Mapping BCI task imagery brain responses using MEG beta power desynchrony effects

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Introduction

Beta-band power desynchrony effects have been traditionally linked to brain motor-related activities, but also broadly linked to cortical engagement during cognitive processing function (Pfurtscheller et al., 1999). We utilized these effects to localize magnetencephalography (MEG) responses related to motor- and cognitive-imagery task activities of a brain-computer interface (BCI) experiment.

Materials & Methods

We analyzed MEG data from two sessions of a BCI experiment completed by 17 healthy individuals. The BCI task consisted of two motor and two cognitive imagery activities. During the motor task, participants imagined the movement of both hands/both feet when the cue appeared on the screen. During cognitive imagery tasks, participants either subtracted two numbers presented as cues or generated words related to an English language letter presented as a cue (**Fig. 1**). Each session consisted of 50 trials of each imagery task with a total of 200 trials. MEG data were preprocessed using a combination of spatiotemporal Max-filtering, signal thresholding, and ICA decomposition. 3-second data after the presentation of a cue from each imagery tasks were analyzed using a differential beamforming analysis against 400 ms pre-cue baseline. To avoid biases due to unequal data segments, active data were segmented and analyzed at 7 non-overlapping 400 ms length windows from 400 to 2800 ms interval. The average of source intervals was reported as presentative beta power effects. Beta source power was estimated using a frequency-resolved DICS beamformer (Gross et al., 2001) in a frequency range of beta 17-25Hz (Youssofzadeh et al., 2020). The cross-spectral density of active and baseline responses were estimated using a fast Fourier transform and multitapering with multiple tapers from discrete prolate spheroidal sequences (dpss) sequence to have sufficiently smooth spectra. Source activations were estimated on cortical surfaces obtained from Freesurfer segmentation analysis of anatomical MR of individuals. Group average source modeling was conducted after projecting source activities of each task responses on a cortical surface template, available in Brainstorm toolbox. Source activations were reported using a 70% maximum of absolute source power (**Fig. 3**).

Fig. 1.

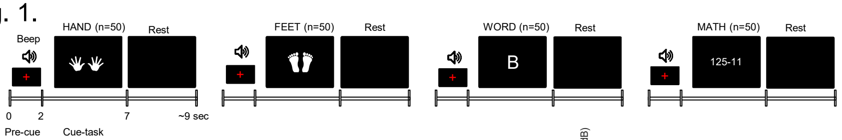

Fig 1. BCI paradigm. Participants completed 2-runs of a task-imagery (BCI) MEG experiment consisting of two motor- (hand and feet movement) and two cognitive (word and math) tasks. During the pre-cue period, a red fixation cross ("+") was presented. During a cue-task period, a picture was presented corresponding to each of the 4 imagery task conditions of HAND, FEET, WORD, and MATH. During the HAND condition participants imagined grasping with hands movement. During the FOOT, participants imagined both feet upward movement. During the WORD, participants generated a word starting with a letter shown on the screen. The letters were randomly selected from A-Z. During the Math condition, participants completed a simple (1-digit against 1-digit) subtraction task.

Fig. 2.

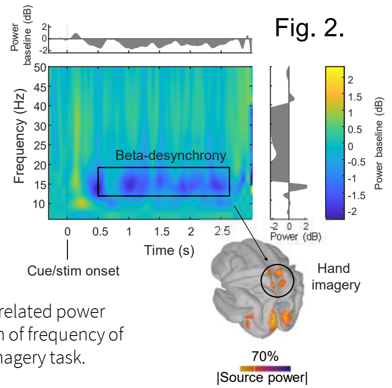

Fig 2. Time-frequency response (TFR) map. Average of all sensor-level event-related power changes relative to baseline (-300, 0 ms) were utilized to support the selection of frequency of interests, findings from an individual completing a Hand movement motor imagery task.

Results

- We utilized beta-desynchrony ERD effects and a frequency-resolved beamformer to localize task-induced magnetencephalography (MEG) activations of a BCI experiment (Pfurtscheller et al., 1999; Gross et al., 2001);
- 17 Participants completed 4 imagery tasks, HAND, FEET, WORD, and MATH;
- Group source localization showed prominent desynchrony effects in bilateral premotor and motor areas during **Hand** and **Feet** conditions, with stronger effects at the left-hemispheric regions.
- Findings for two cognitive conditions (**Word** generation and **Math** solving) showed strong left-hemispheric desynchrony effects in the temporal (superior temporal gyrus) and parietal (supramarginal gyrus) and (inferior) prefrontal gyrus regions, all known to be involved in cognitive (language) and comprehension (arithmetic) processes (**Fig. 3**).

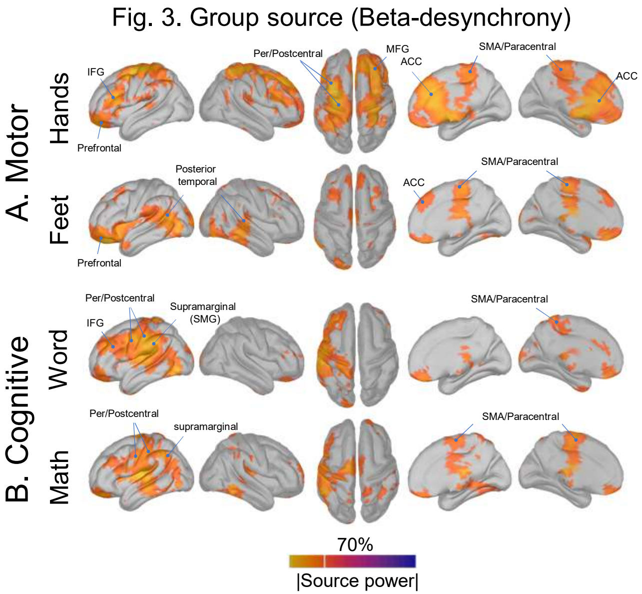

Fig. 3. MEG beta-band (17-25Hz) source responses during BCI motor and cognitive task imagery activities. Group averaged localized sources corresponding to (A) motor (hand and feet motor imagery) and (B) cognitive (word and math imagery) tasks as identified by the DICS beamformer source analysis (post- vs. pre-stimulus intervals) in a frequency range of 17-25Hz in 17 healthy control.

Hands movement (motor) imagery
- Bilateral supplementary motor area (SMA)/ paracentral lobule and precentral and postcentral gyri. These regions has motor and sensory functions related to the lower limb.
- Anterior cingulate cortex (ACC): part of the default network and has been implicated in focus attentional processes.

Feet movement (motor) imagery
- Bilateral SMA and ACC, and bilateral posterior temporal regions (memory-related activities).

Word generation (cognitive) imagery
- Left-hemispheric dominance, asymmetry;
- Left frontoparietal activations, SMG (posterior STG), pre- and post-central gyrus, and IFG cortical regions.

Math solving (cognitive) imagery
- Left-hemispheric dominance, asymmetry;
- Left frontoparietal activations, SMG (posterior STG), pre- and post-central gyrus, and IFG cortical regions (lower than word).

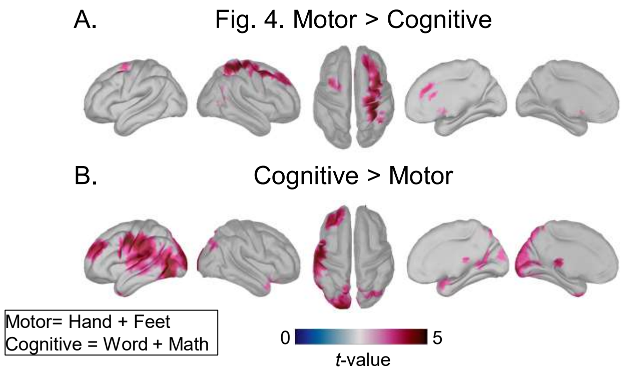

Fig 4. Motor-vs-cognitive tasks source comparison. *t*-values were derived from a between-subject paired sample *t*-test beta desynchrony source power of (A) motor > cognitive and (B) cognitive > motor. Motor: represent average Hand and Feet beta- desynchrony effects. Cognitive: represent average Word and Math beta- desynchrony effects.

Motor > Cognitive
- Right hemispheric dominance, right SMA and

Cognitive > Motor
- Left hemispheric dominance, left SMG and left MFG.

Conclusions

- Our work demonstrates the suitability of beta-power suppression effects for localizing both motor and cognitive activities in a BCI application.
- Biomarkers derived from beta source power can potentially be used for clinical applications, e.g., to characterize motor or cognitive impairments in patients with epilepsy.

References

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Acknowledgments & Software

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- Software is available at, https://github.com/vyoussofzadeh/DICS-beamformer-for-Brainstorm.