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Evaluation of the Benefits of Binaural Hearing on the Telephone for Children with Hearing Loss

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Jace Wolfe*
Erin Schafer†
Emily Mills‡
Andrew John‡
Mary Hudson‡
Solange Anderson§

Abstract

Background: There is a paucity of published studies examining how children with hearing loss understand speech over the telephone. Previous studies on adults with hearing aids have suggested that adults with bilateral hearing aids experience significant difficulty recognizing speech on the telephone when listening with one ear, but the provision of telephone input to both ears substantially improved speech understanding.

Purpose: The objectives of this study were to measure speech recognition in quiet and in noise for a group of older children with hearing loss over the telephone and to evaluate the effects of binaural hearing (e.g., DuoPhone) on speech recognition over the telephone.

Research Design: A cross-sectional, repeated-measures design was used in this study.

Study Sample: A total of 14 children, ages 6–14 yr, participated in the study. Participants were obtained using convenience sampling from a nonprofit clinic population.

Intervention: Speech recognition in quiet and in noise with binaural versus monaural telephone input was compared in pediatric participants.

Data Collection and Analysis: Monosyllabic word recognition was assessed in quiet and classroom noise set at 50 dBA in conditions with monaural and binaural (DuoPhone) telephone input.

Results: The children's speech recognition in quiet and in noise was significantly better with binaural telephone input relative to monaural telephone input.

Conclusions: To obtain optimal performance on the telephone, the following considerations may apply: (1) use of amplification with binaural streaming capabilities (e.g., DuoPhone), (2) counseling of family and children on how to best use the telephone, (3) provision of telecoil with microphone attenuation for improved signal-to-noise ratio, and (4) use of probe tube measures to verify the appropriateness of the telephone programs.

Key Words: speech recognition, hearing aids, noise, telephone, monaural, binaural

Abbreviations: CNC = consonant-nucleus-consonant; DSL = desired sensation level

INTRODUCTION

The standard of care for children with bilateral hearing loss is the provision of hearing technology for both ears. The benefits of binaural hearing are well established and include enhanced loudness and sound quality from binaural summation, improved localization abilities, and improved speech recognition in quiet and especially in noise because of binaural squelch, the head shadow effect, and binaural redundancy (Carhart,

*Hearts for Hearing Foundation, Oklahoma City, OK; †University of North Texas, Speech and Hearing Department, Denton, TX; ‡University of Oklahoma Health Sciences Center, Oklahoma City, OK; §Phonak AG, Stafa, Switzerland

Jace Wolfe, 3525 NW 56th Street, Suite A-150, Oklahoma City, OK 73012; E-mail: Jace.wolfe@heartsforhearing.org

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1965; Harris, 1965; Shaw, 1974; Dermody and Byrne, 1975; Davis and Haggard, 1982). Most studies of the benefits of binaural hearing for children with hearing loss have focused on improvement that occurs in localization and speech understanding in noise (Beggs and Foreman, 1980; Litovsky et al, 2012). There is a paucity of published studies examining how children with hearing loss understand speech over the telephone. Also, to our knowledge, no published studies have evaluated whether children with hearing loss may understand speech over the telephone better while listening with two ears compared with one ear. Yet, the ability for a child with hearing loss to converse over the telephone is an important aspect of communication with friends, parents, and extended family members. In addition, the ability to use a telephone and to comprehend information received through it is critical in emergency situations in which a child needs to converse with a parent or emergency personnel.

Although the authors did not identify any pediatric studies related to telephone use, Picou and Ricketts (2011; 2013) recently reported on two studies in which they examined recognition of recorded speech presented over the telephone for a group of adult hearing-aid users. Speech recognition significantly improved when listening to telephone speech with two ears through wireless streaming from a remote interface device compared with performance with one ear alone. Two important conclusions may be drawn from the Picou and Ricketts studies (2011; 2013). First, adults with moderate to severe hearing loss experienced substantial difficulty with speech recognition while listening with the telephone signal delivered acoustically to one ear. Specifically, 16 of 18 participants understood less than 50% of the speech in the monaural acoustic telephone condition (Picou and Ricketts, 2013). Second, listening on the telephone with both ears resulted in better speech understanding than listening with one ear alone. On average, bilateral listening resulted in a 22% improvement in speech recognition compared with the unilateral condition.

Considering the difficulty that these adults (Picou and Ricketts, 2011; 2013) experienced with speech recognition over the telephone, it is of little surprise that Kochkin (2010) found that approximately 30% of adult hearing aid users reported that they were less than satisfied with their ability to understand speech over the telephone. Hearing aid manufacturers have sought to create solutions to improve hearing aid wearers' ability to converse over the telephone. Most hearing aid companies offer a wireless streaming solution in which the signal from a mobile telephone is wirelessly transmitted (via digital radio frequency communication) to the wearer's hearing aids via a remote interface device (e.g., either a remote control, a mobile telephone dongle, or a streamer worn around the neck of the user). Although speech recognition may be improved on the mobile telephone (Picou and Ricketts, 2011; 2013), these solutions have limitations including the need to purchase a special interface device and the fact that that they are often limited to use with mobile telephones (not landline telephones).

An alternative solution is a feature offered by one manufacturer, Phonak, called DuoPhone. With DuoPhone, the user holds the landline or mobile telephone next to his or her hearing aid, and the signal that is captured by the hearing aid microphone or telecoil is automatically transmitted from one hearing instrument to the other through wireless streaming of the audio signal. DuoPhone may be used in a manual program (i.e., the wearer manually accesses DuoPhone via the program push button or remote control) or as a program that is automatically enabled when a telephone is placed next to the hearing instrument (e.g., Easyphone). Here are potential advantages of DuoPhone: (1) the hearing aid wearer is able to receive the telephone signal binaurally, (2) the hearing aid wearer is able to use the telephone naturally with the handset held next to the ear, (3) the DuoPhone may be used with both a landline and mobile telephone, and (4) the DuoPhone requires no special interface equipment. To date, there have been no published studies examining the potential benefits of DuoPhone for children with hearing loss.

Given the challenges that adult hearing aid wearers experience with the telephone, it is likely that children with hearing loss also experience difficulty understanding speech on the telephone. The primary objective of this study was twofold: (1) to assess speech recognition in quiet and in noise for a group of older children with hearing loss over the telephone, and (2) to examine the potential benefit of binaural hearing (e.g., DuoPhone) for children's speech recognition over the telephone.

METHODS

Participants

A total of 14 children, ages 6–14 yr ($M = 9.5$, $SD = 2.8$), who were served at Hearts for Hearing in Oklahoma City, OK, participated in the study. Convenience sampling was used to obtain the participants, and all participants met the following inclusion criteria:

1. All participants demonstrated a bilateral hearing loss with a better ear four-frequency pure-tone average between 35 and 75 dB HL.
2. All participants had symmetrical hearing thresholds with no more than a 20 dB difference in air-conduction thresholds between ears at 500, 1000, 2000, and 4000 Hz. Figure 1 displays the average audiogram for the children.
3. All participants were consistent users of binaural amplification fitted via real-ear probe microphone measures to the Desired Sensation Level Multistage Input/Output algorithm version 5.0 (DSL

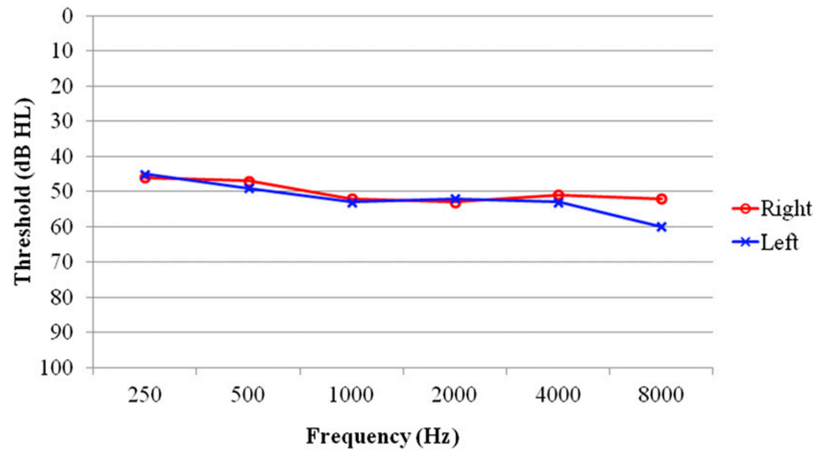

Figure 1. Mean air-conduction thresholds for study participants.

m[i/o] v5.0—hereafter referred to as DSL 5.0) prescriptive target for children. Data logging within the children's personal hearing aids indicated an average of 12 hr of hearing aid use per day (SD = 2.8, range = 7–16 hr/day) for the group of children in this study.
4. All participants spoke English as a primary language.
5. All participants demonstrated expressive and receptive spoken language abilities within 1 yr of their chronological age, as indicated by standardized speech and language assessment conducted by a speech-language pathologist within the past year.

Before study initiation, all parents signed a consent form to permit their children to participate.

Hearing Aid Fitting Procedures

All participants were fitted with Phonak Bolero Q90-M13 behind-the-ear hearing aids. During the fitting, an acoustic feedback test was conducted for both hearing aids for each child to optimize the acoustic feedback cancellation system of the hearing aids. In order to evaluate the DuoPhone feature in isolation of other advanced signal processing features, we disabled the digital noise reduction system and placed the hearing aid microphones in omnidirectional mode.

The Audioscan RM500SL hearing aid analyzer was used to measure real-ear-to-coupler differences for each child, and probe microphone measures were conducted to ensure that the output of the hearing aid matched (±3 dB) the DSL 5.0 target for children at 500, 1000, 2000, and 4000 Hz for the Audioscan *Standard Speech* signal presented at 60 dB SPL (Fig. 2). Once the output of the hearing was fitted to the DSL 5.0 target, several measures were made to verify the output of the hearing aid during telephone use. When creating a telephone program for hearing aid wearers, the audiologist may select from either a program that uses the telecoil as the primary transducer used to capture the signal of interest from the telephone (i.e., a telecoil program) or a program that uses the hearing aid microphone to capture the signal of interest (i.e., an acoustic program with the telephone receiver held next to the hearing aid microphone—telecoil disabled). To determine which program was optimal, we evaluated the performance of two children with both an acoustic and a telecoil program.

To begin, the output of each program was measured via real-ear probe microphone measures. Specifically, the hearing aid was set to the manufacturer's default "acoustic telephone program." Then, the Audioscan analyzer was used to assess the output of the hearing aid via probe microphone measurement while a recorded speech passage was presented over a telephone handset held next to the hearing aid microphone. A study examiner sat next to the participants to ensure that the telephone was properly placed next to the hearing aid microphone. Adjustments were made to the hearing aid gain to ensure that the output of the hearing aid at 500, 1000, and 2000 Hz was at least as high as what was obtained to the 60 dB SPL *Standard Speech* signal (Fig. 3).

Next, the hearing aid manufacturer's default "telecoil telephone program" was enabled with the hearing aid microphone attenuated by 10 dB rather than the software default of 0 dB of attenuation for pediatric users. The 10 dB of microphone attenuation was chosen to agree with the recommendation of hearing assistance technology guidelines that suggest a 10 dB advantage for the hearing assistance technology inputs (American Speech-Language-Hearing Association, 2002; American Academy of Audiology Clinical Practice Guidelines, 2011). Once again, the Audioscan analyzer was used to assess the output of the hearing aid via probe microphone while the recorded speech passage was presented over the telephone handset held next to the hearing aid microphone. Again, a study examiner sat next to the

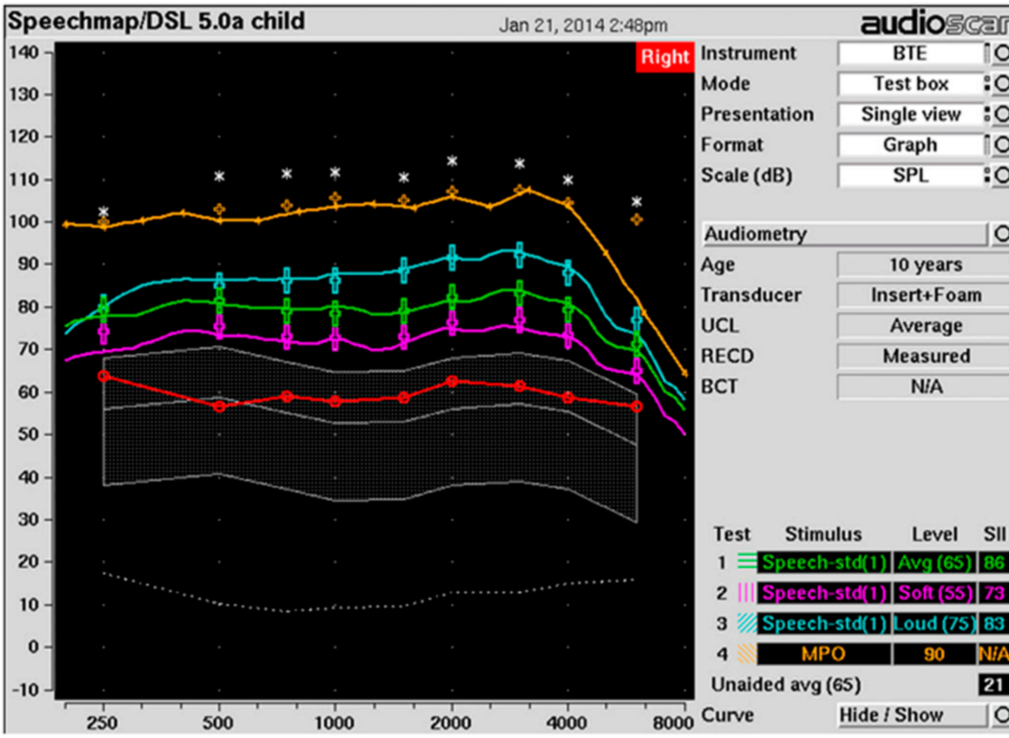

Figure 2. An example of probe microphone measurements obtained for a typical hearing aid fitting in this study.

participants to ensure that the telephone was properly placed next to the body of the hearing aid for telecoil use. Adjustments were made to the hearing aid gain to ensure that the output of the hearing aid matched (within 3 dB) the real-ear output level obtained in the acoustic telephone program (Fig. 3). The examiners queried the participants to confirm that the recorded speech from the telephone was presented at a comfortably loud level. Once the output of the telecoil telephone program was verified by the probe microphone measures as described previously, a second telecoil program was created with the same gain settings, but the DuoPhone feature was enabled to allow for binaural streaming and provision of the telephone signal to both ears simultaneously.

The aforementioned pilot data collected with two participants indicated that speech recognition over the telephone was considerably better with use of the telecoil program compared with the acoustic telephone program. Specifically, word recognition in quiet was 15 percentage points higher with the telecoil program, and word recognition in noise was 23 percentage points higher with the telecoil program compared with performance with the acoustic program. Picou and Ricketts (2011; 2013) also reported better performance with telecoil use relative to the acoustic condition. Therefore, all subsequent assessment of speech recognition over the telephone was conducted while the 14 participants used the monaural and DuoPhone programs with the telecoil enabled.

Test Measures and Equipment

For all 14 children, word recognition of consonant-nucleus-consonant (CNC) words (full list of 50 words per condition) (Peterson and Lehiste, 1962) over the telephone was measured in quiet and in the presence of uncorrelated four-classroom noise (Schafer and Thibodeau, 2006; Schafer et al, 2012). The classroom noise was presented at 50 dBA at the location of the participant from four loudspeakers located in the corners of the test room. The test room (22′ 4″ in length; 15′ 5″ in width; 8′ 9″ in height) had an ambient noise level of 46 dBA as determined with a Quest 1200 Type 1 sound level meter.

The speech stimuli were presented through the compact disc player of a stereo system (Sony CFD-ZW755), which was coupled to a landline telephone (AT&T CL2940) by way of a handset interface (JK Audio Telephone Handset Audio Tap-2 [THAT-2] interface). Specifically, as shown in Figure 4, the handset interface was coupled to the audio output port of the stereo system via a 3.5 mm phono plug-to-RCA audio plug auxiliary cable. Then, the phone output cable (RJ11) of the handset interface was coupled to the receiver handset input port of the landline telephone. This equipment setup allowed for the delivery of recorded speech materials to the landline telephone. The landline telephone was used to call a separate landline telephone (NEC DSX 34B BL Display TEL) in the same examining room. In order to ensure audibility for the test stimuli, the gain control of the telephone used by the participants was set so that the output for the calibration

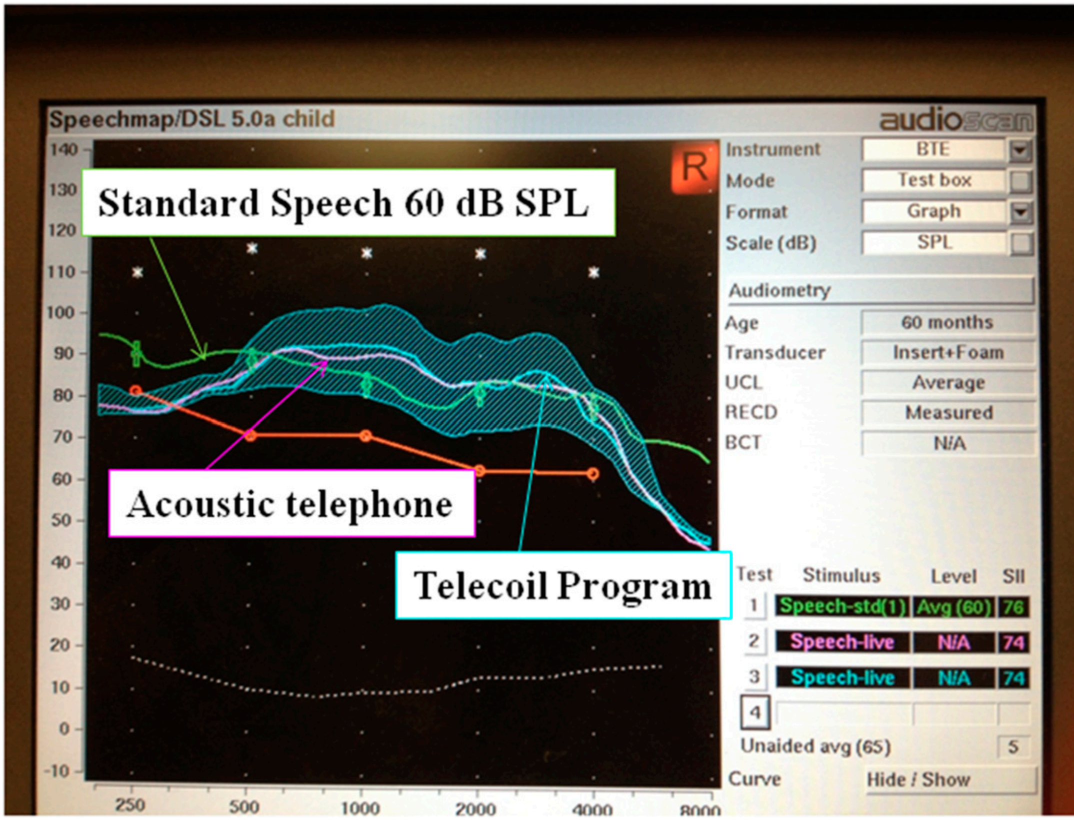

Figure 3. Real-ear output for standard conversational level speech presented from the Audioscan Verifit loudspeaker, for a recorded speech passage presented to the microphone of the microphone (i.e., "Acoustic Telephone"), and for a recorded speech passage presented to the hearing aid telecoil.

signal associated with the CNC word stimuli used in this study matched the output for the 60 dB SPL *Standard Speech* stimulus.

Assessment Protocol

Following the fitting procedures described above, each participant was tested in four listening conditions: (1) monaural phone in quiet, (2) DuoPhone in quiet, (3) monaural phone in noise, and (4) DuoPhone in noise. The order of the listening conditions (quiet; noise) and phone configurations (monaural; DuoPhone) was counterbalanced. In each of the aforementioned conditions, the hearing aid telecoil was used to capture the telephone signal (i.e., the telecoil was enabled in each program). During testing, the examiner ensured that

Figure 4. Sony compact disc player connected to a landline telephone via a THAT-2 telephone interface in order to allow for presentation of recorded speech materials.

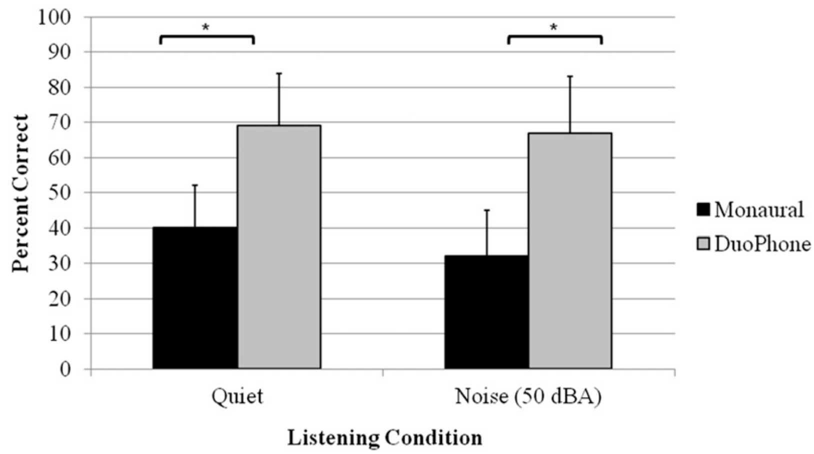

Figure 5. Mean CNC word recognition scores (with 1 SD bar) in quiet and in the presence of noise for the monaural (black) and DuoPhone (gray) conditions. Significant differences at the $p < 0.05$ α level are indicated with the * symbol.

the participant appropriately positioned the telephone next to the hearing aid to allow for reception via the telecoil.

RESULTS

Average word recognition performance in all four conditions is provided in Figure 5, and individual data are provided in Table 1. A two-way repeated-measures analysis of variance was used to examine the effects of the two independent variables: listening condition (quiet; noise) and phone configuration (monaural; DuoPhone). This analyses revealed no significant main effect of listening condition ($F_{[1,56]} = 2.7, p = 0.13$), but a significant main effect of phone configuration ($F_{[1,56]} = 78.0, p < 0.00001$).

Table 1. Individual Scores for Each Listening Condition

	Listening Condition			
Participant #	Monaural Phone: Quiet	DuoPhone: Quiet	Monaural Phone: 50 dBA Noise	DuoPhone: 50 dBA Noise
1	70	90	60	74
2	48	70	32	62
3	42	86	26	68
4	24	80	20	60
5	26	46	48	64
6	34	46	32	34
7	36	78	44	88
8	38	78	26	72
9	44	74	48	82
10	56	78	46	70
11	40	54	38	78
12	26	54	18	40
13	36	64	6	80
14	66	88	38	72
Average (SD)	41.9 (12)	70.4 (15)	34.4 (13)	67.4 (16)

There was no significant interaction effect between listening condition and phone configuration ($F[1,56] = 1.1, p = 0.31$). Post hoc analyses with the Tukey-Kramer multiple comparisons test revealed that speech-recognition performance in both quiet and noise conditions with the DuoPhone was significantly better than both quiet and noise conditions with monaural telephone input.

DISCUSSION

The results of this study, as well as our experiences as we conducted the study, have several clinical implications:

1. The study results indicate that children with hearing loss receive substantial benefit from the DuoPhone feature, which uses wireless binaural streaming to transmit an audio signal from one hearing instrument that is near the telephone handset to the hearing instrument on the opposite side of the head. Recognition of recorded speech in quiet and in noise by study participants had improved by approximately 30% with the DuoPhone. This improvement is similar to the results reported by Picou and Ricketts (2011; 2013) when comparing binaural telephone performance with monaural use. In the present study, the presence of background noise at 50 dBA was not particularly impactful on average performance, which is likely related to the 10 dB reduction of signals presented to the hearing aid microphones.
2. Anecdotally, most of the children in this study and their parents reported that they had difficulty with understanding speech over the telephone in everyday life. In fact, many children and parents reported that they avoid telephone use. For many of the children who did report using the telephone, they noted that

they use the telephone on the "speaker mode," or they remove their hearing aids and increase the volume control on the telephone handset to the maximal setting. Furthermore, when we asked the older children to hold the telephone for testing during the study, most did not appropriately orient the telephone to the hearing aid. Many of the children held the telephone handset over the ear mold rather than over the microphone of the hearing aid, a fact that is concerning considering estimates that suggest that holding the telephone receiver only 1 inch away from the optimal location can decrease the output of the telephone signal by 15 dB (Holmes and Chase, 1985).

3. When comparing an acoustic telephone program with a telecoil program, one benefit of a telecoil program is that the hearing aid microphone may be attenuated to reduce interference from ambient noise. This is not an option with an acoustic telephone program; therefore, it may partially explain the improved performance with the telecoil program versus the acoustic telephone program. As mentioned previously, the sensitivity of the hearing aid microphone was attenuated by 10 dB in the "telephone program" used for this study. We believe that this adjustment may improve word recognition in noise because of the improvement in the signal-to-noise ratio secondary to attenuation of ambient noise captured by the hearing aid microphone. However, it should be noted that hearing aid microphone attenuation may not be desirable for patients with severe to profound hearing loss because it may be too difficult to monitor the level of their own voice or other desired sounds that may also originate from sources other than the telephone (i.e., a parent in the room). It should also be noted that decreased performance with the acoustic telephone program may also be attributed to difficulty the user may encounter with properly orienting the telephone receiver next to the hearing aid microphone. Additional research is needed to further clarify the pros and cons of telecoil and acoustic telephone programs for children.
4. In this study, the telephone programs were accessed manually by the examiners who used a Phonak MyPilot remote control. It may be unrealistic to expect young children to consistently switch to a manually accessible telephone program during everyday use. As a result, it is tempting to consider use of a telephone program that is automatically enabled when the telephone receiver is placed near the hearing aid. Again, additional research is needed to further clarify the pros and cons of manual versus automatic telephone programs for children.
5. The data for this study were collected with use of landline telephones. Given the pervasiveness of mobile telephones, additional research is needed to evaluate children's performance using mobile telephones and to identify methods to optimize mobile telephone use.
6. Probe microphone measures were used to verify the output of the hearing aids in the telecoil and to ensure that test signals were audible. There is a need to develop systematic real-ear clinical procedures to verify the appropriateness of telephone programs for both children and adults.
7. Considering the aforementioned conclusions, we recommend that pediatric audiologists actively promote optimal telephone use for children with hearing loss. A few basic steps in achieving this goal are (1) the use of amplification with binaural streaming capabilities (e.g., DuoPhone) to allow children to hear the telephone signal binaurally, (2) counseling of families and children on how to best use the telephone, (3) the provision of a telecoil program with microphone attenuation for improved signal-to-noise ratio, and (4) the use of probe tube measures to verify the appropriateness of the telephone programs.

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