Noise technologies: What do kids need and what do they want?

This study describes school-age children's performance with and preference for a variety of different types of noise management technologies. Phonak Sky™ V90-P behind-the-ear hearing aids were fitted for 14 children with moderate to moderately-severe hearing loss. Use of the adaptive directional microphone mode resulted in a significant improvement in sentence recognition when speech arrived from the front (mean improvement of 24% relative to the omnidirectional condition. Compared to performance in the omnidirectional condition, use of Real Ear Sound provided an 8% improvement in sentence recognition when the signal arrived from in front of the child and essentially identical sentence recognition when the speech signal arrived from behind the child. Use of Real Ear Sound provided the best performance in the localization assessment. Finally, children expressed a strong preference for the collective use of each of the noise management technologies (i.e., noise gain-frequency response, adaptive directional mode, and noise reduction activated) both when speech arrived from the front and when speech arrived from behind.

Introduction

Research has clearly shown that children who have hearing loss frequently experience communication difficulties in noisy situations. For instance, Wolfe and colleagues (2013) evaluated speech recognition in noise in a classroom environment for a group of 15 school-age children with normal hearing and 15 school-age children with moderate to moderately-severe hearing loss. At a 5 dB signal-to-noise ratio (SNR), they found a mean sentence recognition score of almost 90% correct for the children with normal hearing and approximately 65% correct for the children with hearing loss. Furthermore, Scollie et al. (2010) evaluated the real-world experiences and preferences of 24 children in a study comparing the NAL-NL1 and DSL v4.1 hearing aid fitting prescriptions. The children frequently reported substantial difficulty with communication in noisy situations and expressed a preference for lower levels of hearing aid gain in noisy environments. Furthermore, Hornsby et al. (2017) evaluated subjective fatigue of 60 children with hearing loss and 43 children with normal hearing revealing that children with hearing loss experienced greater levels of fatigue than children with normal hearing. It is reasonable to assume that part of the additional fatigue experienced by children with hearing loss may be attributed to the difficulties they experience in noisy environments. Unfortunately, children with hearing loss must frequently communicate in such environments. For example, Crukley and colleagues (2011) explored the acoustic properties of educational environments and reported that almost 90% of an elementary-age child's school day is spent listening to speech in noise.

Use of adaptive remote microphone technology is the most effective method to improve speech recognition in noisy environments (Wolfe et al., 2013; Wolfe et al. (2017)). However, there are many situations in which the signal of interest is not directed to the remote microphone. For instance, Feilner (2016) examined multiple classrooms across several countries and reported that only 22% of the school day was comprised of direct lecturing from the teacher to students. The remainder of the school day was made

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up of dynamic activities in which there were multiple talkers of interest and in which the specific talker of interest may have varied from moment to moment. To optimize a child's listening experience across these dynamic environments, additional noise management technologies must be considered, such as adaptive directional microphones, automatic noise reduction features, and automatic changes in the gain-frequency response of hearing aids for moderate- to high-level noise environments.

Several researchers have examined the influence of directional microphone technology on speech recognition in noise on children with hearing loss. Their findings have unequivocally shown that use of directional microphone technology results in improved speech recognition when the signal of interest arrives from the front of the listener (Gravel et al., 1999; Kuk et al., 1999; Ricketts, Galster, & Tharpe, 2007; Wolfe et al., 2017). However, Ricketts and colleagues (2007) and Wolfe et al. (2017) also showed that use of directional microphones results in a decrease in speech recognition in noise when signals arrive from behind the listener. This decrease has led some researchers to express reticence about the use of directional microphone technology with young children with hearing loss (AAA, 2013; Bagatto, 2010; OIHP, 2014). Additionally, localization abilities may potentially be hampered by the attenuation of sounds from the rear hemisphere that occurs with use of directional microphones.

Several researchers have also explored the effect of automatic noise reduction on speech recognition, subjective preferences, and listening abilities of children with hearing loss. Stelmachowicz et al. (2010) evaluated the potential benefits and limitations of noise reduction in a group of 16 children with hearing loss and found no difference in speech recognition in noise in both the noise reduction 'on' and 'off' conditions. Although noise reduction technology provided no improvement in speech recognition in noise, Stelmachowicz and colleagues concluded that noise reduction technology may still be beneficial for children because it may potentially improve listening comfort and reduce cognitive load and fatigue. Pittman (2011) evaluated novel word learning in 26 children with hearing loss and reported significantly better word learning ability in the noise reduction 'on' condition relative to the noise reduction 'off' condition, a finding that suggests that a reduction in cognitive load may improve performance on higher-level cognitive tasks.

Several outstanding questions remain regarding the use of noise management technologies with children with hearing loss including:

1) What is the individual contribution of various noise management technologies (e.g., alteration of the gain-frequency response, automatic noise reduction, microphone mode) on speech recognition abilities of children with hearing loss?
2) What is the impact of various microphone modes on the localization abilities of children with hearing loss?
3) What noise management technologies do children with hearing loss prefer to use in classroom environments?

The following study sought to address these three outstanding questions.

Methodology

Fourteen children, aged between 8 years and 14 years, 7 months old (average age was 11 years, 6 months old) with moderate to moderately-severe bilateral hearing loss, were fitted binaurally with Phonak Sky V-90 behind-the-ear (BTE) hearing aids. Real ear probe microphone measurements were completed, and the output of the hearing aids was matched (+/- 5 dB) to the DSL v5.0 pediatric target for speech inputs presented at 55, 65, and 75 dB SPL. A swept pure tone was presented at 85 dB SPL to ensure that the maximum output of the hearing aids did not exceed DSL v5.0 MPO targets. Five different programs were loaded to each hearing aid:

1) The gain-frequency response was matched to the DSL v5.0 pediatric targets, the microphone mode was set to omnidirectional, and automatic noise reduction was disabled.
2) The gain-frequency response was matched to a proprietary Phonak target for noisy conditions. These targets consisted of a modest level of attenuation (no more than 5 dB particularly in the low frequencies compared to the DSL v5.0 pediatric targets for noise), the microphone mode was set to omnidirectional, and automatic noise reduction was enabled.
3) The gain-frequency response was matched to the DSL v5.0 pediatric targets, the microphone mode was set to adaptive directional (i.e., UltraZoom), and automatic noise reduction was disabled.
4) The gain-frequency response was matched to the DSL v5.0 pediatric targets, the microphone mode was set to Phonak's proprietary Real Ear Sound (which seeks to mimic natural directivity of the pinna and restore the head related transfer function which is critical for accurate localization), and automatic noise reduction was disabled.

5) The gain-frequency response was matched to a proprietary Phonak target for noisy conditions. These targets consisted of a modest level of attenuation (no more than 5 dB particularly in the low frequencies compared to the DSL v5.0 pediatric targets for noise), the microphone mode was set to adaptive directional (i.e., UltraZoom), and automatic noise reduction was enabled.

All testing was conducted in a classroom with the following dimensions: 20'4" by 24'2" by 8'9". For all measures completed in this study, test and competing noise signals were presented from an 8-loudspeaker array with loudspeakers positioned at 0, 45, 90, 135, 180, 225, 270, and 315 degrees horizontal azimuth (see Figure 1). The participants sat in the middle of the loudspeaker array and the individual loudspeakers were each located 4'3" away from the participant.
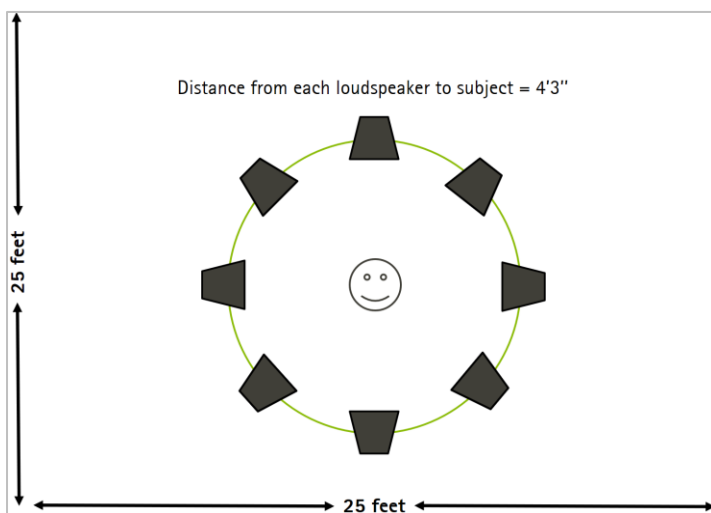

Figure 1. Configuration of simulated classroom study environment.

Speech recognition assessment

With use of each of the five programs described above, sentence recognition was evaluated in two conditions:

1) The speech signal was presented from 0 degrees azimuth, and classroom noise (Schafer & Thibodeau, 2006) was presented from the remaining loudspeakers in the 8-loudspeaker array.
2) The speech signal was presented from 180 degrees azimuth, and classroom noise (Schafer & Thibodeau, 2006) was presented from the remaining loudspeakers in the 8-loudspeaker array.

One full list (20 sentences) of AzBio sentences (Spahr et al., 2012) was presented to evaluate sentence recognition with each of the five programs in each of the two conditions for a total of 10 assessments. The order in which the hearing aid programs and listening conditions were evaluated was counter-balanced. The presentation level of the AzBio sentences was 73 dBA at the location of the subject, a level which should be fairly consistent with the level of speech in typical educational settings (Crukley et al., 2011; Massie & Dillon, 2006; Pearsons et al., 1977). Uncorrelated classroom noise (Schafer & Thibodeau, 2006) was used as the competing noise signal. For each child, the noise level was adjusted to determine the signal-to-noise ratio (SNR) that resulted in a score between 30% to 50% correct for one full list of AzBio sentences presented from the loudspeaker directly in front of the child while the child used Program 1 (i.e., the "baseline condition" — standard gain-frequency response, omnidirectional, automatic noise reduction off). Sentence recognition for each of the five programs and for each listening condition was then completed at the SNR required for 50% correct performance for each child in the baseline condition.

Localization assessment

Localization was evaluated by presenting a recording of a dog barking at a presentation level of 70 dBA (measured at the location of the participant). Classroom noise was also presented at 62 dBA. Localization was evaluated in three conditions:

1) Omnidirectional microphone mode
2) Adaptive directional microphone mode (i.e., Phonak UltraZoom)
3) Phonak Real Ear Sound microphone mode

For each of the three conditions, the dog bark was randomly presented three different times from each of the 8 loudspeakers for a total of 24 signal presentations for each condition. After each of the presentations in each condition, the child pointed to a picture to indicate from which loudspeaker the signal originated (see Figure 2). The score for each condition was measured in a percentage correct.

Figure 2. Response sheet used for evaluation of localization abilities. Children pointed to the number of the loudspeaker that corresponded to the loudspeaker from which they thought the signal originated.

Subjective preference for noise management technology

The children's subjective preference for the use of the various noise management technologies was evaluated in the classroom environment. The "Carrot Passage" from the Connected Speech Test (Cox, Alexander, Gilmore, 1987) (i.e., "The carrot is a long, reddish-yellow vegetable which has several thin leaves and which belongs to the parsley family..."). The Carrot Passage was presented at 73 dBA (measured at the location of the participant), and the classroom noise (Schafer & Thibodeau, 2006) was presented at the same level (i.e., at the same SNR) that was used for each child during speech recognition in noise assessment.

Subjective preference was evaluated in each of the five hearing aid programs for each of two conditions:

1) The speech signal was presented from 0 degrees azimuth, and classroom noise was presented from the remaining loudspeakers in the 8-loudspeaker array.
2) The speech signal was presented from 180 degrees azimuth, and classroom noise was presented from the remaining loudspeakers in the 8-loudspeaker array.

After listening to the full Carrot Passage in a program in one of the listening conditions, each child was asked to rank order each of the five programs from best (i.e., 5) to worst (i.e., 1). The children held a touchscreen tablet during this assessment and adjusted a slider bar to rank each program for "Comfort" ("Which program is the most comfortable?"), "Speech Recognition" ("Which program allows you to understand the speech the best?"), and "Overall Preference" ("Which program is your favorite?"). See Figure 3 for an example of the response screen.

Children provided a ranking for each of these three questions for each of the five programs in each of the two listening conditions for a total of 30 rankings. The order in which the programs and conditions were evaluated was counter-balanced across subjects. Because the program order was counter-balanced and the child controlled the tablet, the evaluation of subjective preference was a double-blinded assessment.
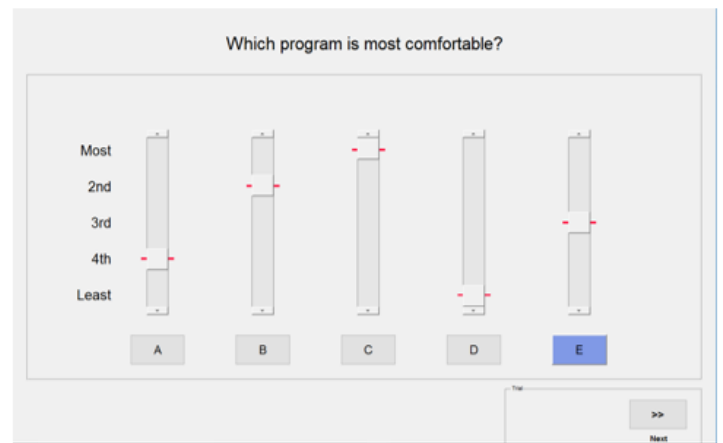

Figure 3. An example of the response screen used to evaluate the children's preference for the various hearing aid programs. Children rank-ordered the programs (from best to worst) after listening to running speech in noise.

Results

Speech recognition in noise

Mean results (with standard deviations) for the speech recognition assessment are shown in Figures 4 (Speech from the front) and 5 (Speech from behind). Repeated measures analysis of variance (RMANOVA) was used to analyze the potential differences that existed across the different programs and listening conditions. The main effects of condition and hearing aid program were both statistically significant (p<.0001). Specifically, significantly higher speech recognition was obtained when the speech signal originated from in front of the child. A statistically significant interaction existed between hearing aid program and listening condition.
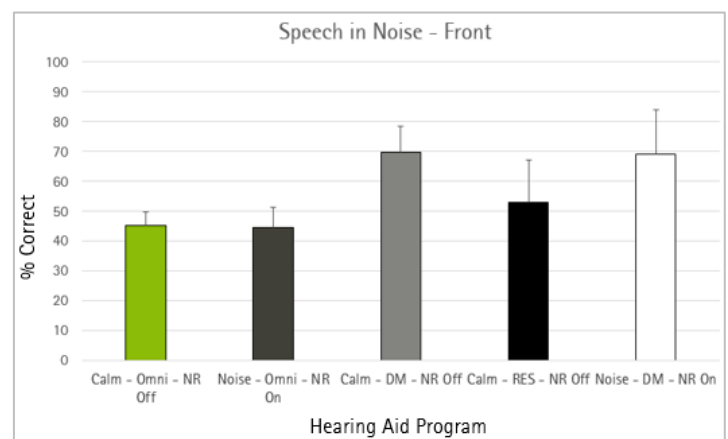

Figure 4. Mean AzBio sentence recognition scores for the various hearing aid programs when used with the speech signal presented from in front of the children. Error bars indicate one standard deviation.
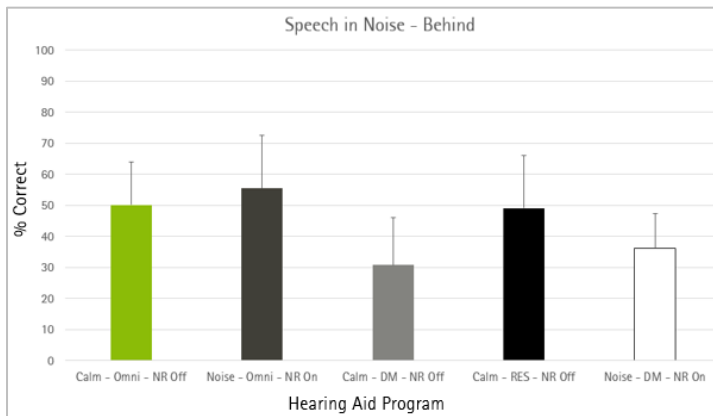
Figure 5. Mean AzBio sentence recognition scores for the various hearing aid programs when used with the speech signal presented from behind the children. Error bars indicate one standard deviation.

Figure 6. Mean scores (% correct) for the localization task with each of the three microphone modes.

For the speech-in-front condition, sentence recognition in noise was better in each of the adaptive directional microphone conditions when compared to the other programs. Additionally, sentence recognition in noise was significantly better in the program in which the Real Ear Sound microphone mode was active as compared to each of the programs using an omnidirectional microphone mode. There was not a statistically significant difference in sentence recognition in noise between the omnidirectional condition with standard gain-frequency response and noise reduction disabled and the omnidirectional condition with the proprietary noise gain-frequency response and automatic noise reduction.

For the speech-from-behind condition, sentence recognition in noise was significantly poorer in the adaptive directional conditions relative to each of the other three microphone modes. There was not a statistically significant difference in sentence recognition in noise obtained with the omnidirectional programs and Real Ear Sound program. Additionally, the gain-frequency response and the inclusion of automatic noise reduction did not influence sentence recognition when the speech signal originated from behind the listener.

Localization

The mean results of the localization data are shown in Figure 6. Localization ability was significantly better in the Real Sound program relative to the programs with other two microphone modes. There was not a statistically significant difference in localization abilities obtained with use of the omnidirectional versus adaptive directional microphone modes.
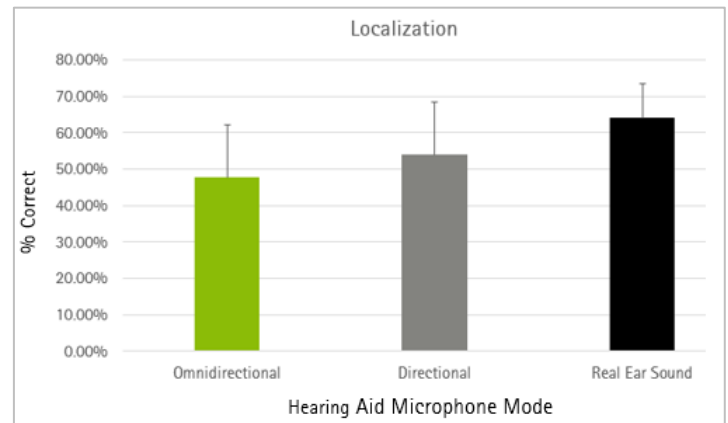
Subjective preference

Two general trends emerged in the assessment of subjective preference for noise management technology. First, the children's subjective preference did not generally differ between the speech-in-front and speech-from-behind conditions. Secondly, the children generally expressed a preference for the use of noise management technology, regardless of listening condition. Specifically, the children expressed a preference for the use of adaptive directional microphone technology over omnidirectional technology for listening comfort, speech recognition, and overall preference. The preference for the use of adaptive directional technology persisted even when for speech recognition when the signal was presented from behind the child. Additionally, the children tended to express a preference for the use of the Phonak proprietary gain-frequency response for noisy conditions as well as for the use of automatic noise reduction. There was an overwhelming preference for the combined use of all three noise management technologies.
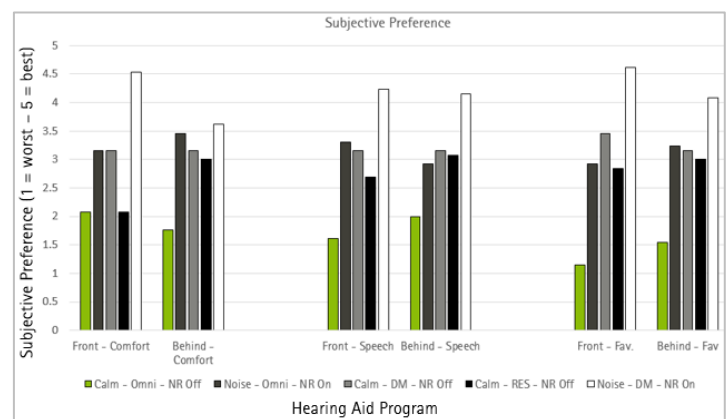

Figure 7. Mean ranking for each of the various hearing aid programs obtained in the subjective preference task. Comfort = Comfort in noise; Speech = Ability to understand speech in noise; Fav. = Overall preference for use in speech-in-noise.

Conclusion

1) The use of Phonak adaptive noise management technologies can provide significant improvement (i.e., 24 percentage points) in sentence recognition in noise when speech arrives from the front of a child in a classroom situation. However, the use of adaptive directional microphone technology can also result in a decrease in speech recognition when the signal of interest arrives from behind the child. These results are consistent with the results of previous studies (Ricketts, Tharpe, & Galster, 2007; Wolfe et al., 2017). Of note, Wolfe and colleagues (2017) did show that when given the opportunity, children will turn to face the signal of interest when it is presented from the back, and when they do orient toward the signal of interest, use of directional microphone technology improves speech recognition.

   Likewise, Ching et al. (2009) and Ricketts and Galster (2008) have shown that infants and school-age children possess the ability to orient toward the signal of interest. Based on the Ching et al. (2009) findings, noted hearing aid researcher, Harvey Dillon (2012), suggested that "infants and children should routinely be fit with advanced directional microphones, and they should receive considerable benefit from them".

2) The results of this study found no detriment in the children's localization abilities with use of adaptive directional technology relative to the omnidirectional condition. Of note, the children were able to localize sound better with the use of the Phonak Real Ear Sound microphone mode, which aims to mimic the acoustical effect of the auricle and preserve the head related transfer function.

3) Quite possibly the most compelling finding of this study is the fact that an overwhelming majority of children expressed a strong preference for the combined use of adaptive directional microphone technology, Phonak's proprietary gain-frequency response for noisy conditions and automatic noise reduction. The children's preference toward the use of adaptive directional microphone technology persisted even when the signal of interest arrived from behind.

   Indeed, previous studies have suggested that children with hearing loss struggle to hear in noise and experience stress and fatigue in realistic listening situations (Hornsby et al., 2017; Scollie et al., 2010). Results from Scollie et al. (2010) also suggested that children may prefer more noise reduction in noisy situations. Given the well-known difficulties that children with hearing loss experience in noisy situations (e.g., poor speech recognition, listening comfort, stress fatigue, cognitive load) and the results of this study suggesting a strong preference for the use of noise management technology even when the signal of interest arrives from behind, clinicians should give serious consideration to the routine use of advanced adaptive noise management technologies for children with hearing loss.

References

American Academy of Audiology Task Force on Pediatric Amplification (2013). American Academy of Audiology Clinical Practice Guideline on Pediatric Amplification. Retrieved on June 28, 2016, from http://audiology-web.s3.amazonaws.com/migrated/PediatricAmplificationGuidelines.pdf_539975b3e7e9f1.74471798.pdf

Bagatto, M., Scollie, S. D., Hyde, M., & Seewald, R. (2010). Protocol for the provision of amplification within the Ontario Infant Hearing Program. *International Journal of Audiology*, 49(1), 70-90.

Ching, T. Y., O'Brien, A., Dillon, H., Chalupper, J., Hartley, L., Hartley, D., Raicevich, G., & Hain, J. (2009). Directional effects on infants and young children in real life: implications for amplification. *Journal of Speech and Language Hearing Research*, 52(5), 1241-1254.

Cox, R. M., Alexander, G. C., & Gilmore, C. (1987). Development of the Connected Speech Test (CST). *Ear and Hearing*, 8(5), 119-126.

Cruckley, J., Scollie, S., & Parsa, V. (2011). An exploration of nonquiet listening at school. *Journal of Educational Audiology*, 17, 23-35.

Dillon, H. (2012). Hearing Aids. New York, NY: Thieme Medical Publishers.

Feilner, M., Rich, S., & Jones, C. (2016). Automatic and directional for kids – Scientific background and implementation of pediatric optimized automatic functions. *Phonak Insight*, retrieved from www.phonakpro.com/evidence, accessed February 19th, 2018.

Gravel, J. S., Fausel, N., Liskow, C., & Chobot, J. (1999). Children's speech recognition in noise using omnidirectional and dual-microphone hearing aid technology. *Ear and Hearing*, 20(1),1–11.

Hornsby, B. W. Y., Gustafson, S. J., Lancaster, H., Cho, S. J., Camarata, S., & Bess, F. H. (2017). Subjective fatigue in children with hearing loss assessed using self- and parent-proxy report. *American Journal of Audiology*, 26(S), 393-407.

Kuk, F., Kollofski, C., Brown, S., Melum, A., & Rosenthal, A. (1999). Use of a digital hearing aid with directional microphones in school-aged children. *Journal of the American Academy of Audiology*, 10(10), 535–548.

Massie, R., & Dillon, H. (2006). The impact of sound-field amplification in mainstream cross-cultural classrooms, Part 1: Educational outcomes. Australian Journal of Education, 50, 62-77.

Ontario Infant Hearing Program (OIHP) (2014). Protocol for the Provision of Amplification Version 2014.01, November 17, 2014.

Pearsons, K. S., Bennett, R. L., & Fidell, S. (1977). Speech levels in various noise environments (Report No. EPA-600/1-77-025)/ Washington, DC: U.S. Environmental Protection Agency.

Pittman, A. (2011). Age-related benefits of digital noise reduction for short-term word learning in children with hearing loss. *Journal of Speech and Language Hearing Research*, 54, 1448-1463.

Ricketts, T., & Galster, J. (2008). Head angle and elevation in classroom environments: Implications for amplification. *Journal of Speech and Language Hearing Research*, 51, 516-525.

Ricketts, T., Galster, J., & Tharpe, A. M. (2007). Directional benefit in simulated classroom environments. *American Journal of Audiology*, 16(2), 130-144.

Schafer, E. C, & Thibodeau, L. M. (2006). Speech recognition in noise in children with cochlear implants while listening in bilateral, bimodal, and FM-system arrangements. *American Journal of Audiology*, 15(2), 114-126.

Scollie, S., Ching, T. Y. C., Seewald, R., Dillon, H., Britton, L., Steinberg, J., & Corcoran, J. (2010). Evaluation of the NAL-NL1 and DSL v4.1 prescriptions for children: Preference in real world use. *International Journal of Audiology*, 49, 49-63.

Spahr, A. J., Dorman, M. F., Litvak, L. M., Van Wie, S., Gifford, R. H., & Loizou, P. C. (2012). Development and validation of the AzBio sentence lists. *Ear and Hearing*, 33(1), 112-117.

Stelmachowicz, R., Lewis, D., Hoover, B., Nishi, K., McCreery, R., Woods, W. (2010). Effects of digital noise reduction on speech perception for children with hearing loss. *Ear and Hearing*, 31(3), 345-355.

Wolfe, J., Duke, M., Schafer, E., Jones, C., & Rakita, L. (2017). Evaluation of adaptive noise management technologies for school-age children with hearing loss. *Journal of the American Academy of Audiology*, 28(5), 415-435.

Wolfe, J., Duke, M., Schafer, E., Jones, C., Rakita, L., & Battles, J. (2017). Evaluation of a remote microphone system with tri-microphone beamformer. Manuscript submitted for publication to the Journal of the American Academy of Audiology

Wolfe, J., Morais, M., Neumann, S., Schafer, E., Mulder, H., Wells, N., John, A., & Hudson, M. (2013). Evaluation of speech recognition with personal FM and classroom audio distribution systems. *Journal of Educational Audiology*, 19, 65-79.

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