Volume 2 Otoprotection, Regeneration, and Telemedicine

Advances in Audiology and Hearing Science

Stavros Hatzopoulos, Editor

Andrea Ciorba and Mark Krumm, Associate Editors

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VOLUME 2

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CHAPTER 1

Assessment of Early Auditory Development in Children After Cochlear Implantation

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ABSTRACT

This chapter presents information on cochlear implants (CIs) and their use in the treatment of childhood hearing loss. Specifically, normal auditory development in children is discussed which is critical for clinicians to understand. A rationale is provided for CIs as a means to promote the auditory development of children with profound hearing loss. In addition, the theoretical foundations of methods for assessing auditory development using questionnaires are provided, as well as their clinical application. The role of questionnaires is important to assure valid and effective CI fitting and early intervention programs. Finally, data on CIs suggest that early implantation with young children at 12 months of age is efficacious. Consequently, delaying this process even a short period of time, may lead to unfavorable and unnecessary outcomes.

1.1 INTRODUCTION

Hearing plays an important role in a child's development. Hair cells in the inner ear transform acoustic energy into neuronal impulses, a transformation which is essential in generating auditory sensation. Damage to these cells can disrupt inner ear function creating sensorineural hearing loss. Depending on the extent and type of damage, an individual's hearing loss (and therefore impairment) may be more or less severe. In most cases, hair cell damage is irreversible. Consequently, there is no effective medical "cure" for hearing impairment. The only available medical intervention is rehabilitation using a hearing prosthesis such as a hearing aid (HA) or cochlear implant (CI). Hearing aids are typically used in cases of mild to severe hearing loss; cochlear implants are usually reserved for cases of profound hearing loss or total or partial deafness.

1.2 AUDITORY DEVELOPMENT

1.2.1 NEUROPHYSIOLOGICAL FUNDAMENTS OF AUDITORY DEVELOPMENT

To understand auditory rehabilitation with a CI, one needs to appreciate how the auditory system develops and what happens to its neural structures when they are stimulated. A rapid growth in neural structures is first seen at the embryonic stage of development. The process is regulated by the expression of genes, but the final stages of development take place in the period after they have already begun to perform their basic function: the perception of sound (Werner et al., 2012). The synchronous activity of neurons in these structures and in the adjoining afferent system stimulates further development. At the same time, lack of appropriate activity leads to weakening or even loss of synaptic connections. These processes happen simultaneously, with the end result being that the most effective connections are the ones that develop.

The process of intensive reorganization of neural structures during development is called developmental neuroplasticity, and the period of particular susceptibility to change is called the critical period (Cramer et al., 2017). During the critical period, even stimuli acting for only a short period of time may have a significant impact on the final organization of a neural unit. Altered perceptional sensitivities, such as caused by hearing loss, can lead to a permanent impairment of components of the central auditory pathway and how it is organized. Sometimes, however, functional perception can be restored, at least partially, if auditory training is provided (e.g., early intervention programs for children with hearing impairments).

Knowledge of the neuroplasticity of cortical auditory centers has been obtained using electrophysiological studies that concentrate on the latencies of cortical auditory evoked potentials (CAEPs). The latency of the first positive peak (P1) in a CAEP waveform is considered to be a biomarker of the maturity of the auditory cortex (Sharma and Dorman, 2006; Sharma et al., 2007). The latency of P1 is the sum of all the synaptic delays in the peripheral and central segments of the auditory pathway, and since it depends on the age it can, therefore, serve as a measure of auditory pathway maturity (Katz, 1994; Eggermont et al., 1997). Studies of CAEPs conducted on people with normal hearing (NH) permit the range of P1 latencies to be determined for each age group. For example, the P1 latency in a newborn is about 300 ms but, with rapid development, by 2–3 years of age the P1 latency is about 125 ms. By adulthood, the P1 latency has shortened to about 60 ms (Sharma et al., 2002).

1.2.2 A MODEL OF AUDITORY DEVELOPMENT

The Aslin and Smith (1988) general model of perception describes three successive stages of auditory development sensory primitives (Level I), which characterizes basic sensory perception; perceptual representations (Level II), which represents complex coding at higher neural levels; and higher-order representations (Level III), which involves cognitive processing. Carney (1996) has used the Aslin and Smith model to divide auditory perceptual development into three corresponding levels, the level of sound detection resulting in sound awareness (Level I), the level of discrimination that allows sounds to be differentiated (Level II), and the level of identification in which sounds are recognized and interpreted (Level III) (Eisenberg et al., 2007).

1.2.3 AUDITORY DEVELOPMENT IN A TYPICALLY DEVELOPING CHILD WITH NORMAL HEARING

From the moment a child is born, its auditory system is ready to react and process acoustic stimuli (Eisenberg, 1976; Aslin et al., 1983). However, even though the auditory system is capable of performing satisfactorily, it is still refining its capabilities, a process that lasts for the next dozen years or more. As mentioned in the previous section, the three main stages of auditory perception are detection, discrimination, and identification (Carney, 1996; Aslin and Smith, 1988). Each stage of development sees a refinement in these auditory perceptions and their progression can be monitored in children by recognizing certain auditory reactions. At an embryonic age, and in newborns, there are already general and nonspecific reactions to sounds. A sound might cause slight changes in behavior (closing of the eyes, an increase in heart rate). Northern and Downs (1991) have published an overview of the behavioral responses of infants, of which the most important are:

1. Reflexive behaviors: fright, general body movement (large motor), pupil dilation, blinking of eyes, spontaneous face movements, the closing of eyes (auditory reflex, reproducibly evoked from about 24–25 weeks gestational age).
2. Orienting behaviors: turning of the head, widening eyes, raising eyebrows, expressing surprise, sudden cessation of vocalization.
3. Attention behaviors: Stopping an activity, increased ability to act, holding the breath or change of breathing rhythm, sudden crying, sudden stopping of crying or vocalization, widening the eyes, smile or other changes of facial expression.

In the first 2 years of a child's life, its auditory reactions change. They may react to sounds of progressively less intensity, may show a wider diversity of reactions, or may show more pertinence and repeatability of reactions to specific acoustic stimuli. In the first months of life (up to about 4 months) an infant may take fright (Moro reflex) or awaken in reaction to a sudden, loud sound. Children aged between 4 and 7 months turn their heads toward a sound source outside their field of vision; by 9 months they can localize a sound coming from the side, and by 13 months localize a sound coming from behind. Between 13 and 24 months of life, a child reacts to speech from another room, coming or responding when called (Northern and Downs, 1991).

1.3 COCHLEAR IMPLANTS

Cochlear implants replace the process of transforming sound into neuronal impulses by electrically stimulating the surviving nerve fibers in effect bypassing the defective hair cells (Wilson et al., 1991). Cochlear implant systems consist of an internal and external part. The internal part is the implant, which comprises a receiver and an electrical stimulator in one unit which feeds into a serial electrode array. The external part is a digital multichannel speech processor (Hochmair et al., 2006). Medically, receiving a cochlear implant involves two basic steps. First is the surgical side, where the implant capsule is placed within a niche made in the temporal bone and covered with a skin flap, after which the electrode array is carefully threaded into the inner ear (cochlea). The second step involves postoperative rehabilitation, which aims to help the new cochlear implant user better learn to hear with his/her implant (Niparko, 2009).

CIs may be offered to children who have little potential for understanding speech using an HA—recognizing that HAs, even when well-fitted, have practical limits (although the definition of "limited benefits" has changed many times over the last 20 years). Originally, only children who had very little residual hearing and who showed no apparent awareness of sound using an HA were considered candidates for a CI. At that time, candidacy was based on the relationship between the degree of residual hearing and the benefit conferred by the use of an HA. Specifically, children with sensorineural hearing loss were classified on a scale from 'good' to 'poor' depending on the pure tone average (PTA) of their hearing as a means to predict HA benefit. The scale runs from bronze (for PTA, >110 dB), to silver (for 110 > PTA > 100 dB), and gold (for 100 > PTA > 90 dB) (Miyamoto et al., 1995). Gradually, the criteria for implantation have been expanded to include children with better residual hearing, and now include silver and gold HA users. This change in qualifying criteria has been justified by the finding that implanted children in all three classes perform better than their peers who have comparable hearing losses and use HAs. More recently, a platinum HA user group has been defined for PTA between 60 and 90 dB (Eisenberg et al., 1998). It has also been shown that hearing in implanted children in the platinum group is better than those with an HA.

As described above, cochlear implantation has been shown to provide clinically significant gains in a child's auditory development. Moreover, prelingually deaf children who benefit most from a CI are those who have received their implants before 2 years of age (Kral and O'Donoghue, 2010). One of the most gratifying outcomes of cochlear implantation is the restoration of a child's ability to understand speech. Technological advances, early diagnosis and implantation, and relaxation of audiological criteria to permit implantation of CIs in children with residual hearing have all improved spoken language outcomes of children with CIs (Skarzynski et al., 2007; Niparko et al., 2010).

Children who receive CIs at a very young age develop age-appropriate spoken language faster than those who receive implants later (Kral and O'Donoghue, 2010; Niparko et al., 2010; Waltzman et al., 1997; Holt and Svirsky, 2008; Dettman et al., 2007). There is ample evidence in the literature of a reciprocal relationship between the development of language skills and social competence (Gallagher, 1993; Windsor, 1995; Redmond and Rice, 1998; McCabe and Meller, 2004). As short-term gains in auditory development translate into medium-term gains in social independence and quality of life (presumably through the communication competency achieved with a CI), there is a need for appropriate assessment instruments, questionnaires, tests, and scales, to monitor the very early auditory development in children with CIs (Fink et al., 2007). These tools are often divided into three categories: questionnaires, closed-set auditory assessment tests, and open-set auditory assessment tests. In the next section, special focus is placed on recent progress in auditory development questionnaires.

1.4 AUDITORY DEVELOPMENT QUESTIONNAIRES

To ensure that assessment tools provide high-quality data and that the scores allow quality decisions and inferences to be made, the tools must be prepared according to guidelines and standards for measurement instruments in education, psychology, and health (American Educational Research Association et al., 2014; International Test Commission, 2000). When constructing an instrument, the key stages include: defining the research problem; preparing a set of test items related to the intended construct (based on relevant theoretical background), specifying the response format, and standardizing, validating, and normalizing the test (Osterlind, 2001; Foddy, 1993). The most fundamental consideration in developing and evaluating a test is its validity.

1.4.1 VALIDATION

Since about the 1940s, there has been an ongoing debate on the theory and practice of how to establish validity. The current broad consensus about what validity entails is that (1) it embodies inferences and interpretations about the use of a test, (2) it is not a characteristic of the test or questionnaire itself, (3) it is a unitary concept, and (4) it is an evaluative judgment. The last edition of Standards for Educational and Psychological Testing [issued in 2014 by the American Educational Research Association (AERA), the American Psychological Association (APA), and the National Council of Measurement in Education (NCME)] states "validity refers to the degree to which evidence and theory support the interpretations of test scores for proposed uses of tests" (p 11). The current understanding of validity refers to all concepts and practices in the educational, psychological, and health fields that can provide evidence for or against the intended interpretation of a test, scale, or questionnaire score (American Educational Research Association et al., 2014).

An additional requirement for a high-quality instrument for assessing early auditory development is a global-wide scope for documenting the benefits of early implantation and providing the information required for health policy decision-making (National Institute for Health and Clinical Excellence, 2004). Such an international perspective requires that a test can be adapted for use in different languages and cultures, and this means more than a simple matter of translation. Fortunately, there is a broad consensus among the professional community interested in cross-lingual and cultural research about the methods, procedures, and statistical techniques necessary for adapting tests and questionnaires (Van de Vijver et al., 2003; Hambleton et al., 2005). For example, the Guidelines for Adapting Tests proposed by the International Test Commission (ITC) is a common reference for best practice in the field (International Test Commission, 2010). The ITC Guidelines sets out the general framework within which a questionnaire should be adapted. Here, "adaptation" is a broad scientific term that includes two main phases: translation, and evaluation of the adapted test or questionnaire. According to state-of-the-art practice, translation should take into account linguistic and cultural differences among the population for whom the adapted version of the test or instrument is intended, provide evidence that the item content is familiar to the intended population, and evidence of the equivalence of both versions (International Test Commission, 2010). To meet those guidelines, translation is commonly executed in accordance with some of the linguistic designs available in the literature (Harkness, 2003). "Evaluation" essentially means gathering evidence of the validity of the translated version of the test or questionnaire. Here, attention needs to be paid to the quality of the evidence gathered for validity, taking into account the intended purpose of the questionnaire or scale and the particular population targeted.

In addition to having core characteristics, development against a theoretical background, sufficient evidence of validity, and availability in multiple languages, high-quality outcome measures should be easy to administer, score, and interpret (Andresen, 2000). In the case of assessing early auditory development, it is extremely important to compare the results obtained after cochlear implantation with normative values to confirm the effectiveness of the intervention.

1.4.2 AUDITORY DEVELOPMENT QUESTIONNAIRES

Several instruments have so far been used to assess the auditory development of very young CI children: Infant–Toddler Meaningful Auditory Integration Scale (IT-MAIS) (Zimmerman-Phillips et al., 1997), Auditory Skills Checklist ASC (Auditory Skills Checklist) (Meinzen-Derr et al., 2007), Parent's Evaluation of Aural/Oral Performance of Children (PEACH) (Ching and Hill, 2007), Functional Auditory Performance Indicators (FAPI) (Stredler-Brown and Johnson, 2001), and LittlEARS Auditory Questionnaire (LEAQ) (Weichbold et al., 2005). However, the published evidence needed to support inferences on auditory development of CI children is scant and not sufficient to assemble an argument for validity based on multiple sources.

IT-MAIS consists of 10 questions designed to interview parents about the frequency with which the target auditory behavior is exhibited in everyday situations (Zimmerman-Phillips et al., 1997). Parents do not fill in the questionnaires by themselves, they are interviewed and their answers interpreted by an interviewer and the total score finally counted. Weichbold et al. (2004) reported on some limitations in their validation study. Poor reliability of the questions designed for the youngest children was found, as well as an effect of how the test was administered. Nevertheless, IT-MAIS has often been used in research as an outcome measure in very young CI children.

The ASC questionnaire was developed to track the progress of functional auditory skills in very young children with sensorineural hearing loss. It is aimed at children who received CIs before 36 months (Meinzen-Derr et al., 2007). The test combines information from parents and the examiner's own observations to gauge the evolution of auditory skills in children with hearing impairment. With ASC it is only possible to monitor the relative progress of rehabilitation and there is no comparison with the auditory development of normal-hearing children. Nevertheless, the authors have reported good reliability and have correlated ASC results with those of IT-MAIS. However, the evidence presented is insufficient to confirm the validity of ASC.

The PEACH Diary was aimed at evaluating the effectiveness of amplification in infants and children with hearing impairment by systematically using parents' observations (Ching and Hill, 2007). Parents are asked to make observations of their children according to the questions included in the tool. They are asked to write down as many examples of the particular behaviors of the child as they can, which are then rated by an audiologist using a graded scale. Use of the questionnaire requires specialized training in order to properly interpret the parents' observations and assign appropriate scores. The PEACH Diary results can be compared with age-related normative values. The PEACH questionnaire is also available in a Rating Scale format. The results of a study conducted by Bagatto and Scollie (2013) indicated close agreement of the normative curve of the PEACH Rating Scale to existing normative data collected with the PEACH Diary. A validation study of the PEACH scale by Ching and Hill revealed that 11 out of 14 items showed high discriminatory power, based on corrected item–total correlations and a high level of consistency for those items (a Cronbach alpha of 0.88). According to the authors, reliability of the scale should be regarded as preliminary, and additional studies, particularly over longer time intervals, are needed. Further studies are also needed to examine the validity of the functional performance scores provided by the PEACH scale, and its sensitivity to differences in amplification strategies (Ching and Hill, 2007).

FAPI assesses the functional auditory skills of children with hearing the loss in seven categories: awareness and meaning of sounds, auditory feedback and integration, localizing a sound source, auditory discrimination, auditory comprehension, short-term auditory memory, and linguistic auditory processing (Stredler-Brown and Johnson, 2001). The authors did not provide information on questionnaire validity. However, Ferreira et al. (2011) attempted to adapt the questionnaire for use in Brazilian hearing impaired children and pointed out some limitations of the instrument. According to the authors, it is not possible to complete the questionnaire in a single session due to its length and complexity. Moreover, the application mode is not standardized for the stated test conditions (Ferreira et al., 2011).

LEAQ evaluates auditory development in infants up to 2 years of age (Weichbold et al., 2005). It is easy to complete, calculate, and interpret the results and takes only around 10 min for a parent to complete the questionnaire. It is possible to compare the results with age-dependent normative values, a step which is crucial for assessing the effectiveness of cochlear implantation in children during this critical period of auditory development. LEAQ has been validated for use in normal-hearing children, both in the original German (Weichbold et al., 2005) and in many other languages. It has shown sensitivity and reliability for assessing auditory development in normal-hearing children under 24 months of age and there is a high correlation of scores with age (Obrycka et al., 2009; Coninx et al., 2009; Bagatto et al., 2011; Geal-Dor et al., 2011; Wanga et al., 2013; García Negro et al., 2016). Moreover, it has been especially validated in a group of cochlear implanted children. A study by Obrycka et al. (2017) provides support for the validity of the LEAQ to monitor early auditory development in infants and toddlers receiving CIs.

TABLE 1.1 Comparison of Features of Questionnaires for Assessing Auditory Development in Infants and Toddlers.

	IT-MAIS	ASC	PEACH rating scale	PEACH diary	ELF	FAPI	LEAQ
Language of development	English	English	English	English	English	English	German
Validity evidence	±	±	±	±	–	–	+
Number of adaptations	4	No data	No data	14	No data	2	>20
Normative values	+	–	+	+	–	–	+
Respondent	Clinician	Parent and clinician	Parent	Parent and clinician	Parent	Parent	Parent
Respondent burden	Training required	easy	Easy	Training required	Training required	Not standardized	Easy and quick
Administrative burden	Easy	Easy	Easy	Complicated	Complicated	Complicated	Easy

Of all the tools presented above, LEAQ has the largest amount of evidence for its validity, the largest number of validated language versions, and has all the features necessary for a high-quality diagnostic tool (Table 1.1).

The LEAQ consists of 35 questions supplemented by examples that can be answered "yes" or "no." The theoretical construct which LEAQ intends to capture and quantify is "auditory development." The questions reflect the most important milestones in preverbal auditory development and are based on empirical and theoretical knowledge of early auditory development. The questions are graded in difficulty so as to reflect the four categories of auditory development: detection, discrimination, identification, and comprehension. Questions 1–16 mostly cover detection and discrimination, mainly covering the child's responses to human voices, music, environmental sounds, or toys producing sounds. Questions 10, 12, 17–21, and 25–30 reflect the ability of a child to identify sounds, for example, their own name, linking names with objects, and recognizing the emotional content of a statement. Questions 22–24 and 31–35 mostly relate to comprehension, which is revealed by understanding spoken commands.

The total score (sum of all "yes" answers to the questions) is compared with age-related expected and minimal values established for children with normal hearing (NH). Validation studies performed so far have shown that over 80% of the variability in LEAQ scores is explained by the chronological age of NH children, showing that auditory development is age-dependent (Coninx et al., 2009; Obrycka et al., 2009).

LEAQ is available in over 20 languages, which enables multicenter studies to be conducted in clinics around the world and the results pooled and compared for meta-analysis. A study by Coninx et al. validated the questionnaire in 15 languages, demonstrating the adequacy of LEAQ's psychometric properties. Pearson correlation coefficients between German expected values and those for other languages was very high (0.988–1.000), showing that LEAQ is language-independent and can be used in multicenter studies. Later studies have confirmed the findings of Coninx et al. (Obrycka et al., 2009; Bagatto et al., 2011; Geal-Dor et al., 2011; Wanga et al., 2013; García Negro et al., 2016). The age-related expected values for normal hearing children for 20 languages are shown in Figure 1.1.

As mentioned, the interpretation of LEAQ total score is based on age-related curves of auditory development obtained from normal-hearing children at ages below 24 months. The curves in Figure 1.1 reflect mean LEAQ total scores. Minimum values are taken to be the lower band of the 95% confidence interval, so the probability of a result occurring below this curve in normal-hearing children is less than 5%. An LEAQ total score above the minimum value line indicates normal auditory development.

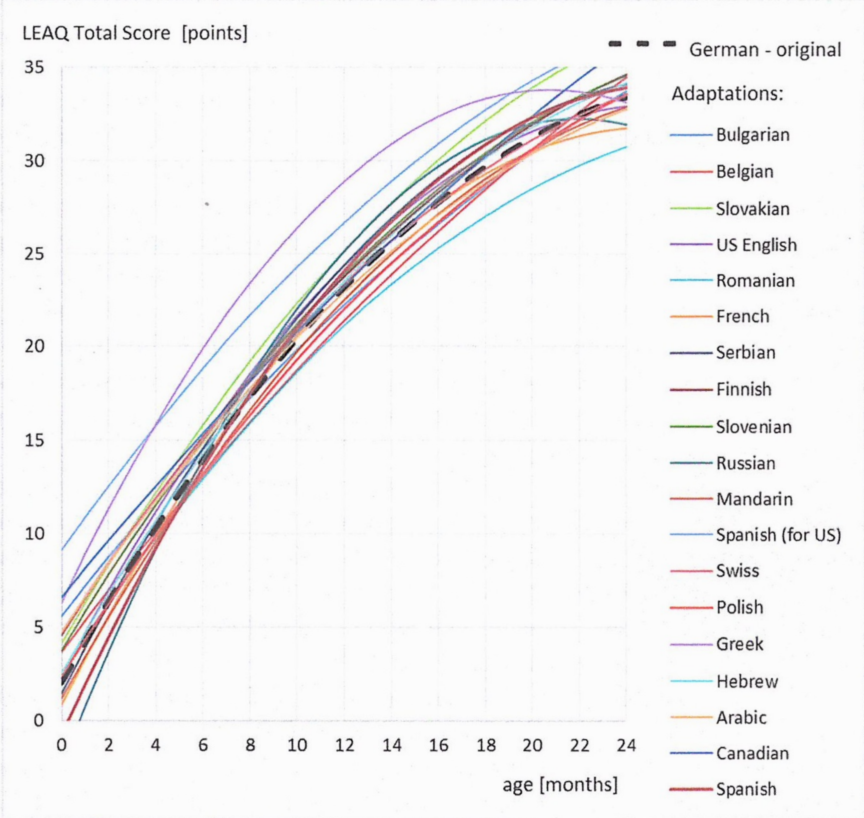
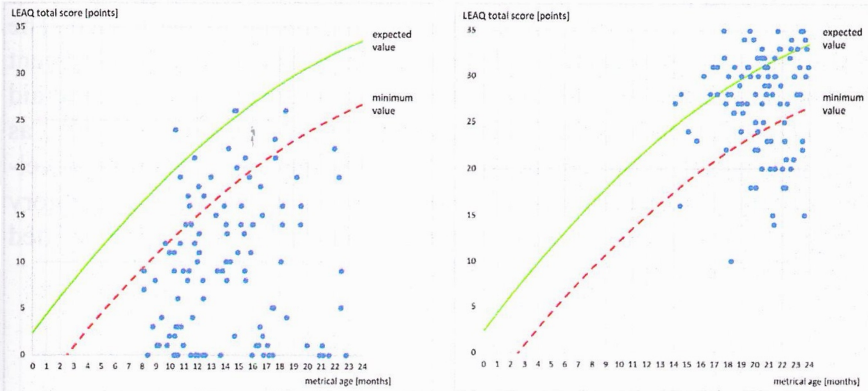


FIGURE 1.1 Age-related expected values on the LEAQ for normal hearing children for 20 languages.

1.4.3 CLINICAL APPLICATION OF LEAQ

Several papers have been published recently on using LEAQ as a tool for assessing auditory development in children with cochlear implants. In general these works compared the performance of CI children with the age-related auditory development of NH children and they showed an increase in LEAQ total score as the duration of CI use rose (May-Mederake et al., 2010; Geal-Dor et al., 2011; Kosaner et al., 2013). A study performed by Obrycka et al. (2014) on a group of 122 children diagnosed with bilateral sensorineural hearing loss and implanted before 24 months of age (range, 7.9–23.5 months), showed poor auditory development before the CI in 86% of children, whereas after 5 months of CI use they achieved auditory development adequate to their age in 72% of cases (Fig. 1.2).



(a) (b)

FIGURE 1.2 (a) Individual LEAQ total scores achieved by children before cochlear implantation; (b) individual LEAQ total scores achieved by children after 5 months of CI use. Solid line, expected value; dotted line, minimum value.

Source: Adapted from Obrycka et al. (2014a).

LEAQ has also been used for long-term observation of 44 children implanted before the age of 12 months (range, 7.9–11.9). The group reached normal levels of auditory development after 10 months of CI use (Obrycka et al., 2014). Figure 1.3 shows that the rate of auditory development in CI children (data points) is, in fact, higher than in NH children (solid line).

The expected values obtained for NH children can also be used to calculate the delay in auditory development. The aim of early intervention with a CI is to provide implanted children with the possibility of reaching, as fast as possible, the same level of auditory development as NH children. Monitoring the delay in auditory development is important in assessing the effectiveness of CIs in very young children. The principle of calculating the delay of auditory development with the LEAQ questionnaire is illustrated in Figure 1.4 and in the animation (animation showing methodology for calculating the delay in auditory development).

Another way of assessing CI effectiveness is to use the patient, intervention, comparator, outcome (PICO) method (Obrycka et al., 2014). To measure CI effectiveness, these researchers compared a group of 32 children (P) who at the time of activation of their CI system (I) were not older than 12 months with another group of 19 hearing aid users (C). To make a fair comparison, children were provided with hearing aids or CI at about the same age. Matching was also done for the age at testing and the level of hearing the loss in both groups. Children from both groups were evaluated with LEAQ 10 months after the first fitting of the device. The LEAQ total score was used to calculate the delay in auditory development (O). The mean delay in auditory development in the group of hearing aid users was 14.3 months greater than in the group of children with Cis, as shown in Figure 1.5. More than 80% of CI children had an auditory development delay of less than 4 months. In comparison, the delay in auditory development was greater than 12 months in almost 70% of children fitted with hearing aids (Obrycka et al., 2014).

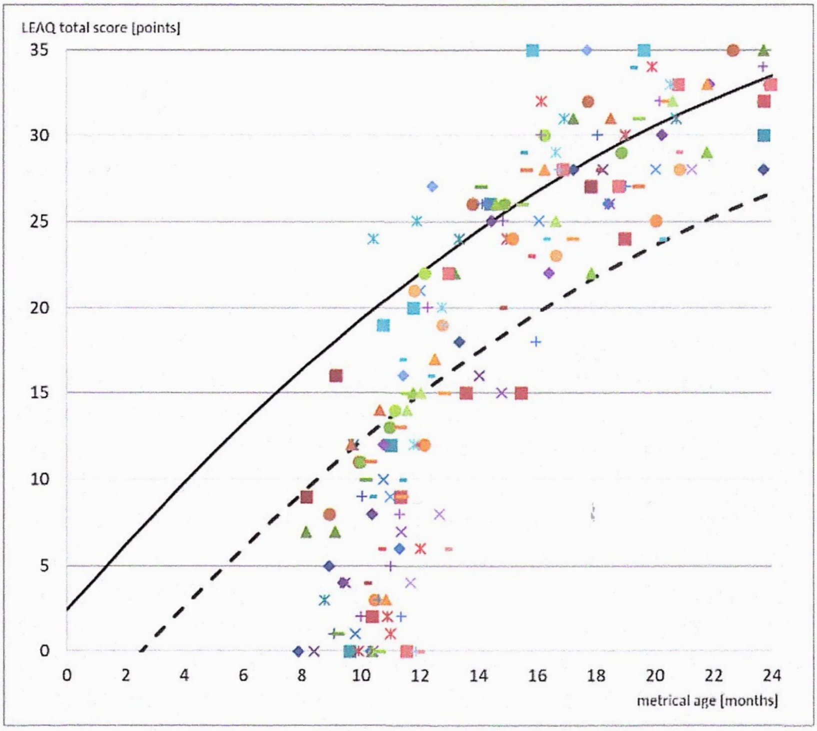


FIGURE 1.3 Individual LEAQ total scores achieved by 44 children implanted under the age of 1 year over 1 year of observation. The results for each child are plotted with a different symbol. Solid line, expected value for NH children; dotted line, minimum value for NH children.

Source: Adapted from Obrycka et al. (2014a).

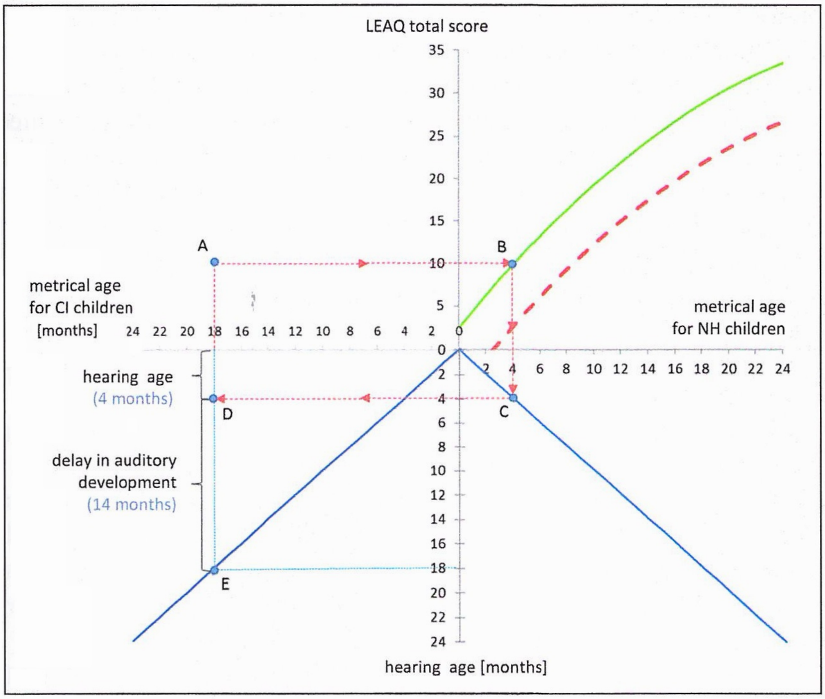


FIGURE 1.4 Methodology for calculating the delay in auditory development based on a hypothetical result from LEAQ. It is assumed here that the child with a hearing loss is 18-months old and their LEAQ score is 10 points (marked A on the graph). The same mean LEAQ total score of 10 points is expected from a normal hearing child of 4 months of the age (B on the graph). For normal-hearing children, hearing age is equal to metrical age (C on the graph); however, for hearing-impaired children, hearing age differs from metrical age. The example shows that the hearing age of the hearing-impaired child is only 4 months (D on the graph) and corresponds to the hearing age of a child with normal hearing who has the same LEAQ total score. The aim of a CI is to compensate for the impairment, that is to provide equal hearing age and metrical age in a child with hearing loss (E on the graph). The difference between the level of full compensation (E) and the current stage in auditory development of the hearing-impaired child (D) is the delay in that child's auditory development. The delay is a quantitative measure of CI effectiveness.

Source: Adapted from Obrycka et al. (2014b).

Clinical applications of the LEAQ described above revealed great variability in auditory performance in CI children. Some children do extremely well with their CIs while others derive only minimal benefit (Fig. 1.2b). Understanding the reasons for the variability in outcomes is one of the most important and challenging research problems in the field today. The available evidence suggests that, in prelingually deaf children, age at implantation is strongly associated with outcome measures (Fryauf-Bertschy et al., 1997; Osberger, et al., 1991; Staller et al., 1991; Waltzman et al., 1994; Waltzman et al., 1997). Children who receive an implant at a young age do much better on a whole range of outcome measures than children who are implanted at older ages. Second, early sensory experience with an HA before implantation also tends to improve the performance of a CI. That is, the amount of residual hearing before a CI accounts for an appreciable fraction of the variability. Together, young age and residual hearing provide significantly better outcomes, as already discussed in the section on CIs.

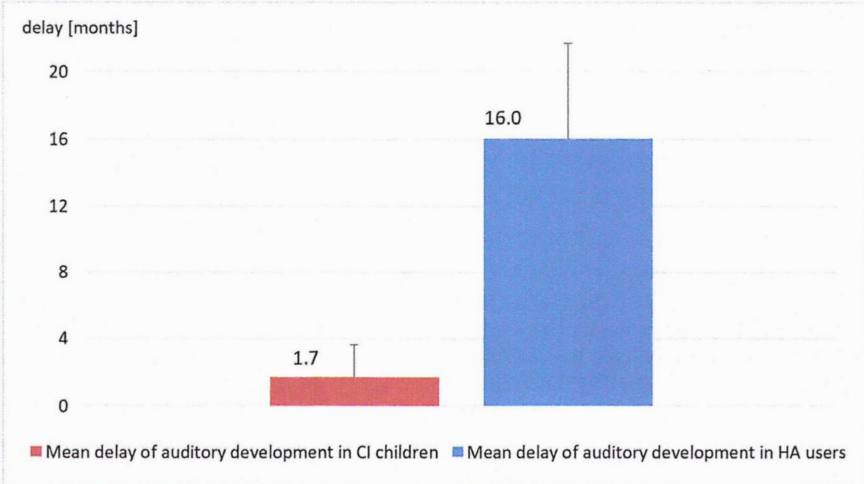


FIGURE 1.5 Mean delay (with standard deviation) of auditory development in a group of cochlear implanted children and a group of comparable hearing aid users.
Source: Adapted from Obrycka et al. (2014b).

However, all previous studies on age at implantation, level of residual hearing, and outcomes have usually been done after a long period of observation, usually in children older than 5 years. Recently, Obrycka et al. (2017) provided support for the validity and reliability of LEAQ to monitor auditory development in very young children with CIs. By applying LEAQ in children younger than 2 years, the authors demonstrated that there were significantly different outcomes between groups of children depending on age at cochlear implantation, duration of HA use before implantation, and the audibility provided by HAs prior to implantation. These results again indicate that children implanted very early (before 12 months of age) develop better than children implanted later (after 12 months of age) and that children who had auditory experience with their HAs before implantation do better than children who did not have such experience.

1.5 CONCLUSIONS

Cochlear implants can provide effective auditory stimulation and enable early auditory development of children with profound hearing loss. Children implanted very early (up to 12 months) develop faster than children implanted between 12 and 24 months of age. Similarly, children with residual hearing before implantation do better than children who did not have the benefits of an HA.

Questionnaires are effective tools for the assessment of early auditory development. A questionnaire can provide a comprehensive assessment of all levels of auditory development: The child's ability to detect, discriminate, and identify sounds. This assessment can be done repeatedly during the first years of hearing rehabilitation.

The LEAQ has demonstrated good normative properties in more than 20 languages and has been validated for the CI pediatric population. LEAQ allows auditory development to be assessed with reference to normal hearing children. LEAQ can be considered a state-of-the-art tool for assessing early auditory development.

MULTIMEDIA ELEMENTS

Readers can access a PowerPoint presentation file showing a methodology for calculating the delay in auditory development. Use arrows keys or the mouse to see the development of the presentation. The material can be accessed using following link: http://www.otoemissions.org/index.php/en/?option=com_content&view=article&id=289.

QUESTIONS

1. Name the three levels of auditory development and link them to a model of general perceptual development.
2. What are the behavioral responses to sounds in infants?

3. What is the concept behind a cochlear implant and describe elements of a cochlear implant system?
4. Who is the best pediatric candidate for cochlear implantation?
5. Describe the characteristics of a good questionnaire.
6. What are the advantages of the LittlEARS Auditory Questionnaire (LEAQ)?

KEYWORDS

- **infants and toddlers**
- **cochlear implant**
- **early implantation**
- **auditory development**
- **questionnaires**
- **validation**

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