Using Independent Components Analysis to Better Understand the Electrophysiology of Error Processing

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BACKGROUND

- Electroencephalography (EEG) is a measure of brain electrical activity from the scalp with components, such as positive and negative deflections in the signal, indexing various mental processes.
- The Pe (error positivity) is a positive deflection in the EEG that follows an error made during certain tasks (e.g. the flanker task), especially if the person is aware of having made the error.
- Typically this deflection is largest at posterior sites (e.g. Cz) and flattens out toward more anterior sites (e.g. Fz).
- In one pilot study and two related studies our laboratory has observed negative deflections at anterior sites, as if the Pe were inverted (mirrored) in polarity.
- The deflections at anterior vs. posterior sites do not seem to be separate events because they occur around the same time (~125-325 ms) suggesting that they are related.
- Other studies have found similar inversions of the Pe at anterior sites, although usually not as large. (e.g. Buzzell *et al.*, 2017; Lo *et al.*, 2015; Schoenberg *et al.*, 2014; Matthewson *et al.*, 2005; Themanson *et al.*, 2006).

Dipole Effects:

- When a brain area is active, it generates an electric field with positive and negative poles referred to as a dipole.
- Positivity over one part of the scalp and negativity over another could reflect (see Dipole Effects figure):
  - A) The positivity at posterior sites and negativity at anterior sites reflect neural events from independent neural generators.
  - B) The positivity at posterior sites and negativity at anterior sites reflect the same neural event from a common neural generator.

Referencing:

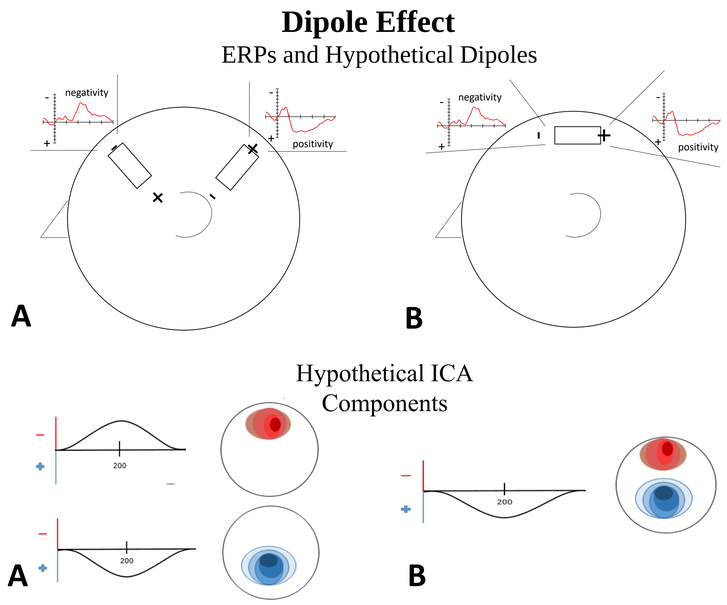
- EEG is a measure of voltage, i.e. the difference in electrical potential between two sites. A site of interest must be measured with respect to a comparison site, called the reference (Electrical Geodesics, Inc., 2006).
- One referencing option is to use the average of all scalp electrodes, but this must be done offline, after recording using some electrode as the initial reference. We use the vertex electrode (Cz) as the initial reference and then re-reference to the average of all scalp electrodes.
- Using an average reference can introduce distortions in the data because positive deflections must be balanced by negative deflections at other locations, and vice-versa. Hence, our anterior negativity may just reflect a mirroring of the classic posterior positivity.

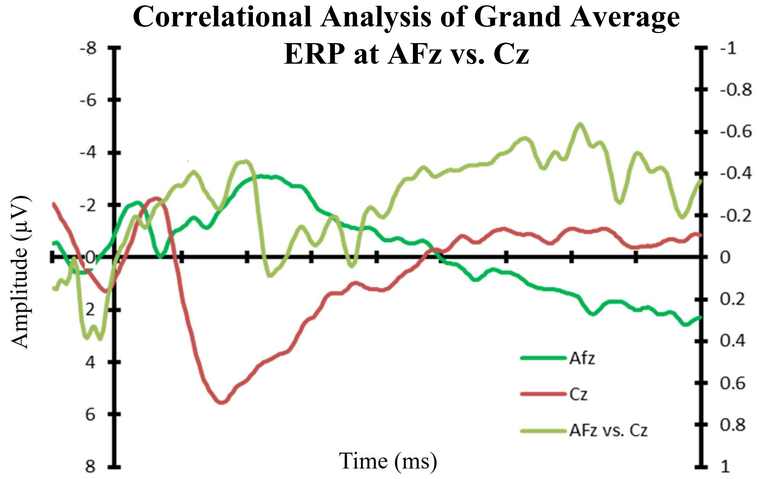
Prior correlational work:

- If the inversion was observed as a result of referencing alone and the anterior negativity is a true mirror-image of the posterior positivity, one would expect to see a consistent, strong correlation between the anterior and posterior sites.
- If the anterior inversion reflects the negative end of a single dipole, one would expect stronger correlations between anterior and posterior sites for the time windows of the Pe (~125-325 ms) than at other times.
- Correlational analyses of our data have shown a stronger correlation between the waveforms leading up to the Pe peak than afterwards (see AFz vs. Cz Grand Average), suggesting a possible dipole influence consistent with a single neural generator (dipole effects condition B).

Using Independent Components Analysis (ICA):

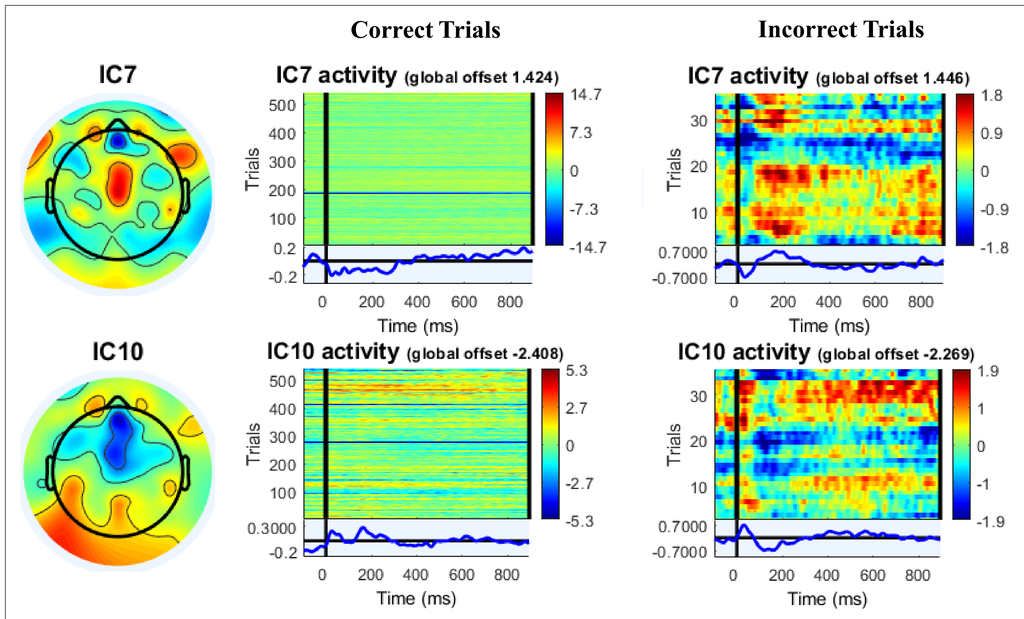
- We are learning to use ICA, a mathematical means of separating EEG data into spatiotemporal components that could reflect the EEG's electrical generator(s).
- We hypothesize finding one set of ICA components within the Pe window that displays both anterior and posterior aspects (dipole effects condition B) rather than two distinct sets of ICA components, one showing an anterior negativity and one posterior positivity.





- Correlations run on EEG amplitude for anterior vs. posterior sites, time point by time point, across the entire 1000 ms time-locked time window (900 ms plus a 100 ms baseline period).
- Pearson's *r* (correlation coefficient) plotted alongside grand average waveforms for all subjects.

SINGLE SUBJECT ICA RESULT AND ANALYSIS



Important Figure Notes:

- The images above detail 2 particular components (IC7, IC10) found in the ICA decomposition of one of our subject's data.
  - The left-most images are scalp activation distributions showing each particular component's approximate activity location
  - The 2 middle images show component activations over time for 540 Flanker trials in which the participant responded correctly, with the corresponding component amplitude below each stack of trials.
  - The 2 right-most images show component activations over time for 36 Flanker trials in which the participant responded incorrectly, with the corresponding component amplitude below each stack of trials.
- It is important to note the differences in the scaling on the correct component amplitudes vs. the incorrect amplitudes.
  - On the plots for component amplitude vs. time, the scale of the y-axis is much larger for the incorrect trials (-0.7μV – 0.7μV) than the correct trials (-0.2μV – 0.3μV); incorrect trials show much larger amplitudes than correct trials, more so than is implied due to auto-scaling.

Component Analysis:

- The spatial distribution and peak timing suggest that components IC7 and IC10 are related to the Pe; they are associated with the same time period and scalp locations as the Pe in the (non-ICA) EEG.
- The IC7 and IC10 component waveforms for incorrect trials display peaks within the 125-325ms Pe window (based on the average Pe time window across all subjects); amplitudes are much smaller in these time windows for correct trials.

METHODS

Participants and Task

- 24 individuals' data from the most recent study of error processing and EEG was used for analysis of correlations between anterior and posterior activity (19 female; age 18-35).
- These participants performed a flanker task to generate performance errors and corresponding error positivities (Pe).

Electrophysiology

- 64-electrode GSN (Electrical Geodesics Inc.)
- 250 Hz sampling; 0.1 to 30 Hz bandpass filter
- Vertex reference; re-referenced to average
- **Pe**: mean amplitude calculated separately at Pz, Cz, FCz, Fz, AFz, and the average of FP1 and FP2 (FPav) over a 125-325 ms window after response.

Independent Components Analysis (ICA)

- We are using ICA through EEGLAB (Delorme & Makeig, 2004) on our data to examine whether the observed positivity and negativity within the Pe window are associated with the same set of ICA components, or whether there are two distinct sets of ICA components, one associated with the positive deflection at posterior sites and one with the negative deflection at anterior sites.
- Preliminary findings presented here are based on ICA with a single subject.

DISCUSSION

- With the right timing, distribution, and greater amplitude for incorrect than correct trials, these ICA findings are more consistent with option B regarding dipole effects, i.e. the classic Pe and observed inverted Pe appear to share a common neural generator, rather than having separate generators.
- It is important to note that the ICA data presented on this poster is from a single participant and not a comprehensive analysis of the data collected from all 24 participants involved in the correlational analysis.
- Moving forward, we will be working to run ICA decomposition and analysis on the rest of the participants' data from our most recent error-processing study.
- This stronger correlation leading up to the Pe peak than afterwards suggests the influence of a dipole, however since the correlation coefficients rise again after dropping, and are large for most of the time window, suggests average referencing may also play a role.
- Our especially large anterior negativities in the time range of the Pe may reflect the combined effects of a dipole and average referencing.

Acknowledgements: Support provided by the Student Blugold Commitment Differential Tuition through a Student-Faculty Research Collaboration grant and UW-Eau Claire Learning and Technology Services. Special thanks to Katie Beard for her work on the correlational analyses. Thanks to Lucas Brandt, Simon Moe, Gabrielle LeBouton, Kelsey Rolefson, Sarah Loew, and Ronnie Lockington for their contributions.