Development of a functional EEG system for determination of awareness using mental imagery

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659.11

Introduction

FMRI has been used to demonstrate awareness and communication in patients who are clinically in the vegetative state (VS) and low-level minimally conscious state (MCS).[1,2]

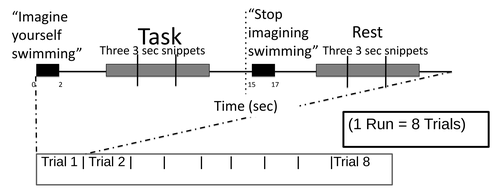
There are obvious practical limitations to the development of a fMRI communication tool for severely brain injured patients.

EEG testing at the bedside has several advantages. It is inexpensive, allows study of patients who cannot travel, and allows repeated testing of patients in different states of arousal.

Quantitative EEG analysis, specifically calculation of power spectra, can be used to index changes in brain activity.

We demonstrate here EEG power spectral changes in healthy controls and patient subjects asked to perform a motor imagery task. Patient subjects chosen all showed significant BOLD changes on a related fMRI task (see 659.7).

Methods



Pre-processing
1. Manual rejection of snippets with visible motion artifact
2. Removal of 60Hz line noise
3. Removal of EMG and eye movement artifact with ICA

Analysis
1.Application of Laplacian montage
2.Application of Multitaper Fourier transform to each snippet[3,4]

Frequency-by-Frequency Analysis

1.Two Group Test (TGT)[4] performed for each channel from 4 to 24Hz

2.FDR applied to TGT results to correct for multiple comparisons (all runs combined only)

Test for Combination of Frequencies

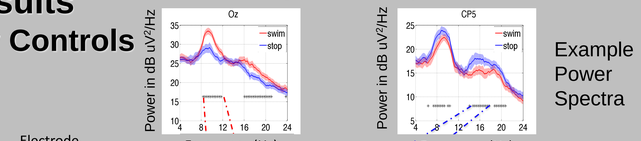
1.Fisher Linear Discriminant (FLD) created for each channel from differences of log power between task and rest, using 2Hz-wide bins, 4 to 24 Hz

2.FLD p-value calculated from 1000 shuffles of task and rest

3.FDR applied to FLD p-value to correct for multiple comparisons

Results Healthy Controls

Single Runs (HC1)



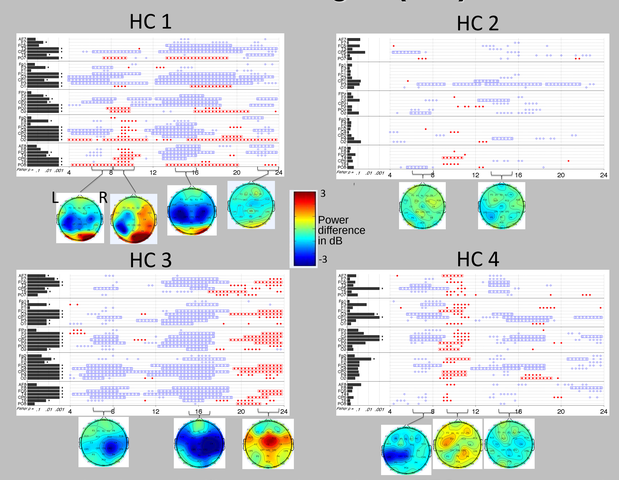
Example Power Spectra

Power Spectral Differences p≤.05

- Swim > Stop
- Stop > Swim

Rectangles drawn around significant differences contiguous over ≥ 2Hz range.

All Runs Averaged (N=4)



All healthy controls show significant and consistent EEG power spectral changes during motor imagery (above) and navigation imagery (not shown).

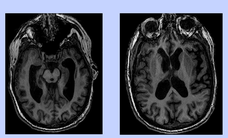
Changes at individual frequency bands, as measured by the TGT, are more sensitive than combinations of changes, as measured by the FLD.

Signal patterns vary across subjects as well as between runs.

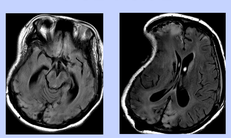
Description of Patient Subjects and Results

Patient Subject		Age	Time (months)	Mechanism of Injury	Diagnosis
1		25	25	trauma	LIS
2	Visit 1	19	6	trauma	MCS
	Visit 2	19	10		Emerged from MCS
3	Visit 1	24	31	Stroke of the pons, midbrain, thalamus and right medial temporo-occipital lobes	MCS
	Visit 2	25	43		MCS

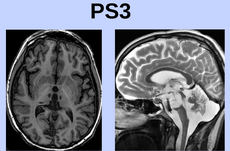
PS1



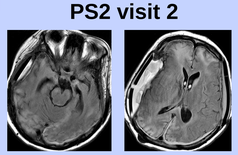
PS2 visit 1

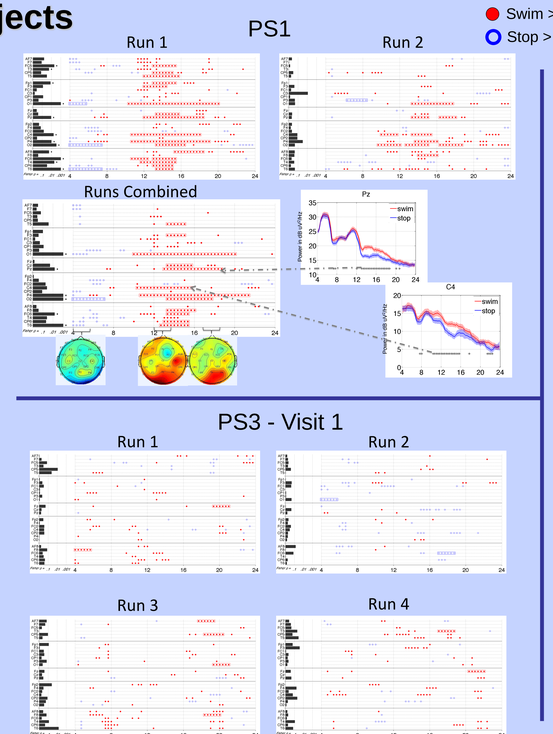


PS3



PS2 visit 2





Criteria for Positive Findings

1 Significant spectral power differences observed at same frequency and channel locations across runs.

2 Spectral power differences remain significant when all runs are averaged, and FDR corrected for multiple comparisons.

Results from PS1 and PS2 - visit 1 meet both criteria and are declared positive, though their frequency locations differ from healthy controls.

Results from PS2 - visit 2 and PS3 at both visits (visit 2 not shown) only meet criteria 1 and are declared indeterminate.

Conclusions

- EEG power spectral analysis can be used to index command following in patients with disorders of consciousness and shows promise for development of a brain computer interface
- Signal patterns vary across healthy controls and patients requiring individualized outcome measures

Limitations

- Variation between runs
  - Seen in Controls and Patient Subjects
  - Leads to indeterminate results in 2 PSs.
  - Implies sensitivity to variations in task performance
- Muscle artifact obscuring signal
  - ICA pre-processing only partly successful and time-intensive
- Future work would benefit from source localization for co-registration with fMRI and automated artifact removal for real-time communication

References

1. Owen AM, et al., Detecting Awareness in the Vegetative State. *Science* 313: 1402, 2006.
2. Monti MM, et al., Willful Modulation of Brain Activity in Disorders of Consciousness. *N Engl J Med* 362: 579-589, 2010.
3. Thomson DJ. Spectrum estimation and harmonic analysis. *Proceedings of the IEEE* 70: 1055–1096, 1982.
4. http://Chronux.org