**Motivation**

For severely brain-injured patients, assessment of cognitive functions such as language processing is critical for prognostication, long-term care, and rehabilitation. In patients with compromised motor function, EEG-based measures have been used to assess high-level (command following) and low-level (tracking of natural speech envelope) language functions. The intermediate level of phoneme processing has not been studied in this population. Here, we develop and apply methods to identify a differential phoneme-class specific response (DPR) and NSE tracking, and apply them in parallel to severely brain-injured patients.

**Methods**

Participants: 26 patient subjects (PS) were tested from a convenience sample enrolled to study long-term recovery in severe brain injury. Participants performed behavioral, EEG, and MMSE tests. Ten healthy controls with no history of neurologic disease were also tested using EEG.

Data Collection: EEG was recorded in all participants using 37 electrodes (augmented 10-20 international system) at 250 Hz. One PS was tested using only 21 electrodes due to small head size. A screening ECG recording was screened for motion artifacts and sleepiness, resulting in rejection of all data for 2 HCs and 2 PSs and 99% of data on average for all other subjects.

Preprocessing: The EEG was band-pass filtered at 2-15 Hz.

Analysis for DPR: The audio was annotated to phonemes using the PTRA toolkit. Segments of 500 ms, time-locked to phoneme onset, were extracted. Responses to the five phoneme classes were compared in 10 pairwise comparisons using Wilcoxon rank sum test applied to EEG responses at each time point, separately for each channel. For NSE analysis, the audio envelope and EEG responses were cut into 2 sec non-overlapping segments and cross-correlated with a maximum lag of 500 ms. To assess statistical significance, a null dataset was generated by randomly shuffling the segments of the audio envelope and correlation times and cross-correlating with the EEG responses. Statistical significance was estimated across timepoints per channel and assigned if the false discovery rate (FDR) corrected p-value was <0.05.

**Differential Phoneme class-specific Responses (DPR)**

**A1. Annotation of speech**

- Alliteration: Adjectives, adverbs, and pronouns
- Emeticism: Verbs, nouns, and adjectives
- Wonderspin: by, wonder, land, and slow
- Wonderstep: by, wonder, land, and slow
- Gobbling: gobble, gobble, gobble, gobble

**A2. Analysis pipeline for DPR**

- DPR analysis of a single trial for identifying echoic and phonemic responses with a significant response pattern.
- DPR temporospatial analysis with significant phoneme and NSE response patterns across channels.
- DPR averaged across all patients and 100 trials, with phoneme and NSE response patterns across channels.
- DPR averaged across all patients and 100 trials, with phoneme and NSE response patterns across channels.

**B1. Audio signal and its envelope**

- NSE analysis of a single trial for identifying echoic and phonemic responses with a significant response pattern.
- Temporospatial analysis with significant phoneme and NSE response patterns across channels.
- DPR averaged across all patients and 100 trials, with phoneme and NSE response patterns across channels.

**B2. Analysis pipeline for NSE tracking**

- NSE tracking of natural speech envelope (NSE)
- Tracking of phonemic and NSE response with a significant response pattern.
- Temporospatial analysis of voice and speech commands with significant phoneme and NSE response patterns across channels.
- DPR averaged across all patients and 100 trials, with phoneme and NSE response patterns across channels.

**Conclusions**

- Differential phoneme-class specific responses and tracking of natural speech envelope have distinct but overlapping dynamics.
- While DPR responses were observed across the scalp, NSE responses were absent in the centro-parieto-occipital region.
- Both responses peaked around 250 ms.

In patient subjects:

- All patients had EEG evidence of language processing at both levels.
- Within the subset of patients studied, those with evidence of language processing (LPS+) in CR (C3-R or in EEG/MMG tests) had early response in DPR (~50 ms) and tracking of NSE (~80 ms).

**References**
