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EEG evidence of phonemic processing in severely brain-injured patients

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Motivation

Assessment of cognitive ability in brain-injured patients is crucial for their care, and language is a key component of cognition. Though processing of speech has previously been studied in brain-injured patients at the level of comprehension, the hierarchical nature of language calls for studies at lower levels as well. Here, using electroencephalography (EEG), we studied language processing at the phonemic level in brain-injured patients.

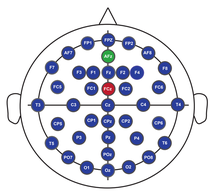
Methods

Participants: 15 patient subjects (PS) were tested (see table). Level of consciousness was classified as minimally conscious state (MCS), confusional state, or cognitive-motor dissociation (CMD) on the basis of the Coma Recovery Scale-Revised (CRS-R) and EEG and/or fMRI tests of command following, at one to three admissions (v1, v2, v3). Ten healthy controls (5M; avg. age: 38 years) with no history of neurologic disease were also tested.

Patient Subjects	Age at 1st Visit/Gender	Etiology of Injury	Age at Injury	Average CRS-R visit 1	Average CRS-R visit 2	Diagnosis	Command Following by fMRI	Command Following by EEG
PS01	23 / F	TBI /hypoxic	12	11	12	CMD	negative	v 2
PS02	24 / M	TBI	19	5	5	CMD	v 1	v 1
PS03	27 / M	TBI	21	17	13	CMD	v 2	v 1 and v 2
PS04	19 / F	TBI	17	9	23	CMD	negative	v 1 and v 2
PS05	26 / M	TBI	22	9	11	CMD	v 1	v 1
PS06	22 / M	TBI	21	17	12	CMD	v 1	v 1
PS07	25 / M	TBI	19	15	—	CMD	v 1	v 1
PS08	24 / M	TBI	16	8	7	CMD	v 2	v 2
PS09	22 / M	TBI	15	10	—	CMD	v 1	negative
PS10	42 / F	TBI /anoxic	25	7	3	CMD	v 1	negative
PS11	49 / M	TBI /hypoxic	40	6	—	CMD	v 1	negative
PS12	22 / F	TBI	16	7	—	MCS	negative	negative
PS13	27 / M	TBI	24	6	—	MCS	negative	negative
PS14	52 / F	anoxic	51	23	23	Confusional	negative	v 1 and v 2
PS15	59 / M	CATH/anoxic	56	23	23	Confusional	not done	indeterminate

TBI: traumatic brain injury; CATH: cardiac arrest, therapeutic hypothermia

Data Collection: EEG was recorded at 250 Hz at 37 electrodes (augmented 10-20 international system), except for PS12, where 21 electrodes were used, due to small head size.



Audio Stimulus: A 148 sec. section of *Alice's Adventures in Wonderland*, read by a female (www.librivox.org) was presented via ear-buds at multiple times during each 2-3 day admission. Testing occurred when the patient appeared most wakeful.

Screening: EEG recordings were analyzed after screening for motion artifacts and drowsiness. Yield was 78.2% (43 of 55 datasets) for PS and 71.8% (23 of 32 datasets) for HC. Data from 2 HCs and PS02 were discarded.

Preprocessing: The EEG was bandpass-filtered at 2-15 Hz. The audio was annotated for phonemes using Praat [1] to obtain markers for extracting time-locked responses.

Analysis

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

The analysis was done at the level of consonant phoneme categories. The audio sample contained 173 **approximants**, 254 **fricatives**, 142 **nasals**, and 312 **plosives**.

The analysis interval was from 20 ms to 420 ms after the start of a phoneme, with the average signal over the 200-ms period prior to the phoneme used as baseline. For each time-point, we determined the Wilcoxon rank-sum statistic for responses to a pair of phoneme classes. An empirical distribution of the statistic was then generated by shuffling phoneme class labels that occurred at similar times in the trial. A difference was considered significant if the raw p-value (two-tailed) obtained from this distribution was below the FDR-corrected cutoff at p=0.05. This procedure was carried out for each channel and all 6 pairwise comparisons.

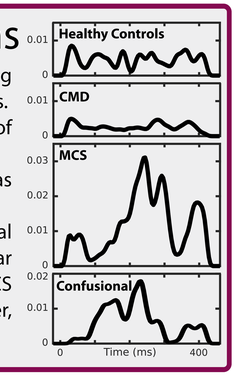
We analyzed the data in two ways:

Spatial pattern: Frequency of significantly different responses, at a given channel and at any time.

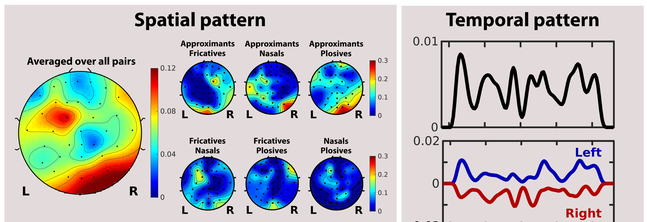
Temporal pattern: Frequency of significantly different responses, averaged across all 6 pairwise comparisons, and all channels, at a given time.

Summary and Conclusions

- We present an EEG-based method of detecting linguistic processing at the level of phoneme class.
- All patients analyzed showed EEG evidence of differential processing of phoneme classes.
- The spatial pattern of differential responses was highly variable in healthy subjects and patients.
- In this limited patient sample, the temporal pattern of responses in CMD patients was similar to that of healthy controls; while responses in MCS and confusional patients tended to occur later, and, surprisingly, with greater frequency.



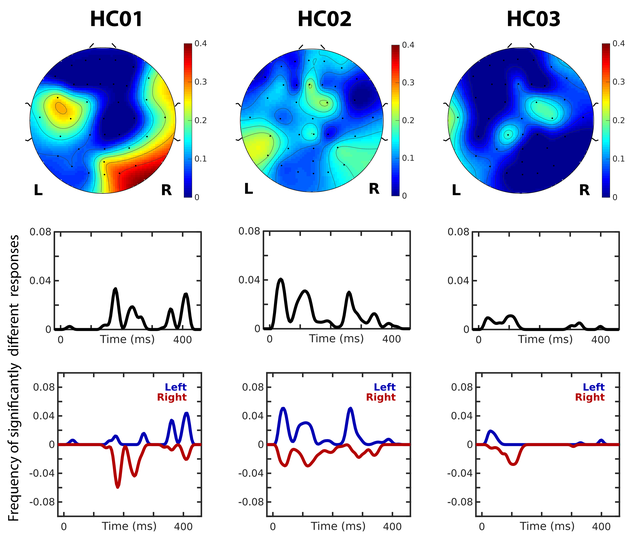
Healthy Controls (n=8)



Scalp topographies showing the frequencies of observing significantly different responses averaged across the 6 phonemic pairs (left), and for individual pairs (right), averaged across healthy controls. As expected from the location of Broca's area, there is a left posterior frontal peak. However, we also observe that there are significant differences between responses to phoneme classes in midline channels and the right hemisphere as well, especially in the posterior occipital region.

Response differences occurred throughout the analysis window (20 to 420 ms), as expected from the results of [2]. There was no systematic dependence of the timecourse of responses on the specific pair of phoneme classes being compared.

As shown by these three examples, there was a wide diversity of spatial and temporal response patterns in healthy controls.



Cognitive-Motor Dissociation (n=10)

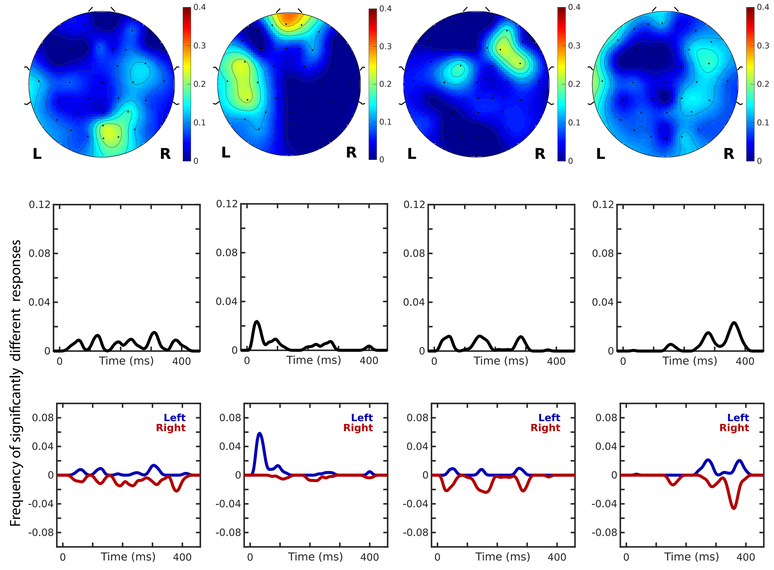
All CMD patients showed EEG evidence of differential processing of phoneme classes. While there was substantial variability across individuals, differential responses tended to occur early in the analysis window.

PS06
1 year post-TBI; predominantly left hemisphere damage; visit 1; CRS-R = 17

PS08
8 years post-TBI; diffuse axonal injury; visit 2, CRS-R = 7

PS09
7 years post-TBI; diffuse axonal injury; visit 1, CRS-R = 10

PS11
9 years post-TBI; severe generalized volume loss; visit 1; CRS-R = 6

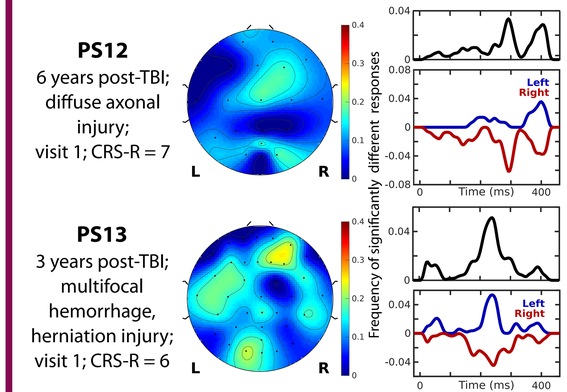


Minimally Conscious State (n=2)

Both MCS patients showed EEG evidence of differential processing of phoneme classes, One had an early peak in differential responses; both had differential responses late in the analysis window.

PS12
6 years post-TBI; diffuse axonal injury; visit 1; CRS-R = 7

PS13
3 years post-TBI; multifocal hemorrhage, herniation injury; visit 1; CRS-R = 6

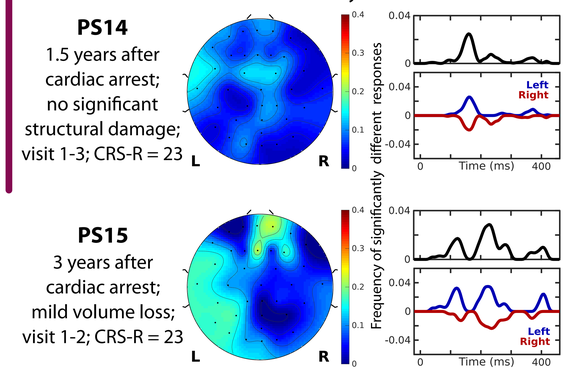


Confusional State (n=2)

Both confusional state patients showed EEG evidence of differential processing of phoneme classes, primarily in the middle and end of the analysis window.

PS14
1.5 years after cardiac arrest; no significant structural damage; visit 1-3; CRS-R = 23

PS15
3 years after cardiac arrest; mild volume loss; visit 1-2; CRS-R = 23



References

1. Boersma, Paul (2001). Praat, a system for doing phonetics by computer. Glot International 5:9/10, 341-345.
2. Khalighinejad, B., da Silva, G. C., & Mesgarani, N. (2017). Dynamic encoding of acoustic features in neural responses to continuous speech. Journal of Neuroscience, 37(8), 2176-2185.