Published in final edited form as:

Cochlear Implants Int. 2011 February ; 12(1): 57–59. doi:10.1179/146701010X486543.

How we do it: Employment of listening-development criteria during assessment of infants who use cochlear implants

Brittan A Barker¹, Maura H Kenworthy², and Elizabeth A Walker²

¹Louisiana State University, USA

²University of Iowa, USA

Abstract

There are currently no formal, standardized procedures for assessing speech processing and perception during infancy. This lack of tools makes interpretation of infant data challenging. This article describes how our clinical research center established listening-development criteria for infants with cochlear implants. The listening-development criteria incorporate programming, audiometric, and parent-report measures to estimate adequate audibility of the speech signal prior to the infants' inclusion in research protocols. This paper operationally defines the listening-development criteria, discusses its importance, and presents data from 10 infants who met the listening criteria on average after 6 months of device use.

Keywords

Cochlear implants; Infant; Audibility; Assessment; Speech perception

In 2000, the Food and Drug Administration approved implantation in infants 12-months-old and older. Today many centers are even implanting children as young as 6-months-old (Waltzman and Roland, 2005). However, the field still lacks a complete understanding of programming issues that contribute to the ability to detect and process sound in these very young children. Much of this gap in knowledge is due to the fact that there are currently no formal, standardized procedures for assessing speech processing and perception during infancy. Our clinical research center established listening-development criteria for infants with cochlear implants (CIs) to address this challenge. The listening-development criteria incorporate programming, audiometric, and parent-report measures to estimate adequate audibility of the speech signal prior to inclusion in research protocols evaluating their listening development. These criteria and the method of their employment are described within.

Why is adequate audibility in infants with CIs important?

Adequate audibility of the speech signal is crucial for spoken language learning. Years of research examining speech perception and spoken language development in typically developing infants and children with hearing aids support this notion (e.g. Jusczyk, 1997; Stelmachowicz *et al.*, 2000). There is a dearth of research, however, exploring audibility of the speech signal in children with CIs. This is likely due to the fact that there is currently no

documented method — behavioral or objective — to measure audibility of the implant's electric signal in its user.

Understanding which aspects of the speech signal are audible by the CI user is important. However, it is particularly important for the infant CI user who has limited language skills, and is therefore unable to provide reliable feedback. The literature focusing on people with hearing loss consistently illustrates that audibility of the speech signal affects spoken language perception (Hogan and Turner, 1998), production (Moore and Bass-Ringdahl, 2002), and comprehension (Vermeulen *et al.*, 2007). This appears to hold true across the lifespan from early childhood (Rvachew *et al.*, 1999) to later adulthood (Humes *et al.*, 1994). It stands to reason that audibility would be equally important in infancy when language acquisition begins.

We believe that researchers and clinicians should have an understanding of each infant's access to the speech signal prior to assessing speech perception and spoken language development. Without knowledge of infant CI users' audibility, such assessments will likely be in vain and result in equivocal infant data (Barker and Tomblin, 2004) and an unclear path for aural habilitation. As our center's first step in gaining an understanding of audibility via CIs we established listening-development criteria for infant users. We currently use these criteria to ensure speech audibility in infant CI users prior to the evaluation of their speech perception skills and listening development.

The listening-development criteria

At our clinical research center we currently monitor each infant's listening development using the succeeding listening criteria. Each infant's listening skills are typically assessed during clinical follow-up visits at 1-month- and 2-months-post-initial stimulation and every 2 months thereafter until the infant reaches the listening criteria.

When an infant meets the listening-development criteria, the following standards are satisfied: (1) *a plateau is noted in the infant's MAP* (i.e. the CI's total electrical stimulation settings for each electrode, as programmed by the audiologist). The plateau is operationally defined in accordance with each child's device. This is due to the fact that the input dynamic range differs across the Cochlear Corporation CIs and the Advanced Bionics CIs as a result of manufacturing variation in engineering and programming (Zeng *et al.*, 2002). For Cochlear Corporation devices, the dynamic ranges are typically set between 45 and 65 clinical units. The dynamic range is set in accordance with behaviorally measured threshold levels using a developmentally appropriate method (e.g. visual-response audiometry (VRA)). Loudness levels are also measured when possible using age-appropriate behavioral methods (e.g. pointing to a sad face when the level is 'too loud') or electrophysiologic methods (e.g. Automatic Neural Response Telemetry (AutoNRT), used for measuring action potentials of the auditory nerve.). For Advanced Bionics devices, the most comfortable levels (M-levels) are typically set between 100 and 300 clinical units across the array. Again, for these children we behaviorally measured threshold levels using a developmentally appropriate method (e.g. VRA). The threshold levels for the device are then set at 1/10 of the most comfortable level. The compliance levels for each electrode are noted when setting C-levels (comfort levels as per Cochlear Corporation devices) and M-levels (most comfortable levels as per Advanced Bionic devices), to ensure that these levels are not exceeded. (2) *An aided, soundfield audiogram is measured using developmentally appropriate methods (e.g. VRA or play audiometry) for the infant while using only her CI(s).* Narrow-band noise at 25 and 45 dB HL serves as the stimuli. These intensity levels were chosen for the listening criteria because at these levels the audio signal is adequately audible, while preventing the internal noise of the device itself from being amplified.

Narrow-band noise is used because soundfield testing with pure tones may not accurately reflect true gain to soft sounds in the real world as a result of the automatic-gain control employed by the CI. Thus, narrow-band noise results in more valid and reliable audiometry than pure-tone assessment in children with hearing loss (Sanders and Josey, 1970), particularly those who use CIs.

Satisfying the listening-development criteria

After establishing these criteria we wanted to determine the rate at which infants satisfy these listening-development criteria. We predicted that there would be great variability in the rate at which the infants satisfied the listening-development criteria. This prediction echoes the individual differences that dominated other spoken language perception and production measures across pediatric CI users for the past 20 years (ASHA, 2004).

We looked at the rate of criteria satisfaction in 10 children (7 males) with profound, bilateral sensori-neural hearing loss (SNHL). All the infants were born to hearing parents and were identified as having SNHL within the first year of life. The infants' ages at the time of surgery for placement of their CI devices ranged from 11 to 21 months with an average age at implantation of 15 months ($SD = 2.76$ months). All the infants were followed longitudinally as part of a comprehensive, CI center study. American English was the primary language spoken in each child's home (i.e. English was spoken more than 50% of the time in the infant's listening environment). Infants and toddlers had no known visual abnormalities. The individual profiles are presented in Table 1.

Individual outcomes

Table 1 illustrates the variability in CI experience at which the infants satisfied the listening-development criteria. Note that these infants met the listening criteria on average after 6.4 months of device use ($SD = 2.5$ months).

Discussion

We found that there are vast individual differences in the rate at which it takes an infant to reach the proposed listening criteria. Infants needed as few as 2 months to as many as 10 months of device experience before meeting the listening criteria. These data suggest that although many researchers and clinicians are quick to begin testing infant CI users shortly after initial stimulation (e.g. Houston *et al.*, 2003; Miyamoto *et al.*, 2003), it may be beneficial to require that listening criteria be met prior to assessment. Such criteria are likely to ensure adequate audibility of the speech signal, resulting in more valid measures of infant speech perception.

Secondly, it is possible that adequate speech audibility in these very young children may also contribute to establishing a thoughtful path for aural habilitation. Once the listening criteria are met, clinicians will be assured of accurate measure of baseline listening behaviors. Such accurate measures will in turn guarantee that clinicians invest time in teaching developmentally appropriate listening skills during this valuable sensitive period. In other words, when adequate audibility is reached a clinician will not spend time drilling sound awareness; rather, it would be more appropriate to teach and facilitate auditory discrimination and localization (Estabrooks, 1998).

Finally, the infants' success in completion of our center's infant speech perception assessments suggest that our listening-development criteria seem to be a promising method of assuring that infants with CIs are perceiving and processing the speech signal prior to experimental and clinical assessment. Nonetheless, based on our experience there is still

much more work to be done. In the future it would be useful to utilize objective measures (i.e. electrical stapedial reflex threshold and electrical compound action potential measures) in conjunction with behavioral measures to produce appropriate speech processor MAPs and more accurate listening criteria. It would also be important to examine long-term data on listening criteria to determine the accuracy and stability of these measures in addition to the factors associated with satisfaction.

Acknowledgments

The authors would like to thank Tanya VanVoorst, Greta Stamper, and Kathryn Engelhardt for gathering listening-development criteria data. We would also like to thank all the infants and their families who contributed to these criteria.

References

- ASHA. Technical report. 2004. Cochlear implants.
- Barker BA, Tomblin JB. Bimodal speech perception in infant hearing aid and cochlear implant users. *Archives of Otolaryngology — Head and Neck Surgery*. 2004; 130:82–86.
- Estabrooks, W. Appendix C: Auditory-verbal ages and stages of development. In: Estabrooks, W., editor. *Cochlear Implants for Kids*. Washington, DC: Alexander Graham Bell Association for the Deaf; 1998.
- Hogan CA, Turner CW. High-frequency audibility: benefits for hearing-impaired listeners. *Journal of the Acoustical Society of America*. 1998; 104:432–441. [PubMed: 9670535]
- Houston DM, Pisoni DB, Kirk KI, Ying EA, Miyamoto RT. Speech perception skills of deaf infants following cochlear implantation: A first report. *International Journal of Pediatric Otorhinolaryngology*. 2003; 67:479–495. [PubMed: 12697350]
- Humes LE, Watson BU, Christensen LA, Cokely CG, Halling DC, Lee L. Factors associated with individual differences in clinical measures of speech recognition among the elderly. *Journal of Speech and Hearing Research*. 1994; 37:465–474. [PubMed: 8028328]
- Jusczyk, PW. *Discovery of Spoken Language*. Cambridge, MA: MIT Press; 1997.
- Miyamoto RT, Houston DM, Kirk KI, Perdew AE, Svirsky MA. Language development in deaf infants following cochlear implantation. *Acta Otolaryngologica*. 2003; 123:241–244.
- Moore JA, Bass-Ringdahl S. Role of infant vocal development in candidacy for and efficacy of cochlear implantation. *Annals of Otology, Rhinology and Laryngology*. 2002; 111:52–55.
- Rvachew S, Slawinski EB, Williams M, Green CL. The impact of early onset otitis media on babbling and early language development. *Journal of the Acoustical Society of America*. 1999; 105:467–475. [PubMed: 9921670]
- Sanders JW, Josey AF. Narrow-band noise audiometry for hard-to-test patients. *Journal of Speech, Language, and Hearing Research*. 1970; 13:74–81.
- Stelmachowicz PG, Hoover BM, Lewis DE, Kortekaas RWL, Pittman AL. The relation between stimulus context, speech audibility, and perception for normal-hearing and hearing-impaired children. *Journal of Speech, Language, and Hearing Research*. 2000; 43:902–914.
- Vermeulen AM, van Bon W, Schreuder R, Knoors H, Snik A. Eading comprehension of deaf children with cochlear implants. *Journal of Deaf Studies and Deaf Education*. 2007; 12:283–302. [PubMed: 17537924]
- Waltzman SB, Roland JT. Cochlear implantation in children younger than 12 months. *Pediatrics*. 2005; 116:e487–e493. [PubMed: 16199675]
- Zeng FG, Grant G, Niparko J, Glavin J, Shannon R, Opie J, Segel P. Speech dynamic range and its effect on cochlear implant performance. *Journal of the Acoustical Society of America*. 2002; 111:377–386. [PubMed: 11831811]

Individual, descriptive data of infants with cochlear implants who met the listening-development criteria

Table 1

ID	M/F	Age at IS	CI device type	Strategy	CI ear(s)	CI use at criteria	Freq use
1	M	17	Nucleus freedom	ACE (RE)	AU	8	14
2	M	13	Nucleus freedom	ACE	AU	6	13
3	F	16	Nucleus freedom	ACE	AD	8	14
4	F	16	Nucleus freedom	ACE	AD	10	10
5	F	12	Nucleus freedom	ACE	AU	4	13
6	M	11	Nucleus freedom	ACE	AU	6	16
7	M	13	Nucleus freedom	ACE	AD	6	—
8	M	15	Nucleus freedom	ACE	AU	10	10
9	M	16	Nucleus freedom	ACE	AU	4	12
10	M	21	Nucleus freedom	ACE	AD	2	—

Note: ID = participant identification number; M/F = male or female; age at IS = participants' age at the time of initial stimulation; CI device type = CI device used by the participant; strategy = processing strategy; CI ear(s) = implanted ear or ears; AU = both ears; AD = right ear; CI use at criteria = amount of time for which the participant used his/her CI relative to the time at which the child met the listening criteria (months); freq use = the participant's frequency of CI(s) use as reported by caregiver(s) at 12-months-post-initial stimulation (hours/day); — no information.