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Unlocking Frequencies of the Brain with Deconvolution

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Summary

The fundamental aim of this study is to improve event-related potential (ERP) preprocessing through the use of innovative algorithms from the realm of geophysical seismic processing, specifically addressing the poor signal-to-noise ratio (SNR) typically found in task-based electroencephalogram (EEG) data.

The motivation in using geophysical based software is the fact that the frequency content and noise issues of EEG data and seismic data are quite similar, despite very different source signals. Geophysical software offers a multitude of well documented, researched and tested algorithms, specifically for signal and image processing, developed to minimize risk in seismic exploration.

The current limitation in standard ERP preprocessing is that the application of a single bandpass filter does not completely remove the unrelated bio-signal and environmental noise embedded in the signal. A new, geophysical flow, with the addition of smoothing and median frequency filters to rid signal of high-frequency noise, deconvolution and latency correction, is critical to improving the signal-to-noise ratio through the removal of unwanted noise.

The application of filtering to both simulated and empirical data offers some improvement but the application of deconvolution and adjusting for timing differences or latencies between individual trials, dramatically preserves the higher frequency content.

Results

An event-related potential (ERP), captures the neural response to the presentation of a stimuli, whether visual, auditory or sensory in nature, reflecting real-time cognitive processing. During a classical ***visual*** word recognition paradigm, known as the lexical decision task (LDT), participants decide whether a set of letter strings represent a word or nonword (Osterhaut, et al., 1995). Studies have shown that different processing stages within visual word recognition are reflected by specific ERP components such as the P1, N1 or P300. Kuriki and Maurer, in their work, established that the earliest relevant ERP component, the N1, is the prominent negative deflection measured at 100 – 250 ms post stimulus across the occipital region of the brain. As the ERP response is generally weak compared to the background signal, it is necessary to repeat a series of time-locked stimuli (trials) and average them to isolate distinct parts of the ERP waveform (Luck, 2005). As shown in Figure 1, the resulting ERP is slightly different for a word and nonword.

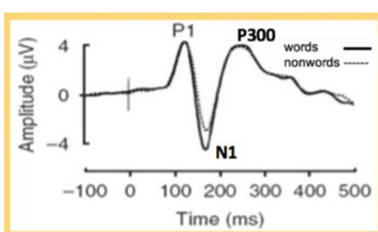


Figure 1 ERP component response at the occipital electrodes for lexical decision task (adapted from van Hees, 2016).

Simulated Data: To understand how filtering and other noise suppression techniques affects the ERP data, a set of simulations were created to evoke the N1 response, based on source dipole locations in the occipital lobe, the visual processing centre of the brain. The N1 response was simulated noise-free, with no amplitude or latency variation (baseline) as shown in Figure 2. Additional simulations varying the amplitude, latency (time) and noise were also created.

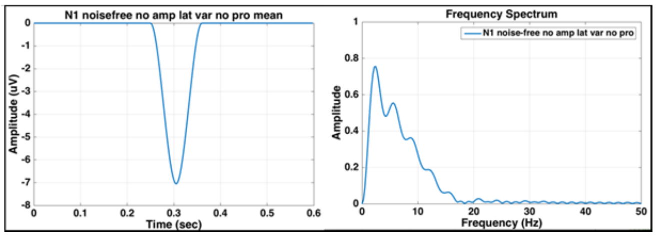


Figure 2 Baseline simulation with no added noise or amplitude/latency variation.

The simulations were subsequently processed using a standard eeg processing flow and a geo processing flow. A comparison of the simulated datasets with eeg processing and geo processing was undertaken to evaluate how well each processing flow could replicate the initial simulated unprocessed baseline model by improving the SNR.

EEG processing (eegpro): The standard flow consisted of a dc bias removal, a Butterworth 0.1- 50 Hz FIR filter, independent component analysis (ICA) to remove eyeblinks, epoch selection and averaging. Unfortunately, averaging smears the ERP response, resulting in a loss of frequency content. Figure 3 is an example of the N1 response with noise, amplitude and latency variation based on the eeg processing flow. It is the aim of processing to rid the signal of noise, and minimize any amplitude or timing variation. The eeg processing attempts to resolve the N1 component but does not quite achieve the original input parameter values (see Figure 2) and loses amplitude and frequency content beyond 10 Hz.

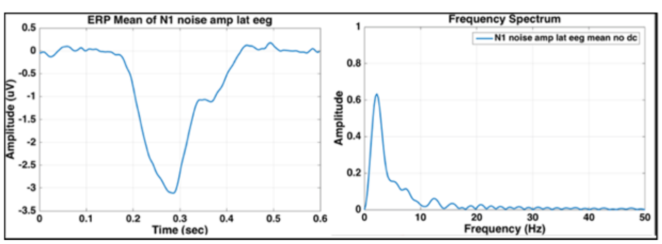


Figure 3 N1 response with noise, amplitude and latency variation based on eeg processing.

Geo processing (geopro): This new processing pipeline consisted of a direct current (dc) bias component removal (to minimize drift), a zero phase 0.1-0.3-40-80 Hz Ormsby filter, a 5 ms smoothing window, a median frequency filter (to target high frequency noise), deconvolution and latency correction. The deconvolution operator was based on the average ERP response across all of the trials. The latency shift involved correcting the timing of each trial such that the N1 peak “lined up”, accounting for the different response times for each of the trials. As depicted in Figure 4, the geo processing flow outlining the results of (1) filters only, (2) filters and deconvolution, and (3) filters, deconvolution and time shift, has not only resolved the N1 component but has restored the frequency content and amplitudes, similar to the baseline model as depicted in Figure 2.

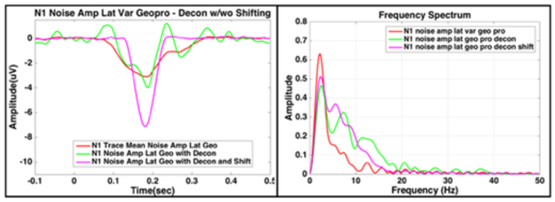
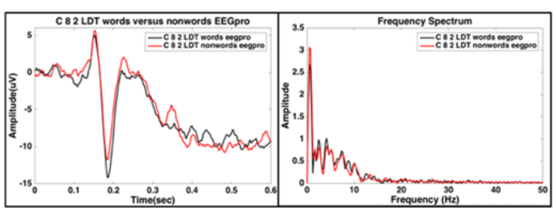


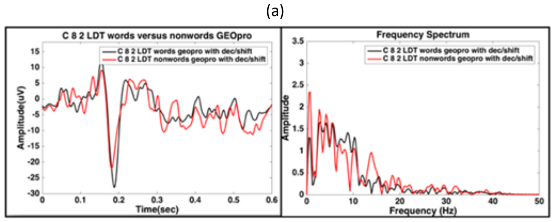
Figure 4 N1 response with noise, amplitude and latency variation based on the geo processing flow.

The simulated data allowed us to understand how changes in noise, amplitude and timing affected the N1 response, mimicking what we might expect to see in real subject data. The knowledge gained from this helped streamline the geophysical processing flow for empirical data.

Empirical Data: The empirical data was collected from 15 participants based on age (18-30 years), level of education (undergraduate and graduate students), language fluency (both oral and written), and handedness. The ERP data was recorded using a 32 channel and 10/20 positioning system. The sample rate was collected at 500 Hz (2 ms) with no pre-set filtering. The recording session lasted approximately 6 minutes, cycling through a random list of 125 letter strings comprising 75 words and 50 non-words.
The N1 ERP waveform and frequency spectrums based on a single participant for the word and nonword condition for the different flows, (a) eeg processing and (b) geo processing, are displayed in Figure 5. Here we can see the classic shape of the N1 component, indicating in this example, that the amplitude response for the word is greater than the nonword and in terms of latency, words have a marginally faster response time than nonwords. The frequency content of the word and nonword of the geo flow (b), is considerably improved over the eeg flow (a).



(a)



(b)

Figure 5 Word and nonword N1 ERP response and frequency spectrum for EEG flow (a) and geophysical flow (b).

Observations, Conclusions

The geophysical processing shows a significant improvement and differentiation in the amplitudes of the word and nonword, especially in the actual values. Specifically, the application of deconvolution and latency shift appears to have made a significant improvement in the frequency content, the result of an improved SNR.

Novel/Additive Information

The novel approach to this study is the focus on both the time and frequency. Typically, in EEG research, results are determined statistically based on the time response to a task only, known as an event-related-potential. By looking at the frequency response too, the need for a new approach to processing is legitimate, and crucial to preserving higher frequencies.

Acknowledgements

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