Supplemental Material S1. Predictor variables for speech-in-babble recognition.

Every measure used as a predictor variable is accessible as either a standardized test instrument or through previously published papers. Citations are given for each measure to direct readers to those sources.

Vocabulary. The Expressive One-Word Picture Vocabulary Test (EOWPVT; Martin & Brownell, 2011) was administered to assess vocabulary knowledge. In this testing, subjects are shown a series of pictures and must label each one in turn. Testing stops after six consecutive errors. Expressive vocabulary was examined rather than receptive vocabulary, because it requires subjects to retrieve items from their lexicons without prompting. This process is slightly more rigorous than selecting the picture out of a set of four that represents a word spoken by an examiner, which is how receptive vocabulary tests are conducted. This is a standardized instrument.

Syntactic Comprehension. For this purpose, the Sentence Comprehension of Syntax subtest from the Comprehensive Assessment of Spoken Language (Carrow-Woolford, 1999) was administered. In this subtest, pairs of sentences that differ in syntactic structure are presented by a videotaped talker on the computer monitor at a level of 68 dB sound pressure level. Each of the 21 test items consists of two pairs of sentences (i.e., four sentences per item). The first sentence in each pair is the same, but the second sentences differ. After each pair of sentences the subject must indicate whether the sentences have the same meaning with a "yes" or "no" response. The subject must correctly respond to both pairs in an item to get a correct score for that item. Testing stops after five consecutive errors. This subtest is sensitive to comprehension of complex syntax, because the presented sentences typically differ in word order or clausal construction. This is a standardized instrument.

Phonological Sensitivity. Scores from a final consonant choice task were used to assess phonological sensitivity. In this task, the subject is presented with a target word via videos shown on the computer monitor and must repeat it. Then three words are presented, and the subject must select the word that ends in the same sound as the target. Stimuli were presented at 68 dB sound pressure level. There are 48 items in total that are sequenced from simplest to hardest. Testing is discontinued after six consecutive errors. See Appendix D of Nittrouer et al. (2012) for exact items.

Verbal Working Memory. An immediate serial recall task was used to assess verbal working memory. A MATLAB routine controls all aspects of the experiment. In this task, the subject is presented auditorily with a set of six nouns: *ball, coat, dog, ham, pack,* and *rake.* These six nouns are presented in each of ten different orders. Stimuli are presented at 68 dB sound pressure level. After presentation, pictures of the words appear at the top of the computer monitor and the subject responds by touching the pictures in the order recalled. The software keeps track of the order of presentation of words, and the order of the subject's recall. Subjects' abilities to recognize all words are assessed prior to testing by presenting each word separately and having subjects select the picture out of six that was said. This check is repeated after testing. All subjects were able to perform this task with perfect accuracy before and after testing. Percent correct order recall out of 60 (six words × ten lists) was the dependent measure. More information on this task can be found in Nittrouer et al. (2013) and in Nittrouer et al. (2017).

Spectral Resolution. A spectral modulation depth detection task was used to assess adolescents' spectral resolution, and a MATLAB routine controlled this procedure. Stimuli were generated with 800 random-phase sinusoidal components, logarithmically spaced between 0.1 kHz and 5.0 kHz, using a sampling rate of 44.1 kHz. Amplitudes of the sinewave components from 0.1 kHz to 1/4 octave above and from 5.0 kHz to 1/4 octave below were increased in a cosine-squared pattern, to eliminate the possibility of audible artifacts associated with the spectral edges. A speech-shaped filter was applied to all stimuli. All stimuli were 500 ms long. Standard stimuli were unmodulated and target stimuli were modulated at a rate of 0.5 cycles per octave. RMS amplitude was equated across standard and target stimuli in each trial, but amplitude across trials roved by +/– 3 dB around 68 dB sound pressure level. A three-interval, forced-choice task was used in which the subject had to select the stimulus that "sounded different" by pointing to one of the numerals *1*, *2*, or *3* on the computer monitor, and saying the number. The experimenter entered the subject's response into the computer. A two-down, one-up adaptive procedure was followed (Levitt, 1971). Starting modulation depth was set at 30 dB and decreased after the first two correct responses. Step size was initially 4 dB, but changed to 2 dB after the first four reversals. A total of 12 reversals were obtained, and the threshold was computed as the mean of the last eight reversals. Two tests were completed, and the dependent measure used in this study was the mean threshold obtained across those tests. More information can be found in Nittrouer et al. (2021).

Sinewave Speech Recognition. The abilities of these adolescents to organize signals lacking detailed structure in such a way as to recover a linguistically relevant pattern was obtained from their scores on a sinewave speech recognition task at fourth grade. The sentences used in this task consisted of four-word sentences fitting the criteria of being syntactically correct, but semantically anomalous (e.g., *Hard checks think tall*). These sentences were originally produced by an adult, male talker. To generate the sinewave versions of the sentences, a PRAAT routine written by Darwin (2003) served as the starting point, but parameters were adjusted on a sentence-by-sentence basis to ensure that extracted center frequencies matched those of the original speech materials, without erroneous values. Smoothing of tracks was performed in PRAAT, and sinewaves were combined at the amplitude values found in the original files. These sentences were presented to children for recognition. They repeated what they heard, and responses were audio-video recorded for later scoring. Twenty-five sentences were presented at 68 dB sound pressure level. The dependent measure was the percent of words repeated correctly (out of 100). More information on these procedures can be found in Nittrouer, Kuess, and Lowenstein (2015).

References

Carrow-Woolfolk, E. (1999). *Comprehensive Assessment of Spoken Language (CASL)*. Pearson Assessments.

Darwin, C. (2003). *Sine-wave speech produced automatically using a script for the PRAAT program*. Retrieved October 15, 2014, from http://www.lifesci.sussex.ac.uk/home/Chris_Darwin/SWS/

Levitt, H. (1971). Transformed up-down methods in psychoacoustics. *The Journal of the Acoustical Society of America, 49*(2), 467–477. https://doi.org/10.1121/1.1912375

Martin, N., & Brownell, R. (2011). *Expressive One-Word Picture Vocabulary Test (EOWPVT-4)*. Academic Therapy Publications, Inc.

Nittrouer, S., Caldwell, A., Lowenstein, J. H., Tarr, E., & Holloman, C. (2012). Emergent literacy in kindergartners with cochlear implants. *Ear and Hearing, 33*(6), 683–697. https://doi.org/10.1097/aud.0b013e318258c98e

Nittrouer, S., Caldwell-Tarr, A., Low, K. E., & Lowenstein, J. H. (2017). Verbal working memory in children with cochlear implants. *Journal of Speech, Language, and Hearing Research, 60*(11), 3342–3364. https://doi.org/10.1044/2017_JSLHR-H-16-0474

Nittrouer, S., Caldwell-Tarr, A., & Lowenstein, J. H. (2013). Working memory in children with cochlear implants: Problems are in storage, not processing. *International Journal of Pediatric Otorhinolaryngology, 77*(11), 1886–1898. https://doi.org/10.1016/j.ijporl.2013.09.001

Nittrouer, S., Kuess, J., & Lowenstein, J. H. (2015). Speech perception of sine-wave signals by children with cochlear implants. *The Journal of the Acoustical Society of America, 137*(5), 2811–2822. https://doi.org/10.1121/1.4919316

Nittrouer, S., Lowenstein, J. H., & Sinex, D. G. (2021). The contribution of spectral processing to the acquisition of phonological sensitivity by adolescent cochlear implant users and normal-hearing controls. *The Journal of the Acoustical Society of America, 150*(3), 2116. https://doi.org/10.1121/10.0006416