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Sensitivity of offset and onset cortical auditory evoked potentials to signals in noise

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HIGHLIGHTS

- The cortical auditory evoked offset response shows sensitivity to signal level changes in noise, whereas the cortical auditory evoked onset response does not.
- The N2 wave in the offset response was particularly pronounced, and was the clearest indicator of offset response magnitude.
- Rectified area amplitudes computed over the range of the offset response captured the same main effects as peak measures.

ABSTRACT

Objective: The purpose of this study was to determine the effects of SNR and signal level on the offset response of the cortical auditory evoked potential (CAEP). Successful listening often depends on how well the auditory system can extract target signals from competing background noise. Both signal onsets and offsets are encoded neurally and contribute to successful listening in noise. Neural onset responses to signals in noise demonstrate a strong sensitivity to signal-to-noise ratio (SNR) rather than signal level; however, the sensitivity of neural offset responses to these cues is not known.
Methods: We analyzed the offset response from two previously published datasets for which only the onset response was reported. For both datasets, CAEPs were recorded from young normal-hearing adults in response to a 1000-Hz tone. For the first dataset, tones were presented at seven different signal levels without background noise, while the second dataset varied both signal level and SNR.
Results: Offset responses demonstrated sensitivity to absolute signal level in quiet, SNR, and to absolute signal level in noise.
Conclusions: Offset sensitivity to signal level when presented in noise contrasts with previously published onset results.
Significance: This sensitivity suggests a potential clinical measure of cortical encoding of signal level in noise.

1. Introduction

Successful perception of target auditory signals in a noisy or complex auditory scene depends on a number of factors, including the successful neural encoding of the signal in the auditory cortex. This encoding can be measured with scalp-recorded cortical auditory evoked potentials (CAEPs), a subset of electroencephalography (EEG) recordings, which can occur in response to both the onset and the offset of the stimulus. It has been suggested that the neural populations responsible for these two responses differ in important ways (Takahashi et al., 2004), and it is possible that they differ in their response to signals in noise. While the onset response has been used as a cortical measure of signal encoding in noise, the offset response has not. In this study we examine the effects of signal level and signal-to-noise ratio (SNR) on the offset response using two previously published onset datasets (Billings et al., 2007, 2009).

The extent to which the auditory evoked offset response differs from the auditory evoked onset response has been a central motivating question in the far-field study of offsets. Many of these studies have focused on shared physiological resources, and while

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many have suggested that the populations responsible for these two responses are the same or strongly overlapping (Hillyard and Picton, 1978; Hari et al., 1987; Joutsiniemi et al., 1989; Pantev et al., 1996), others have demonstrated significant differences (Noda et al., 1998; Wakai et al., 2007). Furthermore, near-field studies support the suggestion that different populations with different functional properties may be responsible for portions of the onset and offset responses. In general, onset units are far more prevalent than offset units and tend to be more tonotopically organized (Abeles and Goldstein, 1972; Phillips and Hall, 1990; He et al., 1997; Galazyuk and Feng, 1997; Recanzone, 2000; Phillips et al., 2002). It has been proposed that the offset response represents a rebound from inhibition, such that greater inhibition results in a larger offset response as inhibition is released (Henry, 1985b; Henry and Lewis, 1988; Phillips et al., 2002; Takahashi et al., 2004). However, other studies have shown that offset responses can occur in the absence of onset-evoked inhibition, and have suggested that different sets of synaptic inputs are contributing to the different responses (Qin et al., 2007; Scholl et al., 2010).

A number of near-field studies examining the onset response have demonstrated robust sensitivity to SNR rather than absolute signal level when signals were presented in noise (Phillips, 1985; Phillips and Cynader, 1985; Phillips and Hall, 1986; Phillips and Kelly, 1992). Far-field evoked potential studies have investigated the effects of background noise on the onset response and have found similar effects, highlighting the encoding of SNR rather than absolute signal level when both cues are available (Burkard and Hecox, 1983; Burkard et al., 1997; Whiting et al., 1998; Kaplan-Neeman et al., 2006). Addressing this question directly, Billings et al. (2009) varied SNR for tonal stimuli at two different signal levels, and found that SNR and not absolute signal level had a significant effect on CAEP latency and amplitude. This sensitivity to SNR rather than signal level holds true for natural speech signals as well (Billings et al., in press). In quiet however, previous studies have demonstrated robust effects of signal level (Adler and Adler, 1989; Billings et al., 2007). Psychophysical studies have demonstrated effects of both SNR and absolute signal level for signals presented in noise (Hawkins and Stevens, 1950; Dirks et al., 1982; Studebaker et al., 1999; Hornsby et al., 2005). These findings suggest that absolute signal level is a behaviorally relevant cue even in the presence of background noise. It is therefore unclear why onsets do not appear to encode absolute signal level in noise. The goal of the present study was to determine whether the offset response shows a similar sensitivity to SNR and absolute signal level cues as the onset response.

Cortical auditory evoked potentials (CAEPs) were used to determine the effects of SNR and signal level on offset responses. Our goal was to analyze the offset response and compare it to the onset response in two previously published datasets (Billings et al., 2007, 2009), and to investigate the extent to which effects of SNR and signal level differ between the two responses.

2. Methods

2.1. Experimental conditions

Subject, stimulus, and recording procedures are described respectively in Billings et al. (2007) and Billings et al. (2009), and are summarized in Table 1. Briefly, Billings et al. (2007) presented 757 ms 1000-Hz pure tones (rise/fall time: 7.57 ms) at seven different intensity levels (30, 40, 50, 60, 70, 80, & 90 dB). Billings et al. (2009) used the same tone stimulus at two different signal levels (60 & 75 dB), but introduced continuous background noise at five different SNRs (20, 10, 0, −5, & −10 dB SNR) as well as testing in quiet. For all conditions in both studies, 400 trials were presented with an inter-stimulus interval (ISI; onset to offset) of 1910 ms using Neuroscan Stim2 and Scan systems (Charlotte, NC). All recordings were made while subjects watched a close-captioned movie of their choice, and responses were bandpass filtered offline from 1 to 30 Hz. While recordings were nose-referenced online in both studies, Billings et al. (2007) used a 32-channel electrode montage, while Billings et al. (2009) used a 64-channel electrode montage. Additionally, it should be noted that the original Billings et al. (2007) study looked at the effect of hearing aid amplification, and we included only the unaided data for analysis in the present study.

2.2. Data analysis

For both datasets, we analyzed Cz and global field power (GFP) waveforms. GFP is the standard deviation of all channels as a function of time (Skrandies, 1989). While the N1, P2, and N2 waves are typically maximal at Cz, the GFP waveform captures more global cortical activity associated with the generating neural dipoles. Because it is a measure of the standard deviation of activity across electrodes, the GFP waveform is less sensitive to recording noise or electrical activity recorded from a specific location on the scalp. In the present study, GFP serves a confirmatory role demonstrating signal level and SNR effects across the scalp. An average reference (rather than a nose reference) was used to minimize noise specific to the reference electrode channel. We focus our analysis here only

Table 1
Outline of the experimental conditions used in Billings et al. (2007) and Billings et al. (2009), the data from which we reanalyze in the present study.

	Subjects				Experimental design				Electrophysiology
	n	Characteristics	Signal	Noise	Duration (ms)	ISI (ms)	Signal level (dB)	SNR (dB)	Recording
(A) Billings et al., 2007	13	Young adults; normal hearing	1000-Hz tone	None	757	1910	30, 40, 50, 60, 70, 80, & 90 dB SPL	N/A	• Passive recording; 400 sweeps for each stimulus • 32-electrode montage; nose-referenced •Bandpass filtered from 1 Hz to 30 Hz
(B) Billings et al., 2009	15	Young adults; normal hearing	1000-Hz tone	Continuous white noise	756	1910	(a) 60 dB SPL (b) 75 dB SPL	Quiet, 20, 10, 0, −5, & −10 dB SNR	• Passive recording; 400 sweeps for each stimulus • 64-electrode montage; nose-referenced • Bandpass filtered from 1 Hz to 30 Hz