Hearing Impaired Children’s Preference for, and Performance with, Four Combinations of Directional Microphone and Digital Noise Reduction Technology

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Abstract

Background: Before advanced noise-management features can be recommended for use in children with hearing loss, evidence regarding their ability to use these features to optimize speech perception is necessary.

Purpose: The purpose of this study was to examine the relation between children’s preference for, and performance with, four combinations of noise-management features in noisy listening environments.

Research Design: Children with hearing loss were asked to repeat short sentences presented in steady-state noise or in multitalker babble while wearing ear-level hearing aids. The aids were programmed with four memories having an orthogonal arrangement of two noise-management features. The children were also asked to indicate the hearing aid memory that they preferred in each of the listening conditions both initially and after a short period of use.

Study Sample: Fifteen children between the ages of 8 and 12 yr with moderate hearing losses, bilaterally.

Results: The children’s preference for noise management aligned well with their performance for at least three of the four listening conditions. The configuration of noise-management features had little effect on speech perception with the exception of reduced performance for speech originating from behind the child while in a directional hearing aid setting. Additionally, the children’s preference appeared to be governed by listening comfort, even under conditions for which a benefit was not expected such as the use of digital noise reduction in the multitalker babble conditions.

Conclusions: The results serve as evidence in support of the use of noise-management features in grade-school children as young as 8 yr of age.

Key Words: Children, digital noise reduction, directional microphones, hearing aids, hearing loss, pediatric, perception, preference, speech perception

Abbreviations: BKB-SIN = Bamford-Kowal-Bench Speech-in-Noise; DIR = directional microphone; DNR = digital noise reduction; DSL = desired sensation level; FM = frequency modulation

It has been well established that children experience more difficulty perceiving speech in noise than adults do. This is due, in part, to their inexperience with language and world knowledge, which limits their ability to use contextual cues to repair a distorted speech signal (Boothroyd, 1997; Blandy and Lutman, 2005). Children with hearing loss experience even more difficulty and require a higher signal-to-noise ratio to perform as well as their normal-hearing counterparts (Finitzo-Hieber and Tillman, 1978; Crandell, 1993; Crandell and Smaldino, 2000; Blandy and Lutman, 2005). Therefore, children with hearing loss are at a greater risk than children with normal hearing for communication breakdown in noise for which the consequences can become serious in certain environments, like school, where accurate communication is essential. It has also been well established that the acoustic environments of most elementary schools contain
significant levels of noise both in and out of the classroom (Knecht et al., 2002; Lundquist et al., 2003; Bradley and Sato, 2008; Sato and Bradley, 2008; Crukley et al., 2011). Although children with hearing loss are taught to advocate for their hearing needs in adverse listening conditions (e.g., requesting repetition, facing the sound source, moving away from noise), they often lack the authority to control many of the noisy situations that occur during school. For example, they are not able to reduce noise coming from classmates, ventilation systems, or street traffic, nor are they able to avoid noise and reverberation in the hallways, gymnasium, cafeteria, or restrooms. Management of these adverse listening environments then rests with the hearing devices that are prescribed to them for personal use (e.g., hearing aids, cochlear implants, frequency-modulation [FM] systems). FM systems have been used successfully in the classroom to significantly improve the signal-to-noise ratio of the teacher’s voice (Hawkins, 1984; Anderson and Goldstein, 2004); however, these devices are not practical outside the classroom at school. In those environments, the noise-management features available in other personal amplification devices (hearing aids, cochlear implants) may provide valuable benefit to children’s successful communication at school.

The most commonly prescribed noise-management features are directional microphones and digital noise reduction. Directional microphones reduce sound originating from behind the hearing aid user while amplifying sounds coming from the front. This is an ideal feature for a child who wishes to listen to one classmate in a noisy environment like the cafeteria. To benefit from this feature, the child must position himself so that he is facing his classmate with the noise from the other children to his back (Walden et al., 2004). Under similar controlled conditions, directional microphones have been shown to enhance the signal-to-noise ratio and improve speech perception in both adults and children (Valente et al., 1995; Gravel et al., 1999; Kuk et al., 1999; Ricketts et al., 2007).

When noise and speech originate from the same location, digital noise reduction technology may be a suitable option. This technology attempts to attenuate the level of steady-state noise while preserving the speech signal as much as possible. This is an ideal feature for a child who is positioned near a constant sound source and wishes to hear other children at various locations (e.g., soccer player in an open field near traffic). Digital noise reduction has been found to reduce listening effort (Walden et al., 2000), increase sound quality (Ricketts and Hornsby, 2005), and improve listening comfort in adults (Bentler et al., 2008). Reports regarding the benefits to speech perception, however, are mixed. Significant improvements have been reported when speech and noise reside in different spectral regions (Rankovic et al., 1992), but no benefits have been observed in adults or in children when the speech and noise overlap spectrally (Bentler et al., 2008; Pittman, 2011b). Some recent evidence suggests, however, that digital noise reduction may improve the signal-to-noise ratio sufficiently to allow older children to learn new words faster in noise than without digital noise reduction (Pittman, 2011a).

Although directional microphones and digital noise reduction have the potential to benefit children in noisy situations, guidelines for use in the pediatric population recommend that they be prescribed with caution (American Academy of Audiology Task Force, 2003). For example, directional microphones are not recommended for young children who must be able to hear caregivers positioned behind them in situations where their safety may be at risk (Gabbard and Schryer, 2003). Likewise, digital noise reduction may be detrimental to young children’s communication development if the overall level becomes too low, reducing their opportunities to learn by overhearing the conversations of others (Akhtar, 2005) or being insufficient for perceiving speech altogether (Stelmachowicz et al., 2010). Therefore, it may be appropriate to withhold these technologies until children are old enough to use them effectively so that learning, language development, and safety are not jeopardized.

When a child is ready, an audiologist can provide a dedicated memory within the hearing aid with one or both of these noise management features so that the child may choose to use them as necessary in noisy environments as suggested by Gravel et al (1999). This would allow the child to have control over adverse listening conditions and may optimize their communication ability. To date, no studies have examined children’s ability to identify noise-management technologies that optimize their speech perception in noise. Several studies, however, have provided important evidence to support such work. Ricketts and Galster (2008) studied the accuracy of children’s head angle and elevation in classroom settings to determine the accuracy with which they could orient to the source sound. The children were between 4 and 17 yr of age and had normal hearing or hearing loss. The children’s orientation relative to the teacher was measured during periods of classroom instruction. It was found that the children were relatively accurate in their ability to orient themselves toward the signal of interest, suggesting that school-age children have the potential to receive benefit from directional microphones in some school settings. These results are consistent with those of Ching et al (2009) who studied the head orientation behavior of 1- to 7-yr-old children with and without hearing loss. They determined that the children were able to orient to an adult talker more than 50% of the time although accuracy decreased when other children were present in the environment.

Children’s ability to provide reliable information about their use and preferences for different hearing
aid characteristics was demonstrated by Scollie et al. (2010). Using an ecologically robust experimental design they evaluated the preferences of 6- to 19-yr-old children for two hearing aid prescriptions over two 8 wk, counterbalanced periods. All but two of the children were able to switch between programs, keep a record of their preferences in a diary provided to them, and give real-life examples of their experiences. The results showed that the children’s preference for one prescription over the other was in line with the output levels of the hearing aids in each memory. Specifically, the children preferred the higher-level output when listening to low-level sounds (e.g., soft speech, sounds from behind, teacher, environmental sounds) and the lower-level output when listening to high-level sounds (e.g., restaurant, automobile, shopping mall). These results suggest that children with hearing loss have clear preferences for the amplified signal they receive and that they can relate that information in a meaningful way to caregivers and clinicians.

However, before advanced noise-management features can be recommended with confidence, it is necessary to determine whether children with hearing loss are able to recognize a benefit to speech perception. Such a demonstration would confirm that they have the potential to use the features optimally. Therefore, the overall goal of this study was to examine the relation between children’s performance with, and preference for, noise-management features in noisy listening environments. Children were fitted with hearing aids having four memories that contained different combinations of digital noise reduction (on, off) and directional microphones (omnidirectional, directional). Speech stimuli were presented from one of two positions (front, back) in two noise conditions (steady state noise, multitalker babble). The children’s speech perception was compared to their initial and final preferences for hearing aid memory in each listening condition. It was hypothesized that the children’s preferences would align with their performance both initially and after a short period of use such that their preferred noise-management setting would correspond with their best speech perception.

METHOD

Participants

Sixteen children with hearing loss (equal numbers of boys and girls) between the ages of 8 and 12 yr were recruited for participation. One child was not able to complete all of the testing and was excluded, leaving a total of 15 children. Figure 1 shows the average hearing threshold levels as a function of audiometric frequency for the right and left ears. On average, participants had mild-to-moderate symmetrical hearing loss. All children had experience with amplification, spoke English as their primary language, and were enrolled in age-appropriate grades in either private or public schools. Table 1 lists each participant’s age, hearing threshold levels, age at which hearing loss was identified, and age at which amplification was provided. On the day of testing, children received a hearing evaluation that included otoscopy and acoustic immittance. Outer- and middle-ear status consistent with that expected was confirmed. Four children did not receive acoustic immittance testing due to equipment malfunction; however, for these children, audiometric testing indicated no significant changes in hearing threshold levels relative to their most recent audiological examination.

Prior to testing, the receptive vocabulary of each child was determined using the Peabody Picture Vocabulary Test IV Form A (Dunn and Dunn, 2007). Measures of receptive vocabulary (raw score, standard score, vocabulary age) provided an estimate of the long-term effects of hearing loss on the children’s lexical development. The results for all of the children were within one standard deviation of the norm with the exception of one child whose scores fell just below one standard deviation (standard score: 84). These results confirmed that no significant deficits in vocabulary existed that might affect their performance on the speech perception task used in this study.

Stimuli

Two sets of speech stimuli were used. The first was a recording of a children’s story titled “Buster Bear.” The story was recorded in quiet and was told by a male talker with a standard American English accent. A 90 sec sample of the story was extracted and presented continuously in the presence of an acoustic competitor (described below). The second set of stimuli was Bamford-Kowal-Bench Speech-in-Noise (BKB-SIN) sentences.
spoken by a different male talker having a standard American English accent (Etymotic Research Inc., 2005). The sentences represent everyday language consistent with a first-grade reading level and were compiled for clinical evaluation of hearing impaired children (Bench et al, 1979). The first eight (of 16 total) sets of BKB-SIN sentences were used. The eight sets of sentences consisted of two lists of 10 sentences each for a total of 160 sentences. Each list of sentences contained 31 target words. (The first sentence contained four target words, and the remaining nine sentences contained three target words each.) For the purpose of this study, one target word was ignored from the first sentence of each set so that each list contained 30 target words. Because the recording quality of some of the sentences was poor, they were replaced with similar sentences from other lists.

Two types of acoustic competitors were presented with the speech stimuli: multitalker babble and broadband noise. The multitalker babble contained conversations of six men and six women recorded separately and then mixed together into a single audio file. Some semantic information was preserved in that small portions of each conversation (a few words) could be selectively followed. The broadband noise contained randomly generated noise shaped to have the same long-term spectrum levels as the multitalker babble competitor. Figure 2 shows the long-term average spectra of the stimuli as a function of frequency. The parameter in the graph is stimulus (two speech stimuli, two noise competitors). The long-term spectra were calculated in 1/3-octaves using a Hanning window with 50% overlap. The figure shows the levels presented in the sound field at the calibrated position (1 m from the source). The speech stimuli were presented at an overall level of 65 dB SPL, and the acoustic competitors were presented at 62 dB SPL for a +3 dB signal-to-noise ratio. Note that the spectra of the speech stimuli reflect the different talkers whereas the spectra of the acoustic competitors were equivalent.

Procedure

Each child was fitted bilaterally with Resound Alera IX behind-the-ear hearing aids. This hearing aid was chosen after testing similar devices from six other

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Table 1. Demographic Characteristics of the Children with HL Including Gender, Age, Hearing Thresholds (in dB HL) as a Function of Frequency (in kHz), Type of Loss, Age at Identification, and Age at First Amplification

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Note: C = conductive; ID = identification; NR = no response; S = sensorineural.

*Not using amplification consistently at the time of the study.
hearing aid manufacturers. The directional microphone and digital noise reduction features of each device were evaluated for effective improvement in signal-to-noise ratio. The ReSound hearing aid offered similarly effective improvements in signal-to-noise ratio for both noise-management features such that perceptible differences could be expected across hearing aid settings (described below). This model also provided four fully programmable memories that could be manipulated by the children using a digital remote control. Representatives of the manufacturer were contacted, and they agreed to provide two hearing devices and a remote control for the study at no charge.

The hearing aids were coupled to the ear using the child’s personal earmold. Children who used in-the-ear or slim-tube hearing aids, and those who did not have their personal earmolds with them at the time of testing, were fitted using temporary (Comply) molds. All children were fit binaurally. The hearing aid manufacturer’s software was used to program and fine-tune the instruments based on the simulated real-ear measures available in the Audioscan Verifit (VF-1) hearing aid test system. Individual thresholds and real-ear-to-coupler differences were obtained and entered into the Verifit prior to fitting. The output of the hearing aid was adjusted to meet the targets prescribed for soft (55 dB SPL), average (65 dB SPL), and loud (75 dB SPL) input levels according to the desired sensation level (DSL) ([i/o] 5.0) fitting algorithm (Scollie et al, 2005). Output levels were equated across memories to reduce any feature-specific bias that might affect the results.

Hearing Aid Memories

Four orthogonal combinations of directional microphone technology and digital noise reduction were programmed into the hearing aids. In two of the memories, the microphones were arranged to provide omnidirectional amplification (“omni” setting in the software) whereas in the other two programs the microphones were arranged to provide directional amplification (“Fixed Directional” setting with the “Directional Mix” set to “high”). Likewise, digital noise reduction was enabled for two memories (“strong”) and disabled in the other two memories (“off”). To demonstrate and confirm the effect of these settings on hearing aid output, one hearing aid was programmed to accommodate the hearing thresholds of a hypothetical nine-yr-old child with a moderate sensorineural hearing loss. The output of the hearing aid was adjusted to DSL targets using age-appropriate average real-ear-to-coupler differences and simulated real-ear measures. The output was equated across the four hearing aid memories and then set to provide the four combinations of directional microphones and digital noise reduction just as would be done for each study participant.

Figure 3 shows output levels as a function of frequency for the four hearing aid memories using the Directional Analysis tool offered in the Audioscan Verifit (VF-1) hearing aid test system. The solid and dashed lines represent the output of the hearing aid for stimuli entering the front and rear microphones, respectively. For each memory, the output associated with the rear microphone was lower than that of the front microphone, but the differences were substantially lower when the microphones were arranged in a directional fashion, that is, minimally amplifying stimuli reaching the rear microphone. It is also interesting to note that the output of both microphones was lower when the digital noise reduction was activated than when it was deactivated. These results indicate that the signal
produced by the hearing aid in these conditions should have a significant impact on performance.

Figure 4 shows the output (waveforms) for each hearing aid memory for the BKB stimuli mixed with the steady-state noise at a nominal signal-to-noise ratio of +4 dB. Each panel represents the output of the hearing aid for the four hearing aid memories. To calculate the effective signal-to-noise ratio, an inversion technique described by Souza et al (2006) was used to isolate the speech signal from the steady-state noise. This procedure was also used by Pittman (2011a, 2011b) to quantify the digital noise reduction of the hearing aids in those studies. (See Souza et al [2006] for a step-by-step description of the procedure.) The measured signal-to-noise ratio for each hearing aid memory is also provided in the figure. These measures showed that, compared to the omnidirectional condition with no digital noise reduction (top panel), directional microphones improved the signal-to-noise ratio by 2 dB (second panel), digital noise reduction improved the signal-to-noise ratio by 4 dB (third panel), and the combined effect of directional microphones and digital noise reduction improved the signal-to-noise ratio by 7 dB (bottom panel). Although the exact signal-to-noise ratio experienced by each child likely varied, these measures indicate the potential for differences in performance across hearing aid memories.

Listening Conditions

In a sound treated room, each child was seated 1 m from two loudspeakers, one directly in front and one directly behind. Figure 5 shows a schematic of the child relative to the front and rear loudspeakers to form four orthogonal listening conditions. Each listening condition involved the speech stimuli presented through one loudspeaker (front or back) and a competitor (multitalker babble or steady-state noise) presented through both loudspeakers. For example, the first panel shows the condition in which speech originated from the front and steady-state noise from the front and rear loudspeakers.

Procedures

The remote control was given to each child to manipulate the hearing aid’s memories. A dedicated button on the remote control changed the memory in both hearing aids simultaneously. The hearing aids were configured to indicate when they were in memory 1, 2, 3, or 4 by generating one, two, three, or four beeps, respectively, while the remote control displayed the number of the memory on a small digital display. The tones generated by the hearing aids were set to occur at a frequency and output level that was audible to each child. The volume control was disabled in both hearing aids. Prior to testing, each child was familiarized with the hearing aids and oriented to the remote control. Because all of the children had current or previous experience with hearing aids, they required minimal orientation to the devices, allowing them to focus their attention on the remote control. The children acclimatized to the remote control after only a few minutes of use. The configuration of the 4 hearing aid memories was counterbalanced across children. That is, each child received a different combination of noise-management features in the four hearing aid memories. This was done to reduce any primacy and order effects that might affect the children’s preference for one memory over another.

Data were collected in three phases. In the first phase, the child was given the remote control, and
his or her preference for a hearing aid memory was obtained in each of the four listening conditions. One examiner was seated in the sound-treated room with the child while a second examiner was seated outside the room to control the stimulus presentation. The child was instructed to listen to the “Buster Bear” story for several seconds in each of the hearing aid memories and then tell the examiner which one he or she “liked best.” No other descriptors were provided to the children that might influence their choice of hearing aid memory. This was repeated for each of the four listening conditions. For example, in one condition, the child heard the multitalker babble originating from the front loudspeaker and the same babble mixed with the “Buster Bear” story from the rear loudspeaker. While listening to the story, the child cycled through the memories using the remote control and indicated the memory (number) that he or she preferred. The “Buster Bear” story was then presented in the next listening condition, and the procedure was repeated. This phase took approximately 5-10 min to complete, depending upon the pace of the individual child.

In the second phase, the children were told that they would hear sentences in the same background noises. They were instructed to ignore the background noise and repeat as much of each sentence as possible. Guessing was encouraged. The examiner was seated with the child, manipulated the hearing aid memories using the remote control, and recorded the children’s responses. At the beginning of each trial the acoustic competitor was presented for several seconds to allow the hearing aid’s digital noise reduction to engage fully. The child repeated one list of sentences in each listening condition. Like the hearing aid memories, the word lists and listening conditions were counterbalanced, which was necessary to reduce order and practice effects. Each list took approximately 1 min to complete.

In the third phase, the child’s preference for hearing aid memory was again obtained in each listening condition using the same procedure and stimuli as in the first phase.

RESULTS

Prior to data analyses, the children’s performance for the BKB sentences was arcsine transformed to equalize the variance across the range of scores (Studebaker, 1985). The children’s initial and final preferences were calculated as the proportion of children who preferred the different hearing aid memories in each listening condition.

Speech Perception

Table 2 shows the children’s average performance (and 1 SD) for each listening condition using each hearing aid setting. Note that the order of hearing aid settings differs from those shown in the previous figures to better transition to the final figures comparing performance and preference. Scores were generally in the midrange of performance (40–60%) but fell by 20–30% for the listening conditions in which the speech stimuli originated from behind and the hearing aid microphones were set to operate directionally. The data were subjected to repeated-measures analysis of variance (ANOVA) with competitor (noise, babble), stimulus location (front, back), and hearing aid memory (4) as the within-subjects factors. Significant main effects were revealed for stimulus location (F(1,14) = 30.186, p < .001, η² = .683, β = .999) and hearing aid memory (F(3,42) = 13.963, p < .001, η² = .499, β = 1) but not for competitor (F(1,14) = .18, p = .896). Significant competitor x hearing aid memory (F(3,42) = 4.063, p = .013, η² = .225, β = .808) and competitor x stimulus location (F(3,42) = 28.962, p < .001, η² = .674, β = 1) interactions were observed. Post hoc analyses for each listening condition revealed no significant differences between the hearing aid settings in the noise competitor when speech originated from the front. However, when the speech originated from behind, performance was significantly better when the microphones were set to operate in an omnidirectional rather than a directional fashion. These results suggest that, in steady state noise, children’s performance is improved with the use of directional microphones, but only when the speech originates from the front. Digital noise reduction, however, did not improve or reduce performance significantly under any listening condition.

The results of the post hoc analyses were not as clear as for the multitalker babble condition when the speech originated from the front. Equally good performance was revealed when one of the two noise-management features was activated (directional microphones or digital noise reduction), but lower performance was observed when both features were activated or deactivated. These
results suggest that too much or too little noise management may have been detrimental to the children’s speech perception. However, when the speech originated from behind the child, performance was significantly better when the microphones were set to operate in an omnidirectional, rather than a directional, fashion. In summary, although children’s speech perception was similar in both competitors, the choice of noise-management features was somewhat critical, more so when the speech originated from behind the child than when it originated from the front.

Preference

Table 3 shows the children’s initial and final preferences of hearing aid memory in each listening condition. Preferences varied somewhat more than performance, although certain trends were observed. In the noise competitor with speech originating from the front, the children initially preferred digital noise reduction. After a short period of use, their preference shifted to include directional microphones as well. Conversely, the children initially preferred omnidirectional microphones when the speech originated from behind, but after a short period of use, they shifted to a preference for digital noise reduction. In the babble conditions, the children clearly preferred digital noise reduction with directional microphones when the speech originated from the front while preferring omnidirectional microphones when the speech originated from behind. The preference data were subjected to two repeated-measures ANOVAs to examine initial and final preferences. The dependent variable was the preferred noise-management configuration with competitor (noise, babble) and stimulus location (front, back) as within-subjects factors. For the children’s initial preferences, a significant main effect was observed for stimulus location (F(1,14) = 9.333, p = .009, η² = .4, β = .811) but not for competitor (F(1,14) = 0, p = 1.00). For the children’s final preferences, no significant main effects were revealed (competitor: F(1,14) = 1.75, p = 2.07; stimulus location: F(1,14) = 1.366, p = .262). These results indicate that the children’s initial preference for a particular type of noise management differed depending on the location of the stimulus but not the type of competitor. However, their final preferences diverged after a short period of use and could not be predicted from the outcomes expected for the respective noise-management features.

Performance versus Preference

Recall that the purpose of the present study was to examine the relation between children’s choice of, and performance with, noise-management features in noisy listening environments. Ideally, children’s preferences will align with their performance indicating that they are able to recognize hearing aid settings that optimize their speech perception in naturalistic environments. Figure 6 shows the relationship between overall performance and preference using radar plots. Results for the front and back stimulus locations are

### Table 2. Average Performance (1 SD) for the BKB Sentences for Each Hearing Aid Memory in the Four Listening Conditions

<table>
<thead>
<tr>
<th>Microphone Arrangement</th>
<th>Digital Noise Reduction Setting</th>
<th>Performance (%)</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Competitor:</td>
<td>Noise</td>
<td>Noise</td>
<td>Babble</td>
<td>Babble</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Speech:</td>
<td>Front</td>
<td>Back</td>
<td>Front</td>
<td>Back</td>
</tr>
<tr>
<td>Omnidirectional</td>
<td>Off</td>
<td>63 (24)</td>
<td>59 (25)</td>
<td>52 (23)</td>
<td>50 (29)</td>
<td></td>
</tr>
<tr>
<td>Omnidirectional</td>
<td>On</td>
<td>57 (24)</td>
<td>49 (22)</td>
<td>60 (22)</td>
<td>56 (24)</td>
<td></td>
</tr>
<tr>
<td>Directional</td>
<td>On</td>
<td>57 (29)</td>
<td>18 (11)</td>
<td>55 (22)</td>
<td>23 (27)</td>
<td></td>
</tr>
<tr>
<td>Directional</td>
<td>Off</td>
<td>67 (23)</td>
<td>24 (17)</td>
<td>71 (21)</td>
<td>27 (19)</td>
<td></td>
</tr>
</tbody>
</table>

### Table 3. Children’s Initial and Final Preferences (in percent of total children) for Each Hearing Aid Memory in the Four Listening Conditions

<table>
<thead>
<tr>
<th>Microphone Arrangement</th>
<th>Digital Noise Reduction Setting</th>
<th>Preferring (% initial/% final)</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Competitor:</td>
<td>Noise</td>
<td>Noise</td>
<td>Babble</td>
<td>Babble</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Speech:</td>
<td>Front</td>
<td>Back</td>
<td>Front</td>
<td>Back</td>
</tr>
<tr>
<td>Omnidirectional</td>
<td>Off</td>
<td>13/13</td>
<td>40/7</td>
<td>0/33</td>
<td>33/7</td>
<td></td>
</tr>
<tr>
<td>Omnidirectional</td>
<td>On</td>
<td>53/13</td>
<td>27/53</td>
<td>13/7</td>
<td>47/67</td>
<td></td>
</tr>
<tr>
<td>Directional</td>
<td>On</td>
<td>33/47</td>
<td>20/33</td>
<td>47/40</td>
<td>7/13</td>
<td></td>
</tr>
<tr>
<td>Directional</td>
<td>Off</td>
<td>0/27</td>
<td>13/7</td>
<td>40/20</td>
<td>13/13</td>
<td></td>
</tr>
</tbody>
</table>
displayed in the upper and lower panels, respectively. The four axes serve the dual purpose of displaying performance (in proportion correct) and preference (in proportion of children) from 0 at the center to a maximum of .8 at each end. Each axis represents one of the four noise-management configurations (memories) arranged such that common settings are adjacent to one another. The sizes of the areas plotted indicates the extent of the performance or preference for each hearing aid setting. Thus, area boundaries that are close to the center (0) would indicate poor performance or little preference whereas area boundaries extending some distance from the center indicate better performance or greater preference. This display was also useful for identifying conditions in which the children selected their preferred hearing aid memory in a random fashion. Random preference would result in boundaries that extend to chance levels (0.25) in all four directions; however, this did not occur for any of the listening conditions.

In the top panel of Figure 6, where the results for the speech originating from the front are shown, performance (gray area) extends some distance from the center in all directions reflecting the relatively equal performance across hearing aid memories. Initial and final preferences (white and hatched areas, respectively) are overlaid onto performance and show an overall preference for digital noise reduction (DNR on) as well as a shift in preference from omni (DIR off) to directional (DIR on) microphones. These results suggest that the children preferred some noise management initially and more noise management after a period of use. It could be argued that, given the nearly equal performance with each hearing aid memory, the children’s choice of noise management would not have affected their performance substantially. Thus, their preferences appeared to be governed by listening comfort. The lower panel shows the performance and preference results for the listening condition in which the speech originated from behind the child. These results are qualitatively different from the results obtained using speech stimuli presented from the front of the listener and indicate that the children’s initial preference for noise management aligned well with their overall performance. However, a portion of children shifted their preference from no noise management to full noise management (DIR on, DNR on) after a short period of use despite the fact that the stimuli originated from behind. It is possible that the children were attempting to further improve their listening comfort.

Figure 7 shows the results for the multitalker babble condition using the same convention as in Figure 6. A comparison of the two figures shows a similar configuration of results with two exceptions. First, the initial and final preferences for the listening condition shown in the upper panel indicate that the children initially preferred directional microphones when listening to multitalker babble (white area), but their final preference was divided between the maximal and minimal noise-management conditions. It is possible that some children attempted to optimize their speech perception whereas others wished to optimize their listening comfort. Even so, performance with each hearing aid memory was similar, suggesting that any configuration of noise management may be sufficient in typical communication environments where the child is facing the sound source. Second, although the children’s preference aligned well with their performance when the speech originated from behind them (lower panel), a clear preference for digital noise reduction emerged after a period of use. This was unexpected given that digital noise reduction is designed for use in steady state noise. These results suggest that children may garner substantial benefit from this type of noise management across a range of competitors, both for perception and for listening comfort.
The purpose of this study was to examine the relation between children's speech perception and their preference for noise-management features. Children were asked to repeat short sentences presented in steady-state noise or in multitalker babble while wearing ear-level hearing aids. The hearing aids were programmed with four memories having an orthogonal arrangement of two noise-management features. In addition, the children indicated the hearing aid memory that they preferred in each of the listening conditions both initially and after a short period of use. As expected, performance decreased in the directional microphone conditions when the speech originated from behind the child. In all other conditions, performance was equally good. These results are consistent with those of Ricketts et al (2007), who reported similar effects in children for directional and omnidirectional microphone arrangements. The results of the present study also showed that the children preferred one or two noise-management features in each of the listening conditions and that those preferences aligned well with their performance. Finally, there were indications that the children preferred noise management that maximized listening comfort. For example, the children preferred digital noise reduction in the multitalker babble conditions even though this feature is not designed for those environments.

The results of the present study also suggest that the type of noise and the noise-management feature have little effect on perception when speech originates from the front of the child. It is only when speech originates from behind the child that the choice of noise management interferes with speech perception. If a child’s hearing aids are set to a directional microphone mode (knowingly or not), he will need to be keenly aware of sounds from behind so that he can orient his head appropriately (Ricketts et al, 2007). Otherwise he could be altogether unaware of sounds originating from behind and fail to recognize what has been missed. Fortunately, the results of the present study indicate that children can recognize hearing aid settings that are detrimental to their speech perception, particularly when speech is located behind them, suggesting that they would know to switch the hearing aid to a more appropriate setting.

Another interesting result involved the agreement between the preference and performance results for the substantively different speech samples. Recall that the preference data were gathered using a sample of continuous discourse, and the performance data were collected using short sentences produced by a different talker. This suggests that the close relationship between perception and preference may be robust enough to extend from clinical to naturalistic listening environments. However, caution should be taken when incorporating a child’s initial preference for any combination of noise management as it will likely change over time. Indeed, the children’s preference for noise management changed in every listening condition after a short period of use (approximately 30 min). Although it is not possible to extrapolate these results to predict children’s long-term acclimatization to these features, the results suggest that children’s initial preferences may not reflect their actual use of these features. It may be wise to initially provide children with several noise-management options until they identify the features that work best for complex environments like those at school.

**DISCUSSION**

The purpose of this study was to examine the relation between children's speech perception and their preference for noise-management features. Children were asked to repeat short sentences presented in steady-state noise or in multitalker babble while wearing ear-level hearing aids. The hearing aids were programmed with four memories having an orthogonal arrangement of two noise-management features. In addition, the children indicated the hearing aid memory that they preferred in each of the listening conditions both initially and after a short period of use. As expected, performance decreased in the directional microphone conditions when the speech originated from behind the child. In all other conditions, performance was equally good. These results are consistent with those of Ricketts et al (2007), who reported similar effects in children for directional and omnidirectional microphone arrangements. The results of the present study also showed that the children preferred one or two noise-management features in each of the listening conditions and that those preferences aligned well with their performance. Finally, there were indications that the children preferred noise management that maximized listening comfort. For example, the children preferred digital noise reduction in the multitalker babble conditions even though this feature is not designed for those environments.

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**Implications for Other Amplification Devices**

An important consideration of the current study is whether the results may be generalized to other hearing devices. That is, can the same effects be expected for
children using different makes and/or models of hearing aids? Although a single device was used in the present study, the same benefits could be expected from other devices that offer similar improvements in signal-to-noise ratio via digital noise reduction and directional microphone features. Audiologists can quantify these improvements for their pediatric patients using several measures available in hearing aid analyzers (e.g., Frye, Audioscan, Interacoustics). These measures are separate from those used to verify the output of the hearing aid and should be used after the aid has been programmed to meet targets for soft, average, and loud speech in each hearing aid memory. In fact, it is critical that the audiologist be aware of the status of all noise-management features in the hearing aid as some features will change the output of the hearing aid substantially, requiring additional adjustments to meet amplification targets.

It is also important to note that while digital noise reduction was preferred by most children without affecting performance, significant decreases in performance occurred for directional microphone technology when speech originated from behind the child. When used properly, and the results suggest that children are able to do so, this feature has the potential to benefit children in many noisy environments. However, caution should be taken to adequately train a child regarding the use of directional microphone technology much like we do with adult patients. Introduction of these features may begin at around 8 yr of age by providing one or both features in separate hearing aid memories and then using the hearing aid’s data logging feature to determine the child’s use of noise management and the need for continued training.

Implications for Hearing Aid Use in Children

A major concern of audiologists is the tendency for children to reject amplification as they get older and begin to exert control over their personal choices. The available evidence suggests that children’s use and acceptance of hearing aids was quite poor until newborn hearing screening became the universal standard (Gaeth and Lounsbury, 1966; Markides, 1989). Since then, hearing aid use by infants and young children has improved (Marttila and Karikoski, 2006; Walker et al, 2013); however, older children’s acceptance of hearing aids continues to decline during the grade-school years and into adulthood (Markides, 1989; Seifert et al, 2001). As many as half of grade-school children with hearing loss opt to wear only one hearing aid or none at all, placing them at greater risk for social, academic, vocational, and emotional problems during adolescence (Hintermair, 2006; Punch et al, 2006; Hintermair, 2007). The most common reason cited for hearing aid rejection by children was that the hearing aids did not work properly (Seifert et al, 2001). Unfortunately, the extant literature does not provide sufficient detail regarding the factors involved in grade-school children’s rejection of their hearing aids, making this an important area for further research. However, it is fairly clear that, for many children, hearing aids are insufficient to help manage the demands of their listening environments. The results of the present study suggest that children may benefit significantly from noise-management features in adverse listening environments, like school, such that they are considered a valued tool for communication. This may, in turn, motivate children to use their hearing aids throughout the school day.

Another contributor to children’s rejection of hearing aids may be the lingering practice of many pediatric audiologists of deactivating all user controls on the hearing aid (volume control, memory switch). While this is appropriate during infancy and early childhood, it prevents the older child from making necessary adjustments in difficult listening environments. In these situations, the child’s choices are reduced to leaving the hearing aids in or taking them out. Like adults, children may share the same or greater self-reported benefit in noise from instruments that allow them to switch between noise-management features (Ricketts et al, 2003). Again, the results of the present study suggest that children are capable of judging the listening environment and choosing appropriate noise management.

Limitations and Future Directions

There are several limitations in the present study that are important to note. First, the children’s preference of noise management was obtained in response to a simple query, “Which one do you like the most?” Although this query appears to have worked well, more could be learned from having the children rate each memory in order of least to most preferred for each listening condition. This would have provided additional, valuable information about the children’s other options and whether they would be appropriate for the listening situation.

Another limitation is the use of simple sentences of known vocabulary to evaluate speech perception. Although such stimuli are considered the gold standard for auditory perceptual research, they do not represent well the environment or the demands of children in educational settings. More appropriate stimuli might include nonsense syllables or words presented in paradigms that require the child to differentiate known from unknown words or to learn from the stimuli in some fashion. Such demands on a child’s auditory cognition are likely to reveal additional benefits or deficits of noise-management features as well as other forms of hearing aid signal processing.
Summary

The most important finding in the current study is the agreement between the children’s preference for noise-management features and their speech perception. An equally important finding is the children’s preference for listening comfort across all listening conditions. Specifically, the children with hearing loss preferred digital noise reduction in both steady-state noise and multitalker babble even though this technology is considered to be only effective for environments containing steady-state noise. Although speech perception may be reduced slightly with some combinations of noise and hearing aid settings, the results serve as evidence supporting the use of these features in grade-school children as young as 8 yr of age.

REFERENCES


