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Independent modulations of high-gamma band spectral activity in human scalp EEG distinct from scalp muscle activity

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QUESTIONS

1. Does high frequency activity (»40 Hz) from scalp EEG contain meaningful information?

2. Can high-frequency EEG activity be distinguished from scalp muscle artifact?

BACKGROUND

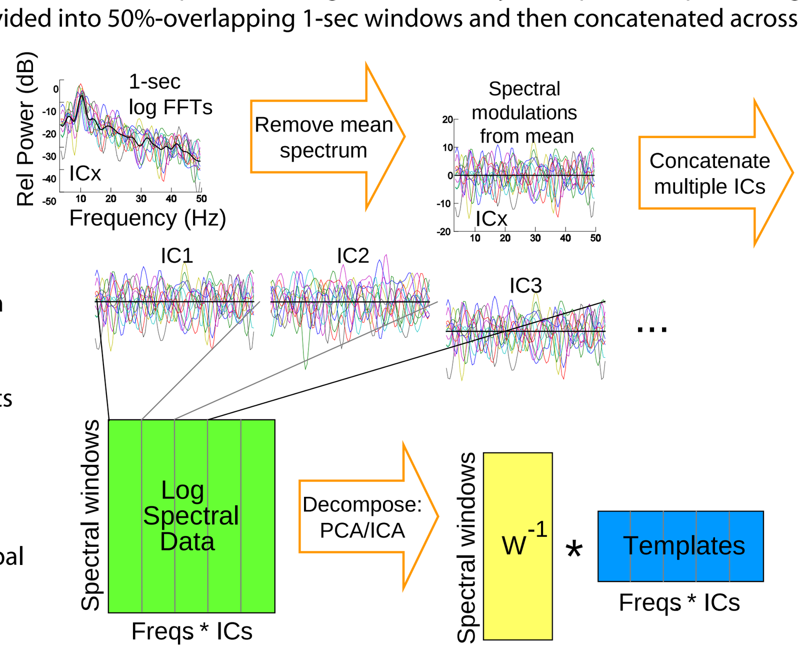
It has long been assumed that high frequency brain activity cannot penetrate the dura, skull and scalp with sufficient strength to be detected, much less modeled, by available EEG analysis techniques. An additional difficulty is the presence of confounding EMG from scalp muscles which is always present in EEG scalp recordings. Here we introduce a new form of independent component analysis (ICA) applied to the log spectrogram of temporally independent component (IC) sources that separates the actions independent broadband, non-periodic modulations (IMs) of brain and muscle (EMG) source activities in high-density scalp EEG.

METHODS

Young adults from the San Diego area (14 male, 20 female; age range: 18-38 (25.5 ± 5)) were guided through a series of emotional scenarios by a pre-recorded auditory narrative. Emotions were introduced with a short suggestion (~15-30 sec) of possible scenarios in which the emotion might arise and associated bodily sensations that might occur for the given emotion. Then during a self-paced silent period subjects attempted to imagine a suitable scenario, real or imaginary, and to experience the suggested emotion. Subjects were asked to maintain each emotional state for ~3-5 min. Data presented here were extracted from these emotional imagination periods

EEG data were submitted to extended infomax ICA (Lee et al., 1999) using the binica (Makeig et al., 1997) in the EEGLAB toolbox (Delorme, 2004).

For each subject, data were extracted from event-free periods during which the subjects reported experiencing the requested emotion. These data was divided into 50%-overlapping 1-sec windows and then concatenated across emotions. For each selected independent component (IC) process, a fast fourier transform (FFT, Welch method) was performed on each 1-sec window between 1 Hz and 128 Hz. The result of this decomposition was transformed into log power (dB = 10*log10(power)). For each component, the mean log power spectrum was subtracted from each epoch so that only fluctuations from the mean spectrum remained (see diagram). Power fluctuations for 10-40 selected components were then concatenated to yield a matrix with size (windows x frequencies * ICs). The resulting matrix was submitted to ICA after removing all but the first 30-50 principal dimensions of the data by principal component analysis (PCA). ICA returned maximally independent modulation (IM) modes or templates, as well as the weight of each IM in each time window (see diagram). To find common IMs across subjects, IM templates from each IC were represented independently and submitted to cluster analysis, sorting first for the frequency range with the highest absolute value and then further clustered by linking templates with minimal euclidean distance. ICs of an IM were labeled as 'comodulated' when more than one template from a single IM were independently grouped into the same cluster.



SUMMARY

1. Second-to-second changes in the levels of very high-frequency EEG activity (> 100 Hz) of EEG sources in these data reflect the actions of broadband modulations in EEG power across both low and high frequencies.

2. These broadband modulations do not reflect changes in scalp muscle activity, but rather adjustments in the high-frequency slope or fall-off in the activity spectra of one or more independent brain EEG processes.

3. Some broadband modulations shift the balance of high- and low-frequency power in brain IC spectra.

4. The broadband modulations reveal the actions of brain systems that control non-periodic / non-oscillatory modes of EEG activity.

1) Broadband modes of log power modulation of independent component (IC) activities

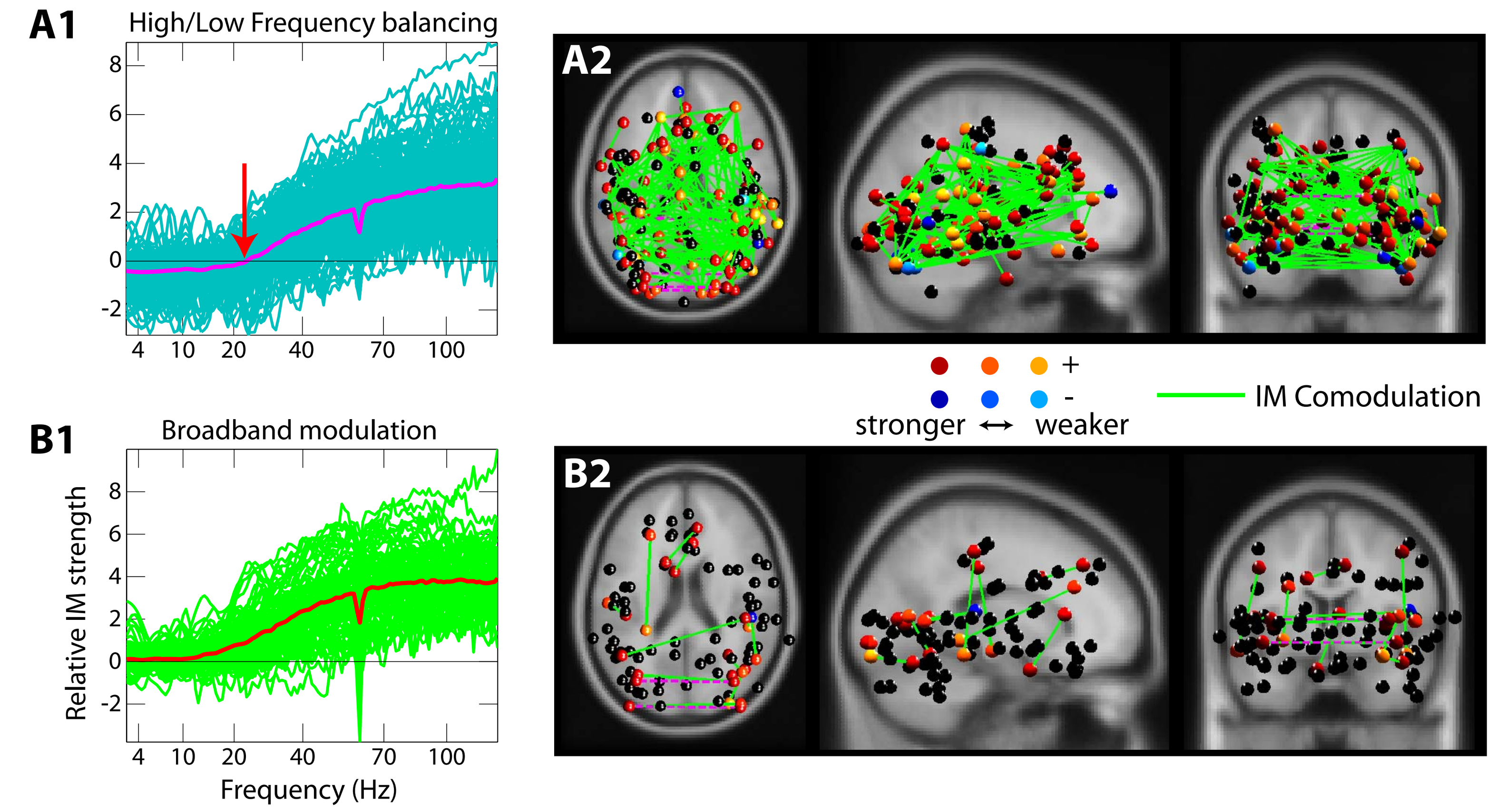


Figure 1. Two clusters of broadband modulations of log spectral power in brain IC signals. **(A)** IMs that shift power from low to high frequencies (or vice versa), often in multiple ICs. **(B)** IMs acting primarily on one IC producing broadband increases or decreases in log power -- equivalent to adjustments in the slope of the IC log frequency spectrum. (33 of 35 subjects are in these clusters)

2) Broadband scalp muscle IMs represent EMG activity

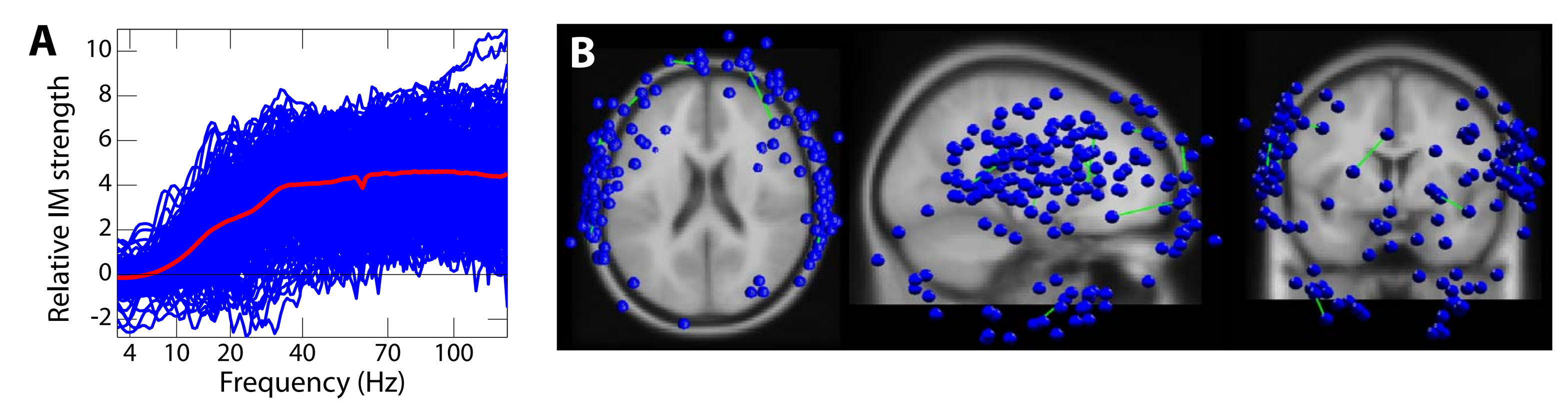
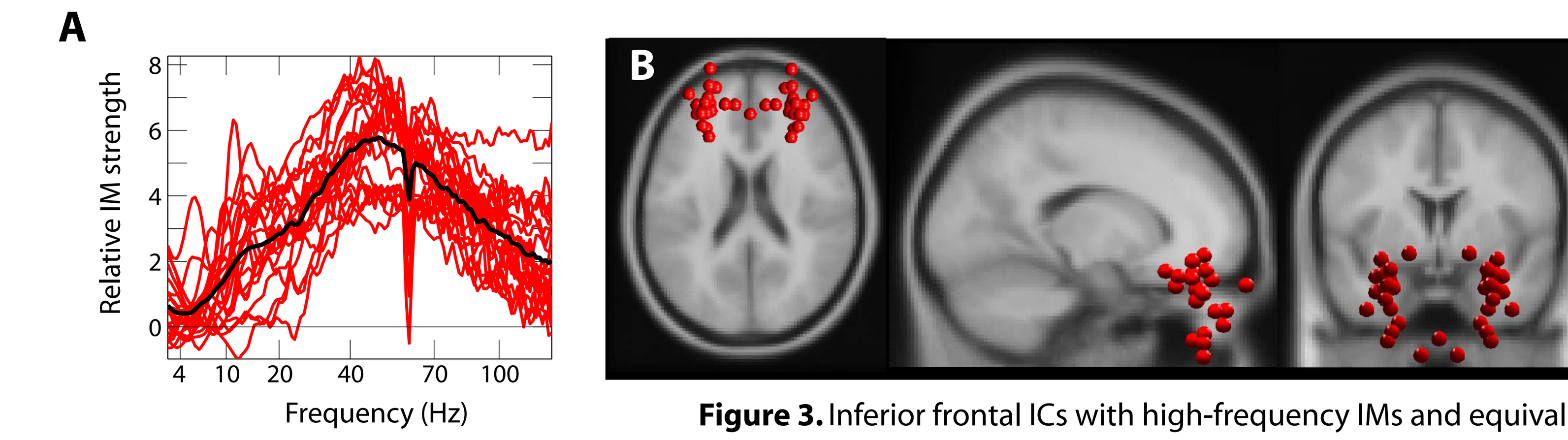


Figure 2. **(A)** Log spectral modulation templates for muscle ICs (mean shown in red) . **(B)** Best-fit equivalent dipoles for the muscle ICs expressing the log spectral modulations in **(A)**. (33/35 subjects represented)

3) Putative oculomotor tremor ICs show modes of log spectral modulation peaking near 50 Hz



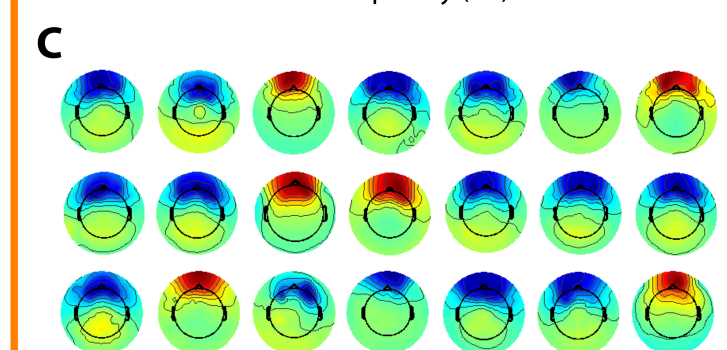
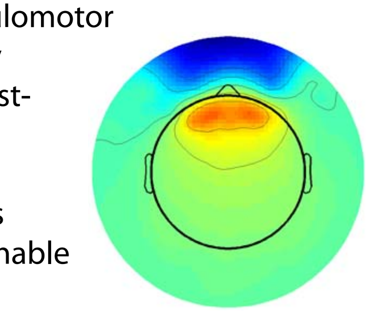


Figure 3. Inferior frontal ICs with high-frequency IMs and equivalent dipole locations compatible with binocular oculomotor tremor. **(A)** IM templates reveal high frequency power modulations peaking near 50 Hz. **(B)** Best-fit equivalent dipole locations were near eye sockets. **(C)** Scalp maps from the ICA inverse weight matrix for each of the inferior frontal ICs reveal a characteristic pattern that is distinguishable from eye blink by the lack of polarity reversal. (compare eyeblink IC map at right) (21/35 Ss)



Eyeblink IC scalp map

4) Broadband modulations of brain IC spectra are independent of muscle activity

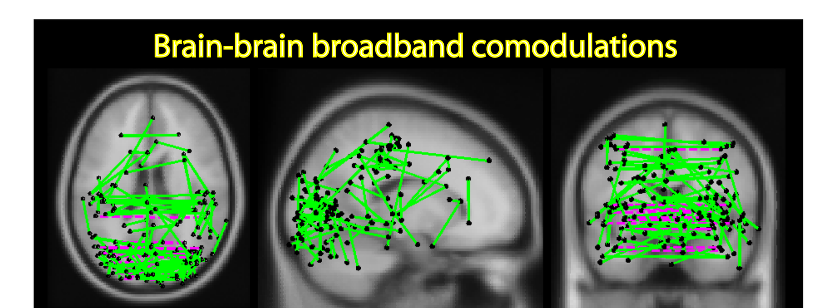
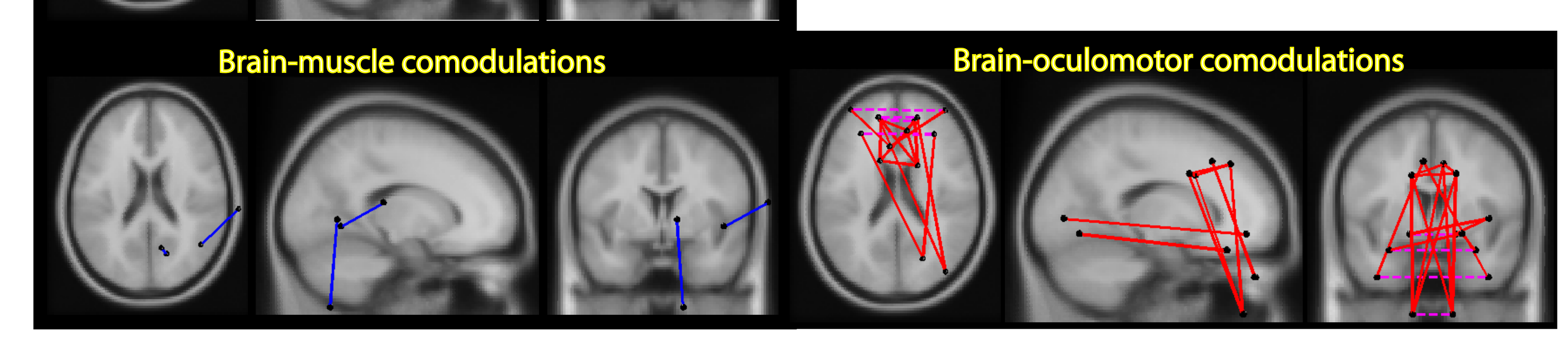
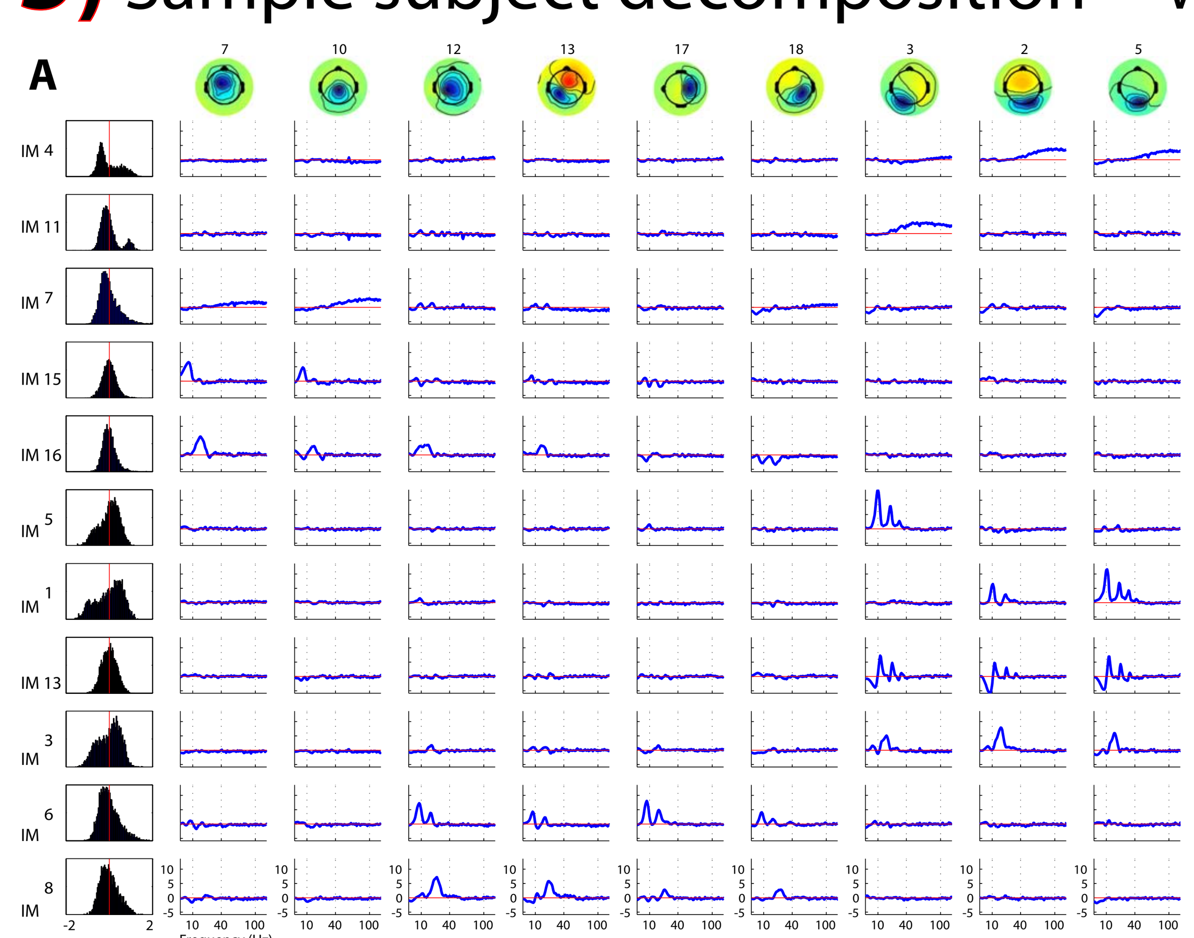
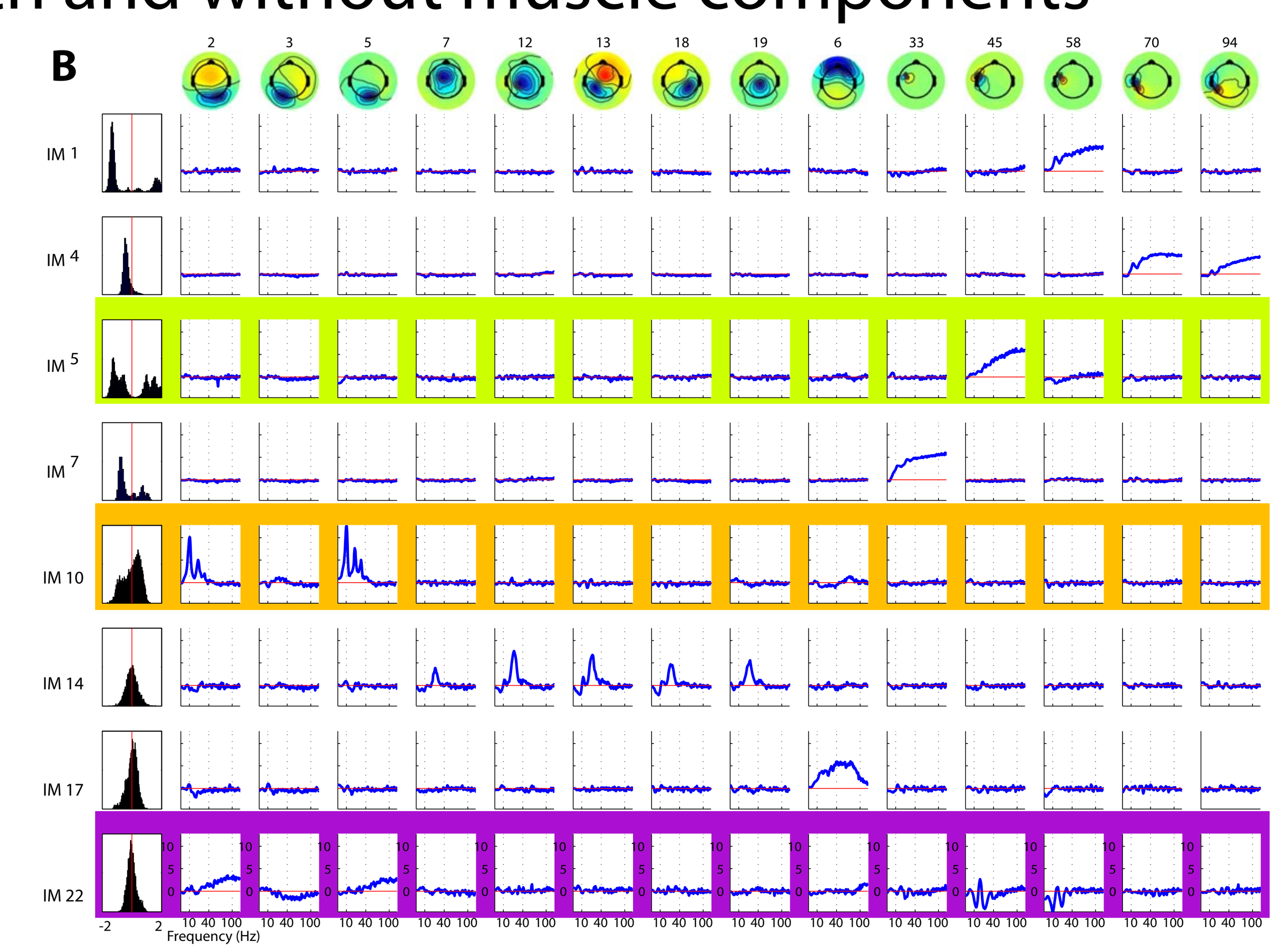


Figure 4. In spectral decompositions including both brain and muscle ICs, broadband IMs affecting both brain and muscle ICs were rarer than broadband IMs affecting more than one brain IC. Black spheres represent equivalent dipole locations. Lines between them (green: brain-brain, blue: brain-muscle, red: brain-oculomotor) connect IM component templates that were correlated (r > 0.75) with the largest IC template for each IM.



5) Sample subject decomposition -- with and without muscle components





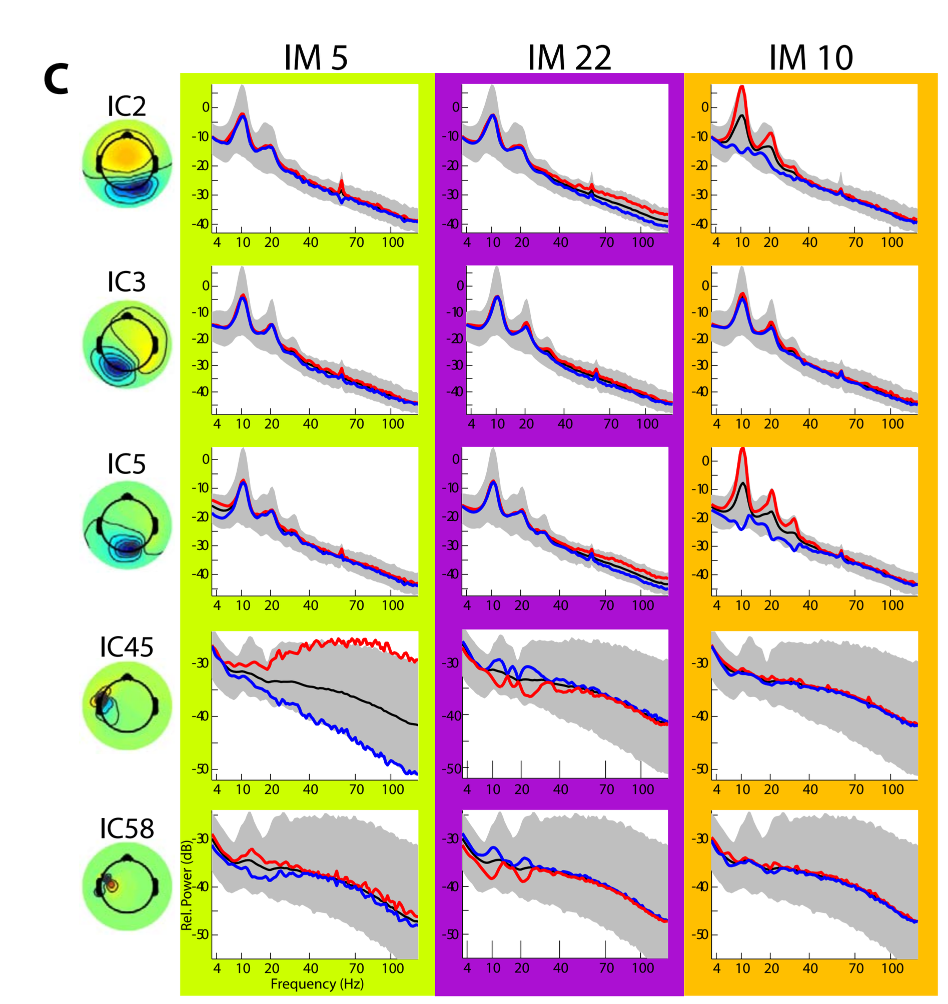


Figure 5. (A) Spectral modulation templates from a brain-IC-only decomposition. Note that individual ICs can express several types of independent spectral modulations including broadband / high-frequency IMs (i.e. rows 1,2,3), beta-band IMs (rows 5,9,11) and alpha-band spindling (rows 6,7,8,10). Histograms on the left show the distributions of IM time weights across all 1-sec spectral windows

(B/C) Single-subject decomposition of brain and muscle IC spectra including broadband EMG IMs (rows 1,2,3,4) independent of brain IC modulations. Note an example (bottom row) of an intriguing mode of broadband comodulation in which brain IC broadband power increases (here, in two occipital ICs) were reciprocally linked to decreases in alpha-band activity of muscle ICs (near the left ear). This joint activity is illustrated in **(C)** in which the extreme effects of three IMs (columns) on several brain and muscle ICs are shown (red and blue traces). Central black traces show the mean log spectra; grey backgrounds show the envelope of the (PCA-reduced) log activity spectra. Note differences between the broadband muscle activity in IM5 (left, 2nd from bottom) and broadband brain activation in IM22 (center top) at the same frequencies. For comparison, IM10 shows typical alpha spindle (co)modulation.