New methods for analyzing trial-to-trial EEG spectral variability

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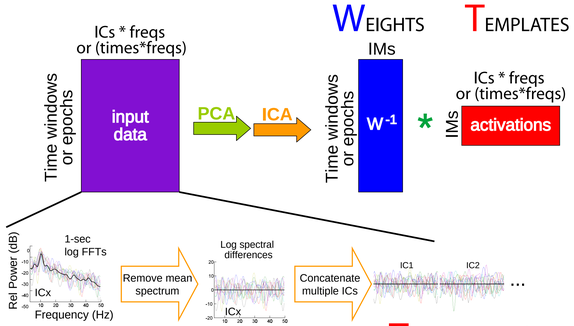
INTRODUCTION

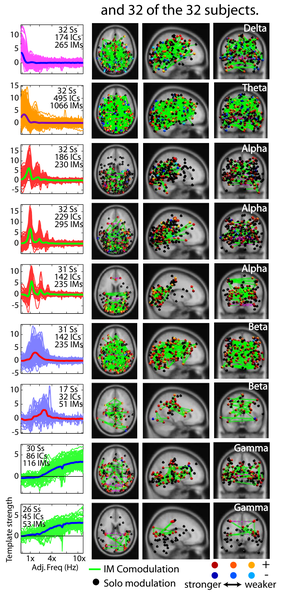
A basic feature of both scalp and intracranial EEG records is its marked second-to-second spectral variability. Known causes of this abundant spectral modulation include central brain arousal systems. Methods are needed to identify independently acting spectral modes and modulations directly from the data, and to identify actions of these modulator processes that are linked to features of the shifting behavioral context.

1) Weights/Template (WT) spectral decomposition

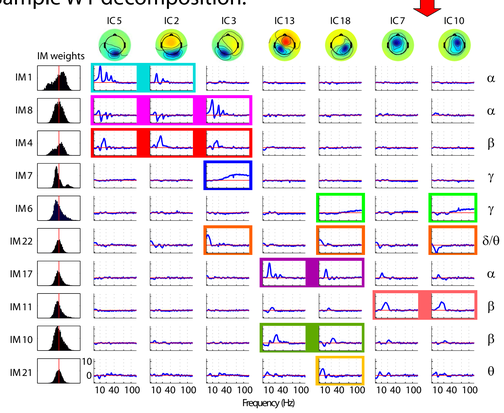
PURPOSE -- find independent modes of frequency modulation within and/or across independent component processes



Independent modulators (IMs) are consistent across subjects, as shown here for 9 IM clusters, each including between 17 and 32 of the 32 subjects.

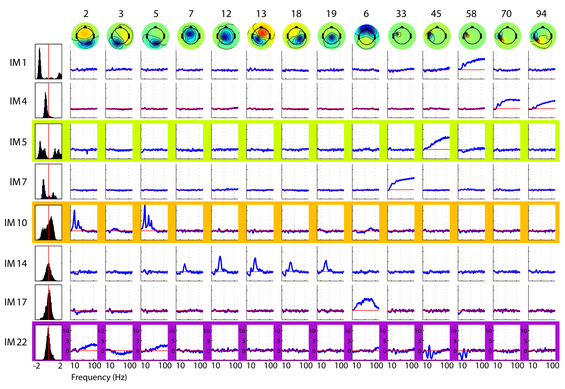


Sample WT decomposition:



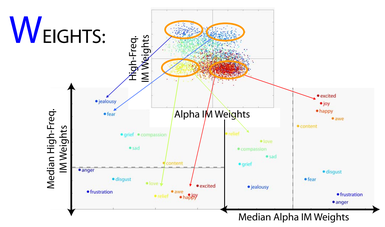
Spectral modulation templates from a brain-IC-only decomposition. Note that individual ICs can express several types of independent spectral modulations including broadband / high-frequency IMs (i.e. rows 4,5), beta-band IMs (rows 3,8,9), alpha-band spindling (rows 1,2,7) as well as theta (row 10) or delta activities (row 6). Histograms on the left show the distributions of IM time weights across all 1-sec spectral windows.

WT decomposition including scalp muscle processes:

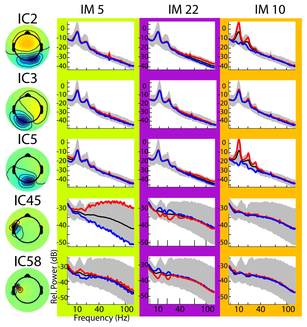


A sample decomposition that Included muscle components confirms that high-frequency activity in brain ICs is not the result of muscle activity since brain and muscle high-frequency activity appear in separate independent modulators (IMs). At right, the same IMs are shown relatvie to their respective mean power spectra to show a more intuitive representation of how the shape of the power spectrum changes with variations in IM weights. Note an intriguing mode of broadband comodulation (IM22) in which brain IC high-frequency power increases (here, in two occipital ICs) while alpha-band activity of muscle ICs (near the left ear) decreases. Brain/muscle interactions might also be better undedrstood using this decomposition.

WEIGHTS:

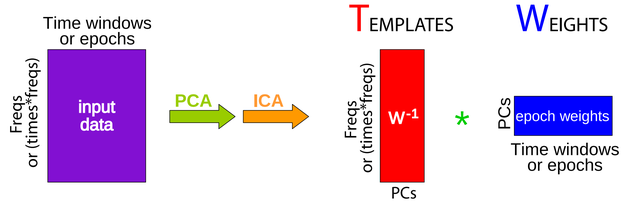


Time window weights from a WT decomposition can be used to associate shifts in IC power with specific behavioral markers. In this case, a subject was asked to experience imaginatively a series of emotions. Imagining different emotions was associated with different component spectra, as indexed by IM weight differences.

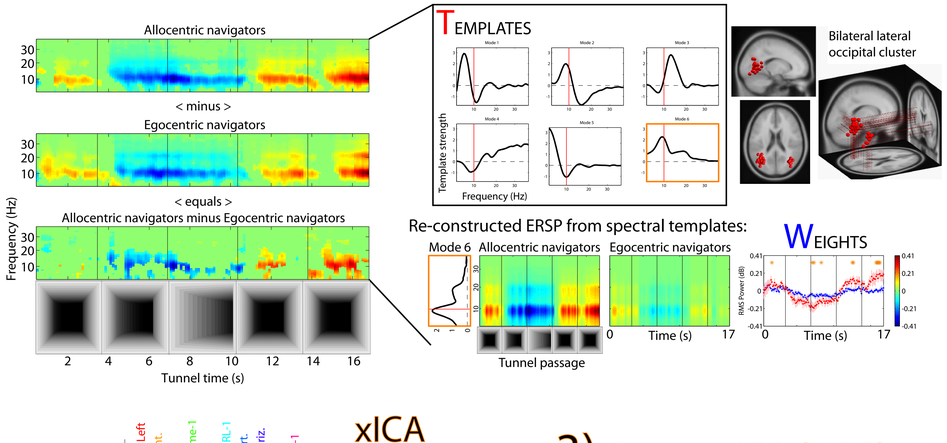


2) Template/Weights (TW) spectral decomposition

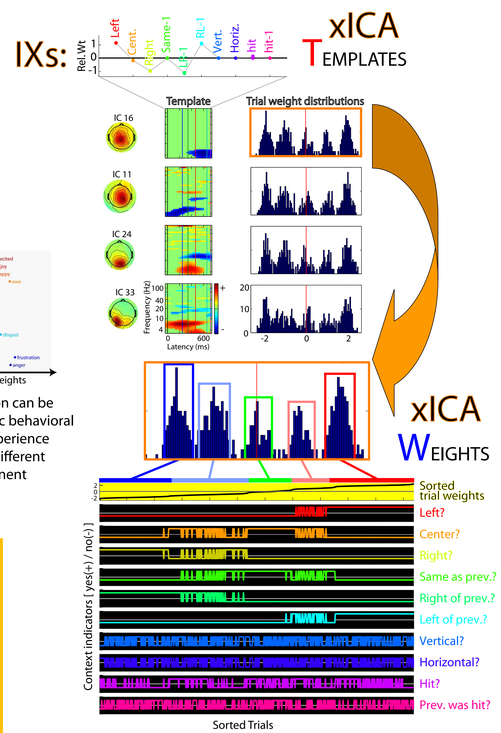
PURPOSE -- find independent, task-related spectral perturbation patterns



Across-subject spectral decomposition (TW):

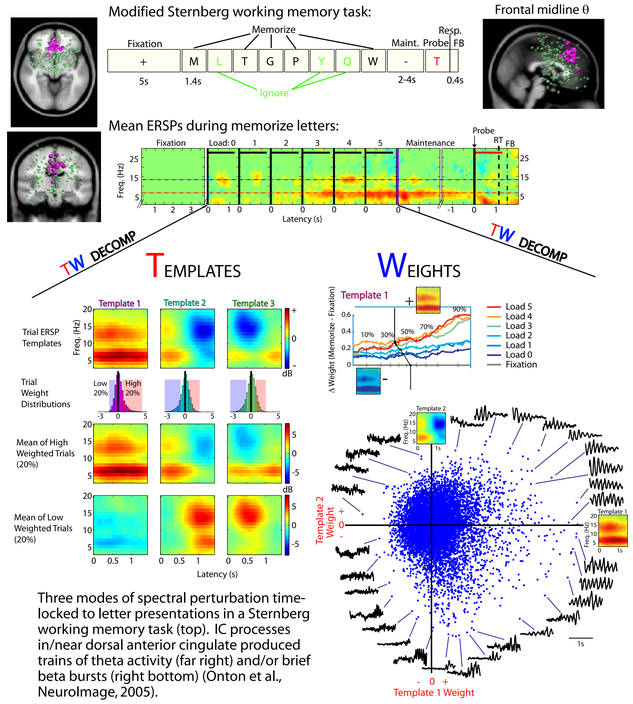


IXs:



A subject performed an active reaching task, sitting in the dark and attempting to touch buttons placed at arm's reach as they were illuminated. Motion capture sensors recorded arm movements, allowing the dynamic phases of each reach movement to be identified and co-registered with EEG activity. Above, a class of identical independent contexts (IXs) for several IC processes, computed separately, identified spectral perturbations associated with reaching to touch a button to the **left** of the previous target location. xICA here identified 5 distinct trial types in the data, each associated with a particular event context.

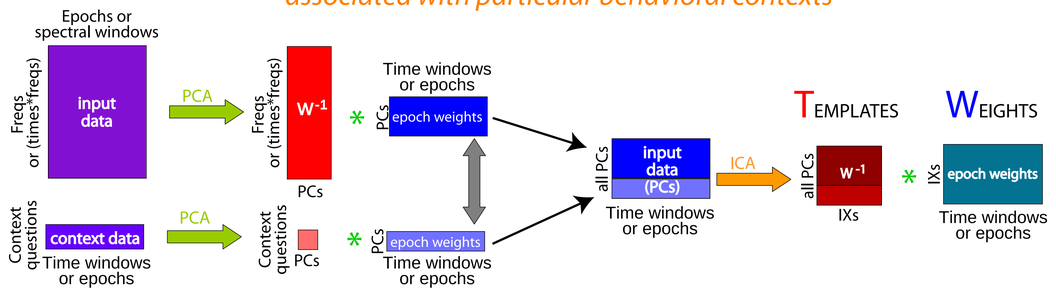
Across-subject ERSP decomposition (TW):



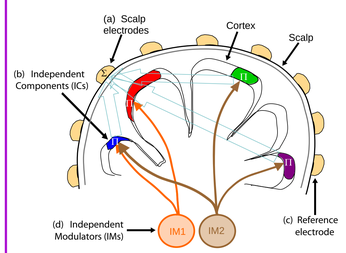
Three modes of spectral perturbation time-locked to letter presentations in a Sternberg working memory task (top). IC processes in/near dorsal anterior cingulate produced trains of theta activity (far right) and/or brief beta bursts (right bottom) (Onton et al., NeuroImage, 2005).

3) Context ICA (xICA): Special case of TW decomposition

PURPOSE -- find independent, task-related spectral perturbations associated with particular behavioral contexts



SUMMARY



Here we model EEG spectral modulations as produced by independent modulator processes of unspecified origin that act multiplicatively on the spectra of independent EEG component processes.

Understanding single-trial dynamics is essential for discovering the physiological significance of EEG activity. While past research has treated trial-to-trial variability as 'noise', results illustrated here demonstrate ways in which discrete modes of spectral variability may play more specific roles.

Here we present data-driven methods for identifying:

1) Modes of spectral modulation (WT)

2) Modes of spectral reactivity in single trials or time windows (TW) .