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Self-Monitoring of Listening Abilities in Normal-Hearing Children, Normal-Hearing Adults, and Children with Cochlear Implants

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Abstract

Background—Self-monitoring has been shown to be an essential skill for various aspects of our lives, including our health, education, and interpersonal relationships. Likewise, the ability to monitor one's speech reception in noisy environments may be a fundamental skill for communication, particularly for those who are often confronted with challenging listening environments, such as students and children with hearing loss.

Purpose—The purpose of this project was to determine if normal-hearing children, normal-hearing adults, and children with cochlear implants can monitor their listening ability in noise and recognize when they are not able to perceive spoken messages.

Research Design—Participants were administered an Objective-Subjective listening task in which their subjective judgments of their ability to understand sentences from the Coordinate Response Measure corpus presented in speech spectrum noise were compared to their objective performance on the same task.

Study Sample—Participants included 41 normal-hearing children, 35 normal-hearing adults, and 10 children with cochlear implants.

Data Collection and Analysis—On the Objective-Subjective listening task, the level of the masker noise remained constant at 63 dB SPL, while the level of the target sentences varied over a 12 dB range in a block of trials. Psychometric functions, relating proportion correct (Objective condition) and proportion perceived as intelligible (Subjective condition) to target/masker ratio (T/M), were estimated for each participant. Thresholds were defined as the T/M required to produce 51% correct (Objective condition) and 51% perceived as intelligible (Subjective condition). Discrepancy scores between listeners' threshold estimates in the Objective and Subjective conditions served as an index of self-monitoring ability. In addition, the normal-hearing children were administered tests of cognitive skills and academic achievement, and results from these measures were compared to findings on the Objective-Subjective listening task.

Results—Nearly half of the children with normal hearing significantly overestimated their listening in noise ability on the Objective-Subjective listening task, compared to less than 9% of the adults. There was a significant correlation between age and results on the Objective-Subjective task, indicating that the younger children in the sample (age 7–12 yr) tended to overestimate their listening ability more than the adolescents and adults. Among the children with cochlear implants, eight of the 10 participants significantly overestimated their listening ability (as compared to 13 of the 24 normal-hearing children in the same age range). We did not find a significant relationship

between results on the Objective-Subjective listening task and performance on the given measures of academic achievement or intelligence.

Conclusions—Findings from this study suggest that many children with normal hearing and children with cochlear implants often fail to recognize when they encounter conditions in which their listening ability is compromised. These results may have practical implications for classroom learning, particularly for children with hearing loss in mainstream settings.

Keywords

Classroom; cochlear implants; education; listening; monitoring; speech perception

Asizable literature in diverse fields of study has emerged over the last several decades exploring people's abilities to monitor various facets of their lives, such as their comprehension, health, emotions, and learning. These studies have demonstrated large differences among individuals and have related measures of self-monitoring abilities to a broad range of outcomes, including reading ability, health, social functioning, weight loss, behavior modification and academic achievement (e.g., Snyder, 1974; August et al, 1984; Zimmerman and Martinez-Pons, 1990; Hacker et al, 2000; Myin-Germeys et al, 2011; Chambliss et al, forthcoming). Clearly the ability to monitor is a valuable skill that has positive effects on learning, behavior, and quality of life.

Like the aforementioned domains, communication is an area in which self-monitoring is seemingly an important skill. For example, to become a more fluent speaker, a person who stutters must be able to monitor his or her speech behaviors in various communication environments (Venkatagiri, 2005). Likewise, a person trying to overcome an articulation deficit must monitor his or her production of sounds outside of therapy sessions (Koegel et al, 1988). In a similar manner, self-monitoring also may be a critical skill for listening in complex acoustical environments. That is, successful communication may be dependent, in part, on a person's ability to monitor his or her reception of spoken messages in noisy environments and recognize when communication breakdowns occur. The ability to monitor one's listening ability may be particularly important for school-age children, given that listening is one of the primary conduits for classroom learning. However, it is not known whether children are proficient in recognizing when they fail to perceive spoken messages, yet this skill may be indispensable for effective communication and learning, especially for children with hearing loss who are likely to experience significant difficulties in everyday listening environments.

Self-monitoring, or monitoring, is cited as a fundamental aspect of several cognitive processes, including metacognition, self-regulation, self-regulated learning, and executive control function (Flavell, 1971; Zimmerman, 1986; Bandura, 1991; Miller and Cohen, 2001). These cognitive processes have several overlapping features but have been examined in largely distinct fields of study. An in-depth discussion of these processes and their intertwining nature is beyond the scope of this paper, but we recognize that the ability to monitor one's communication environment is relevant to these different areas of study. For the purpose of this paper we are going to focus narrowly on the ability of listeners to monitor or judge their reception of spoken messages in noisy environments and the possible implications for communication and learning. We have two motivations for investigating this skill. First, the ability to monitor one's speech reception ability is presumably an important skill for listeners because communication environments, particularly ones in which learning is expected to take place, are notoriously poor (e.g., Sato and Bradley, 2008). Second, children are known to have difficulty listening under such challenging acoustic conditions (e.g., Bradley and Sato, 2008). Thus, the study of self-monitoring may have

particular implications for classroom listening and learning, especially for children with hearing impairment who are schooled in mainstream settings.

CLASSROOM LISTENING AND ACOUSTICS

Observational studies estimate that 60–68% of classroom time is spent on listening activities (Imhof, 2008), yet there is clear consensus that typical classroom acoustics undermine speech perception (e.g., Sanders, 1965; Finitzo-Hieber and Tillman, 1978; Picard and Bradley, 2001; Knecht et al, 2002; Bradley et al, 2003; Bradley and Sato, 2008). According to the American National Standards Institute performance criteria (ANSI-ASA, 2010), appropriate acoustic classroom noise levels should not exceed 35 dB A in unoccupied classrooms; signal-to-noise ratios in occupied classrooms should be at least +15 dB; and reverberation time should not exceed 0.6–0.7 sec. However, research suggests that classrooms typically fail to maintain these acoustical standards. For example, various studies have reported noise levels of 28–67 dB A in unoccupied classrooms and 47–79 dB A in occupied classrooms (Houtgast, 1981; Markides, 1986; Pekkarinen and Viljanen, 1991; Jamieson et al, 2004; Sato and Bradley, 2008), with signal-to-noise ratios between –7 and +11 dB (Blair, 1977; Blake and Busby, 1994; Sato and Bradley, 2008). Furthermore, noise appears to be greater in the classrooms of younger students (e.g., kindergartners) than for older students, arising from higher levels of activity that typify environments with young children.

Picard and Bradley (2001) presented a summary of a number of published studies that measured ambient classroom noise levels, which indicated incremental reductions in noise levels in classrooms from kindergarten to higher academic grades. Picard and Bradley also reported that classrooms that employ “cooperative instruction” methods are characterized by especially high noise levels. In these classrooms, students are encouraged to work together on learning activities in small groups, often with computers. The student-activity noise, combined with intermittent instruction from the teacher and computer noise results in an overall increase of 10 dB in ambient noise levels over traditional classrooms (Picard and Bradley, 2001).

Besides being excessively noisy, classrooms also tend to be reverberant environments, arising from the abundance of hard surfaces within the enclosed space. Recommended reverberation times (RTs) in an unoccupied classroom range from 0.4 to 0.5 (Bistafa and Bradley, 2000), but several studies have reported classroom RTs that have exceeded 1 sec (Knecht et al, 2002). The repercussions of classroom reverberation are not straightforward; however, given that some studies suggest that early-arriving reflections (<50 msec) can actually enhance speech reception, whereas later reflections degrade speech reception (Bistafa and Bradley, 2000; Geersing et al, 2010). In addition, when classrooms are full of students, sound absorption is increased, resulting in reductions in reverberation (Picard and Bradley, 2001; Geersing et al, 2010). Based on these factors, investigators have concluded that noise is more disruptive to classroom listening than reverberation (Picard and Bradley, 2001).

CHILDREN’S LISTENING ABILITIES IN COMPLEX ACOUSTICAL ENVIRONMENTS

Not only has research established that learning environments tend to be characterized by excessive noise and reverberation, studies have also shown that children experience considerable speech reception difficulties in these conditions (Elliott, 1979; Nitttrouer and Boothroyd, 1990; Jamieson et al, 2004; Sato and Bradley, 2008; Neuman et al, 2010). Like adults, children experience accumulative degradation of speech understanding ability with

increasing noise levels and reverberation, but children appear to be affected to a greater degree than adolescents and adults (Elliott, 1979; Picard and Bradley, 2001; Jamieson et al, 2004). For example, Jamieson et al (2004) measured word recognition in a background of recorded classroom noise and found that all children performed poorly at the most difficult signal-to-noise ratio tested, but kindergarten and first grade children also performed poorly at intermediate signal-to-noise ratios. Reverberation appears to have similar developmental effects on speech understanding in children relative to adults, with children not reaching adultlike performance until the teenage years (Finitzo-Hieber and Tillman, 1978; Nábelek and Robinson, 1982; Neuman and Hochberg, 1983; Neuman et al, 2010). Beyond their immature speech reception skills, children are more affected by the attention demands of the task (Wightman et al, 2010) and are less skilled at taking advantage of linguistic context to “fill in the gaps” when faced with poor listening conditions than adolescents and adults (Elliott, 1979; Leech et al, 2007). Collectively, research suggests that the first few years of school are characterized by the noisiest classrooms, yet students in lower grades are poorly equipped to handle the acoustical challenges. As argued by Picard and Bradley (2001), these challenges are faced by students at a time when essential skills are taught in reading, writing, and mathematics, which are foundational for subsequent learning.

A population known to be especially challenged by poor acoustical conditions is children with peripheral hearing loss. Studies investigating speech understanding in noise by children with and without hearing loss have unanimously reported that children with hearing loss have more difficulty listening in noisy and reverberant environments than their normal-hearing counterparts (Finitzo-Hieber and Tillman, 1978; Crandell, 1993; Needleman and Crandell, 1995; Ruscetta et al, 2005). Even children with unilateral or minimal degrees of peripheral hearing loss have been shown to have speech perception deficits relative to their normal-hearing peers in noisy listening environments (Bess et al, 1986; Crandell, 1993). Moreover, the performance gap between children with hearing loss and those with normal hearing becomes more pronounced as acoustic conditions are made more adverse (Finitzo-Hieber and Tillman, 1978; Crandell, 1993).

The speech perception abilities of children with cochlear implants have been studied extensively in recent years. Children with severe-to-profound loss who have undergone cochlear implantation have auditory access that exceeds that of children with similar degrees of hearing loss who use traditional hearing aids. As a result, many children with cochlear implants develop relatively proficient auditory perception skills, and the majority of children with cochlear implants are placed in full-time or part-time mainstream classrooms (Geers et al, 2011). In a study of open-set sentence recognition in high-school age children who received a cochlear implant between 2 and 5 yr of age, the average score was 80% in quiet (Davidson et al, 2010). However, the performance of these children was significantly affected by noise. When the sentences were presented in noise at a signal-to-noise ratio of +10 dB, average performance fell to 52%. Given that signal-to-noise ratios of mainstream classrooms tend to be considerably poorer than +10 dB (Sato and Bradley, 2008), it is likely that listening difficulties are a routine part of the educational experience of children with cochlear implants.

COMPREHENSION MONITORING AND TRAINING

Although the ability of children to monitor their speech processing on a basic level of reception/identification has not been explored, their ability to monitor their comprehension of spoken messages and written text (i.e., a higher level of speech processing) has received considerable attention in the education literature. It turns out that many normal-hearing children are quite poor at recognizing when they do not comprehend spoken passages or written text. Children often fail to detect inconsistencies or ambiguities, even when they are

instructed to look for them (Markman, 1979; Anderson and Beal, 1995; Beck and Robinson, 2001). In addition, children tend to overestimate knowledge gained from uninformative or ambiguous messages, and pass up opportunities to ask for clarification or reread text (Patterson et al, 1981; August et al, 1984; Beck and Robinson, 2001). A number of these studies have shown a positive relationship between the ability of children to monitor their comprehension and their ability to achieve academically (August et al, 1984; Kinnunen and Vauras, 1995). Interestingly, some studies have also shown that comprehension monitoring can be improved with training. In the study by (Kinnunen and Vauras 1995), low-achieving students who were placed in a self-monitoring training group increased their level of comprehension monitoring, which coincided with an improvement in comprehension of expository texts. Similar results have been shown with training in self-monitoring skills and the mastery of mathematical concepts (Schunk, 1983) and composition of written narratives (Beal, 1996). These studies are encouraging because they suggest that self-monitoring is a skill that can be taught and that improvements in self-monitoring ability positively impact learning and achievement.

THE CURRENT STUDY

In summary, the ability to monitor has been shown to be related to positive outcomes in areas of health, education, and personal conduct (August et al, 1984; Zimmerman and Martinez-Pons, 1990; Hacker et al, 2000; Myin-Germeys et al, 2011). Similarly, self-monitoring skills may be valuable for listening and communication, particularly in classroom environments where children are expected to listen and learn in acoustically poor conditions. In such environments it is often up to the listener to recognize when they cannot perceive or understand the spoken content so that they may seek clarification. It is not known, however, if children are proficient at recognizing when they are experiencing auditory perceptual difficulties. Self-monitoring of listening ability may be a particularly important skill for children with hearing loss who are placed in mainstream classrooms. The purpose of this investigation was to determine if listeners are good estimators of their speech perception capabilities and if they can recognize when they are in an acoustic environment in which their speech perception abilities are compromised. To this end, we measured self-monitoring in normal-hearing listeners across a developmental age span and measured this skill in a small sample of children with cochlear implants. Secondly, this study explored possible relationships between the abilities of normal-hearing children to monitor their listening and measures of cognitive/academic performance.

METHOD

General Methods

In designing a measure to examine listeners' abilities to monitor their speech perception, we recognized parallels to the hearing aid literature, specifically, the considerable attention to the discrepancy between listener's performance on objective tests of speech perception and their subjective report of hearing handicap or hearing aid benefit (e.g., Ricketts and Bentler, 1992; Valente et al, 1998; Preminger et al, 2000; Cox et al, 2003). Most of the studies compared objective performance of speech perception using word or sentence lists to subjective reports of hearing aid benefit or preferences using questionnaires, such as the Hearing Handicap Inventory for Adults (HHIA; Newman et al, 1990), Abbreviated Profile of Hearing Aid Benefit (APHAB; Cox and Alexander, 1995), or the Profile of Hearing Aid Performance (PHAP; Cox and Gilmore, 1990). Saunders and colleagues suggested that the discrepancy between subjective and objective outcomes may be driven, in part, by the fact that the materials and procedures for measuring speech intelligibility do not directly relate to the items of the questionnaires that are used to measure subjective benefit (Saunders and Cienkowski, 2002; Saunders et al, 2004; Saunders and Forsline, 2006). In response, these

investigators developed a test, known as the Performance-Perceptual Test (PPT), that used identical materials for measuring objective and subjective outcomes. In the PPT listeners are administered the Hearing in Noise Test (HINT; Nilsson et al, 1994) materials in two conditions. In the “Performance” condition, the listeners respond by repeating the spoken sentences. In the “Perceptual” condition, the listeners respond by saying “yes” or “no” after each sentence according to whether they thought they recognized each word of the sentence. Both conditions are administered adaptively and determine the signal-to-noise ratio (i.e., threshold) at which the listeners can understand 50% of the sentences. A third metric is then computed, the Performance-Perception Discrepancy (PPDIS), which is the difference between the Performance threshold and the Perception threshold.

The PPT provides an index of self-monitoring ability because it provides a direct comparison of listener’s objective speech reception performance in noise to their subjective perception of their performance. Thus, it measures the ability of listeners to recognize when they are in listening conditions in which they are not able to understand the spoken message. In the current study we sought to use a similar paradigm to compare listeners’ subjective perception of their speech reception performance to their objective performance. We chose the Coordinate Response Measure (CRM; Bolia et al, 2000), which is a closed-set task that requires the participant to listen to a target phrase and respond by clicking a color-number combination according to the content of the message. On this task, the level of the target varies from trial to trial, which allowed us to plot complete psychometric functions in both the Objective and Subjective conditions, illustrating proportion correct (or proportion of perceived correct) as a function of target/masker ratio (T/M). The advantage of this procedure over an adaptive procedure is that it allowed us to present speech at a number of fixed T/M, ranging from easy to very difficult. Therefore, listeners were not continually tested at difficult T/M corresponding to approximately 50% performance, which may be tiresome for children. Another advantage of the CRM is that, unlike other sentence tests (e.g., HINT), the sentences can be reused without memory influencing performance, so testing was not restricted by the number of sentences on the test lists. Finally, the CRM carries no linguistic context, which makes it an ideal choice for comparing data among adults and children of various ages, given that children do not capitalize on linguistic cues when listening to speech in noise as well as adolescence and adults (Elliott, 1979; Nittrouer and Boothroyd, 1990).

Participants

Forty-one children with normal hearing, aged 7–17 yr, and 35 adults with normal hearing, aged 18–40 yr, participated in this study. Each of the normal-hearing participants underwent a hearing screening, which demonstrated normal hearing sensitivity, bilaterally, as defined by audiometric thresholds ≤ 20 dB HL at all octave frequencies 250–8000 Hz.

A group of 10 children with cochlear implants, aged 8.2–11.8 yr, also participated in the study. The demographic and audiological information of these participants is reported in Table 1. There were four boys and six girls in this group. With the exception of one child who acquired his hearing loss secondary to bacterial meningitis at 3 yr of age, all of the children in the sample were identified with bilateral deafness before 1 yr of age. At the time of the study all of the children had at least 5 yr of cochlear implant experience. Two of the children had bilateral cochlear implants (CI02 and CI08) that they received sequentially. The remainder of the children used a single implant. All of the participants were native English speakers and were recruited via local audiology clinics and online advertisement.

Stimuli

Stimuli for the Objective-Subjective listening task were selected from the corpus of CRM sentences (Bolia et al, 2000). The CRM is comprised of 2048 spoken sentences in the form of “Ready (*call sign*) go to (*color, number*) now.” All the sentences were the same except for three words (i.e., the call sign, the color, and the number). A total of 256 sentences result from the various sentence combination of the eight call signs (*Baron, Ringo, Charlie, Arrow, Tiger, Laker, Hopper, and Eagle*), four colors (*red, white, green, and blue*) and eight numbers (1–8). The sentences are spoken by eight different talkers (four male and four female). The sentences used were drawn from those with the call sign “Baron.” The sentences were presented with a speech-spectrum noise, which served as the masking stimulus. The speech spectrum noise was a 3.2 sec white Gaussian noise filtered to have the long-term average spectrum of all of the CRM sentences. The onset of the noise was 500 msec prior to the onset of the speech, and the offset was roughly 500 msec after the offset of the speech. The stimuli were mixed, attenuated digitally, and converted to analog form using Digital Audio Laboratories Card Deluxe 24-bit sound card at a 48 kHz sampling rate.

Procedures

There were two conditions in the experiment. In the first condition (Objective), the participants were asked to respond to the CRM stimuli by selecting the target color and number of the spoken message. In the second condition (Subjective), participants were asked to respond to the CRM stimuli by reporting whether they heard the spoken message and think they could select the correct color and number.

For both conditions, participants were seated in front of a computer screen in a semi-anechoic room ($T_{60} = .06$ sec, 200–8000 Hz bandwidth) with acoustically absorptive walls and ceiling or in a sound-isolated room (IAC 1200). All of the children with cochlear implants were tested in the semi-anechoic room. The screen displayed a start button and 32 response buttons organized within four color matrices each containing eight buttons corresponding to the numbers 1–8. The listeners were instructed to attend to the speech message containing the call sign “Baron” and to ignore the masking noise. The experiment was controlled and executed via a custom program written in MATLAB. Using a computer mouse, the participants initiated each trial by clicking on the yellow start button displayed in the middle of the screen. In the Objective condition, the participant responded by clicking on the button corresponding to the heard color and number spoken by the “Baron” talker. Responses that accurately identified both the color and the number of the target sentences were scored as correct by the computer program. In the Subjective condition, the four color matrices on the display screen disappeared after each sentence was presented. The listener then selected one of two responses: (1) a happy face, displayed next to the statement, “Yes, I got it!” or (2) a sad face, displayed by the statement, “No, I did not get it.” Participants did not receive feedback regarding their responses in either condition.

For the normal-hearing participants, the stimuli were presented bilaterally via calibrated Beyer DT990-Pro headphones. The overall level (rms) of the masker was held constant for all conditions at a level of 63 dB SPL. The level of the target was varied from trial to trial in 3 dB steps so that an entire psychometric function, from chance levels (i.e., approximately 3%) to near perfect performance (i.e., approximately 100%) could be estimated. The maximum target level presented to any normal-hearing participant was approximately 69 dB SPL. Participants with cochlear implants were tested in the same manner as the participants with normal hearing, with the exception that the stimuli were presented in the soundfield through loudspeakers, instead of under headphones. The loudspeakers (Cambridge Sound Works) were positioned at an ear-level height, 3 ft from the listener at angles of -30° and $+30^\circ$ azimuth relative to the listener. The maximum target level presented to any child with

an implant was approximately 72 dB SPL. No programming modifications or adjustments of user settings were made to participants' cochlear implant(s) for the experiment.

Pilot testing revealed that we had to be particularly careful when instructing listeners on the Subjective portion of the experiment. Our goal was to have listeners respond "Yes, I got it!" when they were confident that they heard and understood the spoken message. Children, in particular, had to be assured that there were no "correct" or "incorrect" answers in this condition. After piloting various sets of instructions for the Subjective condition, we settled on the following verbal instructions:

In this condition you will hear the Baron commands like last time, but this time instead of clicking the color and number, you are going to tell us whether or not you understood the color and number. If you heard the color and number and think you could pick the correct answer, click on the Happy Face box that says, "Yes, I got it!" If you did not hear the color and number or don't think you could pick the correct answer, click on the Sad Face box that says, "No, I did not get it."

With the children, we followed up the instructions with some questions to make sure that they understood the Subjective condition. Specifically, we asked them how they were to respond if they heard the color but not the number or if they heard the number but not the color (in both cases the listener was instructed to respond, "No, I did not get it"). In addition, we gave the children some examples in which we mimicked CRM sentences with the color or number garbled and asked how they would respond.

Prior to the experimental runs, participants were administered 30 practice trials in the baseline conditions (i.e., no masker was presented). The baseline practice runs were given to familiarize the participants to the talkers and to assure perfect performance at each target level. Following the practice trials, a minimum of five runs of 60 trials were presented in each of the two conditions. In some cases additional runs were necessary to estimate the entire psychometric function.

Data Analysis

For each condition complete psychometric functions were plotted illustrating performance in percent correct as a function of target/masker ratio. The psychometric functions were fitted with a logistic function using PSIGNIFIT in MATLAB (Wichmann and Hill, 2001a, 2001b). Thresholds (with confidence intervals) were estimated from the fitted functions for each participant in each condition. Threshold was defined as the T/M ratio corresponding to 51% correct.

The threshold estimates were used to calculate a discrepancy score that reflected the accuracy in which the listeners estimated their abilities to understand speech in noise. Specifically, we compared threshold estimates in the Objective and Subjective conditions and calculated a Objective-Subjective discrepancy score by subtracting the listener's Subjective threshold from his or her Objective threshold. A positive discrepancy score indicated that the listener overestimated his or her speech understanding ability on the task. A negative discrepancy score indicated that the listener underestimated his or her speech understanding ability on the task.

Spearman rank-order correlation coefficients were computed to assess the relationship between age and performance in the Objective and Subjective tasks. A nonparametric measure was chosen because variability in the subjective thresholds decreased as a function of age.

Cognitive and Academic Achievement Assessments

One of the goals of the current study was to explore the relationship between children's ability to judge their speech understanding in noise and their cognitive abilities and/or level of academic achievement. Therefore, normal-hearing children were administered the Kaufman Brief Intelligence Test, Second Edition (KBIT-2; Kaufman and Kaufman, 2004a) to evaluate cognitive abilities, and the Wide Range Achievement Test, Fourth Edition (WRAT-4; Wilkinson and Robertson, 2006) to access academic aptitude. Because of the small number of children with cochlear implants in the study sample, the relationship between Objective-Subjective results and academic/cognitive abilities was not explored in this group.

The KBIT-2 is an individually administered test designed to measure verbal and nonverbal intelligence in children and adults, aged 4–90 yr. The Verbal component comprises two subtests (Verbal Knowledge and Riddles) and measures word knowledge, range of general information, and reasoning ability. The Nonverbal component consists of the Matrices subtest, which measures the ability to solve new problems by perceiving relationships and completing visual analogies. The mean test-retest reliability of the KBIT-2 is .91 for the Verbal Score and .83 for the Nonverbal Score. Scores from the KBIT-2 correlate with other tests of cognitive ability, including the Wechsler Intelligence Scale for Children-Third Edition (WISC-III; Wechsler, 1991) and Forth Edition (WISC-IV; Wechsler, 2003).

The WRAT-4 measures basic academic skills of word reading, sentence comprehension, spelling, and math computation in children and adults (aged 5–94 yr). The mean test-retest reliability for the WRAT-4 is .86 across the four subtests. Scores from the WRAT-4 correlate well with other tests of academic achievement, including the Woodcock-Johnson III Test of Achievement (W-J III; Woodcock et al, 2001) and the Kaufman Test of Educational Achievement, Second Edition (KTEA-II; Kaufman and Kaufman, 2004b). All participants were administered the Word Reading, Spelling, and Math Computation Subtests.

Raw scores on the KBIT-2 (Verbal and Nonverbal subtests) and the WRAT-4 (Word Reading, Spelling, and Math) were converted to standard scores, which represents a child's score relative to the scores of children of the same age in the standardized sample. All standard scores had a mean of 100 and SD of 15.

RESULTS

Normal-Hearing Listeners

Objective-Subjective Listening Task—All children and adults with normal hearing demonstrated near-perfect performance (97–100% correct) in the Objective baseline condition (no masker) at all target levels. Normal-hearing participants were tested at target levels between 45 and 69 dB SPL.

Figure 1 presents the fitted psychometric functions (i.e., proportion correct or perceived correct as a function of T/M) for four representative adults (left panels) and four representative children (right panels) with normal hearing. Data from the Objective condition are represented by open circles and data from the Subjective condition are represented by solid circles. The error bars show the 95% confidence limits of the estimated thresholds. As seen in the representative psychometric functions on the left side of the figure, there was little variability among adults in both the Objective and Subjective conditions. In addition, as seen in the overlapping curves, adults were quite accurate at estimating their speech reception ability on this task. Their results in the Subjective condition closely approximated those in the Objective condition. The average adult

threshold estimate in the Objective condition was -7.5 dB ($SD = 0.6$), and the average adult threshold estimate in the Subjective condition was -7.6 dB ($SD = 0.9$). Among the adults, the average confidence interval for the threshold estimate was 1.6 dB for the Objective condition and 1.3 dB for the Subjective condition.

Compared to the adult findings, results from the normal-hearing children were quite variable, particularly in the Subjective condition. In addition, many of the children overestimated their speech reception ability, as illustrated by how the psychometric curves in the Subjective condition are shifted considerably to the left of the psychometric curves in the Objective condition for listeners NH42 and NH43, aged 7 and 11 yr, respectively. In contrast, listener NH06, aged 16 yr, showed comparable performance in the Subjective and Objective conditions, suggesting that he was quite proficient at estimating his speech reception ability. NH12 appeared to overestimate by a small amount, but the differences between results in the two conditions did not exceed confidence limits. For the normal-hearing children the average threshold estimate in the Objective condition was -6.4 dB ($SD = 1.0$) and the average threshold estimate in the Subjective condition was -8.1 dB ($SD = 2.0$). Like the adults, the children were quite reliable in their responses, as seen by the small confidence intervals, in both the Objective and Subjective conditions.

Given that previous research suggests that many children lack self-monitoring skills in areas such as comprehension and learning (Markman and Gorin, 1981; Patterson et al, 1981; Beal, 1996), we examined results in both conditions across age. Figure 2 displays psychometric function threshold estimates as a function of age in the Objective and Subjective conditions. The bold horizontal lines intersecting the figure represent the mean adult threshold estimates in the Objective and Subjective conditions. The dashed lines represent ± 1.96 SD, thus indicating the region in which 95% of the adult thresholds fell. As seen in the left panel, results in the Objective condition are characterized by a noticeable decline in threshold estimates between 7 and approximately 15 yr of age. In other words, adolescents outperformed the younger children in the sample and performed more similarly to the adults in the Objective condition. This finding that children do not exhibit adultlike performance on this task until about 15 yr of age is consistent with the results from Wightman et al (2010). The relationship between age and performance in the Objective condition was analyzed by calculating a Spearman rank-order correlation coefficient for the normal-hearing children (i.e., aged 7–17 yr) and for the adults (i.e., aged 18+). Results suggested a significant negative correlation between age and threshold estimates for the children, $\rho(41) = -.634$ ($p < .001$) but no relationship between age and threshold estimates among the adults $\rho(30) = .212$ ($p = .223$).

Threshold estimates as a function of age in the Subjective condition are displayed in the right panel of Figure 2. In this condition there was far greater variability in thresholds among listeners than in the Objective condition, but overall, the children's estimations of their speech reception ability in the Subjective condition appeared to be very similar to the adolescents and adults. That is, as seen in Figure 2, there does not appear to be a relationship between age and threshold estimates in the Subjective condition. This was confirmed by Spearman correlations, which indicated no significant correlations between age and threshold estimates among the children, $\rho(41) = -.028$ ($p = .872$), or the adults, $\rho(35) = .136$ ($p = .435$). Collectively results suggest that, on average, children perceive that they understand speech in noise as well as adults, but they don't actually achieve adult levels of performance until around 15 yr of age.

Objective-Subjective discrepancy scores were calculated by subtracting the participants' threshold estimates in the Subjective condition from their threshold estimates in the Objective condition. Accordingly, a positive discrepancy score indicated an overestimation

of speech reception ability, and negative discrepancy scores indicated an underestimation of speech reception ability. Thus, the closer the discrepancy score was to zero, the more accurate the participant was in monitoring his or her speech reception ability. Figure 3 displays Objective-Subjective discrepancy scores as a function of age. The participants who significantly overestimated their speech perception performance (i.e., the Subjective threshold was lower than the Objective threshold, and the confidence intervals did not overlap) are identified by the triangles pointing up, and the participants who significantly underestimated performance (i.e., Objective thresholds were higher than the Subjective thresholds, and the confidence intervals did not overlap) are identified by the triangles pointing down. The open circles represented participants who neither significantly overestimated nor underestimated their speech reception ability (i.e., thresholds were within 95% confidence limits).

As seen in the Figure 3, there was considerable variability in Objective-Subjective discrepancy scores among the children. The discrepancy scores of many of the children indicated that there was a tendency for children to overestimate speech reception ability. Among the 41 child participants (aged 7–17 yr), 19 (46.3%) significantly overestimated their speech reception ability. Among the children who overestimated their ability, the Objective-Subjective discrepancy scores ranged from 2–8.5 dB. In addition, it appeared that age contributed to the ability to monitor ones listening, in that there was a greater tendency among the children than the adolescents and adults to significantly overestimate their speech reception abilities on the task. Among the 35 adults, only three significantly overestimated their speech perception ability. These three adults overestimated their abilities by approximately 2 dB.

There were a small number of normal-hearing participants who significantly underestimated their speech-reception ability (i.e., two children/adolescents and two adults). That is, their Subjective threshold estimates were significantly higher (i.e., poorer) than their Objective threshold estimates. The range of Objective-Subjective threshold discrepancy scores among these participants was –1.5 to –2 dB. The remaining participants (22 of the 41 children/adolescents and 32 of the 35 adults) were fairly accurate in estimating their speech reception ability. For these participants, the confidence intervals for the Objective and Subjective thresholds overlapped.

Cognitive and Academic Achievement Tests—Forty of the 41 normal-hearing children were administered the Word Reading, Spelling, and Math subtests of the WRAT-4. The one child with normal hearing who did not complete the WRAT-4 was not available to return to the laboratory for testing. Table 2 reports means, SDs, and range of standard scores (based on age) for each of the subtests. With the exception of one child who scored just below the average range on the Spelling subtest, the standard scores of all of the children fell between the average range (within ± 1 SD of the mean standard score of 100) and the upper extreme range ($+3$ SD of a mean of 100) on each of the subtests. Overall, the children in this study performed quite well on the test compared to the general population, with over half scoring above the 85th percentile ($+1$ SD) on the Word Reading and Spelling subtests and 43% of the children scoring above the 85th percentile on the Math subtest.

Table 2 also reports results from the Verbal and Nonverbal subtests of the KBIT-2 for the 37 normal-hearing children who were available to complete this test. Similar to performance on the WRAT-4, all of the children scored between the average range (within ± 1 SD of the mean standard score of 100) and the upper extreme range ($+3$ SD above the mean standard score of 100) on both the Verbal and Nonverbal sections. Similar to the WRAT-4, the overall performance of the children in this study was superior to that of the general population, with over half of the children scoring above the 85th percentile ($+1$ SD) on the

Verbal section, and 35% of the children scoring above the 85th percentile on the Nonverbal section.

Relationship between Objective-Subjective Listening Task Results and Measures of Cognition/Academic Achievement—Table 3 reports Spearman rank-order correlation coefficients among the psychometric function threshold estimates and threshold discrepancy scores on the Objective-Subjective listening task and standard scores from the subtests of the KBIT-2 and WRAT. None of the measures from the Objective-Subjective listening task (i.e., Objective thresholds, Subjective thresholds, Objective-Subjective discrepancy scores) were significantly correlated with standard scores on any of the subtests of the KBIT-2 or WRAT-4. The potential reasons why we did not find a significant relationship between the Objective-Subjective task and cognitive abilities or academic performance are considered in the “Discussion” section below.

Children with Cochlear Implants

Objective-Subjective Listening Task—The ten children with cochlear implants demonstrated near-perfect performance (97–100% correct) in the Objective baseline condition (no masker), at all target levels. For the participants with cochlear implants the target levels were between 45 and 72 dB SPL.

Figure 4 presents the fitted psychometric functions (i.e., proportion correct or perceived correct as a function of T/M) for the children with cochlear implants. The open circles represent proportion correct in the Objective condition, and the solid circles represent data in the Subjective condition. Fitted functions are plotted for each condition. The error bars show the 95% confidence limits of the estimated thresholds (51% correct). In the Subjective condition psychometric functions could not be estimated with good reliability for two of the children with cochlear implants (CI01 and CI05) because their responses in this condition did not fall below 70%, even at the lowest T/M tested, in which their performance in the Objective condition was at chance levels.

As suggested by the data shown in Figure 4, there was considerable variability across children in the estimated thresholds in the Subjective condition. Nevertheless, with the exception of participants CI01 and CI05, the children with cochlear implants produced monotonic psychometric functions that spanned nearly the entire range of performance from chance (3% correct) to perfect (100% correct). Confidence intervals for the threshold estimates were approximately 2 dB. The average threshold estimate among the children with cochlear implants was -2.8 dB in the Objective condition and -5.9 dB¹ in the Subjective condition.

Objective-Subjective discrepancy scores were calculated for the eight children with cochlear implants for whom psychometric function thresholds were estimated. Of the eight children, six significantly overestimated their speech reception ability (i.e., Subjective and Objective threshold confidence limits did not overlap). The two children for whom threshold estimates could not be calculated (CI01 and CI05) also overestimated their performance, as seen by the fact that their Subjective “performances” never fell below 70%, even at low T/Ms at which their Objective performances were at chance levels. Therefore eight of the ten children with cochlear implants significantly overestimated their speech reception ability. The two remaining children (CI03 and CI08) were the most accurate at estimating their

¹Only eight of the ten listeners with cochlear implants were included in the calculation of the average threshold estimate in the Subjective condition. CI01 and CI05 were excluded from the average because their psychometric function threshold could not be calculated in this condition.

speech reception performance in the cochlear implant group. None of the children with cochlear implants significantly underestimated their speech reception performance.

The data from the participants with cochlear implants were compared to the data from the 25 participants with normal hearing who were in the same age range as the children with cochlear implants (i.e., 8.0–12.0 yr). In order that all of the children with cochlear implants could be included in the analysis, “proportion difference scores” were computed for each listener and analyzed in lieu of threshold discrepancy scores. Proportion difference scores were calculated in the following manner: (1) A proportion score in the Objective condition was computed for each listener by averaging the proportion correct at the two T/Ms just above and below the .51 threshold in that condition. (2) A proportion score in the Subjective condition was computed for each listener by averaging the proportion judged correct at the same T/Ms that were used for calculating the proportion score in the Objective condition. (3) The proportion difference score was calculated for each listener by subtracting the Subjective proportion score from the Objective proportion score. Thus, the proportion difference score served as an index of Objective-Subjective discrepancy for each listener. The median proportion difference score was $-.22$, 95% CI $[-.10, .30]$ for the children with cochlear implants and $-.13$ $[-.03, .23]$ for the same-age children with normal hearing. A Mann-Whitney U test [$U(n_1 = 10, n_2 = 25) = 177, p = .049$] indicated a significant difference in the scores of the two groups, but the magnitude of the effect ($\theta = 0.71, [0.493, 0.852]$) was negligible as indicated by the fact that the 95% confidence interval for θ overlapped 0.5, which implies no effect (Newcombe, 2006).

DISCUSSION

Effective listening and learning may be predicated on one's ability to recognize when communication breakdowns occur so that obstacles can be overcome and clarification can be sought. Obstacles to communication may include ambiguous messages, complex content, unintelligible speakers, hearing loss, and environmental noise/distractions. Several of these obstacles occur frequently in school classrooms, where effective listening is essential to learning. Noise, in particular, is an enduring problem in school classrooms and has been shown to have deleterious effects on speech perception in children (e.g., Elliott, 1979; Jamieson et al, 2004). Children with hearing loss are particularly vulnerable to the poor listening conditions of typical classrooms. The purpose of this research was to determine if listeners are able to monitor their speech reception capabilities in noise and recognize when they are not able to perceive spoken messages. Participants' subjective judgments of their ability to understand spoken messages in noise were compared to their objective performance on the same speech perception task. The study sample included normal-hearing children, adolescents, and adults in order to examine the development of self-monitoring in listeners with normal hearing. In addition, we explored self-monitoring skills in a small sample of children with cochlear implants.

Self-Monitoring of Speech Reception in Normal Hearing Children, Adolescents, and Adults

As expected, normal-hearing adults were quite accurate at judging their ability to understand the spoken messages in noise. Across adult participants, the average psychometric function threshold estimate in the Subjective condition was nearly identical to that in the Objective condition. Moreover, individual thresholds estimated from psychometric functions in the Objective and Subjective conditions for most adult participants were within 1 dB of each other. This is consistent with previous studies that demonstrated that most adults are remarkably accurate at estimating their listening in noise abilities on the Performance-Perceptual Test (PPT; Saunders and Cienkowski, 2002; Saunders et al, 2004; Saunders and Forsline, 2006). Specifically, these three studies reported that the average discrepancy

between the performance (objective) and perceptual (subjective) thresholds on this adaptive task was less than one test step size (i.e., 2 dB).

Among the normal-hearing children there was considerable variability in the ability to judge their speech reception performance. Some children were quite accurate in judging their ability to understand speech in noise, whereas about half of the children significantly overestimated their ability. The average discrepancy between the psychometric function threshold estimates in the Objective and Subjective conditions indicated that the normal-hearing children overestimated their listening ability by approximately 2 dB, although some children greatly overestimated their ability. Specifically, Objective-Subjective threshold discrepancy scores of 31% of the children exceeded 3 dB, and some children overestimated their abilities by more than 5 dB. Age appeared to play a factor in the children's ability to estimate their listening ability, as there was a greater tendency of the younger children (i.e., aged 7–12 yr) to overestimate their listening abilities than adolescents and adults. Overall, these findings suggest that many children do not reliably recognize when their speech understanding is disrupted by poor acoustic conditions.

Comparing the data in the Objective condition to that in the Subjective condition across age (Fig. 2), we see that the younger children in the sample tended to rate their speech perception ability at a level that was very similar to adolescents and adults, but their objective performance was poorer than that of the older children and adults. Thus, the poorer performance of the children on the Objective condition appears to be underlying the greater discrepancy between Subjective and Objective ratings seen in children relative to adolescents and adults. In other words, many of the children estimated that their speech reception ability was commensurate with that of the adults, but their actual performance was considerably poorer. One can envision a noisy communication environment where adults perceive only minimal listening difficulties and therefore do not recognize that the acoustic environment is compromising the listening abilities of their children/students. The children, in turn, may be experiencing listening difficulties but may not perceive that they are having trouble.

Our finding that the children tended to overestimate their speech understanding in noise is consistent with previous studies that have examined the ability of normal-hearing children to monitor their own comprehension of written texts and spoken messages (Markman, 1979; Markman and Gorin, 1981; Patterson et al, 1981; August et al, 1984; Anderson and Beal, 1995). These studies have shown that children often miss ambiguities or inconsistencies in error detection paradigms (Markman, 1979; Anderson and Beal, 1995), fail to detect blatant inadequacies in sets of verbal instructions (Flavell, 1971), attempt to carry out inadequate instructions (Markman, 1979), do not ask questions or report confusing messages when given the opportunity (August et al, 1984), and fail to report missing pages in written texts (August et al, 1984). It is not well understood why children fail to recognize communication difficulties. In a study of comprehension monitoring by Flavell et al (1981), typically developing children were given a set of inadequate instructions for how to build a structure out of blocks and asked to replicate the block structure to the exact specifications given by the examiner. The investigators reported that kindergarten children “would often show a brief flicker of problem detection while listening and building (e.g., a momentary pause), followed by no subsequent evidence that they were still aware of or bothered by the problem” (pp. 35–36). Studies have also suggested that, even if children are able to recognize a communication problem, they may not be able to pinpoint the problem clearly enough to report it explicitly or ask for additional information (Anderson and Beal, 1995). Finally, children are prone to blame the listener rather than the speaker when communication is unsuccessful, even when the listener is clearly not at fault, and they may be reluctant to signal that they do not understand and ask for clarification when the speaker

is an authority figure, such as a teacher (Robinson and Robinson, 1982; McDevitt et al, 1990). Collectively, findings from these previous studies and the current study suggest that the skills needed to recognize and overcome communication breakdowns may not be fully developed until adolescence.

This disparity between estimated understanding and actual performance may have a distinct bearing on classroom learning. Given the unfavorable listening conditions of typical classrooms, children will frequently encounter communication breakdowns in their learning environment but may not recognize them when they occur. Specifically, children appear to be less skilled than adolescents and adults at monitoring their listening, are poorer at understanding speech in noise, and tend to be in noisy classrooms. They are also at an age at which fundamental educational concepts are taught. Nevertheless, in the current study we did not identify significant relationships between results from the Objective-Subjective listening task and performance on the tests of academic achievement or cognitive ability. This may suggest that classroom learning is largely impervious to the inability of many children to monitor their listening ability in noisy environments. Seemingly, there is considerable redundancy involved in classroom learning. Academic concepts are often reiterated and conveyed in multiple formats (e.g., direct verbal instruction, written materials, group activities, class discussions), so when students “miss” a learning point via direct instruction from the teacher, it is possible that the concept is reinforced in another modality. Nevertheless, the relevance of self-monitoring of listening to classroom learning should not be entirely discounted based on the lack of relationship between monitoring and academic/cognitive test scores observed in the current study. A notable limitation of the current study was that the study sample consisted largely of children having above-average cognitive abilities and academic skills. Thus, with regard to cognitive ability and academic achievement, our sample was not representative of the general population. It is possible that the range of academic/cognitive abilities in our sample (i.e., all participants scored in the average or above average range) was inadequate to demonstrate plausible relationships between self-monitoring and academic/cognitive performance. Future studies should include children with a broader range of academic and cognitive aptitude than seen in the current study.

Future research should also consider the effects of feedback on self-monitoring abilities. Participants in the current study were not made aware of their performance in the Objective-Subjective task. It is possible that many of the children who overestimated their performance may have provided more reasonable judgments of their speech reception abilities in the Subjective condition if they had received trial-by-trial or overall feedback on their performance in the Objective condition. Presumably, students have several sources of feedback available to them in classrooms on which to gauge their performance (e.g., exams, assignments, class discussions, quizzes). It is possible that these sources of feedback allow students to monitor their academic performance in a proficient manner. Future studies should include a feedback component in the experimental design in order to obtain additional understanding of student self-monitoring abilities in environments that more closely resemble the dynamics of classroom learning.

Self-Monitoring of Speech Reception in Children with Cochlear Implants

Similar to many of the normal-hearing children, the children with cochlear implants also appeared to overestimate their listening-in-noise ability. Specifically, eight of the ten children with cochlear implants rated their subjective judgments of listening ability significantly above their actual (objective) performance. Definitive interpretations of these data are restricted by the small number of children with cochlear implants in this study, but these results suggest that many children with cochlear implants are unaware of their speech reception difficulties when confronted by adverse listening environments. Given the

unfavorable acoustic conditions of many communication environments (particularly classrooms), as well as speech reception deficits characteristic of this population, it is likely that children with cochlear implants (as well as other children with hearing loss) encounter frequent situations in which their speech reception is compromised. Educational audiologists will often instruct students with hearing loss to advocate for themselves by seeking clarification or alerting their teacher of communication difficulties, but these students first need to recognize when their speech understanding is compromised. Thus, the ability to monitor one's speech reception may be a critical skill for learning in oral classrooms.

The current study suggests many children with hearing loss may forgo opportunities to seek clarification because they may be unaware of instances in which they fail to perceive spoken messages. Future studies should include larger samples of children with hearing loss so that potential relationships between the ability to monitor speech perception and academic achievement can be explored in this population. In addition, future studies should consider the potential benefits of self-monitoring training with this population. Studies in various areas of academic learning have shown that instruction can improve students' ability to monitor their comprehension of reading materials, the clarity of their own written narratives, and their mastery of mathematical concepts (Schunk, 1983; Kinnunen and Vauras, 1995; Beal, 1996). These studies have also suggested that improvements in self-monitoring ability positively influence learning and educational achievement. It is possible that instruction in self-monitoring may be beneficial to classroom listening for students with hearing loss and others with communication deficits.

CONCLUSION

The current study examined the abilities of listeners to monitor their speech reception in noisy environments. Results from this study suggest that whereas normal-hearing adolescents and adults are generally very proficient at monitoring their listening abilities, many children with normal hearing and children with cochlear implants do not reliably recognize instances in which their speech recognition is compromised. Given the poor acoustical conditions commonly found in classrooms and the considerable time dedicated to listening activities in the school day, self-monitoring of communication ability may be a particularly relevant topic for researchers, clinicians, and teachers who work with children with and without hearing loss.

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Abbreviations

CRM	Coordinate Response Measure
HINT	Hearing in Noise Test
KBIT-2	Kaufman Brief Intelligence Test, Second Edition
PPT	Performance-Perceptual Teston

T/M	target/masker ratio
WRAT-4	Wide Range Achievement Test, Fourth Edition

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Figure 1.

Psychometric functions from four representative normal-hearing children (left panels) and four representative adults (right panels). The open circles represent performance in the Objective condition, and the solid circles represent data from the Subjective condition. The 51% threshold estimates are indicated in each condition by crosses, and the horizontal error bars indicate the 95% confidence intervals for the estimated thresholds. The participants' identification codes and ages (in years) are listed in the bottom right of each panel.

Figure 2.
Individual threshold estimates (T/M at 51% correct) with 95% confidence intervals as a function of age (in years) in the Objective condition (left panel) and the Subjective condition (right panel).

Figure 3.

Objective-Subjective threshold discrepancy scores as a function of age (in years). The circles represent the Objective-Subjective discrepancy scores of participants who accurately estimated their performance (i.e., their Subjective threshold was within 95% confidence limits of the Objective threshold). The triangles pointing up indicate thresholds in the Subjective condition were significantly lower than thresholds in the Objective condition (i.e., the participant overestimated his or her ability). The triangles pointing down represent Subjective thresholds that were significantly higher than Objective thresholds (i.e., the participant significantly underestimated his or her ability).

Figure 4.

Psychometric functions from the 10 participants with cochlear implants. The open circles represent performance in the Objective condition, and the solid circles represent data from the Subjective condition. The participants' identification codes and ages (in years) are listed in the bottom right of each panel. The top eight panels display psychometric functions and thresholds in each condition for eight of the 10 participants with cochlear implants. The threshold estimates are indicated in each condition by crosses, and the horizontal error bars indicate the 95% confidence intervals for the estimated thresholds. Reliable estimates of thresholds could not be calculated for two of the participants (CI01 and CI05) in the Subjective condition because their responses in this condition did not fall below 70%, even

at the lowest T/M tested. Consequently only the data points are displayed for these two participants.

Table 1

Demographic and Audiologic Information of Participants with Cochlear Implants

ID	Age (yr)	Gender	Age of Identification (yr)	Side of Implant	Age of Implantation		Etiology of Hearing Loss
					1st/2nd Implant (yr)		
CI01	10.4	M	3.6	R	3.8		Bacterial meningitis
CI02	10.1	F	Birth	Bilateral	1.7/7.7		Idiopathic
CI03	11.8	M	0.5	L	2.1/2.7*		Bacterial meningitis
CI04	8.9	F	Birth	L	1.2		Connexin 26
CI05	8.2	F	Birth	R	1.2		Connexin 26
CI06	9.3	M	Birth	R	1.6		Idiopathic
CI07	10.7	F	Birth	R	5.5		Idiopathic
CI08	11.5	F	0.5	Bilateral	5.4/11.4		Idiopathic
CI09	10.7	F	Birth	L	3.9		Idiopathic
CI10	10.5	M	Birth	L	2.0/4.0*		Idiopathic

* CI03 and CI10 both received cochlear implants on the right side, which were subsequently removed because of infection/head trauma. Both children received a replacement cochlear implant on the left side.

Results (standard scores) of the Normal-Hearing Children on the Wide Range Achievement Test, Revised (WRAT-R) and Kaufman Brief Intelligence Test, Second Edition (KBIT-2)

Table 2

	WRAT-R Word Reading (n = 40)	WRAT-R Spelling (n = 40)	WRAT-R Math (n = 40)	KBIT-2 Verbal (n = 37)	KBIT-2 Nonverbal (n = 37)
Mean	118.9	115.5	112.2	111.4	115.2
SD	11.8	14.6	14.2	11.2	12.8
Range	88–145	84–145	89–142	96–136	87–139

Table 3
Spearman Rank-Order Correlation Coefficients among Scores on the Objective-Subjective Task and Scores on the WRAT-2 and KBIT

	KBIT-2 Nonverbal	KBIT-2 Verbal	WRAT-R Word Reading	WRAT-R Spelling	WRAT-R Math
Objective Threshold	-.193 (n = 37)	-.117 (n = 37)	-.330 (n = 40)	-.175 (n = 40)	-.048 (n = 40)
Subjective Threshold	.121 (n = 37)	.019 (n = 37)	-.145 (n = 40)	.001 (n = 40)	.072 (n = 40)
Objective-Subjective Threshold Difference	-.180 (n = 37)	-.079 (n = 37)	-.003 (n = 40)	-.038 (n = 40)	.024 (n = 40)