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Dynamics of infant cortical auditory evoked potentials (CAEPs) for tone and speech tokens

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ABSTRACT

Objectives: Cortical auditory evoked potentials (CAEPs) to tones and speech sounds were obtained in infants to: (1) further knowledge of auditory development above the level of the brainstem during the first year of life; (2) establish CAEP input–output functions for tonal and speech stimuli as a function of stimulus level and (3) elaborate the data-base that establishes CAEP in infants tested while awake using clinically relevant stimuli, thus providing methodology that would have translation to pediatric audiological assessment. Hypotheses concerning CAEP development were that the latency and amplitude input–output functions would reflect immaturity in encoding stimulus level.

In a second experiment, infants were tested with the same stimuli used to evoke the CAEPs. Thresholds for these stimuli were determined using observer-based psychophysical techniques. The hypothesis was that the behavioral thresholds would be correlated with CAEP input–output functions because of shared cortical response areas known to be active in sound detection.

Design: 36 infants, between the ages of 4 and 12 months (mean = 8 months, s.d. = 1.8 months) and 9 young adults (mean age 21 years) with normal hearing were tested. First, CAEPs amplitude and latency input–output functions were obtained for 4 tone bursts and 7 speech tokens. The tone bursts stimuli were 50 ms tokens of pure tones at 0.5, 1.0, 2.0 and 4.0 kHz. The speech sound tokens, /a/, /i/, /o/, /u/, /m/, /s/, and /ʃ/, were created from natural speech samples and were also 50 ms in duration. CAEPs were obtained for tone burst and speech token stimuli at 10 dB level decrements in descending order from 70 dB SPL. All CAEP tests were completed while the infants were awake and engaged in quiet play.

For the second experiment, observer-based psychophysical methods were used to establish perceptual threshold for the same speech sound and tone tokens.

Results: Infant CAEP component latencies were prolonged by 100–150 ms in comparison to adults. CAEP latency-intensity input output functions were steeper in infants compared to adults. CAEP amplitude growth functions with respect to stimulus SPL are adult-like at this age, particularly for the earliest component, P1–N1.

Infant perceptual thresholds were elevated with respect to those found in adults. Furthermore, perceptual thresholds were higher, on average, than levels at which CAEPs could be obtained. When CAEP amplitudes were plotted with respect to perceptual threshold (dB SL), the infant CAEP amplitude growth slopes were steeper than in adults.

Conclusions: Although CAEP latencies indicate immaturity in neural transmission at the level of the cortex, amplitude growth with respect to stimulus SPL is adult-like at this age, particularly for the earliest component, P1–N1. The latency and amplitude input–output functions may provide additional information as to how infants perceive stimulus level. The reasons for the discrepancy between electrophysiologic and perceptual threshold may be due to immaturity in perceptual temporal resolution abilities and the broad-band listening strategy employed by infants.

The findings from the current study can be translated to the clinical setting. It is possible to use tonal or speech sound tokens to evoke CAEPs in an awake, passively alert infant, and thus determine whether these sounds activate the auditory cortex. This could be beneficial in the verification of hearing aid or cochlear implant benefit.

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1. Introduction

During the past 35 years, much knowledge of infant auditory system development and capacity has been obtained from the auditory brainstem responses (ABR). ABR absolute and interpeak latencies of components Wave I–V reflect increased capacity for neural synchrony and temporal processing that follows the time-course for brainstem myelination over the first 18 months of life [1]. ABR thresholds for clicks and tone bursts suggest that adult-like sensitivity is obtained during the first year of life, at least in the mid-high frequencies, well before perceptual thresholds approximate adult levels [2].

Much less is known about the how cortical auditory evoked potentials (CAEPs) may reflect aspects of perceptual development in infants. One hypothesis is that perceptual thresholds are dependent upon maturation at more rostral levels of the auditory system, particularly the auditory cortex. By testing CAEPs in awake, alert infants, we aimed to show that these evoked potentials could be used as a metric of physiological development in the same way that ABRs are used at the level of the brainstem. That is, the motivation was to use CAEP to understand underlying physiological processes and the neural substrates of perception.

Wunderlich and Cone-Wesson [3] provided a comprehensive review of the development of CAEP in early infancy summarizing the immaturities of CAEP recorded in infants and children compared to responses obtained from adults. At term, and in the early months of life, the typical CAEP waveform recorded in the midline has as its most prominent features a broad positive peak, P2, followed by a broad negative trough, N2. Earlier peaks, P1 and N1 may sometimes be seen but are much less frequently evoked [4–9] and, when present, are small relative to P2 and N2. In the newborn period P2 has a peak latency around 200–250 ms and N2 around 300–550 ms [10–13]. The source of the P2 CAEP component in newborn infants has been localized to the temporal lobe in or near the auditory areas [14]. Developmental changes during the first year 3 years of life include decreasing response latencies and greater prominence of later components [10,15]. The peak latencies of P2 and N2 recorded at the vertex in sleeping infants have generally been found to decrease with age, most markedly over the first months of life. When tested in awake infants, CAEP peak latencies do not necessarily show the same developmental trend although the waveforms have similar morphology to those in sleeping infants. The latency of P2 becomes less variable with age over the first 4 months of life [16].

Clicks and tones have been used to evoke CAEP in infants but there are few systematic studies of stimulus effects in this age group. One exception is the research by Wunderlich et al. [28] who investigated the effect of frequency on the CAEP in infants and young children. They found that 400 Hz tones evoked larger amplitude CAEP than did tones at 3000 Hz. To date, there has been no systematic study of infant CAEP latency and amplitude as a function of stimulus level, nor are there studies that have sought to relate the CAEP latencies and amplitudes to how infants perceive the same stimulus.

Speech sounds have also been used to evoke CAEPs in young infants [17]. Kurtzberg et al. [17] found topographical differences in the CAEP of newborns that reflected frequency based differences in the place of articulation of consonants (/da/ vs. /ba/) and morphological differences that reflected voice onset time (/ta/ vs. /da/ and /ba/). Novak et al. [18] recorded CAEPs to formants extracted from synthesized CV syllables but found no systematic effect of formant center frequency on the responses recorded during the first 6 months of life. Wunderlich et al. [28] also used speech tokens to evoke CAEP in infants and young children. In newborns, the speech tokens evoked a much larger amplitude response than did tones, but this finding was not consistent in older infants or children. In these previous studies, the speech tokens were presented at one level, known to be above threshold and to approximate a conversational level, that is, 50–60 dB HL. There were no attempts to determine how stimulus level would affect CAEP latencies and amplitudes.

Despite the paucity of research on stimulus effects on infant CAEPs, these evoked responses have been used in clinical research to evaluate neurological integrity and to estimate hearing loss in infants since the 1960s [7,19]. Although the use of CAEP use for audiometric purposes was largely eclipsed by the ABR during the past 30 years, some recent clinical research results have re-invigorated their relevance. Sharma et al. [23,24] have demonstrated that CAEPs indicate cortical plasticity and development brought on by the use of cochlear implants. Their studies indicate that CAEP latency change in the first months of implant use can be used as a "biomarker" of expected auditory maturation or plasticity following electrical stimulation of the auditory nerve. They have also shown, furthermore, that those implanted after 7 years of age do not demonstrate the CAEP latency shifts to age-appropriate values, despite long periods of electrical stimulation with cochlear implant use. These findings are correlated with attenuated speech perception benefits from implantation in comparison to those who are implanted before 3.5 years of age.

Another clinically relevant study was completed by Rance et al. [22]. They tested for CAEPs in a group of infants and young children diagnosed with auditory neuropathy spectrum disorder (ANSD) and an age-matched group of children with sensorineural hearing loss (SNHL). Rance et al. found that CAEPs for tones and speech tokens were present in over 85% of those with SNHL, but for only 60% of those with ANSD. Whereas absence of CAEPs in the SNHL group could be accounted for on the basis of severity of loss and stimulus output limits, this was not the case for those with ANSD. That is, CAEP presence/absence in response to a suprathreshold stimulus was not related to the severity of the pure tone hearing loss, nor was it attributable to age. There was a strong positive correlation between the presence of CAEP and the child's speech perception abilities. These findings suggested that CAEP could be used clinically as a prognostic measure in infants and young children with ANSD.

More recently, the use of CAEPs in the verification of hearing aid fittings in infants has also been suggested as a clinical application [20]. To this end, Golding et al. [21] obtained CAEPs in response to brief speech sound tokens in infants with hearing loss. The infants were tested in sound field with and without their hearing aids. The presence of a CAEP indicated that the hearing aids provided enough gain to evoke a response to speech sound tokens presented at a conversational level. The CAEP findings were positively correlated with responses to a parent questionnaire regarding functional hearing abilities demonstrated by infants when using their amplification.

Although Rance et al. [22], Sharma et al. [23], Sharma et al. [24] and Golding et al. [21] correlated their CAEP results with behavioral indicators of auditory function, the routine use of CAEP in pediatric audiology is limited by lack of information about CAEP stimulus dependencies in this age group. The effect of stimulus level on CAEP has not been systematically investigated in infants. Whereas otoacoustic emissions reflect mature cochlear function in the newborn period [46] and ABR thresholds and latency-intensity functions are adult-like by 6 months of age, in contrast, CAEP latencies for stimuli presented at normal speech levels (~50–60 dB HL) indicate immaturity into early childhood [3]. Immaturity in CAEP latency and scalp topography suggested that there could be developmental-dependencies in the encoding of stimulus level at the level of the cortex that would ultimately affect perceptual detection thresholds.