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The Electrically-Evoked Cortical Auditory Event-Related Potential in Children with Auditory Brainstem Implants

Shuman He, MD, PhD[1], **F.B. Teagle Holly, AuD**[1], **Matthew Ewend, MD, FACS**[2], **Lillian Henderson, MA**[1], and **Craig A. Buchman, MD**[1]

[1]Department Otolaryngology – Head and Neck Surgery, The University of North Carolina at Chapel Hill, Chapel Hill, North Carolina

[2]Department of Neurosurgery, The University of North Carolina at Chapel Hill, Chapel Hill, North Carolina

Abstract

Objective—This study explored the feasibility of measuring electrically-evoked cortical auditory event-related potentials (eERPs) in children with auditory brainstem implants (ABIs).

Design—Five children with unilateral ABIs ranging in age from2.8 to 10.2yrs (mean: 5.2yrs) participated in this study. The stimulus was a 100-ms biphasic pulse train that was delivered to individual electrodes in a monopolar stimulation mode. Electrophysiological recordings of the onset eERP were conducted in all subjects.

Results—The onset eERP was recorded in four subjects who demonstrated auditory perception. These eERP responses showed variations in waveform morphology across subjects and stimulating electrode locations. No eERPs were observed in one subject who received no auditory sensation from ABI stimulation.

Conclusions—eERPs can be recorded in children with ABIs who develop auditory perception. The morphology of the eERP can vary across subjects and also across stimulating electrode locations within subjects.

Keywords

Auditory brainstem implant; electrically-evoked cortical auditory event-related potentials

INTRODUCTION

The auditory brainstem implant (ABI) by passes the cochlea and the auditory nerve and directly stimulates the cochlear nucleus in the auditory brainstem. It has been recently used to establish auditory sensation in patients who have either absent or abnormally small auditory nerves (Choi et al., 2011; Colletti et al., 2001; 2002; 2004; 2005; 2009; Colletti &

Correspondence: Shuman He, MD, PhD, G190 Physicians Office Building, 170 Manning Drive, Dept. Otolaryngology – Head and Neck Surgery, University of North Carolina at Chapel Hill, Chapel Hill, NC 27599-7600, Phone: 919-419-1449, Fax: 919-419-1399, shuman_he@med.unc.edu.

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Shannon, 2005; Nevison et al., 2002; Sennaroglu et al., 2009). The most important step in the programming process of the ABI is to determine which electrode(s) need to be deactivated due to non-auditory sensation. The electrically-evoked auditory brainstem response (eABR) has been previously used to determine which electrodes to activate and to assist in the programming process in patients with ABIs (Colletti et al., 2001, 2002, 2004a, 2004b, 2005; Goffi-Gomez et al., 2012; O'Driscoll et al., 2011a, 2011b). However, recent studies have shown that the presence of the eABR did not guarantee auditory sensation (Goffi-Gomez et al., 2012; O'Driscoll et al., 2011b). For some patients with ABIs, some electrodes need to be deactivated over time due to increases in non-auditory sensation even though robust eABRs were initially recorded from these electrodes (Nevison et al., 2002; Goffi-Gomez et al., 2012). These results suggest that the eABR may not be an optimal indicator for determining which electrodes should be active in program settings for patients with ABIs. Compared with the eABR, the electrically-evoked cortical auditory event-related potential (eERP) reflects auditory processing at a central rather than peripheral level (Näätänen and Picton, 1987). One particular advantage the eERP has over the eABR is that it can be evoked using the same stimuli as those used for behavioral measures. In addition, it has been shown that eERPs recorded from cochlear implant (CI) electrodes that produce non-auditory sensation show different mophological characteristics compared with those evoked by true auditory stimulation (He et al., 2012). Therefore, the eERP holds great promise for being used as an objective tool to assist in the programming process in patients with ABIs. However, methods for collecting and measuring eERPs haven ever been reported in patients with ABIs. This brief report demonstrates the feasibility of measuring eERPs in children with ABIs.

METHODS

Subjects

Five pre-lingually deaf child subjects (S1 – S5) participated in this study. All subjects were unilaterally implanted with the Cochlear Nucleus 24 ABI and had at least one month of ABI use prior to participating in the study. Robust electrically-evoked intra-operative eABRs were recorded from electrodes tested in this study for S2, S4 and S5. Initially, eABRs were recorded at two electrodesin S3 but responses could not be replicated two weeks later. The presence/absence of the intra-operative eABR in S1 is unknown since he was implanted at another center abroad. All subjects except for S3 demonstrated reliable responses to auditory stimulation with their ABI devices. Detailed demographic information of these subjects is listed in Table 1. Their averaged hearing thresholds with the ABI of 500, 1k and 2k Hz at the time of testing are also listed in Table 1. All subjects and/or their legal guardians provided written informed consent to the procedures as approved by the local Biomedical Institutional Review Board.

Procedures

Stimuli—Stimuli were created using custom-designed software incorporating NIC (version 2) programming routines. The speech processor was by passed and electrical stimulation was directly delivered to individual electrodes at pulse widths and pulse rates selected for individual subjects based on values from the speech processor MAP in use at the time. The

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stimulus was a 100-ms train of biphasic pulses with an inter-stimulation interval of 800 ms delivered in the monopolar stimulation mode (MP1+2). The stimulus was presented at the maximum comfortable level that was measured for each testing electrode and each subject.

eERP recordings—Electroencephalographic (EEG) activity was recorded using a Neuroscan system (version 4.4) and a SynAmp^2 amplifier. EEG was recorded differentially between electrodes positioned at the vertex (Cz) and the contralateral mastoid. A ground electrode was placed on the low forehead (Fpz). Eye-blink activity was monitored using a pair of electrodes placed above and below the eye that was contralateral to the stimulating ear. Electrode impedances were maintained below 5000 Ohms with an inter-electrode impedance difference of less than 2000 Ohms. The recording window included a 100 ms pre-stimulus baseline and a 700 ms post-stimulus time. The EEG was sampled at a rate of 1000 Hz, amplified (×10 gain), and analog filtered on-line between 0.1 and 100 Hz (12 dB/octave slope). The artifact rejection threshold was 100 μV. After eye-blink rejection, at least 100 artifact-free sweeps were averaged and at least three averaged responses were recorded from each stimulating electrode in each subject except for S1. In S1, two replications of 100 artifact-free sweeps were recorded at electrodes 13 and 15 due to time constraint. Responses were then baseline corrected, digitally filtered between 1–30 Hz (12 dB/octave) offline before response analysis. The neural response was determined to be present only if all replications recorded for the same stimulation condition were repeatable. Response peaks were identified and latencies were measured by one experienced auditory electrophysiologist (author SH). All peaks in this study are described in terms of latency. For example, P50 refers to a positive peak occurring 50 ms after stimulus onset.

RESULTS

Neural responses were not observedinS3 who received no auditory sensation from ABI stimulation. Responses recorded in the other four subjects were robust with good repeatability. These responses showed two types of morphology. One type of neural response is largely dominated by a single vertex-positive peak occurring between approximately 40ms and 100 ms after stimulus onset. This type of neural response was referred to as a Type I response in this study. They were recorded at electrodes 13 and 15 in S1, at electrodes 14–16, 18–19 and 21 in S2, and at electrodes 2–8 in S4. Figure 1 shows exemplary Type I responses recorded in these three subjects.

The other type of neural response consisted of multiple vertex-positive peaks occurring within a time window of 25–700 ms after stimulus onset. This type of neural response was referred to as a Type II response in this study. They were recorded at electrode 21 in S1, electrodes 17 and 22 in S2, and at electrodes 15, 18 and 22 in S5. Figure 2 shows exemplary Type II responses recorded in S1, S2and S5. Traces recorded in S4 contain contaminations of electrical stimulus artifact at the beginning of responses. Compared to responses shown in Figure 1, these responses tend to have larger amplitudes.

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DISCUSSION

Overall, these preliminary results demonstrate the feasibility of measuring eERPs in children with ABIs. Two types of neural responses were recorded in this study: responses dominated by as ingle vertex-positive peak (Type I) and those dominated by multiple vertex positive peaks (Type II). In general, the Type II response tended to be larger in amplitude than the Type I response. There was no consistent trend in terms of which waveform morphology was recorded for individual subjects or electrode locations. Responses recorded at different electrode locations in the same subject could show different types of waveform morphology.

O'Driscoll et al. (2011b) reported that morphology of the eABR recorded in patients with ABIs can vary from one to four vertex-positive peaks. They also observed variations in waveform morphology across subjects and also across electrode locations within individual subjects, which is consistent with results of this study.

It should be pointed out that the Type I response observed in this study was similar to the "multiphasic responses" reported in children with CIs (Gordon et al., 2011; Sharma et al., 2009). This type of response probably reflects auditory activity-dependent maturation in the auditory cortex (Gordon et al., 2011). To date, the source of the Type II response remains to be determined. eERPs recorded in one CI user with cochlear nerve deficiencies (CNDs) in He et al. (2012) demonstrate some characteristics that are similar to the Type II response recorded in this study. This subject also reported a non-auditory "feeling" when Type II-like responses were recorded. In this study, S1reported auditory sensation when electrodes 13 and 15 were stimulated and a tingling sensation around the neck in addition to auditory sensation when electrode 21 was stimulated. These results suggest the possibility that responses evoked by auditory stimulation might have different morphology from those elicited by non-auditory stimulation. Due to their young ages, subjects S2 and S5 were not able to distinguish between auditory and somatosensory stimulation. Therefore, it remains unknown whether they heard or felt the stimulation when these Type II responses were recorded. Further studies are warranted to investigate neural generators for these two types of eERPs and to understand the utility of this technology in optimizing performance among this challenging population of patients.

CONCLUSIONS

eERPs could be recorded in pediatric patients with ABIs who developed reliable responses to auditory stimulation. Variations in waveform morphology exist across listeners and among stimulating electrode locations.

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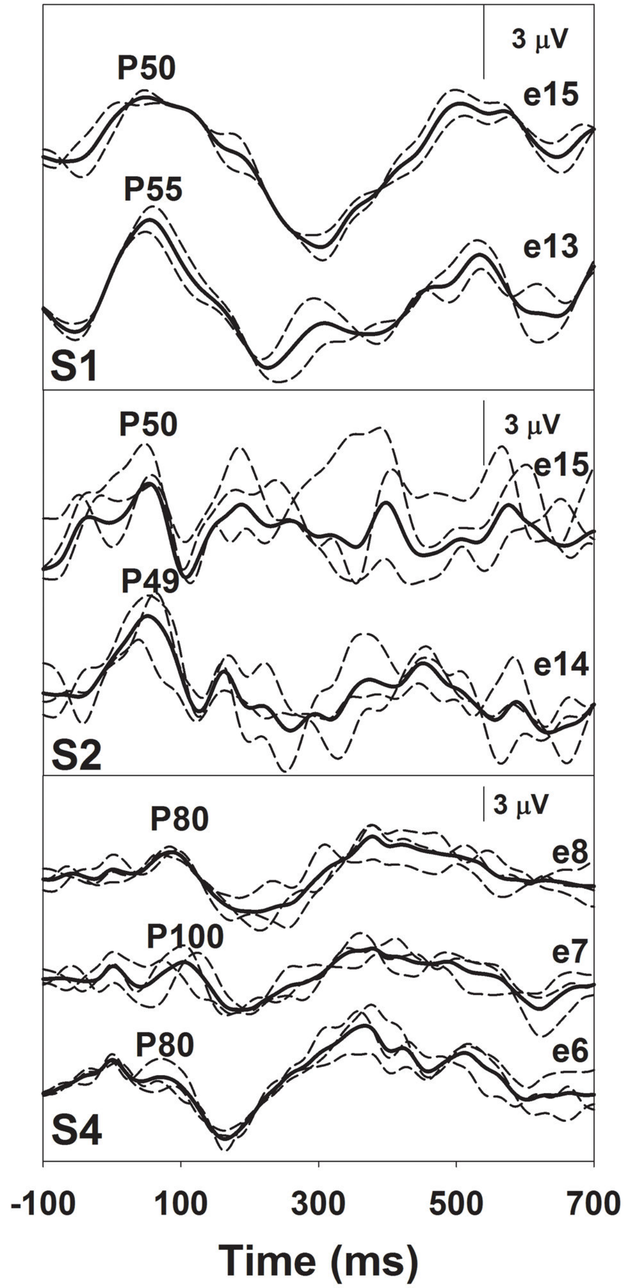

Figure 1.

The Type I eERP recorded in subjects S1, S2 and S4. Black dashed lines represent averaged response of 100 artifact free epochs and black lines represent averaged response of all replicates measured from the same electrode. Identifiable peaks and stimulating electrodes used to elicit these responses are labeled for these traces. Peaks are labeled by their latencies. Subject numbers are indicated in the bottom left corner.

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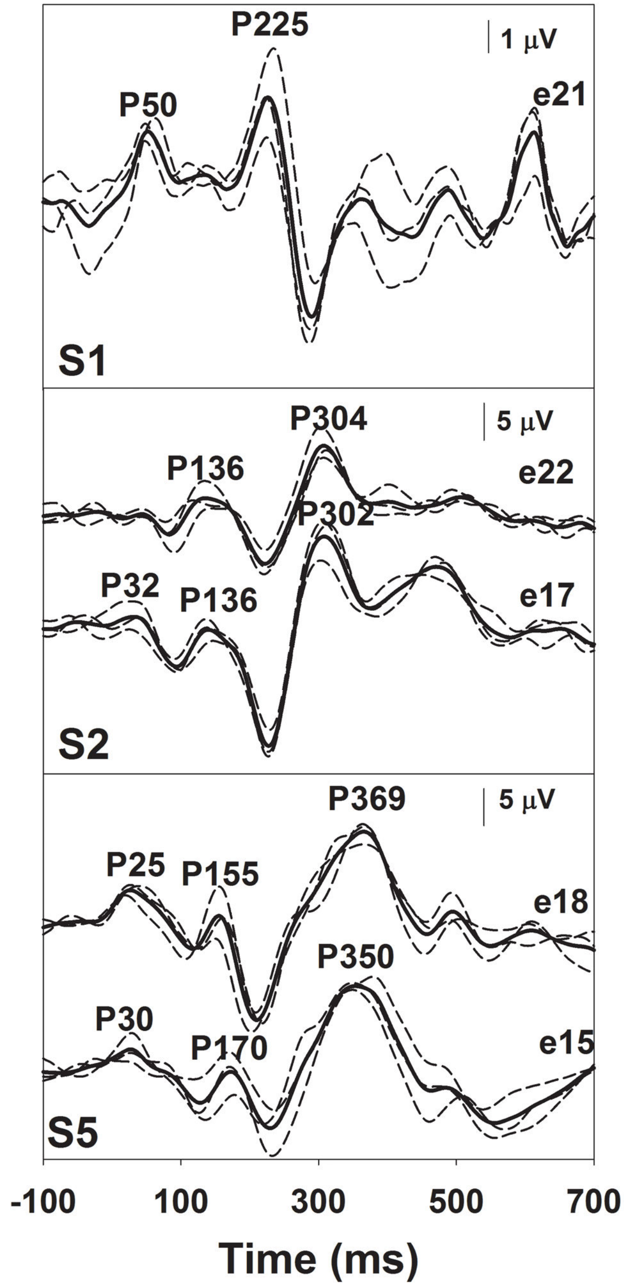

Figure 2.

Type II responses recorded in subjects S1, S2 and S5. Black dashed lines represent averaged response of 100 artifact free epochs and black lines represent averaged response of all replicates measured from the same electrode. Identifiable peaks and stimulating electrodes used to elicit these responses are labeled for these traces. Peaks are labeled by their latencies. Subject numbers are indicated in the lower left corner.

Table 1

Participant demographic information. For all subjects, the pulse rate used in their MAPs and also in this study was 250 pulses per second per channel.

Subject number	Gender	Etiology	Status of the auditory nerve	Age at implantation (yr)	Ear tested	Age at testing (yr)	Number of active electrodes in the programming MAP	Primary communication mode	Electrode tested in this study	Pulse width (µs/phase)	3 FAHT (dB HL)
S1	M	Goldenhar Syndrome	CND	3.3	R	10.2	17	Spoken Language/Signed English	13, 15, 21	100–150	28.33
S2	M	CHARGE syndrome	CND	3.3	L	3.8	9	Cued Speech	14–19, 21, 22	100–150	26.67
S3	F	Unknown	Absent	2.6	L	2.8	12	Total Communication	11–22	400	NR
S4	M	CHARGE syndrome	CND	3.5	R	3.8	7	Signed English	2–8	100	46.67
S5	F	Unknown	CND	5.6	R	5.8	14	Signed English	15, 18, 22	100–150	40

CND: cochlear nerve deficiency.

NR: no response

3-FAHT: 3-frequency averaged hearing threshold with the ABI

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