Weill Cornell Medicine
Graduate School of Medical Sciences

EEG Evidence of Low-Level Speech Processing in Severe Brain Injury

Parul Jain[1], Mary M. Conte[2], Henning U. Voss[3,4], Jonathan D. Victor[2,5,6], Nicholas D. Schiff[2,5,6]

[1]Weill Cornell Graduate School of Medical Sciences, New York, NY 10065; [2]Feil Family Brain and Mind Research Institute, Weill Cornell Medical College, New York, NY 10065; [3]College of Human Ecology, Cornell University, Ithaca, NY 14850; [4]Department of Radiology, Weill Cornell Medicine, New York, NY 10065; [5]Department of Neurology, New York Presbyterian Hospital, New York, NY 10065; [6]The Rockefeller University Hospital, New York, NY 10065

Support by: NIH HD51912
The Jerold B. Katz Foundation
The James S. McDonnell Foundation
Fred Plum Fellowship in Systems Neurology and Neuroscience

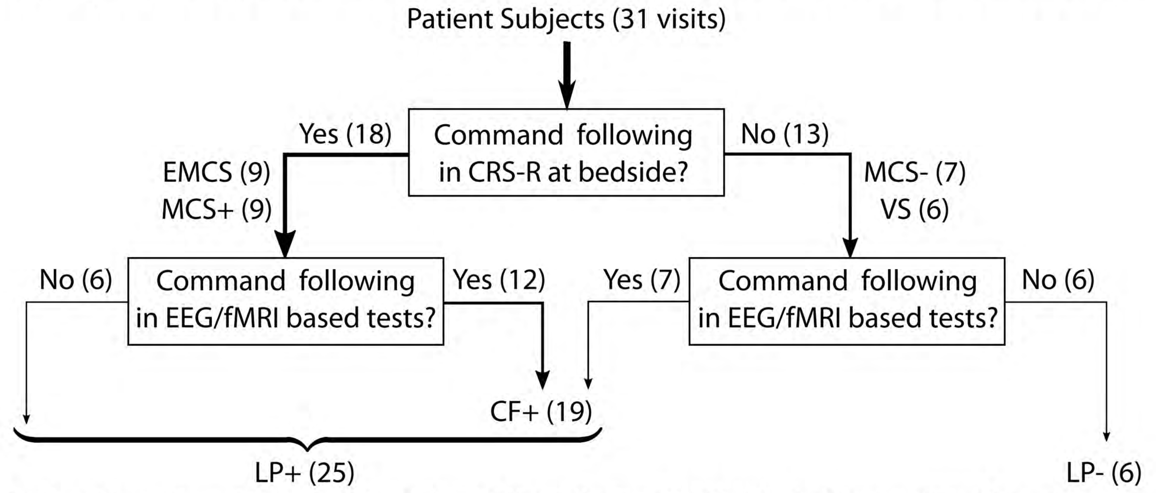
Motivation

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)[1] and low-level (tracking of natural speech envelope (NSE))[2] language function; 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. Patients performed behavioral, EEG, and fMRI tests. Ten healthy controls with no history of neurologic disease were also tested using EEG.

Patient Classification: we classified patients based on results of behavioral testing (CRS-R) and EEG/fMRI-based responses to motor imagery commands. The decision tree for classification is shown below.



Numbers in parentheses indicate number of visits. **VS**: Vegetative State; **MCS**: Minimally Conscious State; **CF+**: patients with evidence of command following in EEG/fMRI tests; **LP+/-**: patients with/without the evidence of language processing in CRS-R or EEG/fMRI tests

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.

Screening: EEG recordings were screened for motion artifacts and drowsiness, resulting in rejection of all data for 2 HCs and 2 PSs and 15% datasets on average for all other subjects .

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

Analysis: For DPR, the audio was annotated for phonemes using the P2FA toolkit[3]. Segments of 500 ms, time-locked to phoneme onset were extracted. Responses to the five phoneme classes were compared in ten 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 10,000 times and cross-correlating it 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.

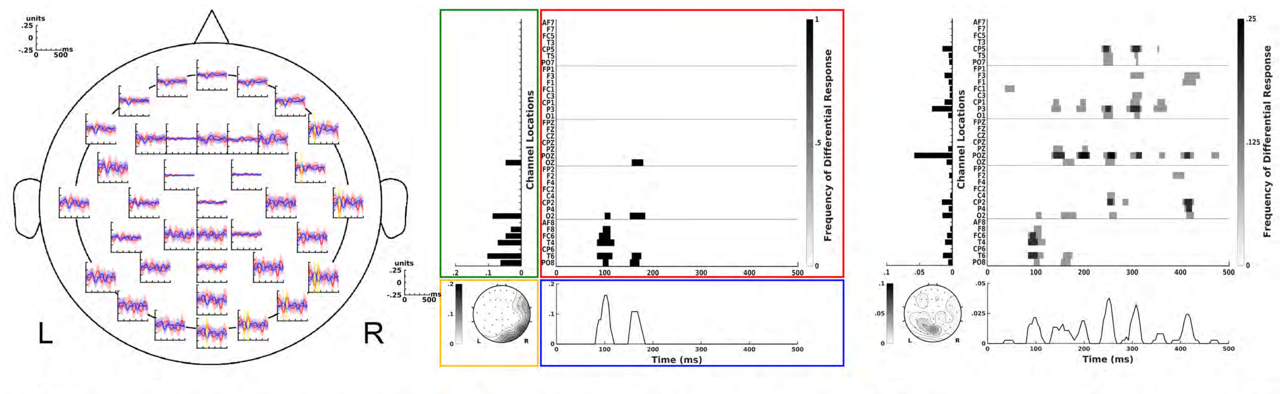
Differential Phoneme class-specific Responses (DPR)

A1. Annotation of speech

Alice's	Adventures	in	Wonderland,	by	...
ˈæləsəz	ædˈvɛnʧərz	ɪn	ˈwʌndərˌlænd,	baɪ	...
ˈæləsəz	ædˈvɛnʧərz	ɪn	ˈwʌndərˌlænd,	baɪ	...

Approximants: l, r, w
Fricatives: s, v, z
Nasals: n, m
Plosives: d, ʧ, b
Vowels: æ, ə, ɛ, ɪ, ʌ, a

A2. Analysis pipeline for DPR

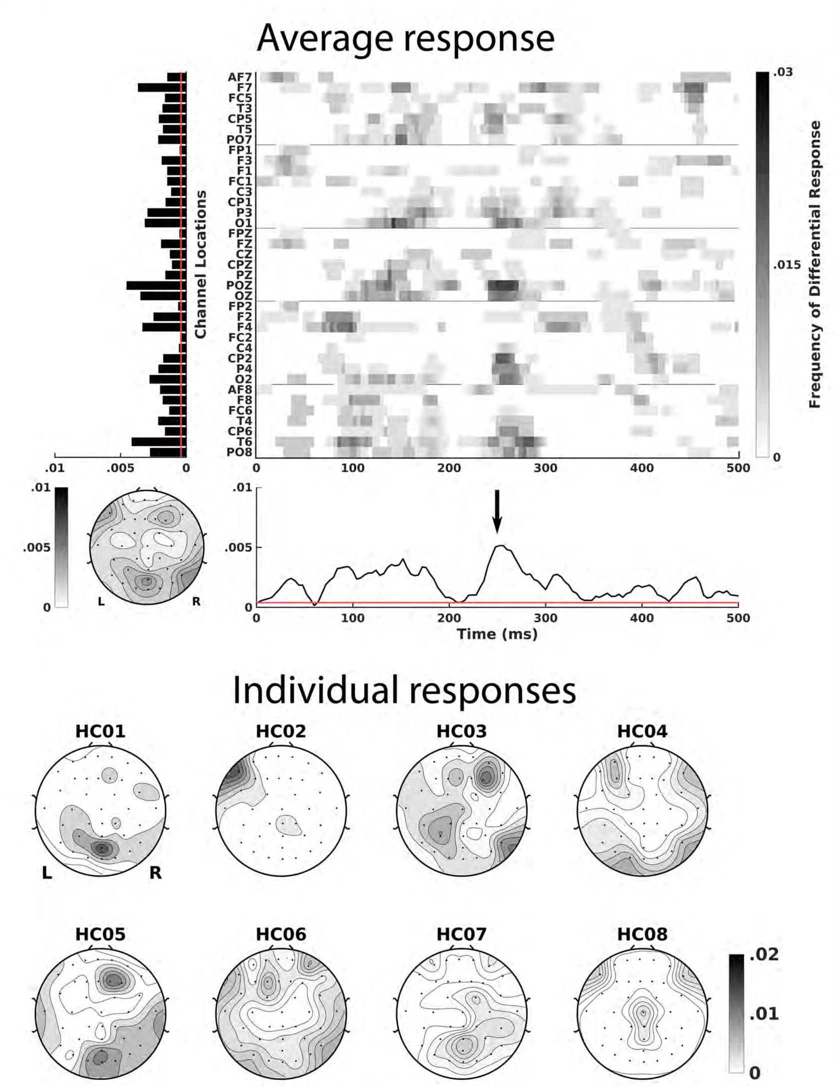


DPR analysis of a single trial for a healthy control. Red: response to plosives. Blue: response to vowels. Yellow: significant differences.

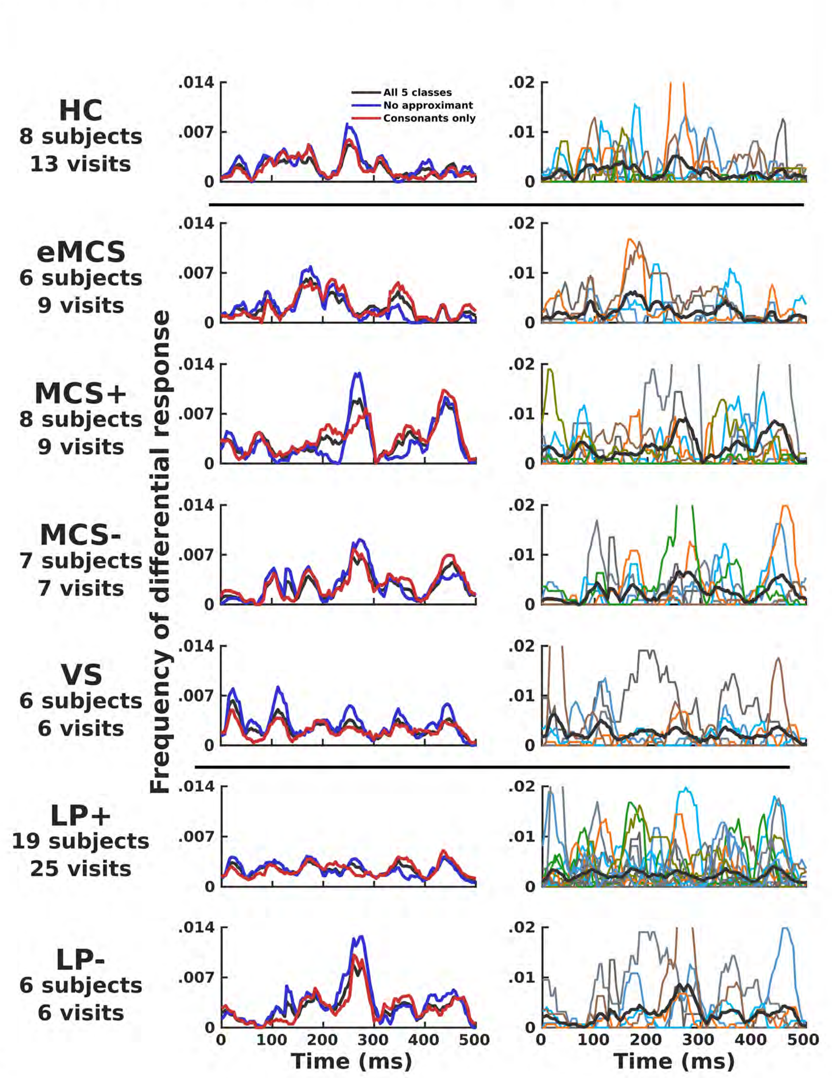
Red: DPR spatiotemporal "fingerprint": channels and times with a significant difference in responses. Blue: temporal dependence. Green, yellow: Spatial dependence.

DPR averaged across all 10 phoneme pairs. Chance level is ~0.0004.

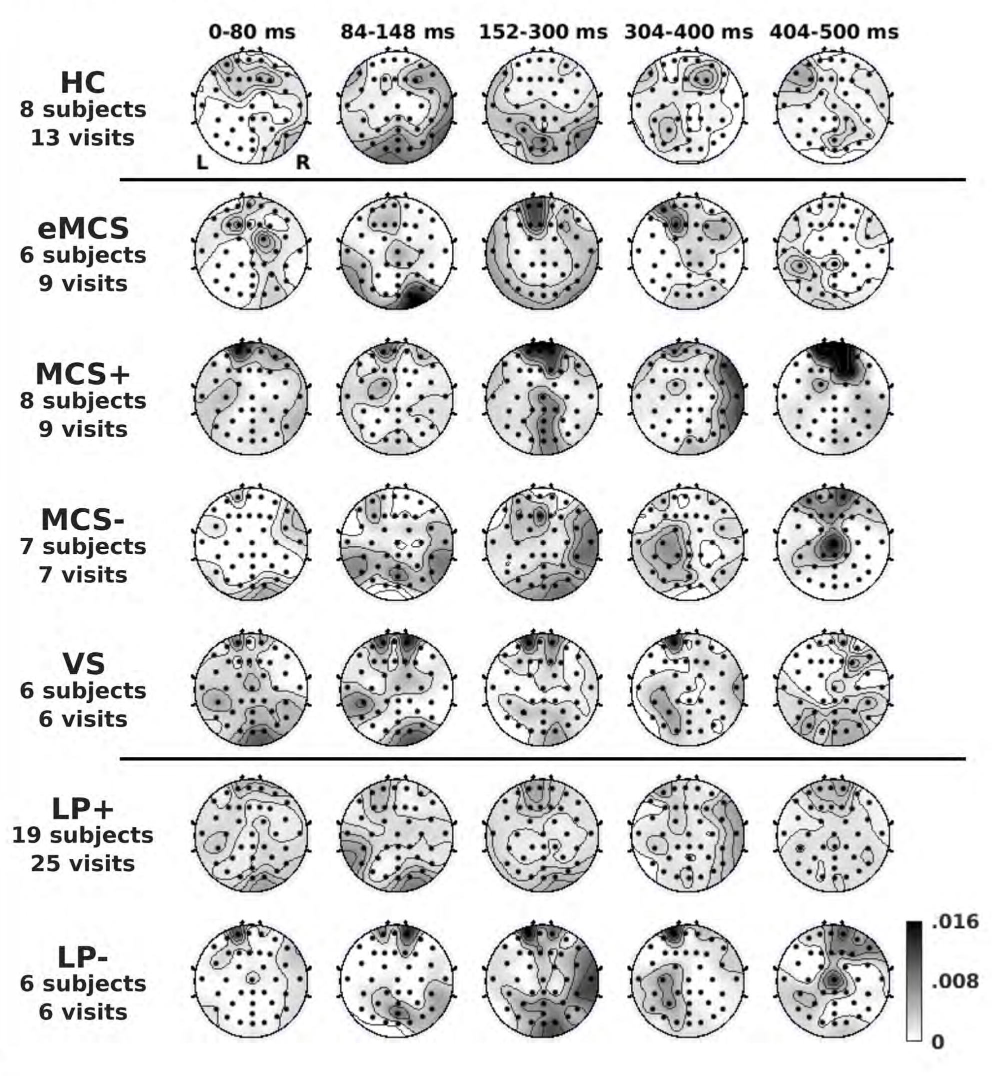
A3. DPR in healthy controls



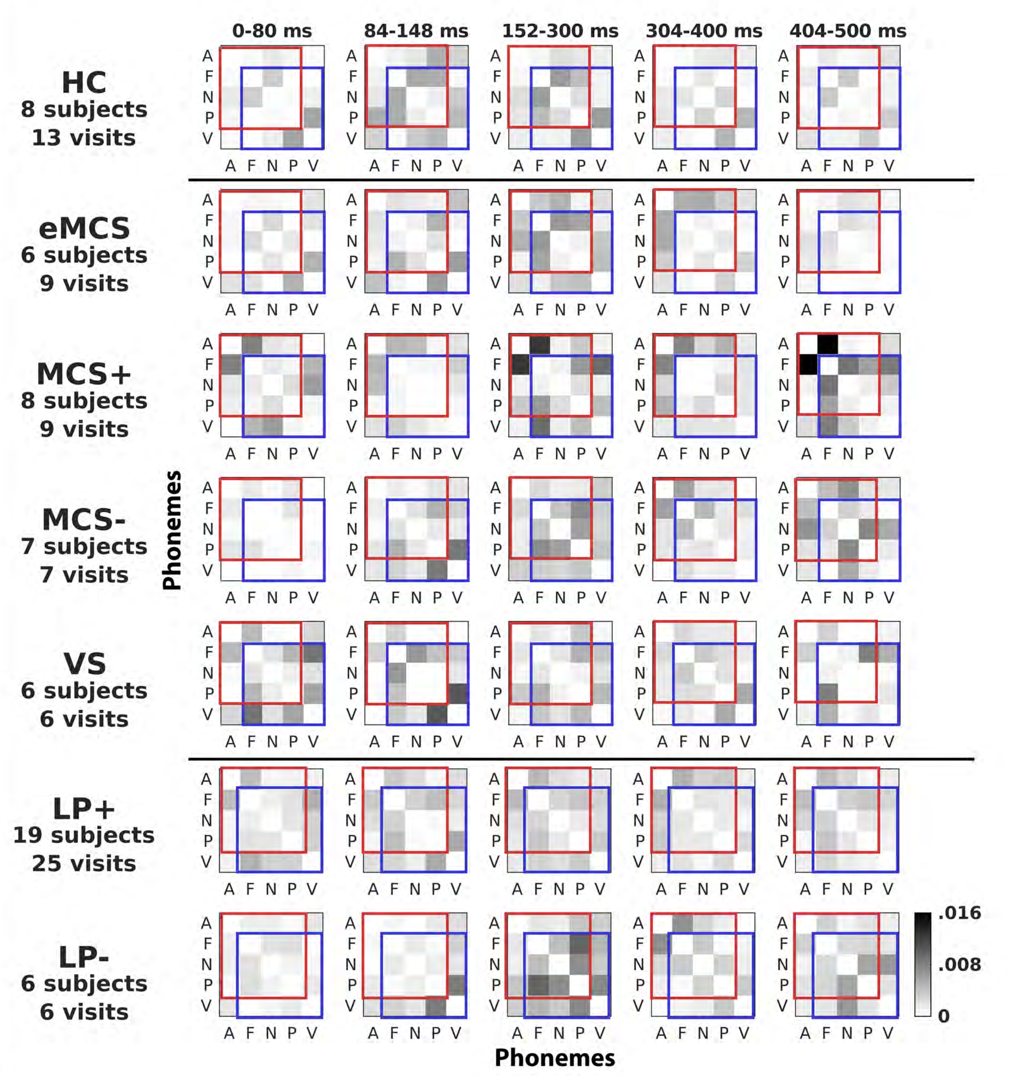
A4. Temporal dependence



A5. Spatial dependence

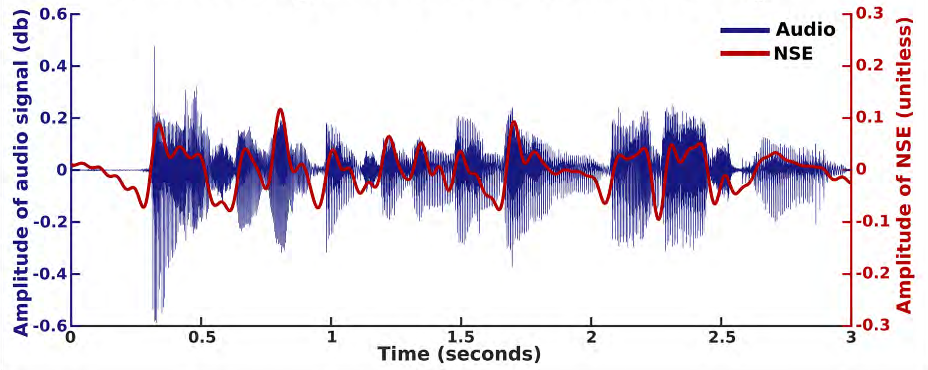


A6. Phoneme-pair dependence

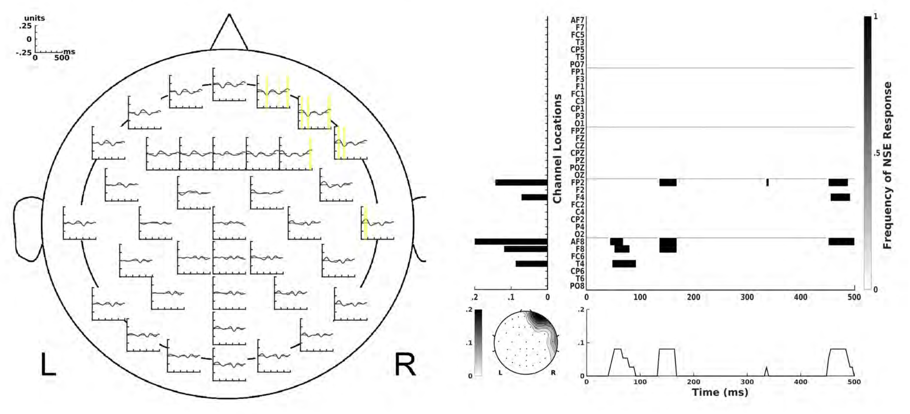


Tracking of Natural Speech Envelope (NSE)

B1. Audio signal and its envelope



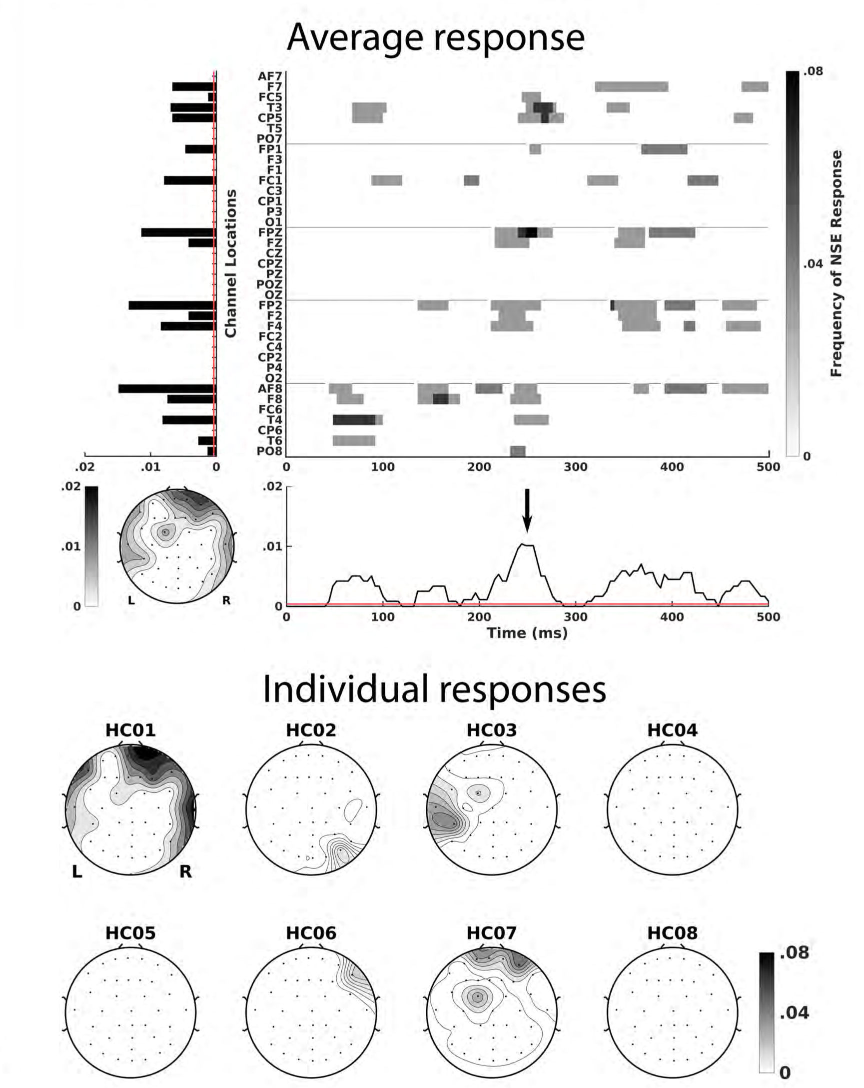
B2. Analysis pipeline for NSE tracking



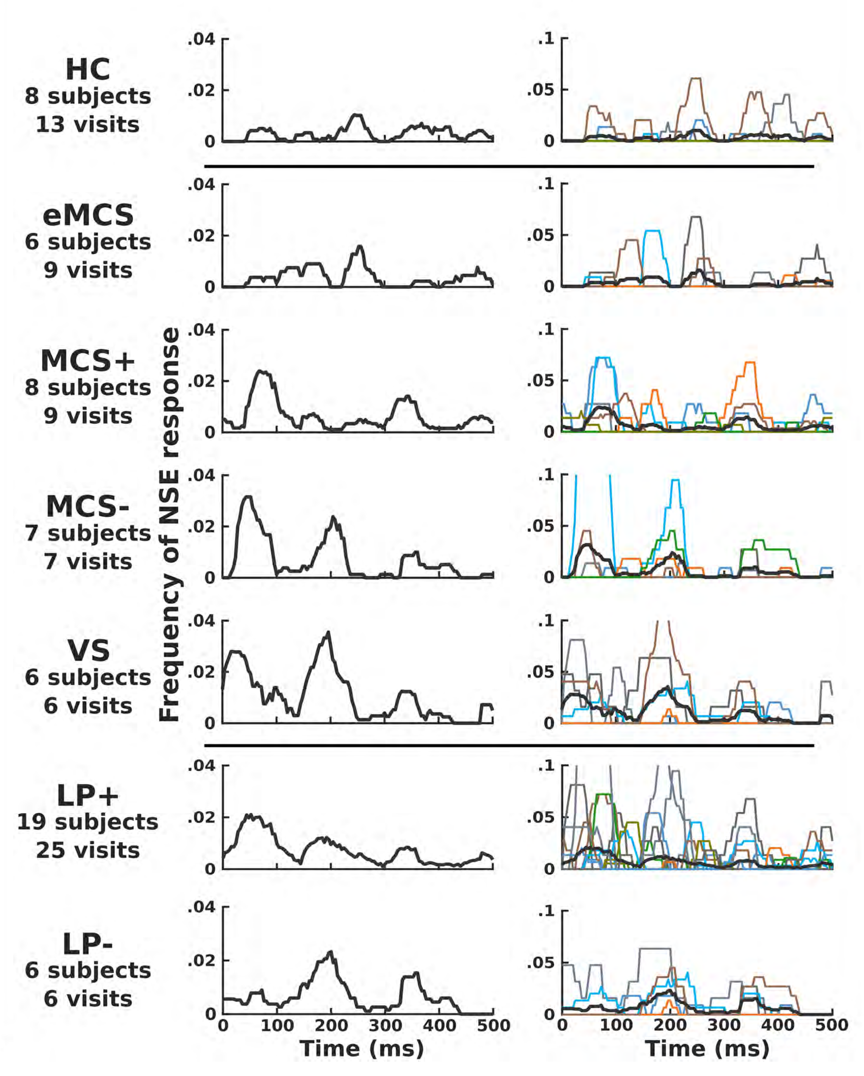
NSE analysis of a single trial for a healthy control. Black: cross-correlation of EEG response with speech envelope for different lags. Yellow: significant values.

Spatiotemporal fingerprint, temporal dependence, and spatial dependence of the NSE tracking response

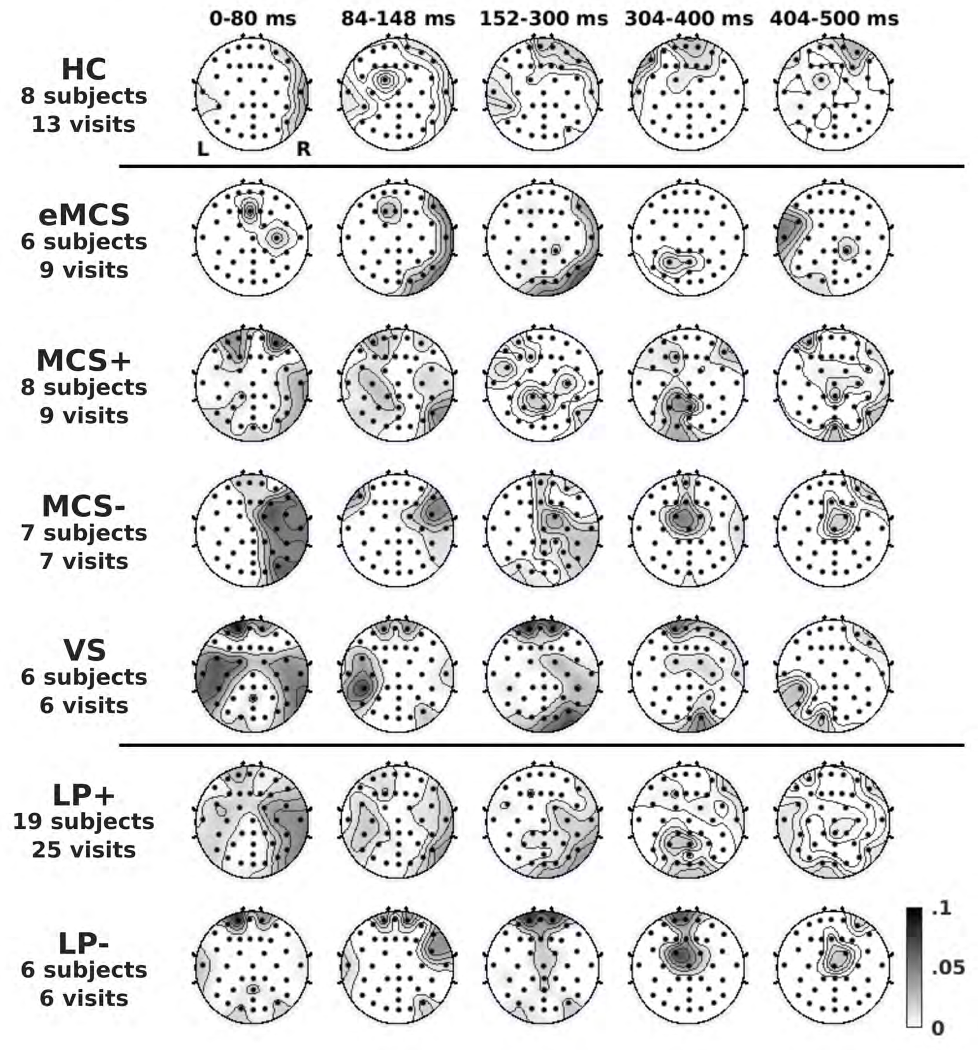
B3. NSE tracking in healthy controls



B4. Temporal dependence



B5. Spatial dependence



Conclusions

In healthy controls:

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

References

1. Forgacs PB, Conte MM, Fridman EA, Voss HU, Victor JD, Schiff ND. Preservation of electroencephalographic organization in patients with impaired consciousness and imaging-based evidence of command-following. *Annals of Neurology*. 2014;76(6):869-879.
2. Braiman C, Fridman EA, Conte MM, et al. Cortical Response to the Natural Speech Envelope Correlates with Neuroimaging Evidence of Cognition in Severe Brain Injury. *Current Biology*. 2018;28(23):3833-3839.e3.
3. Yuan, J., & Liberman, M. (2008). Speaker identification on the SCOTUS corpus. *Journal of the Acoustical Society of America*, 123(5), 3878.