was fixed at 60 dB HL. The results showed that SNR affects the latency and amplitude of the wave V peak differentially for the different stimuli. A difference in the performance of children and adults was also observed. SNR measurements using ABR provide an objective index of brainstem ability to process sound in the presence of background noise. This measure is important and can be used to assess the sound-in-noise processing ability in the difficult-to-test population such as infants and children where measures of signal-to-noise tests cannot be administered.

Keywords ABR · Electrophysiological evaluation · Effect of background noise · SNR

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Introduction

Auditory brainstem responses (ABR) are series of surface recorded potentials that reflect the activity of the eighth nerve and the various nuclei in the brainstem. The presence of a normal ABR signifies normal neural synchrony and processing of sound at the level of the brainstem [1, 2]. The ABR is sensitive to several characteristics of the stimulus for instance type, duration, intensity, frequency, bandwidth, and rate. Recently, speech elicited ABR have been shown to be an objective measurement of speech processing in the brainstem [1–4].

It is well known that background noise impairs the listening abilities of individuals with normal hearing [5–7] and individuals with hearing impairments [6, 7]. Both physiological and psychophysical experiments show degraded auditory performance in the presence of background noise. Background noise typically adversely affects: (i) Detection tasks e.g., elevates auditory thresholds for tones and speech [8, 9], and (ii) Speech intelligibility tasks [10]. The importance of signal-to-noise ratio (SNR) is well documented in behavioral speech perception experiments [5–7], 11], and psychophysical measurements [12–14].

Communication in difficult listening environments depends on how the auditory system can extract signals of interest from other competing information. Listening in background noise, in particular, presents a difficult challenge that often leads to communication breakdowns [6, 7]. Several factors contribute to the ability to hear a signal in the presence of noise including, but not limited to, reduced audibility, as well as how signals in noise are encoded throughout the brainstem and central auditory systems. Although the effect of signal-to-noise ratio (SNR) has been demonstrated in several human psychophysical and speech perception studies and animal physiological studies, the relation between SNR and absolute tone level as measured by human brainstem electrophysiology is less clear. One approach to studying how signal level and SNR are processed in the human brainstem is to use ABR [15]. ABR as a measure of brainstem function can provide valuable information about how large populations of neurons, recorded at the scalp, are encoding signals in noise [15].

The measurement of the ability to process auditory input in background noise is very important from both scientific and clinical perspectives. For instance, in the clinical population, it would help in the diagnosis and management of the auditory disorder, and in scientific research, it would advance our knowledge on the processing of signals in the auditory system. Studies on ABR related to the encoding of signals in ipsilateral noise are very limited. Only one study by Burkard and Hecox [16] investigated the interaction between click stimulus parameters and ipsilateral SNR. There are dozens of behavioral measures of auditory ability in noise that are frequently used in the clinic, for example, speech-in-noise, tone-in-noise, hearing-in-noise test, etc. The behavioral measures can be used in adults and older children but cannot be administered in difficult-to-test populations, for instance, infants, toddlers, children, and adults with severe or multiple disabilities.

Currently, there are no objective tests that can assess auditory ability in noise. ABR appears to be a test of choice for such purposes as it can be reliably recorded in newborns and other difficult-to-test populations. Also, ABR can be evoked by a wide range of stimuli such as click, tone burst, and speech. Another motivation for this study was to identify if the human auditory brainstem is responsible for differential processing of sound in the presence of noise between children and adults. It is well known that adults and children significantly differ in speech-in-noise tasks even when the language variable is controlled. However, it is also unknown if and how the human auditory brainstem in adult and children differ to process sounds in background noise. The lack of studies in this area and the motivation for objective tests for measuring SNR laid the foundation for current research. The purpose of this study was to determine the effect of signal-to-noise ratio (SNR) on brainstem activity to further increase our understanding of how the human central auditory system encodes signals in noise. We systematically investigated the effect of various SNRs on the latency and amplitude of ABR to a range of stimuli. We also compared the latency and amplitude of ABR recorded in various ipsilateral SNRs in children and adults.

Method

Participants

Participants were divided into two groups in the present study. One group was normal hearing children (n = 10, males) age ranged from 7 to 12 years whereas, the other group was adults (n = 10, males) age ranged from 18 to 40 years. Both the groups had normal hearing threshold (< 20 dB HL) for the octave frequencies of 250 to 8000 Hz, normal middle ear function and no history of ontological and neurological impairments. Consent was taken from the parents of children. Whereas adult participants signed the consent form prior to the participation.

Instrumentation

Diagnostic Audiometer OB 922 was used for estimating the pure-tone thresholds. Middle ear functioning was assessed by using GSI tympstar middle ear analyzer. ABR measurements were carried out by Intelligent Hearing System (IHS) with Smart EP Version 3.94 USbez.

Procedure

Participants reclined on a cot inside a double-walled sound isolating room. Surface electrodes recorded electrical activity from test ear mastoid (inverting electrode), forehead (non- inverting electrode) and non-test ear mastoid (ground electrode) using disc electrodes. Inter-electrode impedance was ≤ 5 kΩ. ABR was recorded with click, tone burst and speech stimuli. A speech token /da/ of 40 ms duration, a 1000 Hz tone burst and click was used as stimuli. ABR to all the three stimuli were measured in four conditions; Quiet, + 10 dB SNR, 0 dB SNR and − 10 dB SNR. The broadband noise was presented in ipsilateral condition and the level was varied to achieve a given SNR, while the stimulus level was fixed at 60 dB HL for all stimuli. The testing was done by using ER-3A insert earphones. The protocol used to record ABR is presented in Table 1. It is important to note that because ABR waveform and peak differ for the three types of stimuli used in this study that is the reason only wave V was considered for simple and direct comparison. Also, a few pilots recording suggested wave V as the only reliable peak in the presence of ipsilateral noise. All the participants were

Table 1 Acquisition parameters for ABR recording

Acquisition parameters	
Mode	Monaural stimulation
Electrode type	Disc electrode
Stimulus rate	11.1/sec
Polarity	Alternating
Number of Sweeps	1500
No of channels	Single channel
Filter settings	100 Hz – 3000 Hz
Notch Filter	On
Analysis window	25 ms
Reliability	Twice for all the conditions
Gain	1,00,000 times
Artifact rejection	40 µV

asked to respond initially before actual testing if they can detect the test signal in various SNR conditions.

Results

The condition of -10 SNR was not considered for statistical analysis as ABR was not present for any participants for all the studied parameters at − 10 SNR condition. Separate statistical analysis was done on the two parameters of ABR under investigation; Latency and Amplitude of wave V. The mean and standard deviation of the latency of wave V for both the groups (adults and children) in three conditions (Quiet, + 10 dB SNR and dB SNR) obtained for clicks, /da/ and 1000 Hz tone bursts stimuli are shown in Figs. 1, 2 and 3, respectively. Mixed ANOVA was done to check the effect of different stimuli (Click, speech stimuli /da/ and 1000 Hz tone-burst) and different testing conditions (Quiet, + 10 dB SNR and 0 dB SNR) on the latency of wave V of ABR in children and adults. Overall, adults and children show significantly different latency of wave V peak for three stimuli and at different conditions [F(1,18) = 8.175 $p < 0.001$]. Latency of wave V was significantly different [F(2,36) = 352.398, $p < 0.001$] for clicks, /da/ and 1000 Hz tone bursts stimuli in both adult and children at different conditions. Latency of wave V in quiet, + 10 dB SNR and 0 dB SNR was significantly different [F(2,36) = 232.182 $p < 0.001$] in both adults and children for clicks, /da/ and 1000 Hz tone bursts stimuli.

Figures 4, 5 and 6 show the mean and standard deviation of the amplitude of wave V for both the groups in three conditions (Quiet, + 10 dB SNR and dB SNR) obtained for clicks, /da/ and 1000 Hz tone bursts stimuli, respectively. Mixed ANOVA was done to check the effect of different stimuli (Click, speech stimuli /da/ and 1000 Hz tone-burst) and different testing conditions (Quiet, + 10 dB SNR and 0 dB SNR) on the amplitude of wave V of ABR in children and adults. Overall, adults and children show significantly different amplitude of wave V peak for three stimuli and at different conditions [F (1,18) = 11.709, $p < 0.001$]. Amplitude of wave V was significantly different [F (2, 36) = 44.447, $p < 0.001$] for clicks, /da/ and 1000 Hz tone bursts stimuli in both adult and children at different conditions. Amplitude of wave V in quiet, + 10 dB SNR and 0 dB SNR was significantly different [F (2, 36) = 1226.503, $p < 0.001$] in both adults and children for clicks, /da/ and 1000 Hz tone bursts stimuli.

Discussion

Importance of SNR Measurement

It is evident from the literature that signal to noise ratio (SNR) affects various psychophysical and physiological audiological tests [5–7, 13, 14]. The competing noise has an inhibitory effect on the outer hair-cells functioning, which reduces the amplitude of otoacoustic emissions [17]. Varying SNR results in different auditory thresholds for

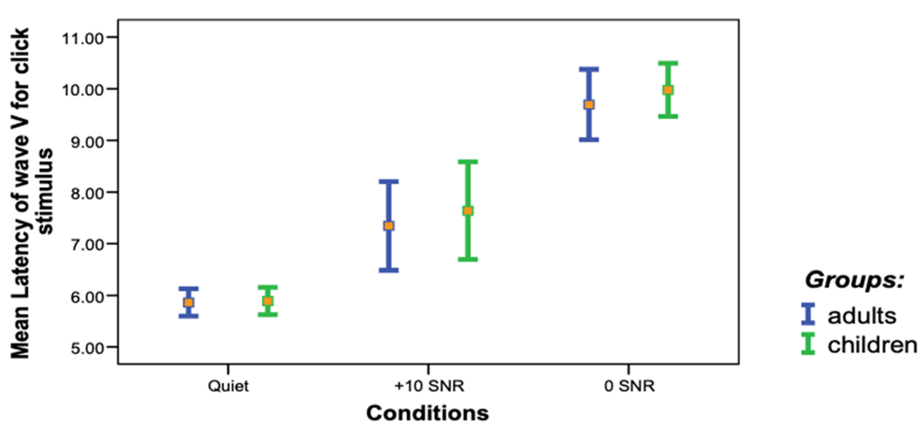

Fig. 1 Graph showing Mean latency with Standard Deviation of wave V for click stimulus in the three conditions (Quiet, + 10 dB SNR and 0 dB SNR) for adults and children

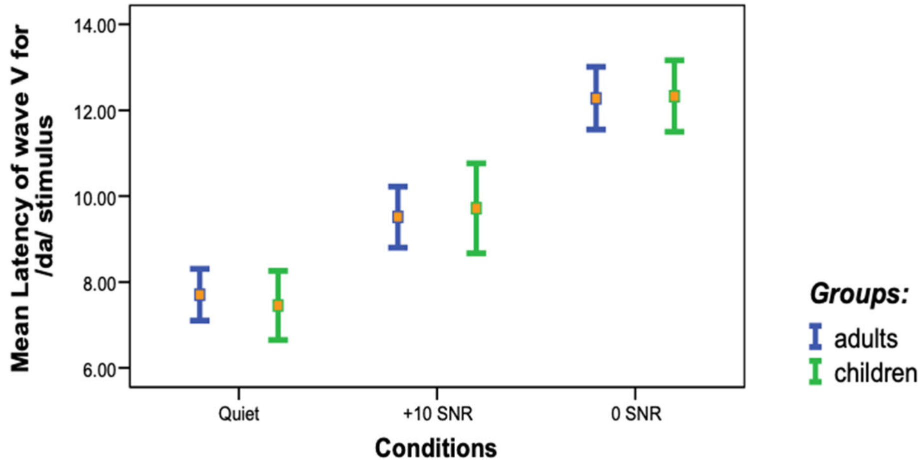

Fig. 2 Graph showing Mean latency with Standard Deviation of wave V for /da/ stimulus in three conditions (Quiet, + 10 dB SNR and 0 dB SNR) for adults and children

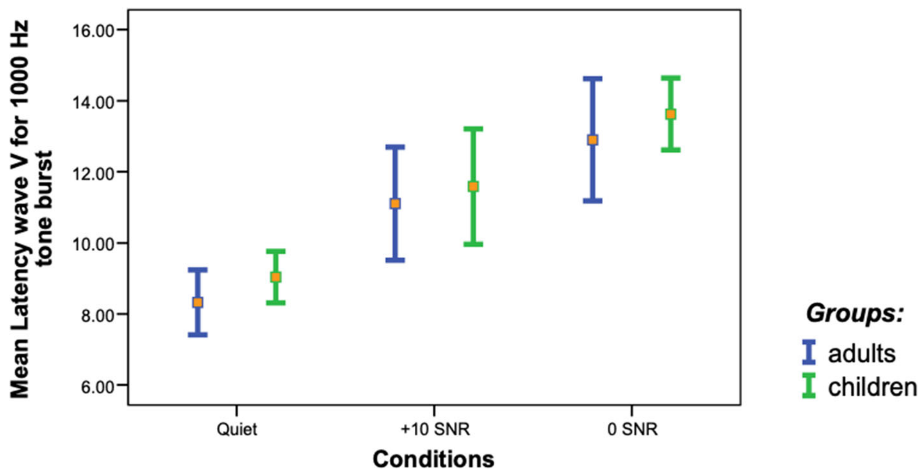

Fig. 3 Graph showing Mean latency with Standard Deviation of wave V for 1000 Hz tone burst stimulus in the three conditions (Quiet, + 10 dB SNR and 0 dB SNR) for adults and children

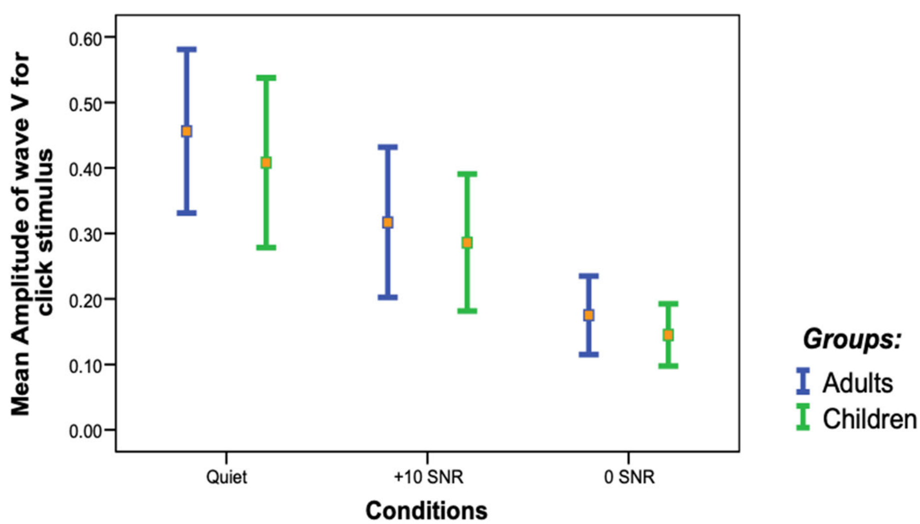

Fig. 4 Graph showing Mean amplitude with Standard Deviation of wave V for click stimulus in the three conditions (Quiet, + 10 dB SNR and 0 dB SNR) for adults and children

tone and speech stimuli [8, 9] also, speech intelligibility scores vary with the changing SNR [10].

Several audiological tests are performed by varying SNR and hold clinical significance. Speech in Noise tests which utilize different SNR's are psychophysical and theses tests are used to assess auditory processing disorders [18]. The suppression effects that are evident by decrease in the amplitude of otoacoustic emissions when an additional stimulus (tone) is added are used to assess the function of the efferent auditory system [19]. So, further,

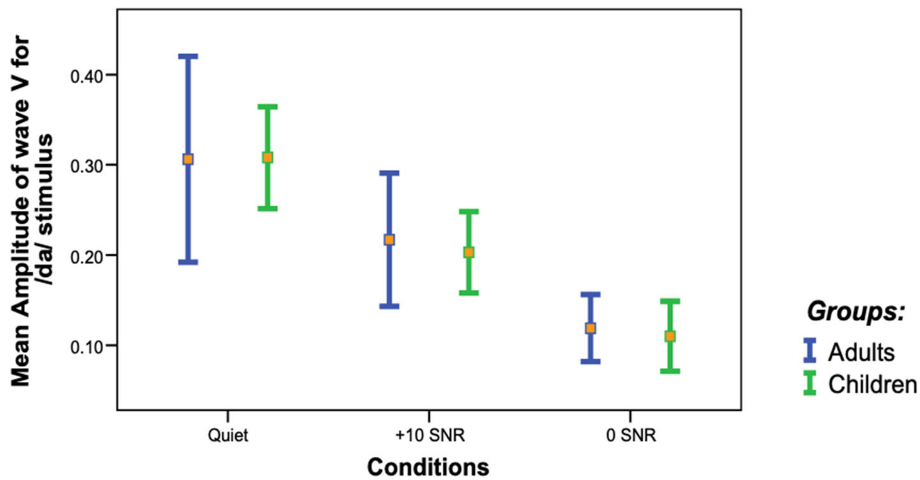

Fig. 5 Graph showing Mean amplitude with Standard Deviation of wave V for /da/ stimulus in the three conditions (Quiet, + 10 dB SNR and 0 dB SNR) for adults and children

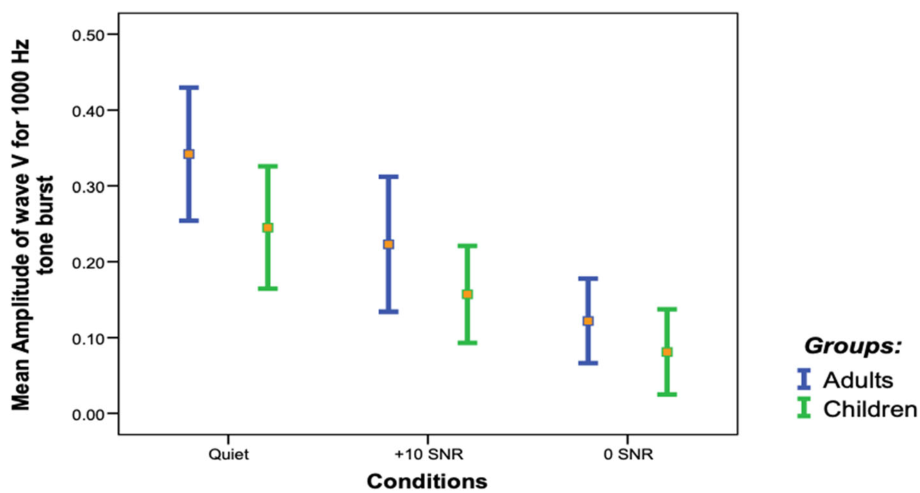

Fig. 6 Graph showing Mean amplitude with Standard Deviation of wave V for 1000 Hz tone burst the three conditions (Quiet, + 10 dB SNR and 0 dB SNR) for adults and children

the measure of the effect of different SNR on ABR can be utilized as a clinical tool to assess the sound-in-noise processing ability objectively.

Effect of SNR on ABR for Three Types of Stimuli

The result revealed that there is a significant effect of SNR on the latency and amplitude of ABR wave V for the three stimulus conditions in both groups. The latency of wave V was significantly different for quiet and different noise conditions for all three stimuli. The latency of wave V increased as the SNR decreased (i.e. at + 10, and 0 dB SNR) for both groups. Conversely, ABR wave V was absent at − 10 dB SNR, for both groups. Similarly, the amplitude of ABR wave V was also significantly different for quiet and different noise conditions for all three stimuli. Unlike latency, amplitude decreased with the decreasing SNR in both groups. The results of latency and amplitude variations of the ABR wave V for different SNR conditions correlate with the results of Bucard and Hicox [16] in adults with click and 1000 Hz stimuli. The variation in latency and amplitude of the wave V for 1000 Hz tone-burst was larger than click and speech stimuli. This could be because single frequency tone burst excites a smaller area on the basilar membrane whereas, click and speech stimulus excites a larger area on the basilar membrane in the cochlea. Thus, the masking effect on tone-burst was more than that on clicks and /da/ stimuli.

Effect of SNR on ABR in Children and Adults

Overall results showed that the SNR affects children and adults differently in terms of increase in latency and decrease in amplitude of the ABR wave V. Further, the Independent t-test results revealed that the difference in both latency and amplitude occurs only at 1000 Hz tone-burst, but not for click and speech stimuli in both the groups at different SNR. The result for click stimuli is concurrent with the findings of Burkard & Sims [20] where no difference was observed between children and adults with changing SNR for click stimuli. This may be attributable to the fact that noise has more adverse effect on the auditory function of children than adults. This correlates with the results of Stuart [21] and Hall et al. [22] on differential functioning of children and adults for speech reception threshold and spondee recognition, respectively. The adverse effect of noise may also account for the differential performance in children and adults for tone-burst because single frequency tone burst excites a smaller area on the basilar membrane whereas, click and speech stimulus excites a larger area on the basilar membrane in the cochlea hence, more. The present findings also suggest that the difference in speech-in-noise perception between children and adults can at least be partly due to the sound-in-noise processing at the level of the auditory brainstem.

Relationship Between Behavioral Response and ABR to Stimuli in Different Condition

For behavioral response participants in both the groups were able to detect all the stimulus in quiet, at + 10 SNR and 0 SNR but not at − 10 dB SNR. The difficulty to detect stimuli was increased as the SNR was decreased. Similarly, for ABR when the SNR decreased the latency of wave V increased and the amplitude decreased. Conversely, at − 10 dB SNR, the wave V was absent for all the stimuli in both groups.

Clinical Implications

Measurement of ABR in ipsilateral SNR can be performed in infants and difficult-to-test populations. The concept of ipsilateral SNR measurement can be used at least in two ways; (i) the ipsilateral SNR level can be used as a reliable measure by varying it to find the minimum SNR needed to record ABR reliably, and (ii) the ABR can be recorded in several pre-determined SNR level to measure latency/amplitude- SNR functions. These measures are particularly important as conventional measures of SNR such as speech-in-noise cannot be used in this population. The information on SNR estimated from ABR measurement may be used for hearing rehabilitation purposes and for monitoring the benefits of auditory training and management.

Conclusion

Based on the results of the study few conclusions can be drawn. SNR affects the latency and amplitude of the wave V peak differentially for the different stimuli. A difference in the performance of children and adults was also observed. SNR measurements using ABR provide an objective index of brainstem ability to process sound in the presence of background noise. This measure is important and can be used to assess the sound-in-noise processing ability in the difficult-to-test population such as infants and children with communication disorders where conventional measures using signal-to-noise tests cannot be administered. Future studies may be directed towards finding how ABR can be used for estimating SNR depending on various test parameters and the characteristics in the clinical population.

Author contributions U.S., and B.S. designed the experiment, B.S., & R.J. collected the data, U.S., and B.S. analyzed the data and wrote the paper.

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Declarations

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent Taken from all the participants.

References

1. Akhoun I, Moulin A, Jeanvoine A, Ménard M, Buret F, Vollaire C, Scorretti R, Veuillet E, Berger-Vachon C, Collet L, Thai-Van H (2008) Speech auditory brainstem response (speech ABR) characteristics depending on recording conditions, and hearing status: An experimental parametric study. J Neurosci Methods 175:196–205. https://doi.org/10.1016/j.jneumeth.2008.07.026
2. Lin Y-H, Ho H-C, Wu H-P (2009) Comparison of auditory steady-state responses and auditory brainstem responses in audiometric assessment of adults with sensorineural hearing loss. Auris Nasus Larynx 36:140–145. https://doi.org/10.1016/j.anl.2008.04.009
3. Sanfins MD, Hatzopoulos S, Donadon C, Diniz TA, Borges LR, Skarzynski PH, Colella-Santos MF (2018) An analysis of the parameters used in speech ABR assessment protocols. J Int Adv Otol 14:100–105. https://doi.org/10.5152/iao.2018.3574
4. Akhoun I, Gallégo S, Moulin A, Ménard M, Veuillet E, Berger-Vachon C, Collet L, Thai-Van H (2008) The temporal relationship between speech auditory brainstem responses and the acoustic pattern of the phoneme /ba/ in normal-hearing adults. Clin Neurophysiol Off J Int Fed Clin Neurophysiol 119:922–933. https://doi.org/10.1016/j.clinph.2007.12.010
5. Shukla B, Rao BS, Saxena U, Verma H (2018) Measurement of speech in noise abilities in laboratory and real-world noise. Indian J Otol 24:109. https://doi.org/10.4103/indianjotol.INDIANJOTOL_134_17
6. Carhart R, Tillman TW (1970) Interaction of competing speech signals with hearing losses. Arch Otolaryngol 91:273–279. https://doi.org/10.1001/archotol.1970.00770040379010

7. McArdle RA, Wilson RH, Burks CA (2005) Speech recognition in multitalker babble using digits, words, and sentences. J Am Acad Audiol 16:726–739. https://doi.org/10.3766/jaaa.16.9.9
8. Buss E, Hall JW, Grose JH (2006) Development and the role of internal noise in detection and discrimination thresholds with narrow band stimuli. J Acoust Soc Am 120:2777–2788. https://doi.org/10.1121/1.2354024
9. Persson P, Harder H, Arlinger S, Magnuson B (2001) Speech recognition in background noise: monaural versus binaural listening conditions in normal-hearing patients. Otol Neurotol 22:625–630. https://doi.org/10.1097/00129492-200109000-00011
10. Rhebergen KS, Versfeld NJ, Dreschler WA (2008) Prediction of the intelligibility for speech in real-life background noises for subjects with normal hearing. Ear Hear 29:169–175. https://doi.org/10.1097/AUD.0b013e31816476d4
11. Rance G, Barker E, Mok M, Dowell R, Rincon A, Garratt R (2007) Speech perception in noise for children with auditory neuropathy/dys-synchrony type hearing loss. Ear Hear 28(3):351–360
12. Toner MA, Emanuel FW, Parker D (1990) Relationship of spectral noise levels to psychophysical scaling of vowel roughness. J Speech Hear Res 33:238–244. https://doi.org/10.1044/jshr.3302.238
13. Bidelman GM (2016) Relative contribution of envelope and fine structure to the subcortical encoding of noise-degraded speech. J Acoust Soc Am 140:EL358–EL363. https://doi.org/10.1121/1.4965248
14. Bidelman GM, Howell M (2016) Functional changes in inter- and intra-hemispheric cortical processing underlying degraded speech perception. Neuroimage 124:581–590. https://doi.org/10.1016/j.neuroimage.2015.09.020
15. Skoe E, Kraus N (2010) Auditory brainstem response to complex sounds: a tutorial. Ear Hear 31:302–324. https://doi.org/10.1097/AUD.0b013e3181cdb272
16. Burkard R, Hecox K (1983) The effect of broadband noise on the human brainstem auditory evoked response. I. Rate and intensity effects. J Acoust Soc Am 74:1204–1213. https://doi.org/10.1121/1.390024
17. Moulin A, Collet L, Duclaux R (1993) Contralateral auditory stimulation alters acoustic distortion products in humans. Hear Res 65:193–210. https://doi.org/10.1016/0378-5955(93)90213-k
18. Hutcherson RW, Dirks DD, Morgan DE (1979) Evaluation of the speech perception in noise (SPIN) test. Otolaryngol Head Neck Surg 87:239–245. https://doi.org/10.1177/019459987908700215
19. Aslihan Kulekci U, Yusuf Kemal K, Mehmet Birol U, Bulent G, Cagil S, Ediz Y, Aysun B, Peyami C, Nebil G (2009) Otoacoustic emissions and effects of contralateral white noise stimulation on transient evoked otoacoustic emissions in diabetic children. Int J Pediatr Otorhinolaryngol 73:555–559. https://doi.org/10.1016/j.ijporl.2008.12.002
20. Burkard RF, Sims D (2002) A comparison of the effects of broadband masking noise on the auditory brainstem response in young and older adults. Am J Audiol 11:13–22. https://doi.org/10.1044/1059-0889(2002/004)
21. Stuart A (2008) Reception thresholds for sentences in quiet, continuous noise, and interrupted noise in school-age children. J Am Academy Audiol 19(2):135–146
22. Hall JW, Grose JH, Buss E, Dev MB (2002) Spondee recognition in a two-talker masker and a speech-shaped noise masker in adults and children. Ear Hear 23:159–165. https://doi.org/10.1097/00003446-200204000-00008