Auditory Sensitivity in Children Using the Auditory Steady-State Response

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Objective: To determine the effectiveness of auditory steady-state response (ASSR) as a measure of hearing sensitivity in young children suspect for significant hearing loss.

Design: Within-subject comparisons of click auditory brainstem response (ABR) thresholds and ASSR thresholds.

Subjects: The study population comprised 42 children suspect for hearing loss and subsequently referred for hearing assessment using electrophysiologic techniques.

Main Outcome Measures: Electrophysiologic threshold responses for click ABR and ASSR stimuli (0.5, 1, 2, and 4 kHz) for right and left ears.

Results: Based on ABR and ASSR thresholds, 50% of the subjects demonstrated significant hearing loss in the severe to profound range. In some subjects, ASSRs were present at higher stimulus levels when click ABRs were absent. Significant correlations \( (P < .05) \) were found between high-frequency ASSR and click ABR thresholds for this study sample. For some subjects, ASSR findings suggested differences between ears that were not observable from the no-response click ABR results.

Conclusions: Auditory steady-state response testing may provide additional information for children who demonstrate hearing levels in the severe to profound range. This information may be helpful when selecting the ear for cochlear implantation for a young hearing-impaired child. Multiple objective methods, such as ABR and ASSR testing, may be needed to determine accurate hearing sensitivity for young children being considered for sensory devices, and in particular, cochlear implants.

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With the implementation of universal newborn hearing screening in many states in the United States, increased numbers of children will be identified at birth with hearing loss and subsequently evaluated for hearing aids and/or cochlear implants. Studies confirm the benefits of early intervention in children with hearing loss who have received hearing aids or cochlear implants at younger ages. For young children, early diagnosis of hearing loss and fitting of sensory devices allow access to sound and the potential to develop speech, language, and listening skills needed for oral communication. As children are increasingly younger at the time of cochlear implant evaluation, there is less dependence on speech perception measures and greater reliance on audiometric and electrophysiologic measures for determining pediatric candidacy. Ideally, hearing levels are estimated for individual frequencies that are critical for the perception of speech.

Auditory evoked potentials play an important role in the assessment of hearing for young children. The auditory brainstem response (ABR) test has been the most widely used objective measure in children, since it allows assessment for those who are sleeping or sedated or for newborns. The auditory steady-state response (ASSR) has been suggested as a tool for hearing assessment for children. Auditory steady-state responses are scalp-recorded potentials elicited in response to sinusoidal amplitude and/or frequency-modulated tones. The response is periodic or continuous and phase-locked to the modulation envelope. As with ABR, ASSR can be recorded at low levels in sleeping and sedated subjects, including infants.

Several researchers have reported that ASSRs may be advantageous for the estimation of hearing thresholds for children who have an absent ABR to click
stimuli (eg, at 100 dB nHL [normalized hearing level]). Maximum output levels for clinical ABR systems are 130 dB sound pressure level (SPL) (peak). Normal-hearing subjects have a behavioral threshold for click stimuli at 30 to 36 dB SPL. After correcting for hearing level, the maximum presentation levels for click stimuli are 94 to 100 dB nHL. If a child has hearing loss that exceeds this amount, click stimuli cannot accurately describe the level of hearing sensitivity. Since the stimulus used to record an ASSR is a continuous signal, it is possible to deliver higher average SPL levels compared with those delivered with short-duration click stimuli. This suggests that ASSRs may provide a measure of residual hearing in young cochlear implant candidates by providing estimated thresholds to frequency-specific stimuli presented at high stimulus levels if needed.

Compared with published reports on ABR, there have been fewer systematic studies of ASSR recordings in the young pediatric population. Young children and those with significant hearing loss represent the ultimate challenge for accurate prediction of hearing, subsequent fitting of hearing aids, and appropriate recommendation for cochlear implant candidacy and ear selection. The goal of the present study was to determine the effectiveness of ASSR as a measure of hearing sensitivity in young children suspect for substantial hearing loss.

METHODS

The completed protocol was reviewed and approved by the institutional review board of the Medical College of Wisconsin/Children's Hospital of Wisconsin, Milwaukee. Informed consent was obtained from either the parent or legal guardian of each subject.

SUBJECTS

The study population comprised 42 children, who ranged in age from 1 to 54 months, with an average age of 18 months. Subjects were referred to the Department of Otolaryngology or Audiology at Children's Hospital of Wisconsin for hearing assessment using electrophysiologic techniques. In addition, all subjects had normal middle ear function and no diagnosed secondary handicaps.

ABR STIMULI AND RECORDING

At the time of ABR testing, subjects were either in natural sleep or sedated with chloral hydrate using standard clinical procedures. Surface recording electrodes were applied to the forehead, nape of the neck, and earlobes of both ears. Responses were recorded with a Nicolet Spirit diagnostic system (NicoletBiomedical Inc, Madison, Wis). Monaural rarefaction click stimuli were delivered via insert earphones and were 100 microseconds in duration presented at a rate of 31 Hz, with a maximum presentation level of 102 dB hearing level (HL). The raw electroencephalographic signal was amplified and bandpass filtered with cutoff frequencies of 100 and 3000 Hz (Butterworth filter, 12 dB/octave). Recording of neural activity included 2 or 3 replications of 1000 sweeps using a 15-millisecond window. Auditory brainstem response wave V thresholds were determined using visual detection methods, and typical amplitudes at threshold were 0.08 to 0.11 µV. The time to obtain thresholds in both ears with click stimuli was approximately 10 minutes.

ASSR STIMULI AND RECORDING

On completion of the standard clinical ABR test protocol, the recording electrode leads were connected to the Evoked Response Audiometer (ERA Systems Ltd, Melbourne, Australia) amplifier and the insert earphones used with the Evoked Response Audiometer unit were placed. At this time, the evoked-potential recordings were obtained with a steady-state stimulus. Figure 1 shows an example of the time waveform and frequency spectrum for a steady-state stimulus, as well as a hypothetical vector response. From the time domain (Figure 1A), the carrier frequency of 1000 Hz can be seen within the 100-Hz modulation frequency. The major energy of the carrier and 2 sidebands are easily visualized in the frequency spectrum (Figure 1B). The vector response display (Figure 1C) shows the phase relationship between the stimulus and response for each sample in a trial. The angle of the vector represents the phase relationship between the stimulus and response, whereas the length of the vector reflects the response amplitude.

The ASSR test stimuli consisted of 4 tones (carrier frequencies) at 500, 1000, 2000, and 4000 Hz that were amplitude (100%) and frequency (10%) modulated at a rate of 74, 81, 88, and 95 Hz, respectively. Maximum presentation levels were 124, 128, 125, and 123 dB HL for the frequencies 500, 1000, 2000, and 4000 Hz, respectively. The ASSR thresholds

Figure 1. Time waveform (A) and frequency spectrum (B) for a steady-state stimulus with a carrier frequency of 1000 Hz and a modulation frequency of 100 Hz. The vector plot (C) is an example of the displayed response to a steady-state stimulus.
were determined with automatic algorithms that are based on phase coherence statistics with a maximum of 64 samples. The time to obtain ASSR thresholds for both ears at 1 frequency was approximately 10 minutes.

**RESULTS**

**Figure 2** shows the comparison between the presence and absence of responses to click and steady-state stimuli (n=80 tested ears). Within each bar, the dark portion represents the number of tested ears with responses present at 2 or more steady-state frequencies (0.5, 1, 2, and 4 kHz); the gray portion represents tested ears with responses at 1 steady-state frequency.

**Figure 3** displays the distribution of response thresholds for 76 of 80 tested ears for click ABR and high-frequency ASSR, which was defined as the threshold for 2 kHz, 4 kHz, or their average when both frequencies were tested. The electrophysiologic threshold ranges for each category reflect typical audiometric ranges for click ABR thresholds before behavioral corrections are applied. Based on click ABR and ASSR thresholds, a large number of children (50%) demonstrated significant hearing loss in the severe to profound range.

In **Figure 4**, the relationship between click auditory brainstem response (ABR) threshold and auditory steady-state response (ASSR) thresholds for 2 kHz (A), 4 kHz (B), and the average of the 2 frequencies (C). Correlations were significant at $P<.05$. The gray boundaries indicate the stimulus-level limits dictated by the equipment used for ABR and ASSR. The linear regression analysis excludes the absent ABR and ASSR data points (top gray area) in each panel. HL indicates hearing level.
at either 2 kHz (Figure 4A), 4 kHz (Figure 4B), or the average of 2 and 4 kHz (Figure 4C) for all tested subjects. There is a significant correlation (P<.05) between high-frequency ASSR and click ABR thresholds for this sample.

The Table displays ASSR thresholds for 10 subjects who had absent ABR in both ears but present ASSR in either the right and/or left ear. The data indicate that in some instances (subjects 6, 7, 11, and 15), differences in auditory thresholds between ears exist. These differences were not observable from the click ABR measures. This information may be useful when selecting which ear will receive a cochlear implant for a young hearing-impaired child. In this study, 16 (38%) of 42 subjects who were evaluated using ASSR and ABR measures were subsequently determined to be cochlear implant candidates and successfully received implants.

### Table

<table>
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<tr>
<th>Subject No.</th>
<th>Right Ear</th>
<th>Left Ear</th>
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<tbody>
<tr>
<td></td>
<td>0.5 kHz</td>
<td>1 kHz</td>
</tr>
<tr>
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<td>128</td>
</tr>
<tr>
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</table>

Abbreviations: ABR, auditory brainstem response; ASSR, auditory steady-state response; HL, hearing level; NR, no response; ellipsis, did not test.

In summary, ASSR thresholds were present in some subjects at higher stimulus levels when click ABR thresholds were absent. There was a strong correlation between click ABR and ASSR thresholds for 2 kHz, 4 kHz, and their average for this study sample. Auditory steady-state response testing may provide additional information for children who demonstrate hearing levels in the severe to profound range, representing those who could be evaluated for cochlear implantation. In addition, ASSR testing may assist in the detection of ear differences that are not evident when there is a no-response ABR test result for both ears.

Based on these findings, both ABR and ASSR techniques may be used to provide an estimate of hearing sensitivity in children. It is suggested, however, that if a child has a no-response ABR, additional electrophysiologic testing be conducted to acquire a more complete assessment of the child’s hearing. A combination of ABR and ASSR thresholds complements the evaluation of auditory sensitivity. As the age of identification of hearing loss is reduced, the need for accurate objective electrophysiologic methods for determining auditory thresholds is increased, and this need may be served by multiple objective methods. For young children, ASSR thresholds may provide critical information for accurate hearing aid settings and potentially could assist to separate frequencies with thresholds in the severe vs profound hearing loss range. Identifying children early with accurate hearing assessment leads to earlier fitting of sensory devices, including cochlear implants, which minimizes delays in auditory, speech, and language development. Finally, continued research is needed to better understand ASSR with respect to stimulus level, frequency specificity, and degree of hearing loss, which will assist in the refinement of guidelines for clinical application.

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This study was presented at the Ninth Symposium on Cochlear Implants in Children, April 24, 2003, Washington, DC.

We acknowledge the following individuals for assistance with data collection: Ryan Gregg, AuD, Amy Hartman, MA, Julie Gobler, MA, and Wendy Dwigans, MS.

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### Comment

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