# Independent modulators of regional EEG alpha sub-band power during a working memory task


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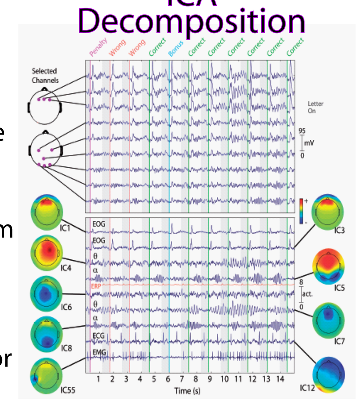
## BACKGROUND

Previous studies have suggested that upper and lower alpha-band power are separately regulated during certain cognitive processes. A shortcoming of those studies was that alpha power was summed across several scalp channels.

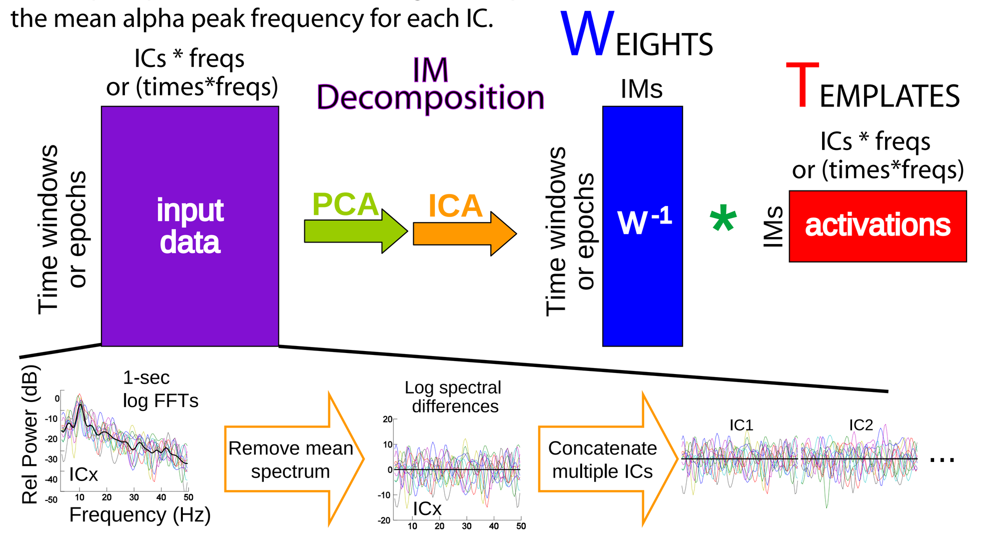
Here we show that alpha sub-bands are, indeed, separately regulated and occur within single EEG independent component or source domains.

## ANALYSIS



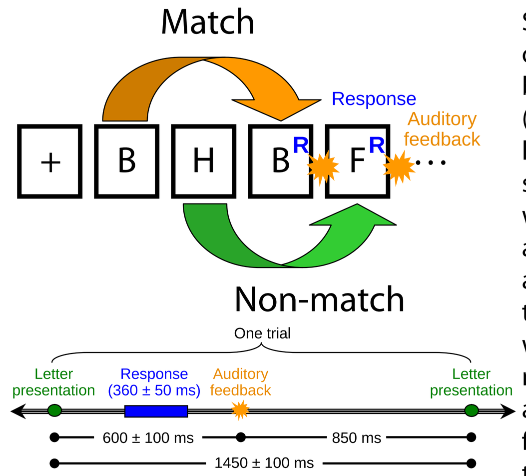

EEG data from each task was decomposed within-subject using independent component analysis (ICA) to isolate temporallyindependent sources of EEG activity from the mixed data recorded at each scalp channel (see inset for channel/IC comparison. Brain independent components (ICs) were selected for each subject based on estimated equivalent dipole location, power spectrum and event-related activity.

Independent modulator (IM) decomposition was performed on power spectra from 1-sec epochs of data using variably overlapping windows (every 75-200 ms for event-related datasets and every 500 ms for emotion imagination dataset). For each IC, 1-sec spectral windows were decomposed using wavelet analysis to yield a individual power spectra. The mean power spectrum across windows was removed, leaving only spectral modulations from the mean for each window. These spectral modulations were then concatenated for all brain ICs (see diagram). These (windows x freqs) matrices were decomposed by principal component analysis (PCA) and the top 100 PCs were further decomposed by ICA to find independent modulators of the power spectra. The 'activations' matrix reveals the spectral templates of each IM and the inverse 'weight matrix' gives the strength of each template during each input spectral window (see diagram). Alpha IMs were defined to be +/- 2. 5 Hz around the mean alpha peak frequency for each IC.



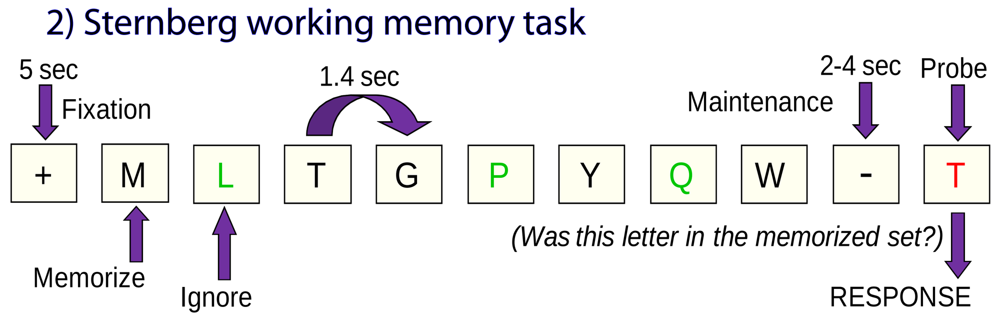

## TASKS

### 1) Twoback continuous performance task




Subjects were presented a sequence of single letters whose durations varied based on subject performance (SOA ~1.5 s). Beginning with the third letter, subjects responded to each letter, specifying with a right or left thumb press whether the current letter was the same as the one presented two before. An auditory feedback signal at letter offset told the subject of whether their answer was correct or wrong. 850 ms later, the next letter was presented. Correct responses added 1 cent, and incorrect responses or failures to respond deducted 1 cent from the subject's performance bonus. After 20 percent of correct responses, a different feedback tone signaled a larger (5 cent) 'bonus.' Similarly, following 10 percent of incorrect responses another tone signaled a larger (5 cent) 'penalty'. Finally, in 6 percent of trials, a 'neutral' feedback signal withheld performance feedback.

### 2) Sternberg working memory task

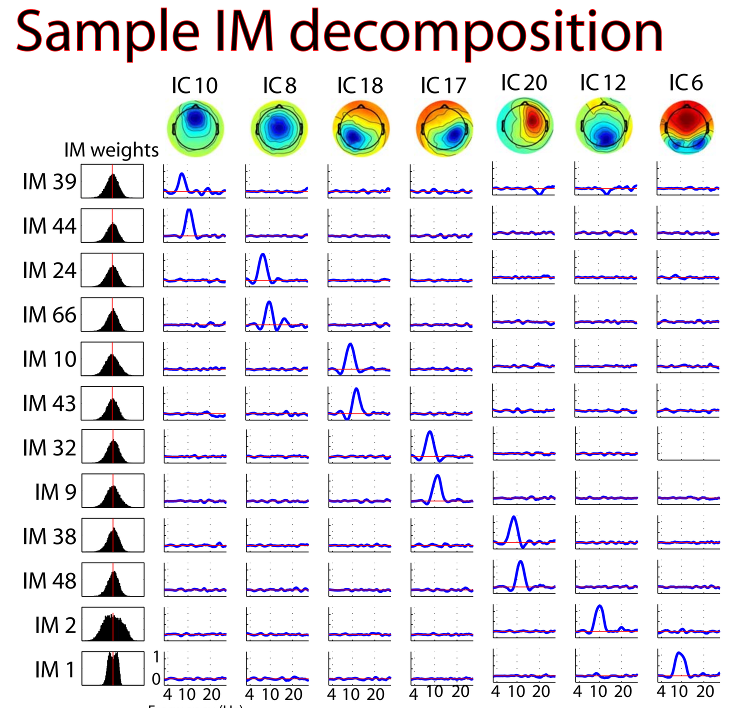



Each trial began with a 5-sec fixation cross, followed by 7 letters presented sequentially. Between 3 and 7 of the letters were black (to be memorized) and between 0 and 4 were colored green (to be ignored). After a variable delay period (2-4 sec), a red-colored probe letter was presented, to which subjects had to respond 'yes' or 'no', via a left or right mouse click, whether the probe letter was presented among the black (memorize) letters.

### 3) Emotion imagination

Imagination of emotional states was encouraged and guided by a set of pre-recorded verbal suggestions. Guided imagery narratives focused on fifteen emotions were then presented, separated by voice-guided relaxation interludes. For example, for the emotion 'excitement', a suggested situation was "perhaps something you dreamed of experiencing is finally about to arrive, something that opens up new exciting possibilities for you." Emotion sequence alternated pseudo-randomly between positive emotions (love, joy, happiness, relief, compassion, contentedness, excitement, awe) and negative emotions (anger, jealousy, disgust, frustration, fear, sadness, grief). Subjects were asked to take as much time as they needed to recall or imagine a scenario that would induce an experience of the suggested emotion. Subjects were asked to employ whatever imagery they deemed suitable for stimulating a vivid and embodied experience of the suggested emotion, and to pay attention to somatic sensations associated with the target emotion.

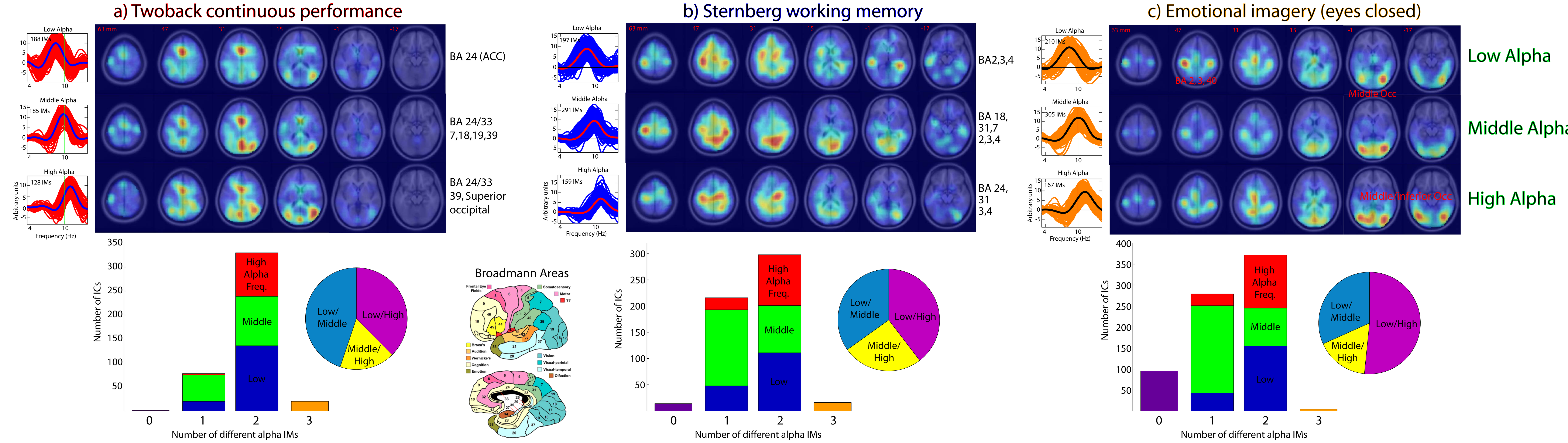
## Sample IM decomposition




## 1) What brain sources express alpha modulators?

### ... and how many alpha modulators does each source have?

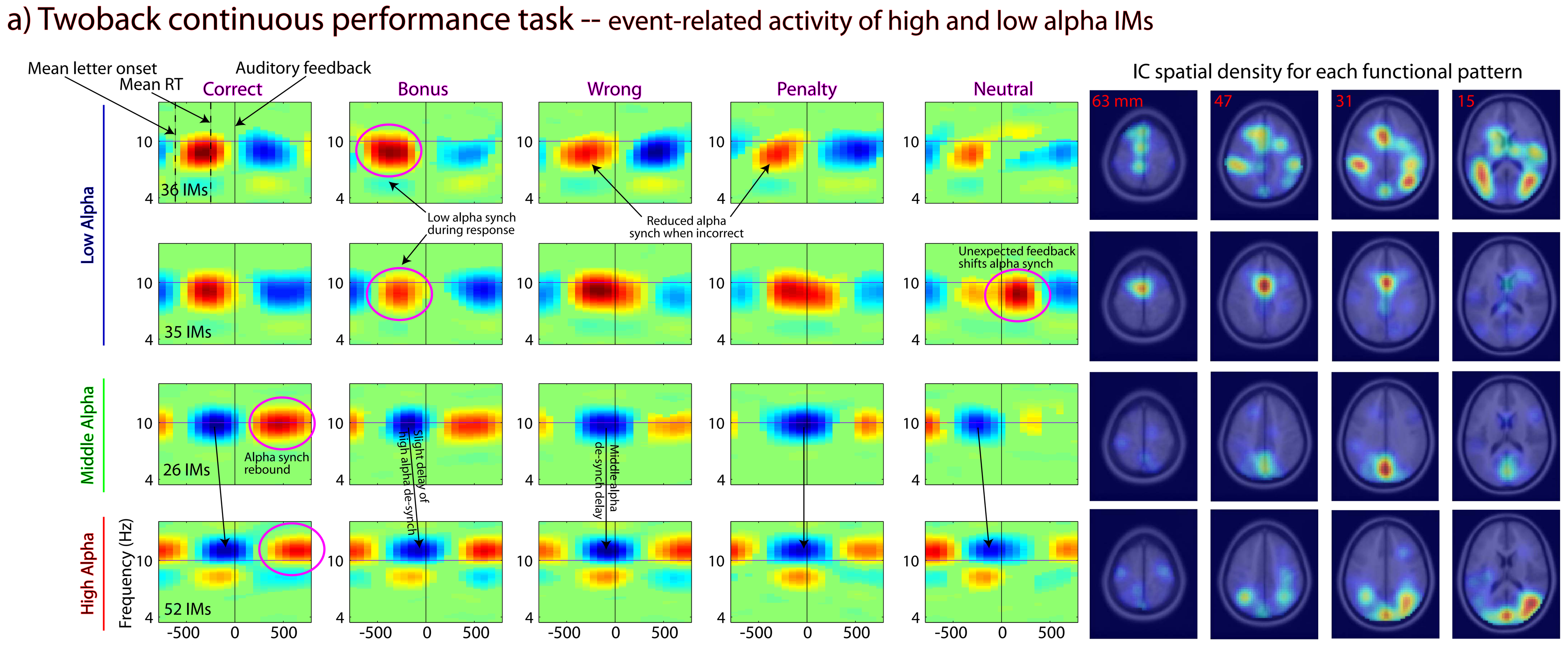
a) Twoback continuous performance — b) Sternberg working memory — c) Emotional imagery (eyes closed)




**Question1. Quantification of alpha modulators (IMs) within components (ICs).** Across 3 different tasks with variable cognitive demand, the number of alpha modulators (low, middle or high frequency) varies slightly. However, individual ICs (putatively cortical source domains) usually express more than one alpha IM in all 3 tasks presented here. When 1 alpha IM is expressed, it is most often witha frequency close to the mean alpha frequency (larger green segment for 'number of different alpha IMs' equal to 1 bars). When 2 alpha IMs are expressed, the combination usually favored low/middle or low/high frequencies as opposed to middle/high, though these distributions were more equally split during the Sternberg task (medium cognitive load). Rarely were there no alpha modulators in either working memory task, whereas about 100 ICs in the emotional imagery task showed no alpha IMs. In all 3 tasks, it was rare for a single IC to express all three low, middle and high alpha IMs.

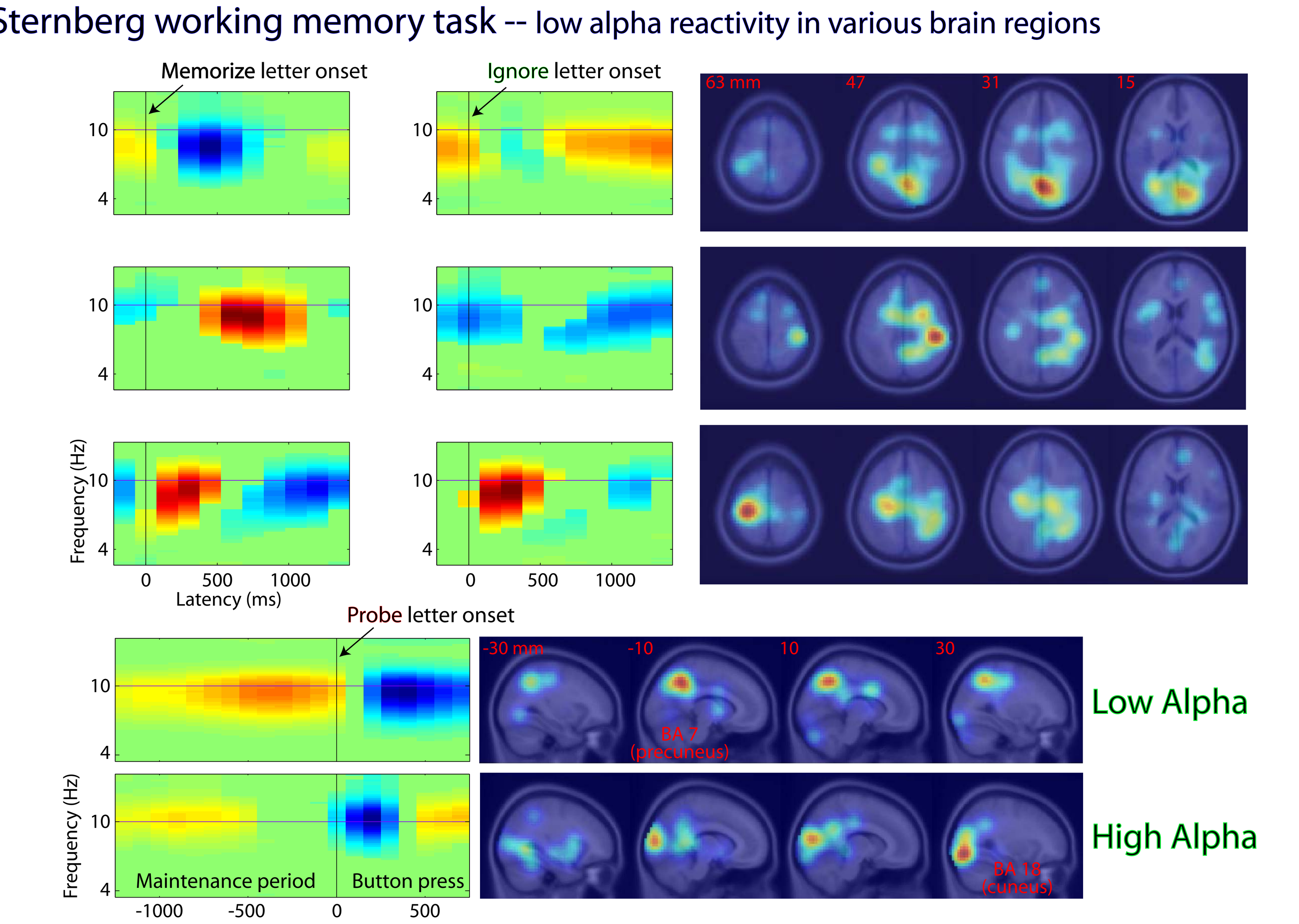
## 2) What are the task-related functions of high and low alpha?

### a) Twoback continuous performance task -- event-related activity of high and low alpha IMs



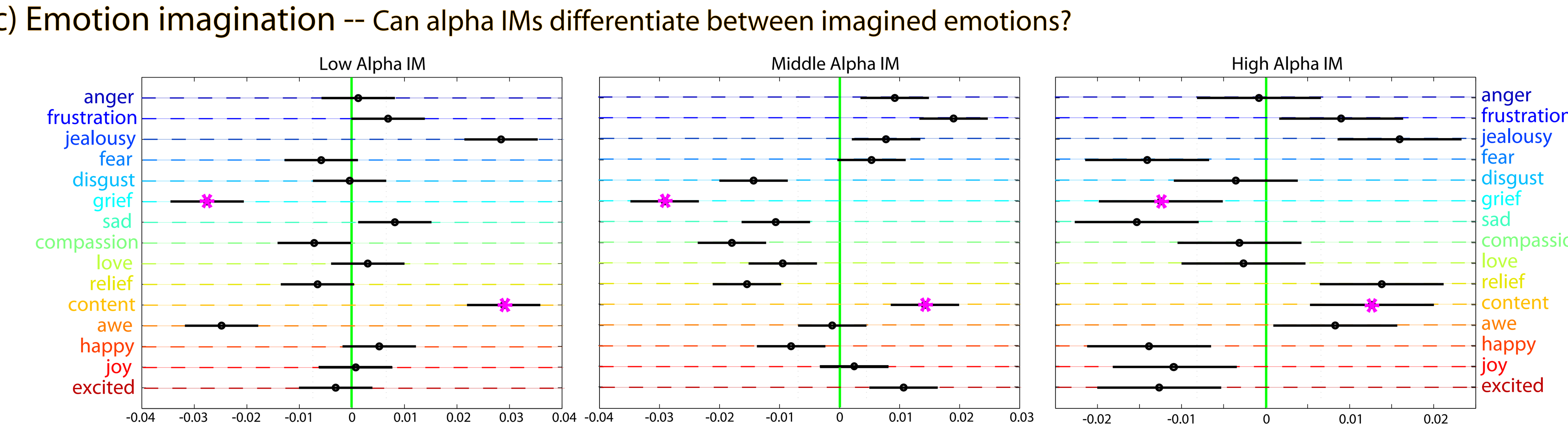

Low, middle and high alpha IMs respond with variable patterns and latencies relative to the events in the twoback task. Furthermore, low alpha (top 2 rows) show differential activation patterns between the 5 task conditions, notably between correct/wrong trials and when given an unexpected neutral feedback tone (2nd row).

### b) Sternberg working memory task -- low alpha reactivity in various brain regions




IM analysis in the Sternberg task reveals various patterns of low alpha activity during letter presentation occurring in spatially distinct areas of the brain. In addition, low alpha IM activity is altered by task condition, specifically whether the current letter is to be memorized or ignored. Finally, during the memory maintenance period and probe presentation, low and high alpha express slightly different time courses and localize to parietal (low alpha) or occipital (high alpha) cortex.

### c) Emotion imagination -- Can alpha IMs differentiate between imagined emotions?




Median IMs weights during each emotion period for low, middle and high alpha IMs collected across 32 subjects. Non-overlapping confidence intervals in each panel represent emotions whose means are significantly different from each other at $p < 0.05$.

* Emotions that have similar median weights in all 3 alpha IM clusters.

## SUMMARY

Functional brain imaging using EEG can elucidate the spatial location, temporal pattern and functional significance of oscillatory activity in the brain

- Alpha IMs are less widespread during eyes closed condition, constrained to occipital regions and are situated more inferior
- Alpha IMs are found prominently in ACC during a cognitively demanding and motivationally intense task.