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Improving Brain Signal Imaging with Geophysics

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Summary

The ultimate goal of this research is to create a novel preprocessing flow for electroencephalogram (EEG) recordings using geophysical software and algorithms. This new flow will specifically address the signal-to-noise ratio (SNR) through implementation of noise attenuation techniques. To test this, we will use a simulated event-related potential (ERP) dataset with user-specified parameters for amplitude and latency for each of the component waveforms typically elicited during a language comprehension and cognitive processing task. The superposition of these component waveforms contributes to the overall ERP response, but can be individually extracted by looking at specific areas within the brain. Different geophysical algorithms will be tested separately and collectively to produce an effective preprocessing flow that will extract key metrics (amplitude, and timing of the peak potentials) for each of these component waveforms. The simulated dataset will also allow for the testing and comparison of standard EEG preprocessing and the new geophysical preprocessing flow.

Introduction

Medical imaging applications such as EEG's, measure the electrical activity of the brain (1). Using a series of electrodes placed on the scalp, EEG's record spontaneous neural oscillations within the cerebral cortex to assess and localize brain function (2). The voltage recorded at an active electrode is not the actual electrical discharge at that location, but reflects the difference between the active and a specified reference site (potential difference) (1, 3). In addition, activity recorded from each of the electrodes does not reflect the activity from neurons directly below the electrode but rather from a complex series of neural responses from different brain regions (4). When a participant is performing a task, components of an elicited waveform can be extracted from the EEG and averaged across trials. In this study, the stimuli presented is a classical visual word recognition paradigm known as the lexical decision task (LDT), involving word/nonword decisions about letter strings (5). The ensuing waveform, referred to as an ERP, is made up of a series of peaks (+ voltage and – voltage deflections) representing the summed post-synaptic electrical potential activity from neurons synchronously firing in response to a specific external stimulus (6). For tasks related to language processing, two components of the ERP, the N170 and P300, are isolated at the occipital and parietal electrodes (7-9), and measured for amplitude strength, and latency. These results allow researchers to determine the relationship between the type of stimuli and its temporal neural processing response.

Unfortunately, EEG measures not only record signal from the cerebral cortex, but also signal from spurious internal and external sources, known as artifact. Extracting artifact from EEG signal and preserving the weak ERP response, is challenging. Multiple trials and/or multiple participants are needed to create a discernible waveform and obtain robust components within the ERP. To improve the SNR, the different sources of noise are removed or attenuated through a multi-step preprocessing pipeline. Although signal averaging is effective in removing large artifact and some random noise, EEG recordings still contain unwanted signal (10). The effect of noise is therefore a critical issue in EEG recordings specifically in the integrity and extraction of an ERP during standard EEG preprocessing.

Geophysical signal analysis also suffers from some of the same issues encountered in EEG and ERP recordings in terms of poor signal-to-noise ratio (SNR), and noise saturation from internal and external sources. In addition, EEG and seismic signal analysis bear similar characteristics in terms of the total frequency band, the necessity for filtering unwanted noise, and the enigma of an “unknown” source wavelet inherent in the data. Therefore, developing a new preprocessing flow for EEG catering to noise attenuation adapted from seismic exploration is both plausible, and warranted. By integrating this synergy, the objective is to highlight the brain signal, minimize measurement noise and isolate key metrics of the ERP components.

Theory and/or Method

The new geophysical preprocessing flow will be tested on a simulated ERP dataset before applying it to empirical data. A simulated dataset with user-specified ERP parameters for amplitude and latency of the different component waveforms will be created. To facilitate this attempt to improve S/N, we plan to enhance standard EEG preprocessing by developing signal processing tools adopted from geophysical exploration. Different geophysical algorithms will be adapted and tested, such as different Butterworth and Ormsby filters, amplitude enhancement techniques, and deconvolution (11-13), and directed across the delta, theta and alpha frequency bands: 0.1 - 13 Hz. The simulated dataset will allow for the testing and comparison of the standard preprocessing EEG typically employed in the Brain Dynamics Lab at the University of Calgary, with individual processes, and a combined geophysical preprocessing flow in extracting the key metrics of the component waveforms. This dataset will also enable us to investigate whether decreasing or increasing the number of participants or trials effects the integrity of the ERP waveform for both preprocessing flows. A statistical comparison of the components and their respective measurements elicited from the standard versus geophysical preprocessing flow will allow us to gauge which flow is more effective (Figure 1).

Example of Preprocessing Methodology

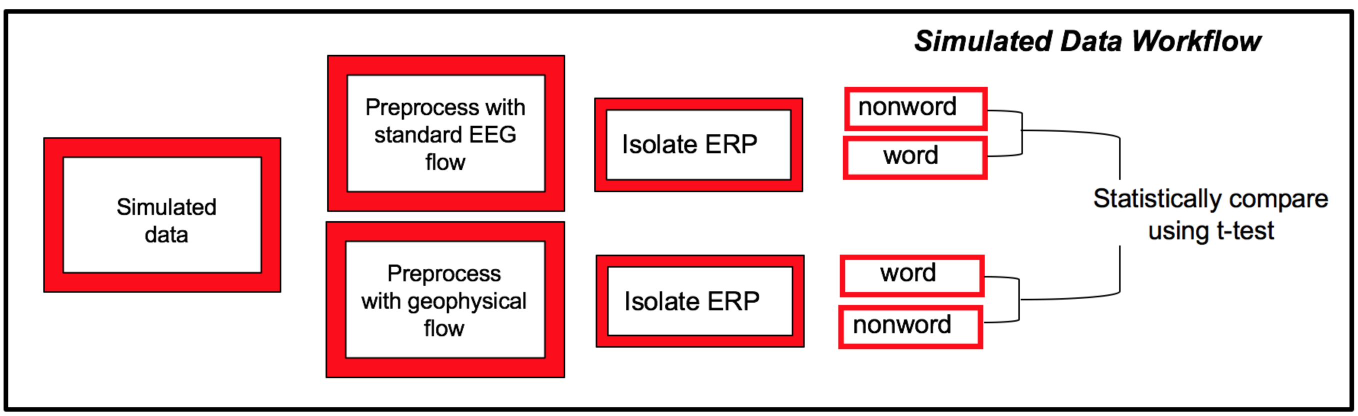

Figure 1. Methodology for comparison of EEG preprocessing flows.

Conclusions

This research involves a cross-disciplinary collaboration in brain signal analysis. The anticipated outcome is to create a viable and novel way of processing of EEG signals such that the resulting cleaner, and “noise free” dataset will allow for better extraction of ERP components and key metrics. This, in turn, will translate into the need for fewer trials and/or fewer participants. Establishing an effective EEG signal processing flow to elicit key brain metrics related to cognition will serve as a guideline for future psychological research, as well as other imaging modalities.

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