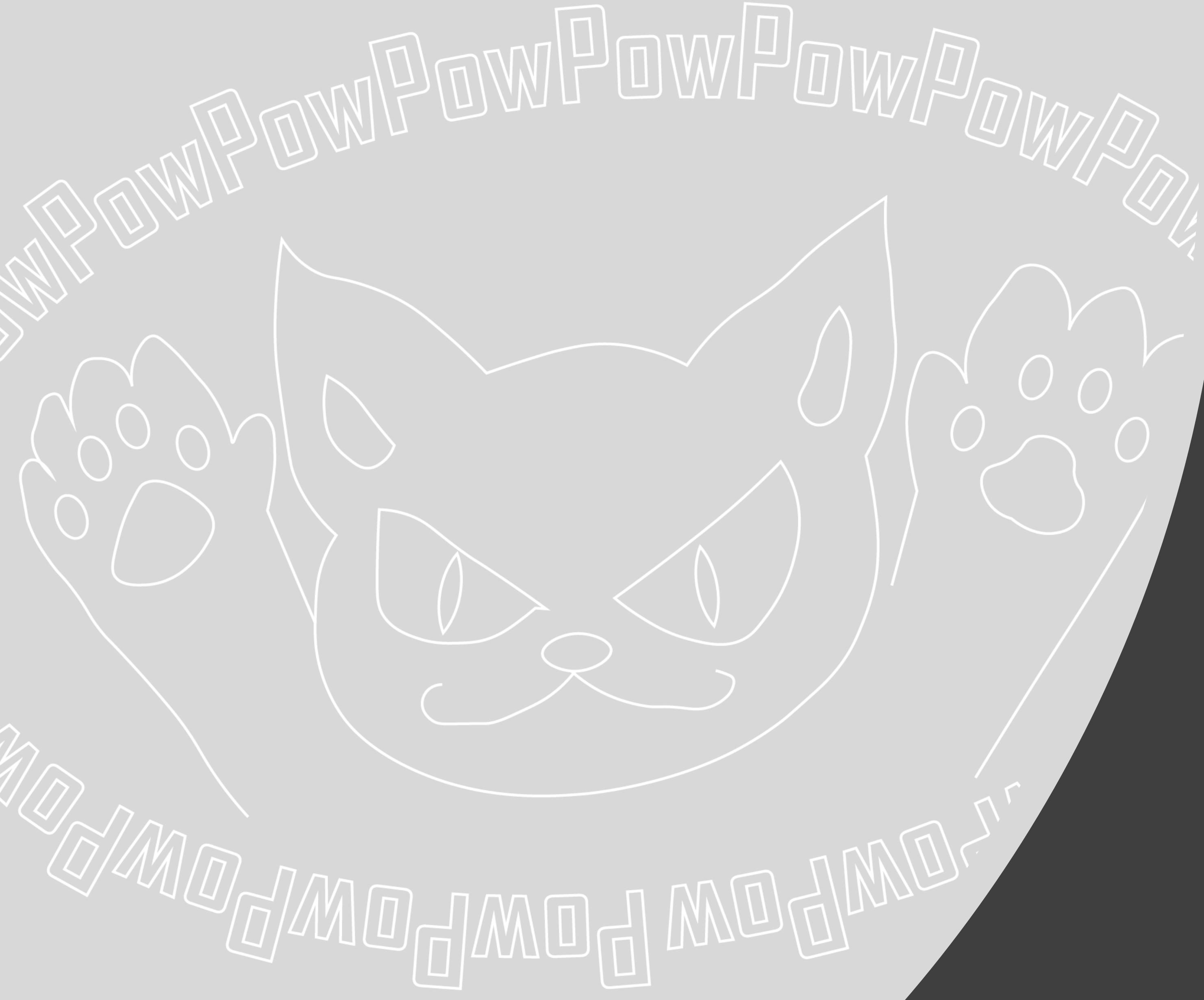


Artwork by Mayumi and Makoto Miyakoshi

Cross-frequency power-power coupling analysis toolbox (PowPowCAT)

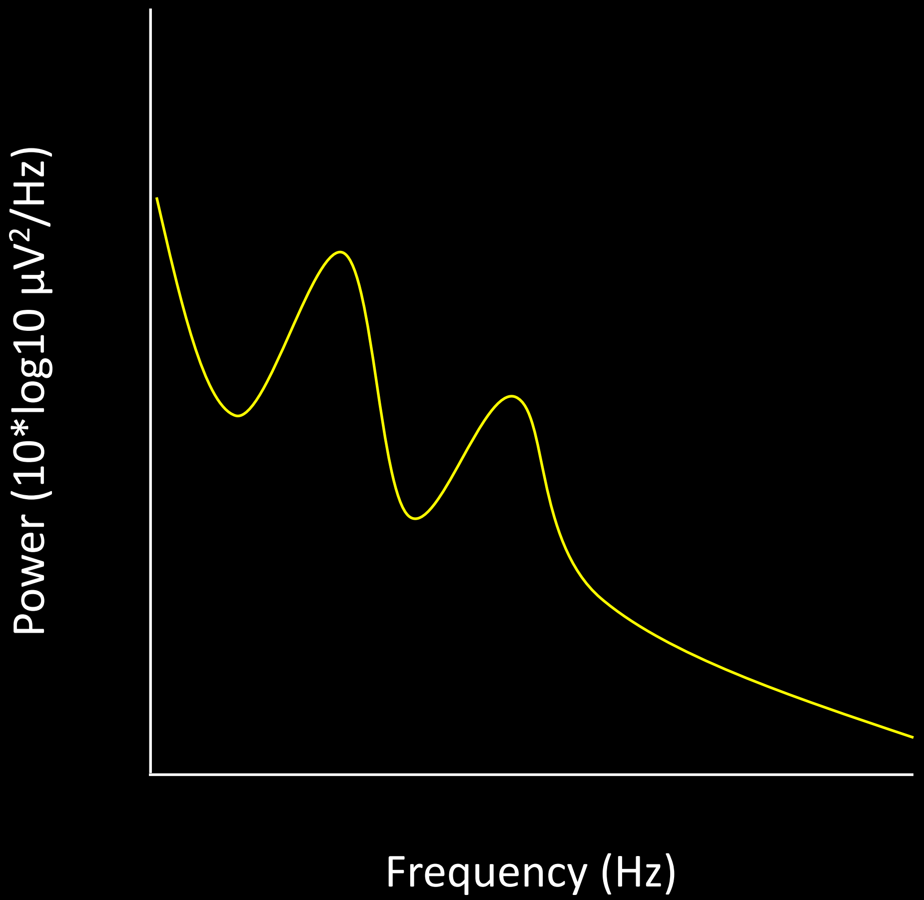
Makoto Miyakoshi

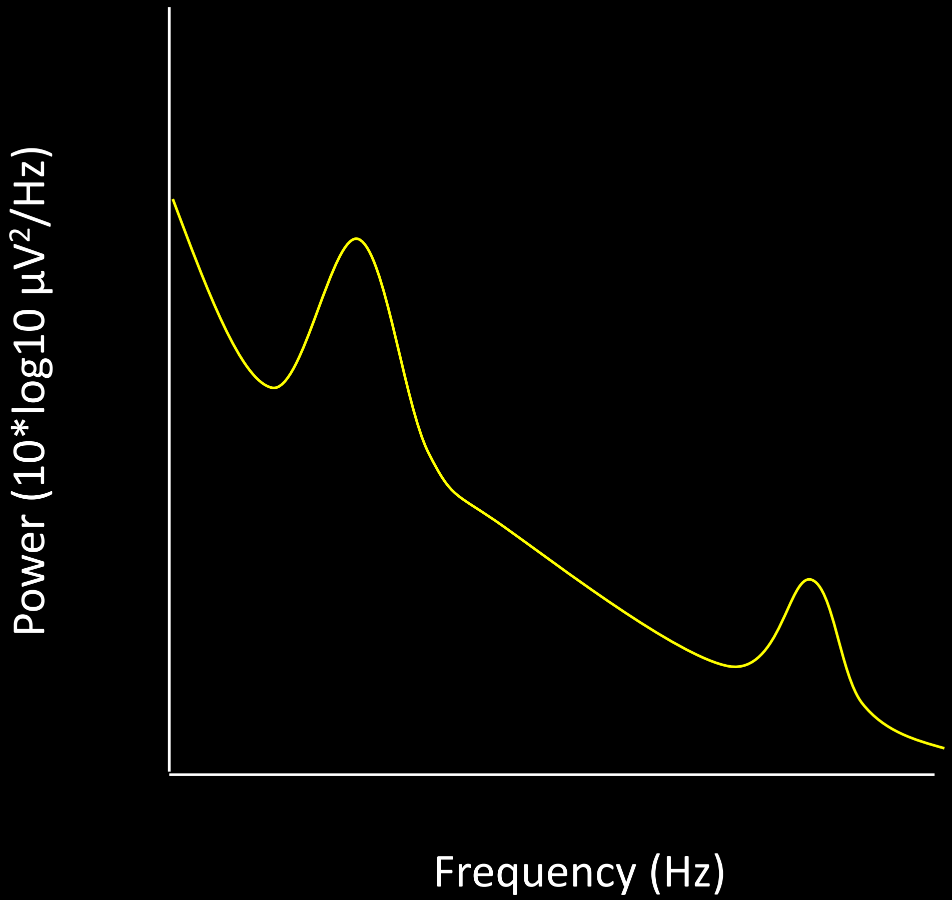
SCCN, INC, UC San Diego

The 34th EEGLAB workshop

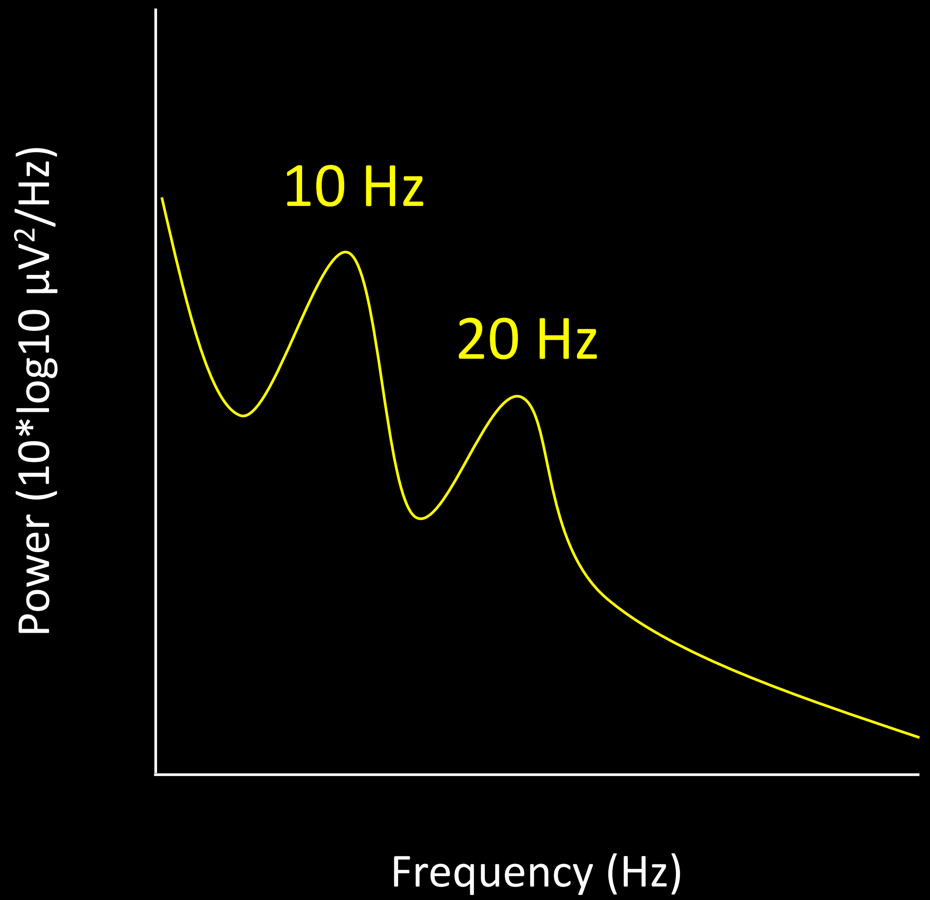
Nov 18, 2022 5:15-5:40 pm

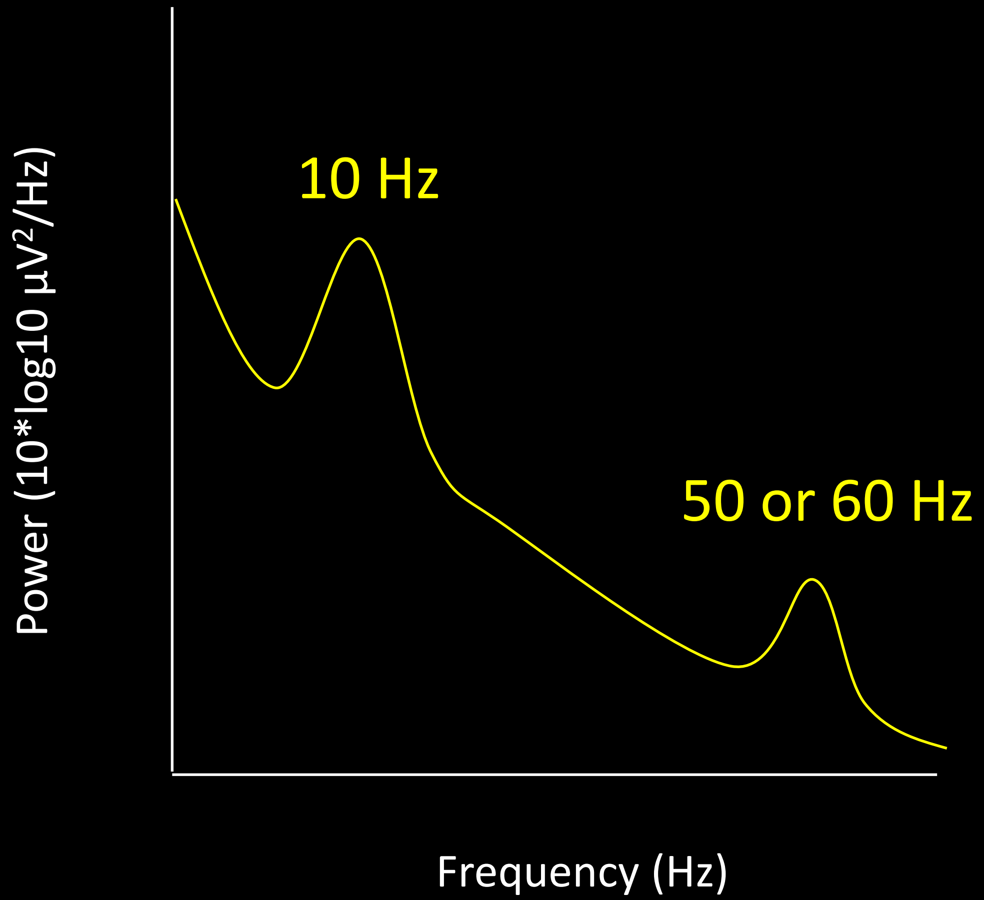
What’s the difference?



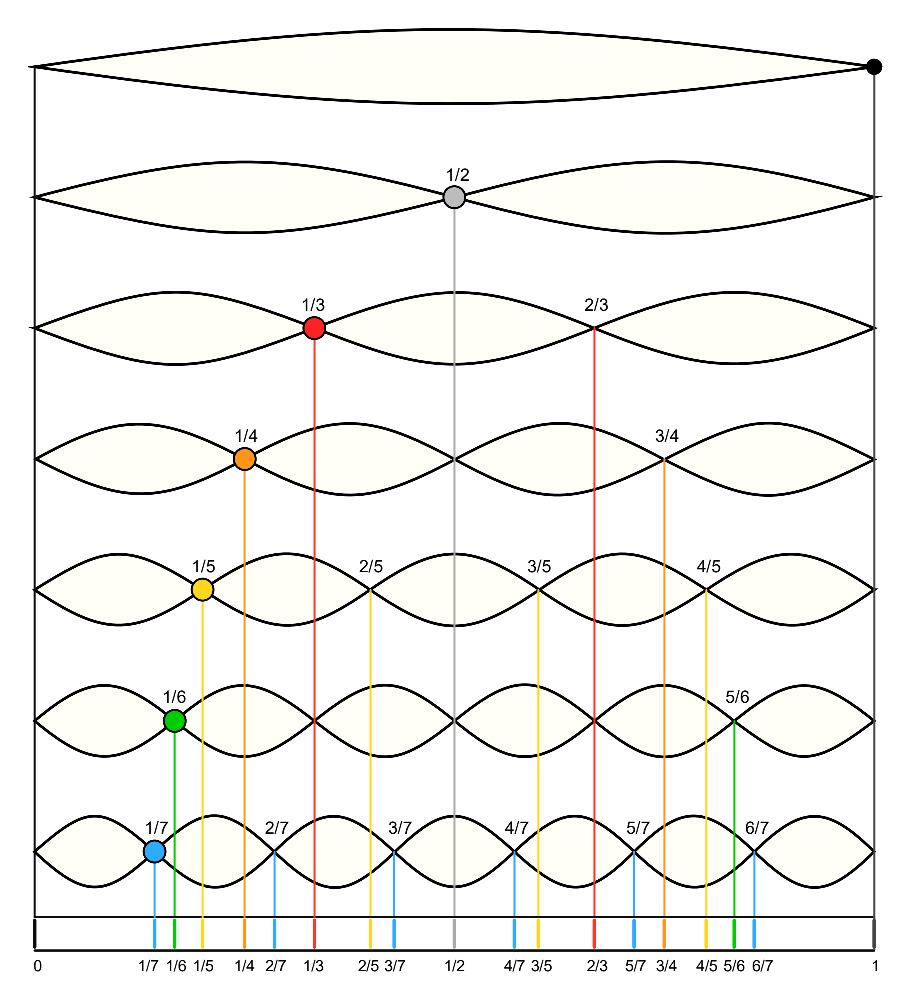


How about this?

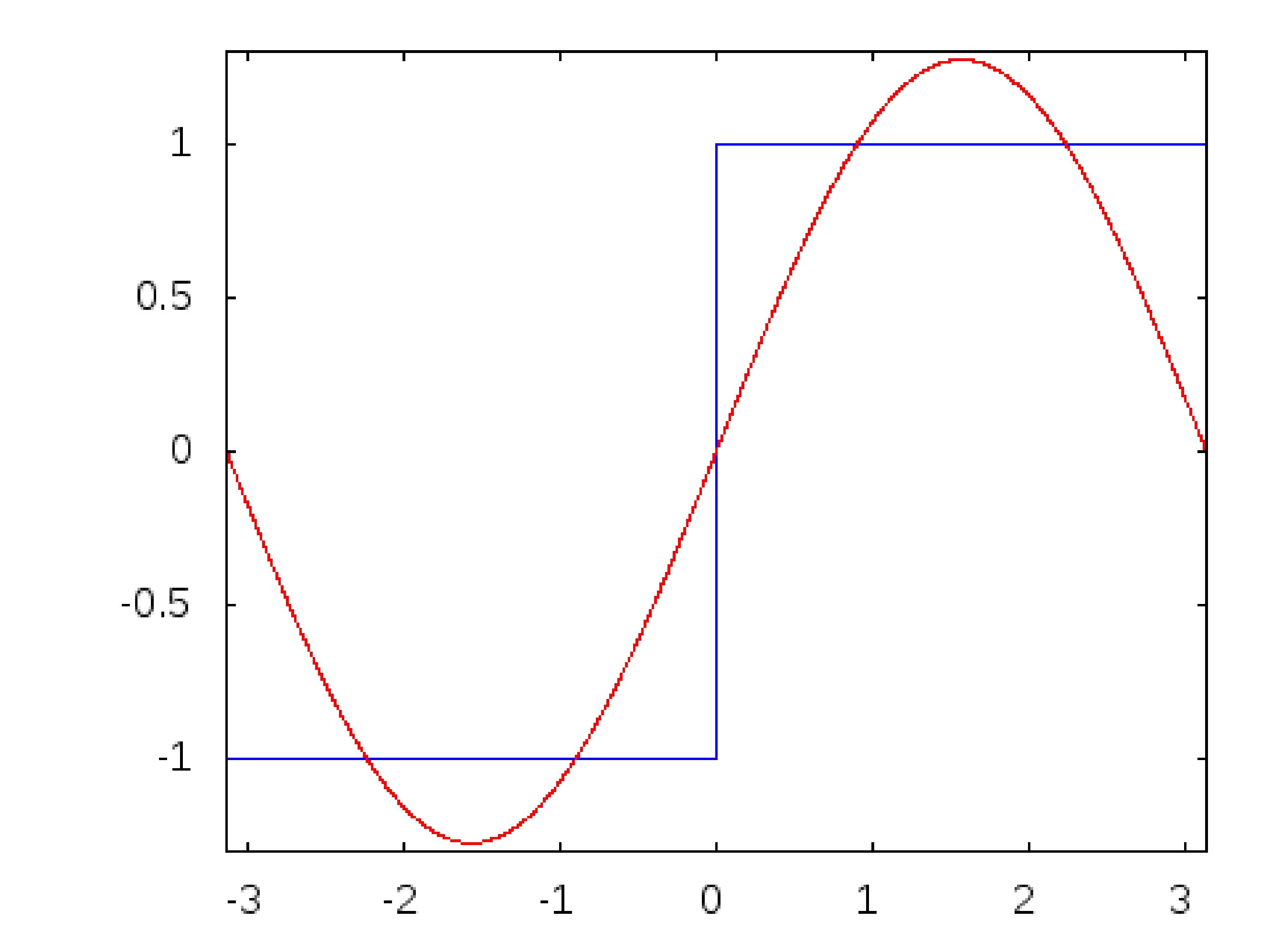




What is harmonics?

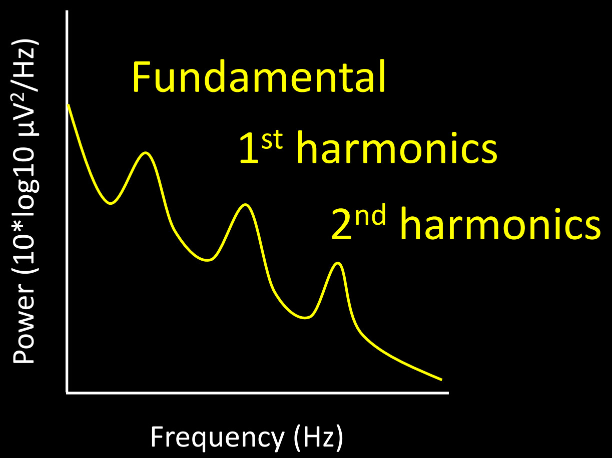


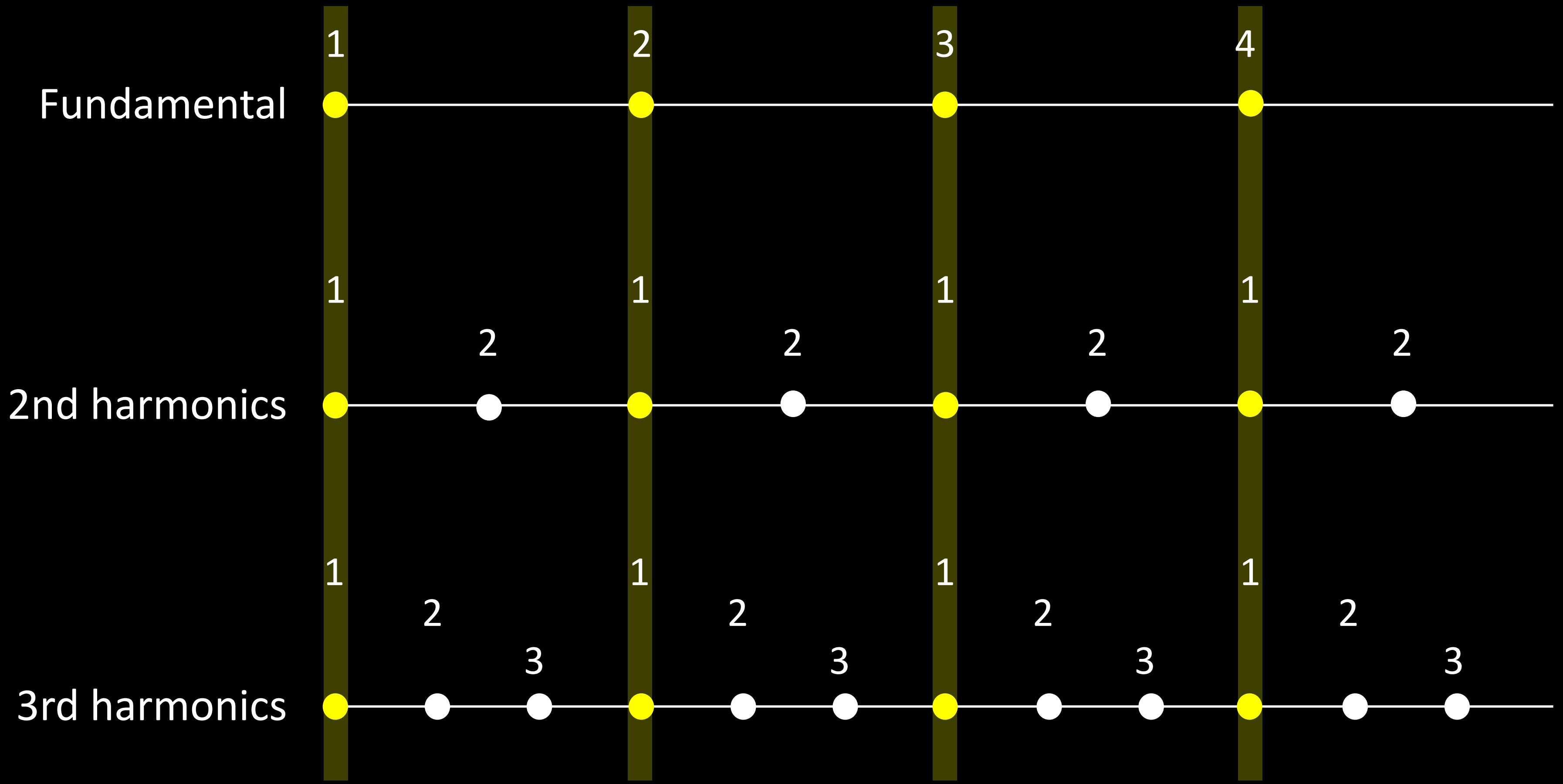
Wikipedia ‘harmonics’



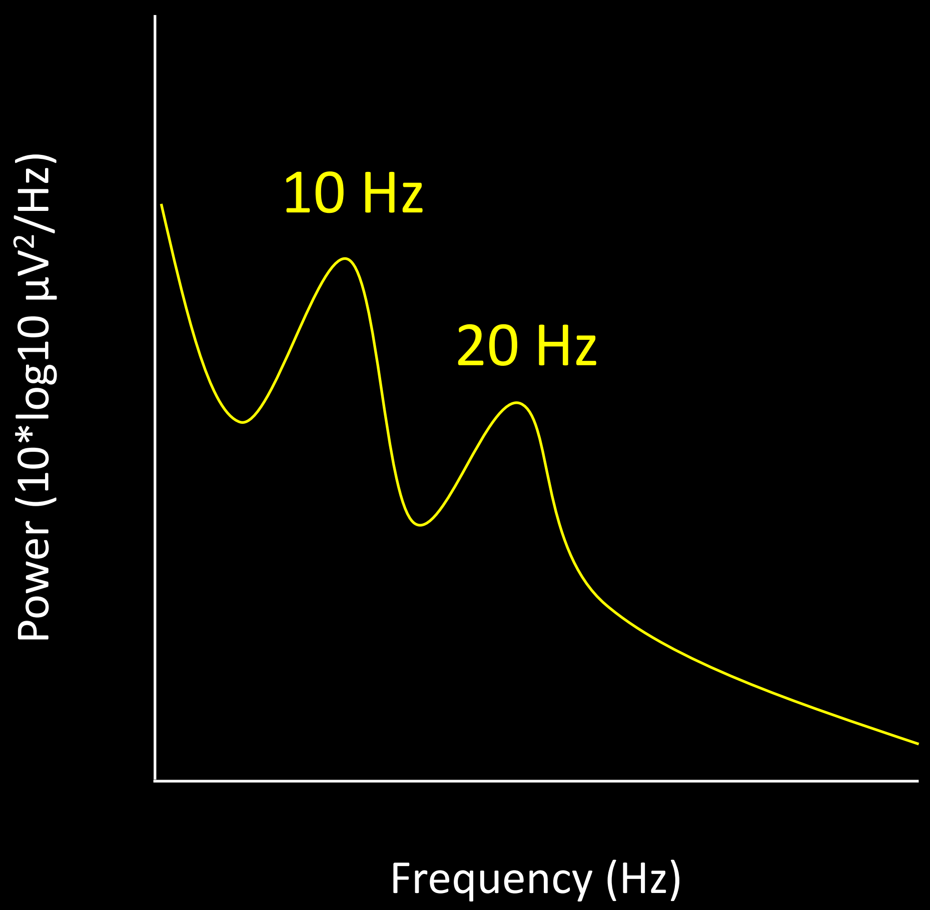
Wikipedia ‘square wave’

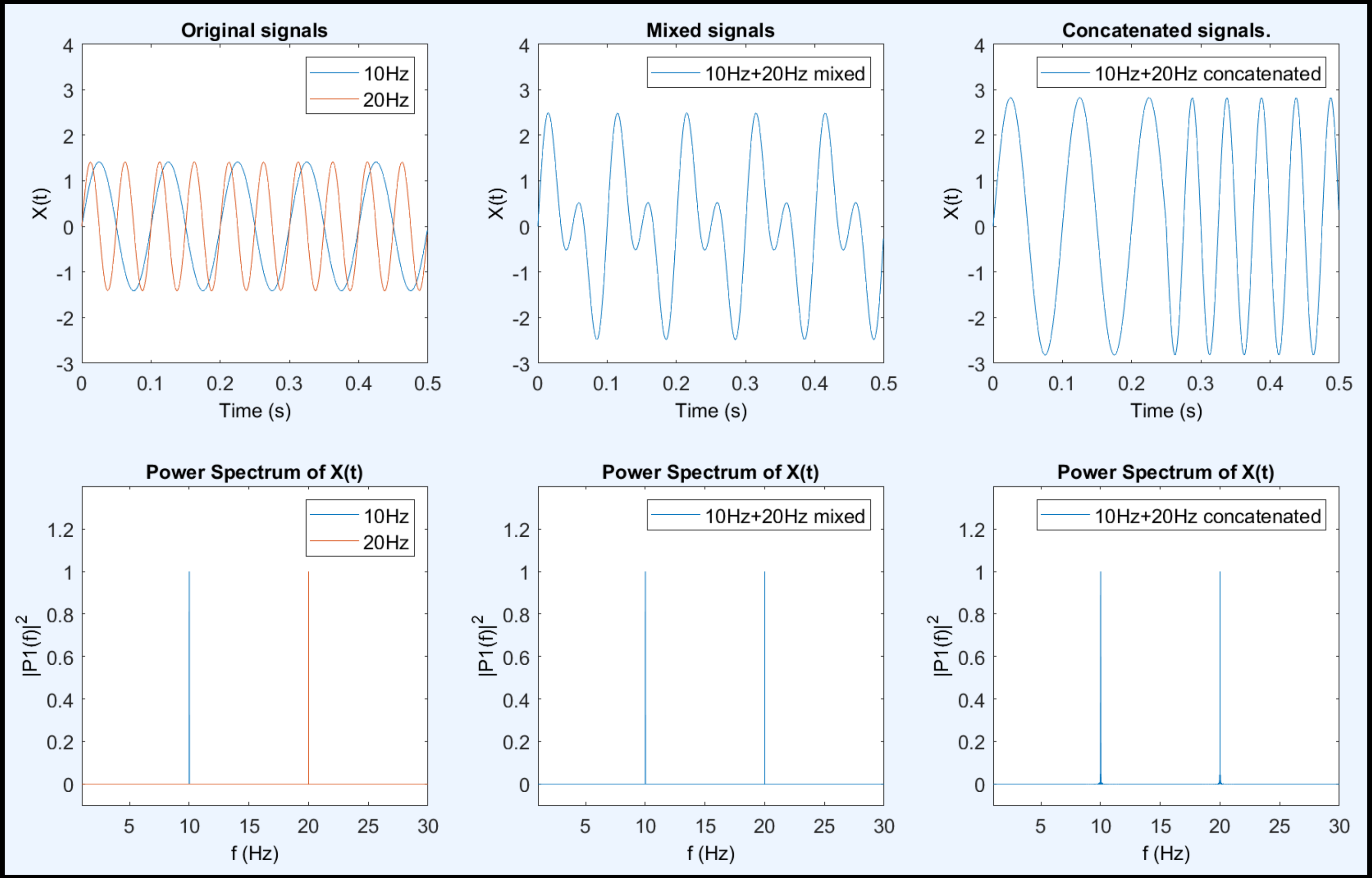
Virtual John Iversen’s explanation





Double peaks does not guarantee cross-frequency coupling

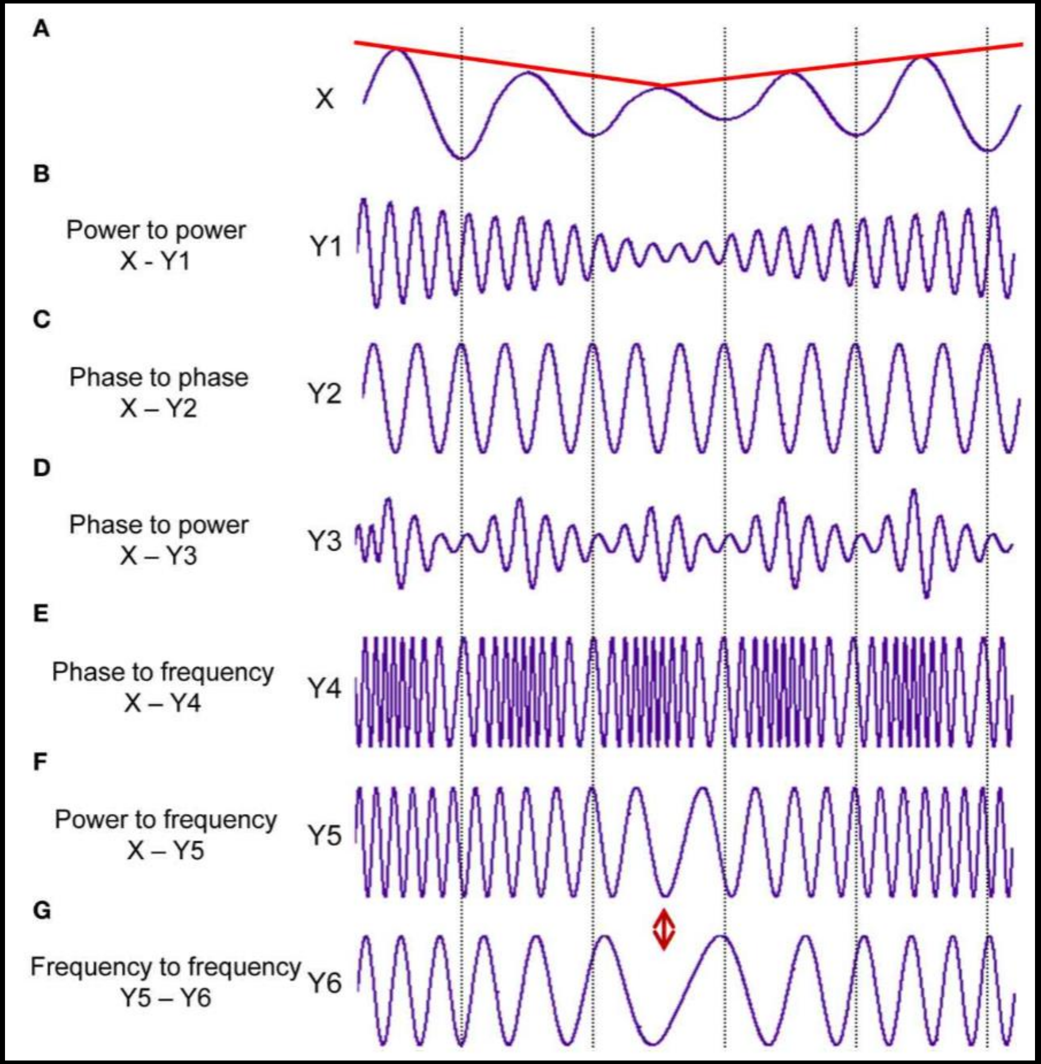




Thammasan and Miyakoshi (2020)

Why do I like power-power coupling?

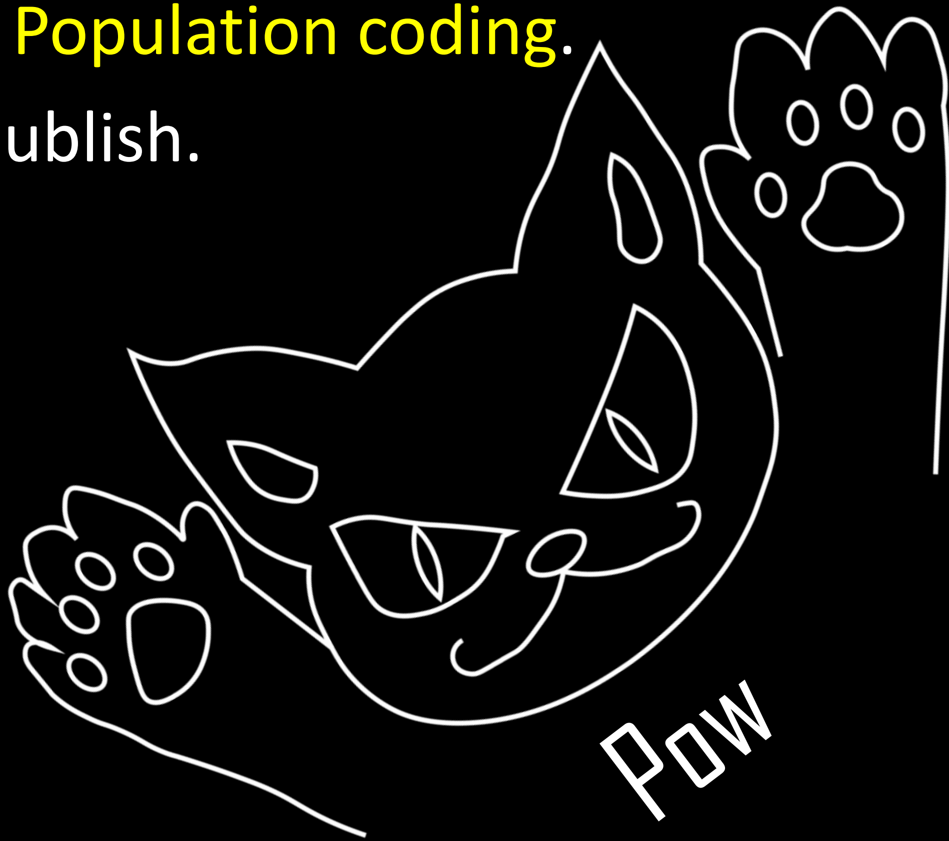
List of cross-frequency couplings

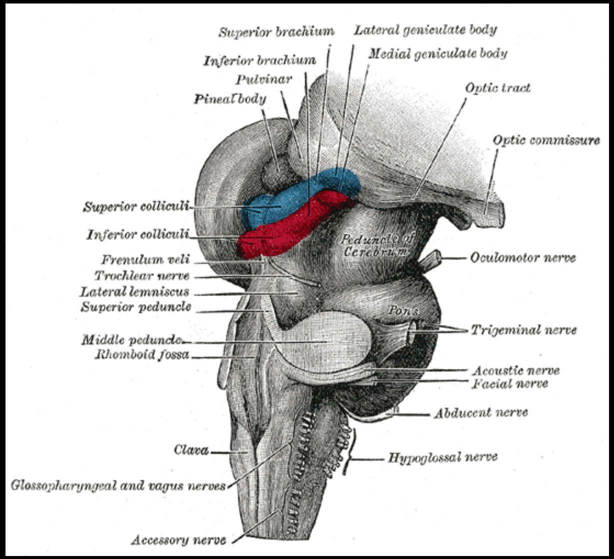


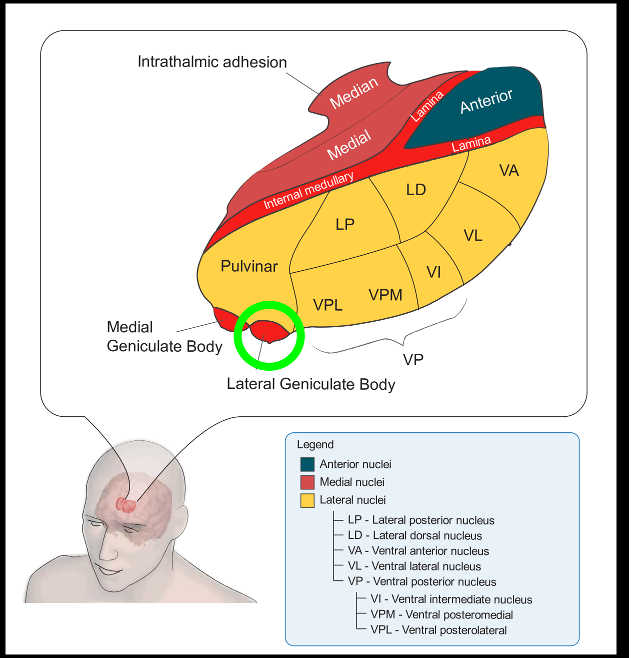
Jirsa and Müller (2013)

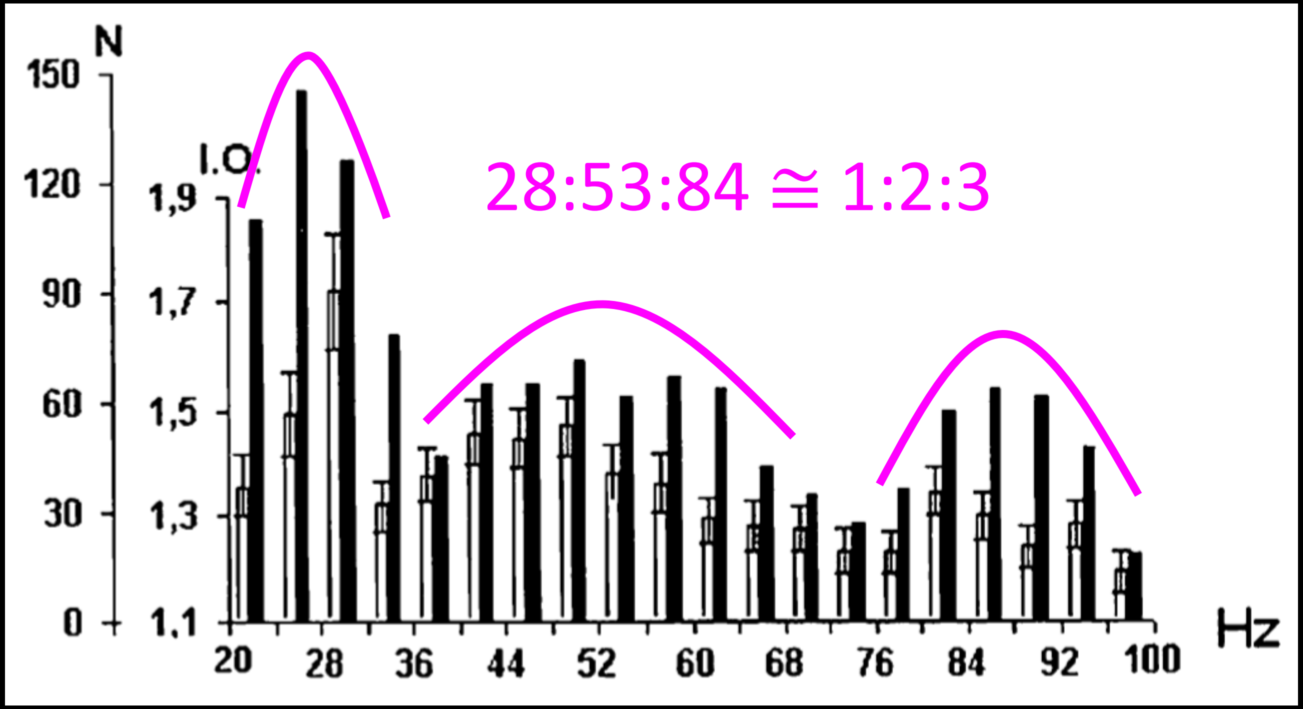
Reasons to analyze EEG power rather than phase

- Phase is a noisy metric, has weird dependency on amplitude contrary to the intuition, etc.
- Power is based on a good biological priciple: Population coding.
- ‘PowPowCAT’ is a good name which I must publish.





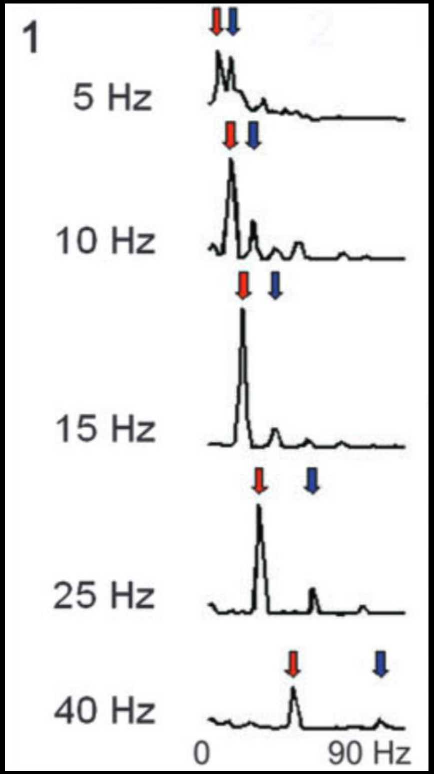




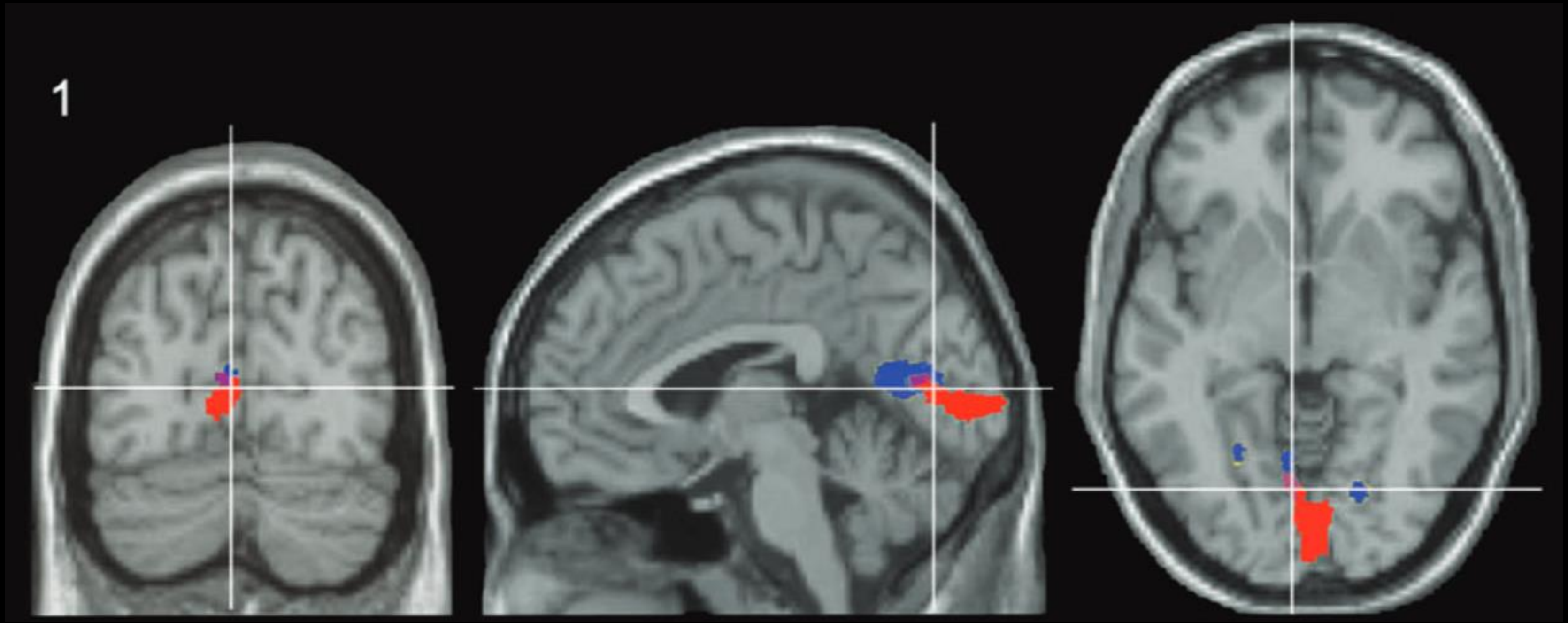
Wikipedia 'lateral geniculate nucleus'

On- and off-neuron responses recorded from cat lateral geniculate nucleus (LGN) during visual stimulation.

Podvigin et al. (2004)

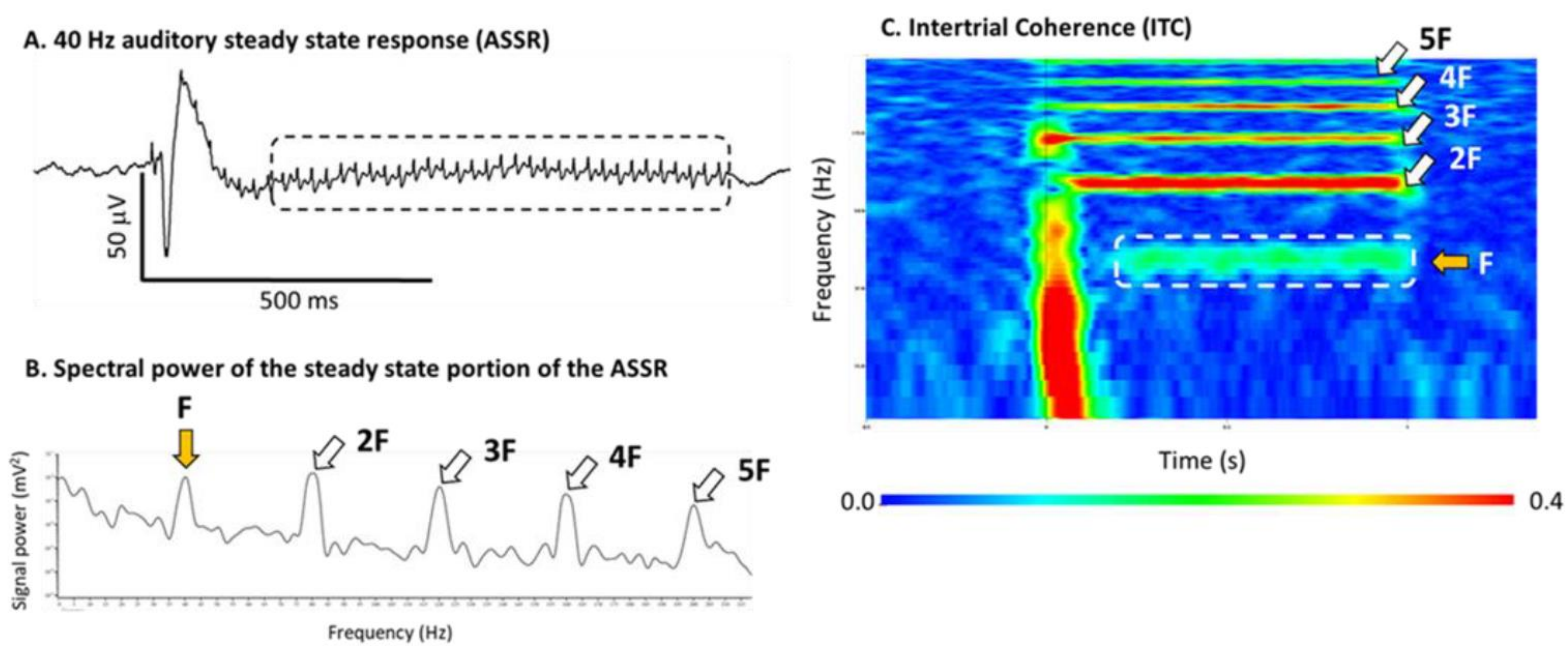


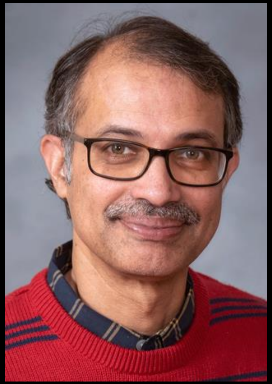
Power Spectral Density of averaged Steady-State Visual Evoked Potential (SSVEP) at Oz, O1, O2.



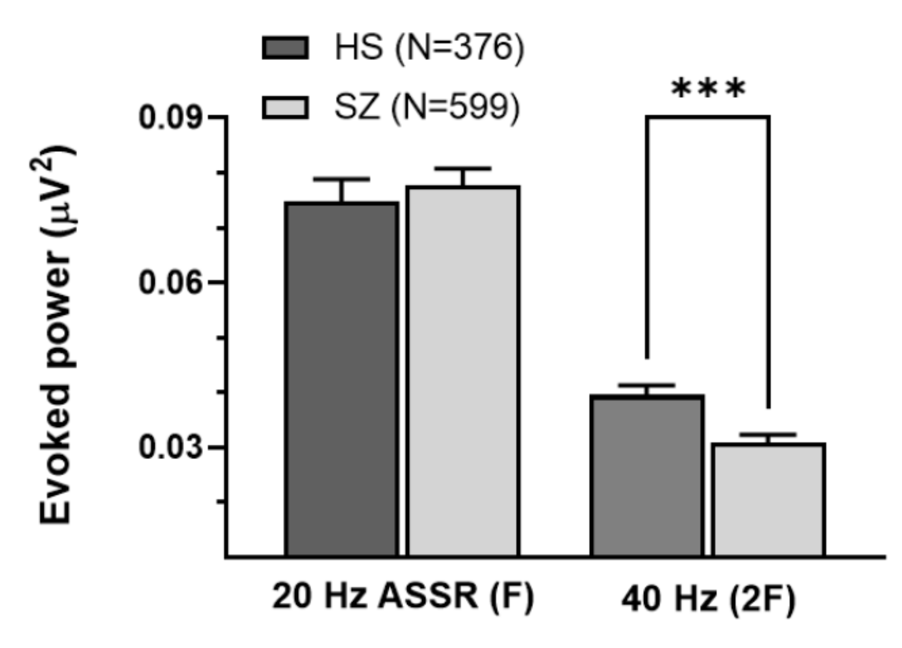
Regional cerebral blood flow (rCBF) measured with $H_2^{15}O$ PET. Red, fundamental freq-weighted. Blue, first harmonics-weighted.

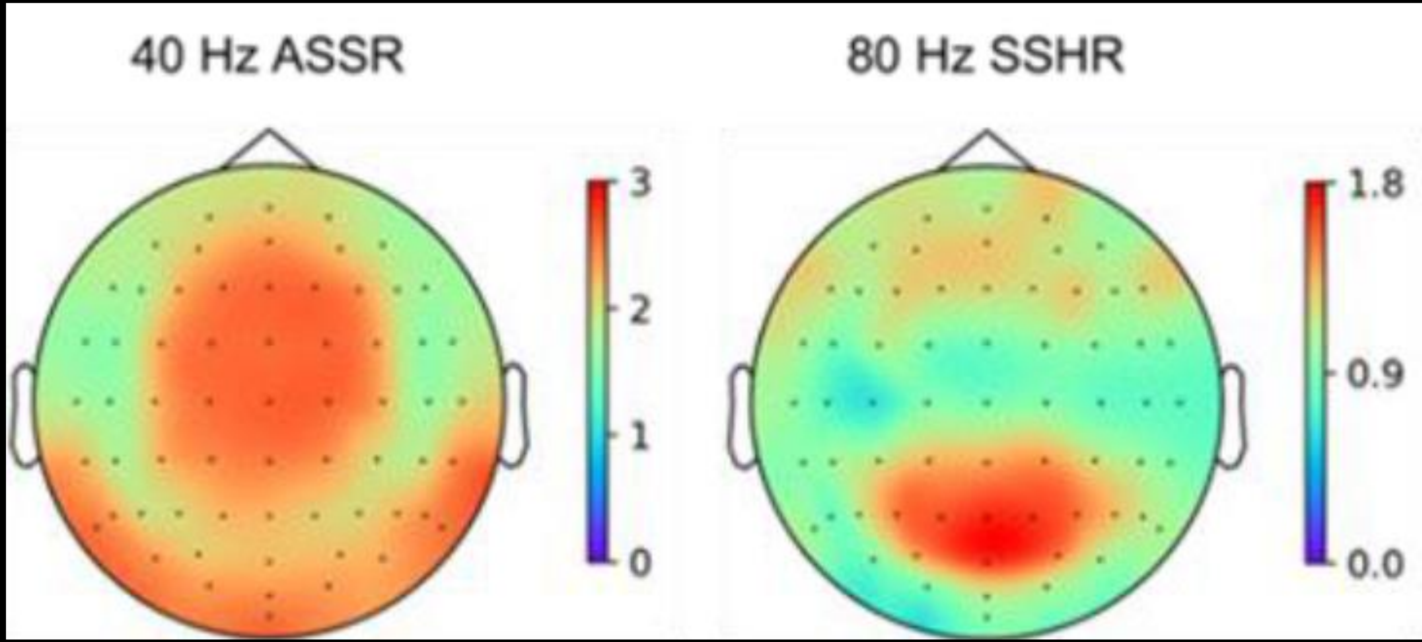
Pastor et al. (2006)





Unpublished data by courtesy of Siva Digavalli
(East Tennessee State University Pharmaceutical)





Unpublished data by courtesy of Juan Molina and Greg Light (UCSD Psychiatry)

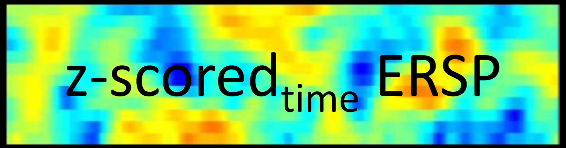
How to calculate power-power coupling

Comodulogram as spectral covariance

When *X* is the time-frequency decomposed power with length *k*,,

$$\mathrm{Comodulogram(X)} =$$

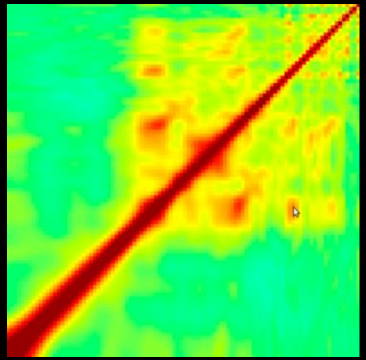
$\mathrm{mean}_{\mathrm{time}}$ (



×

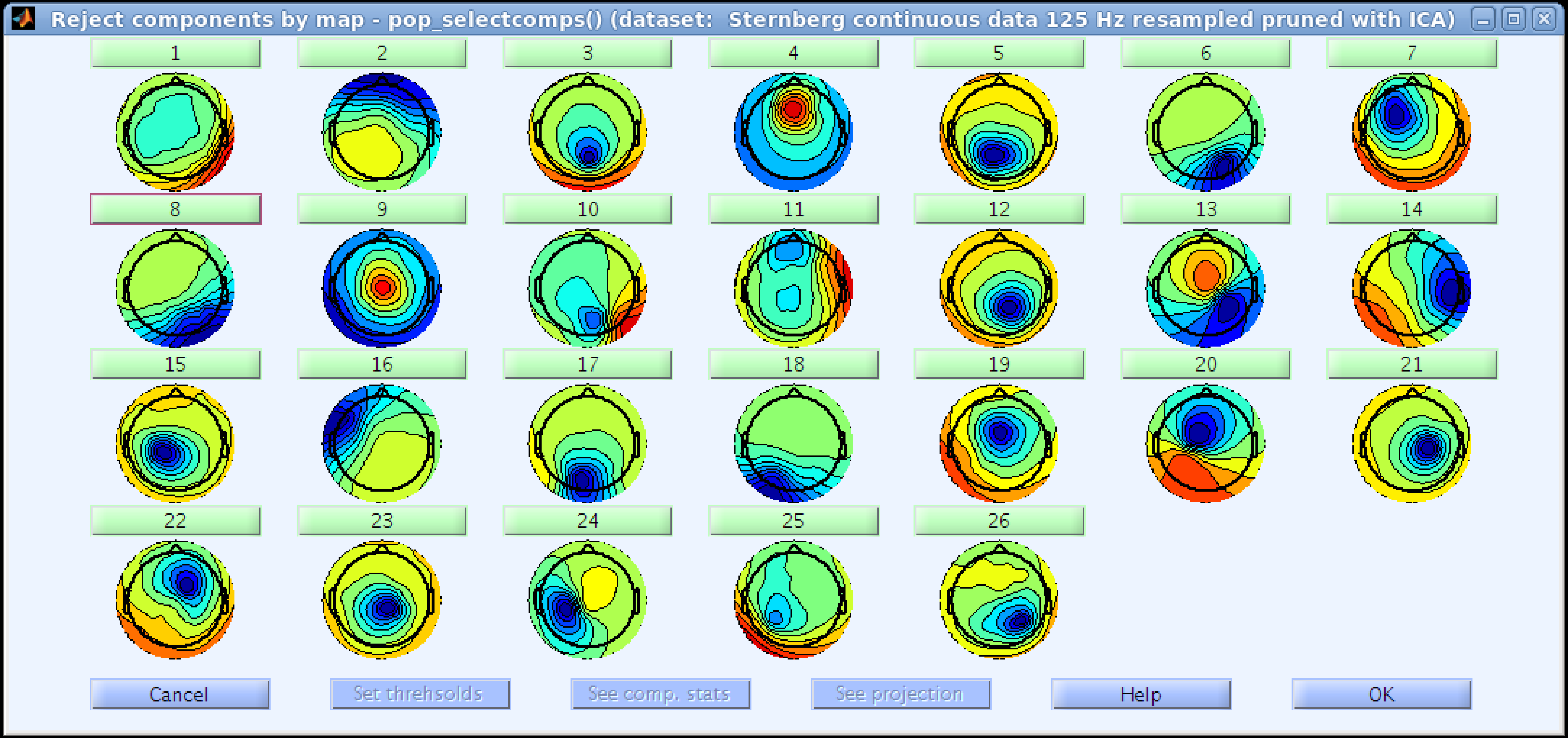
)

=

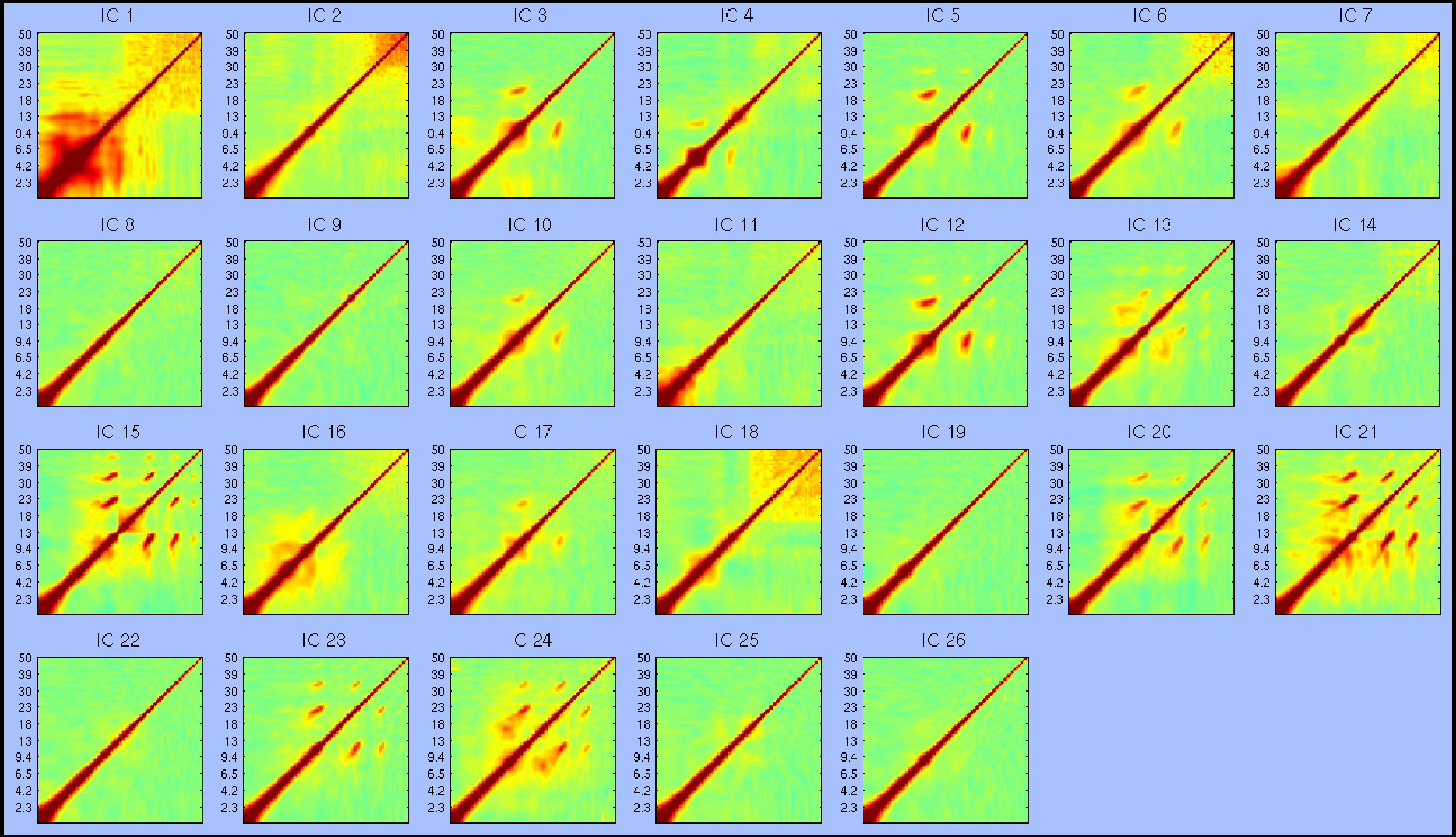


Demonstration of PowPowCAT

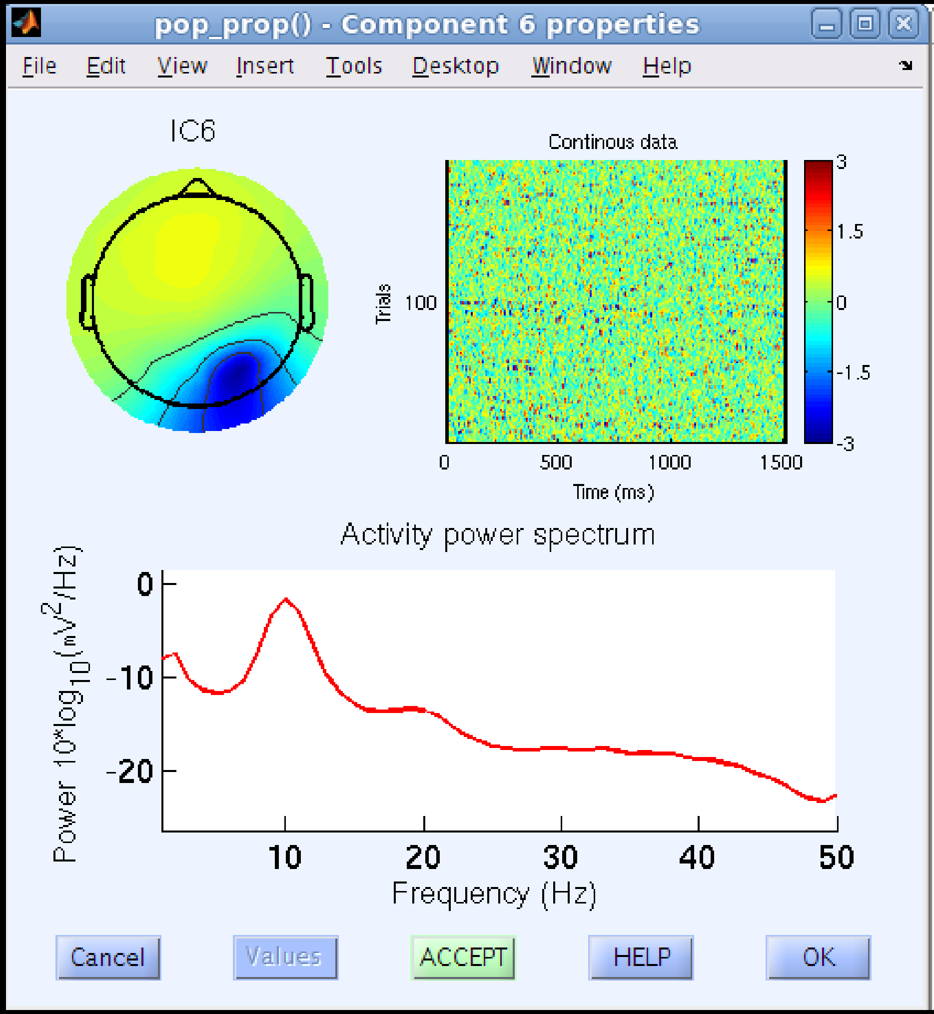
‘stern_125.set’ (tutorial dataset) IC scalp topos

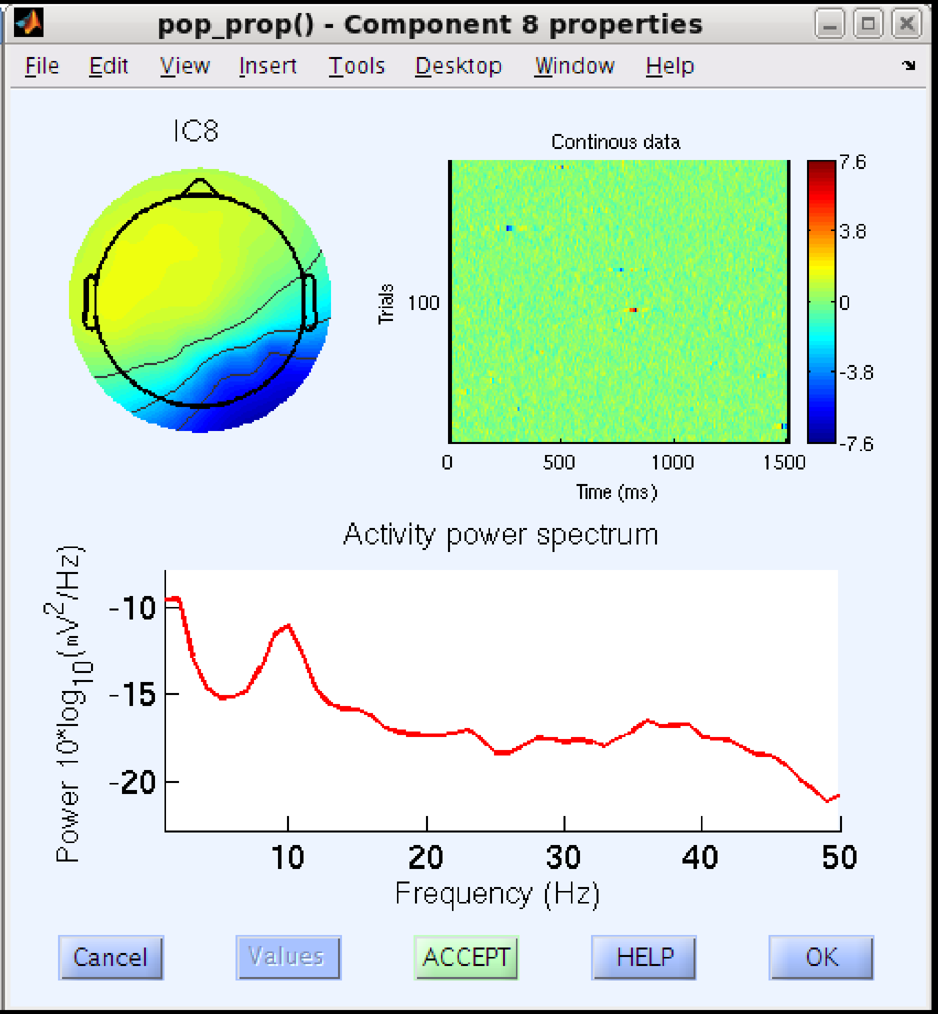


‘stern_125.set’ Comodulogram

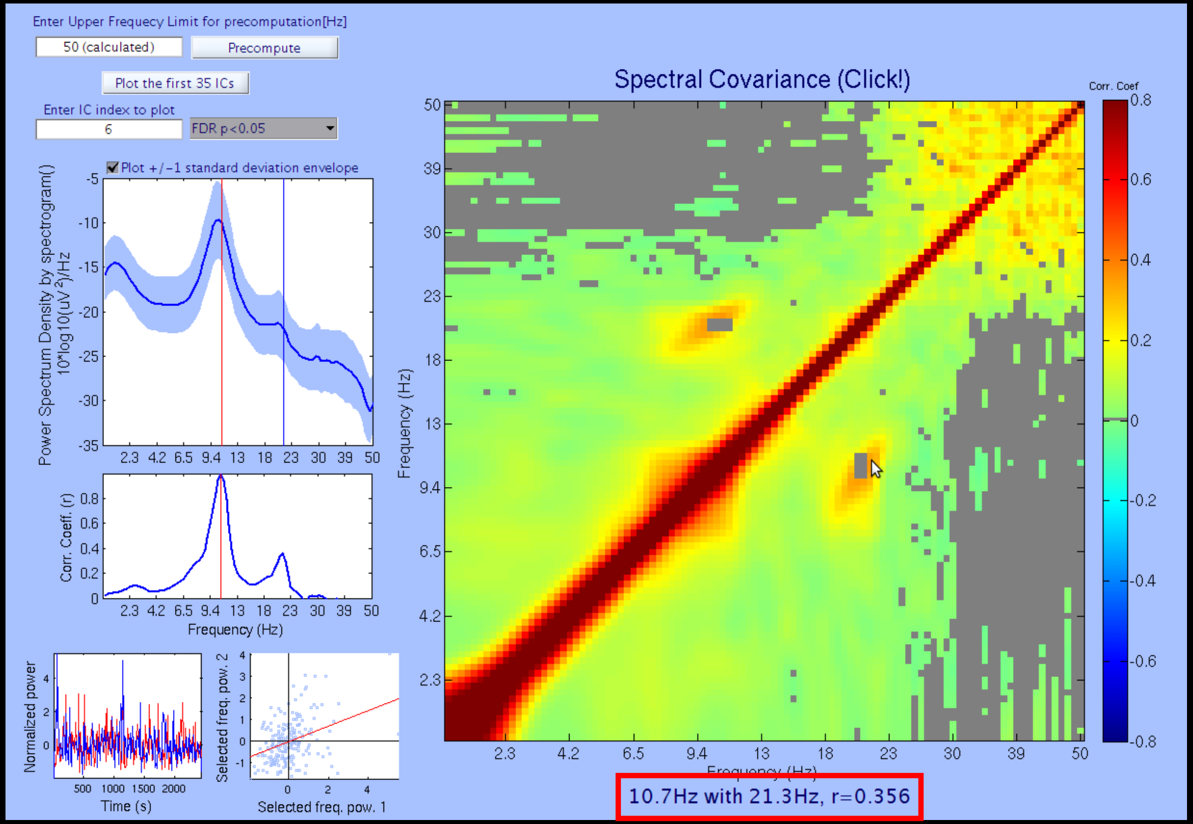


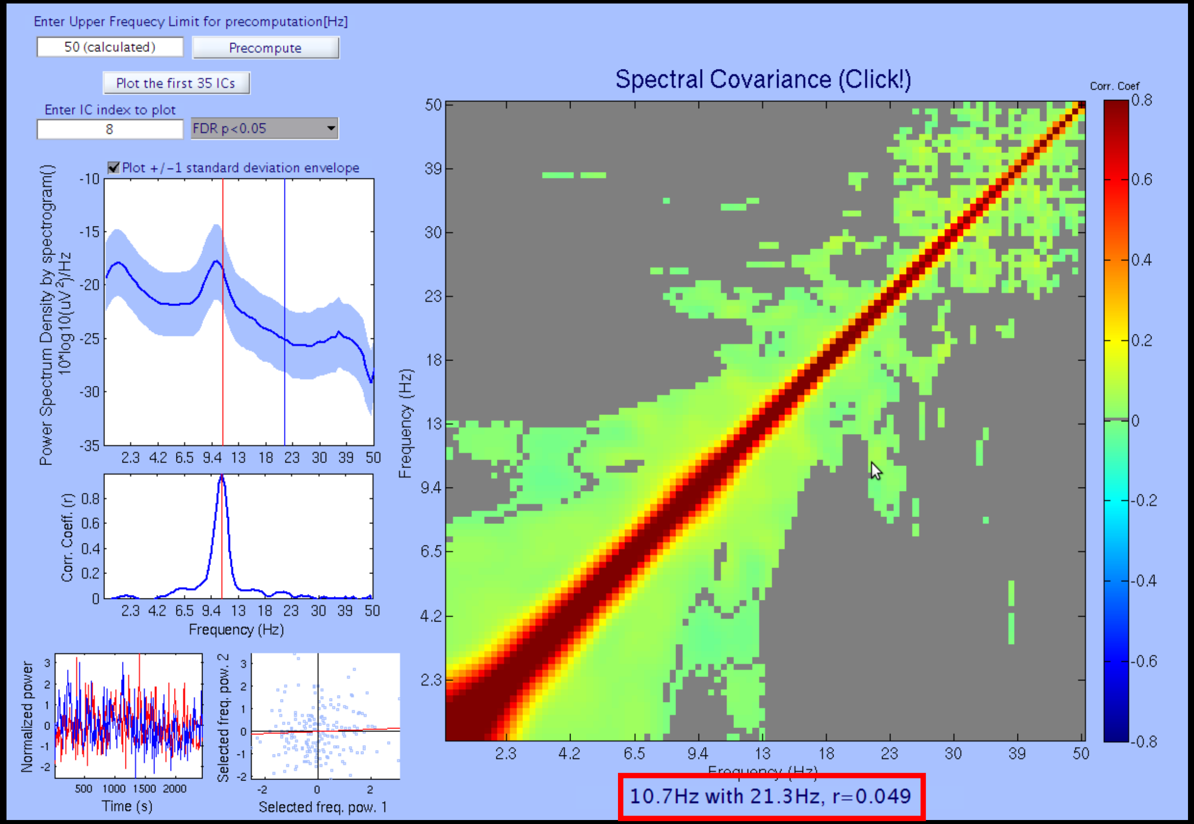
IC6 vs. IC8—What's the best description of the difference?



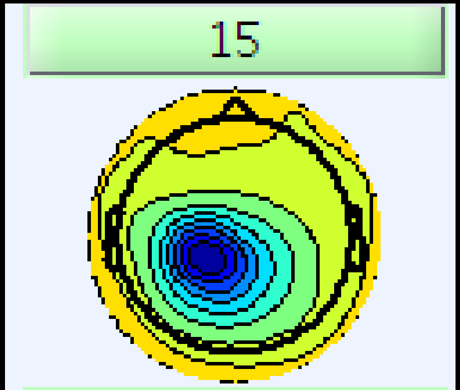


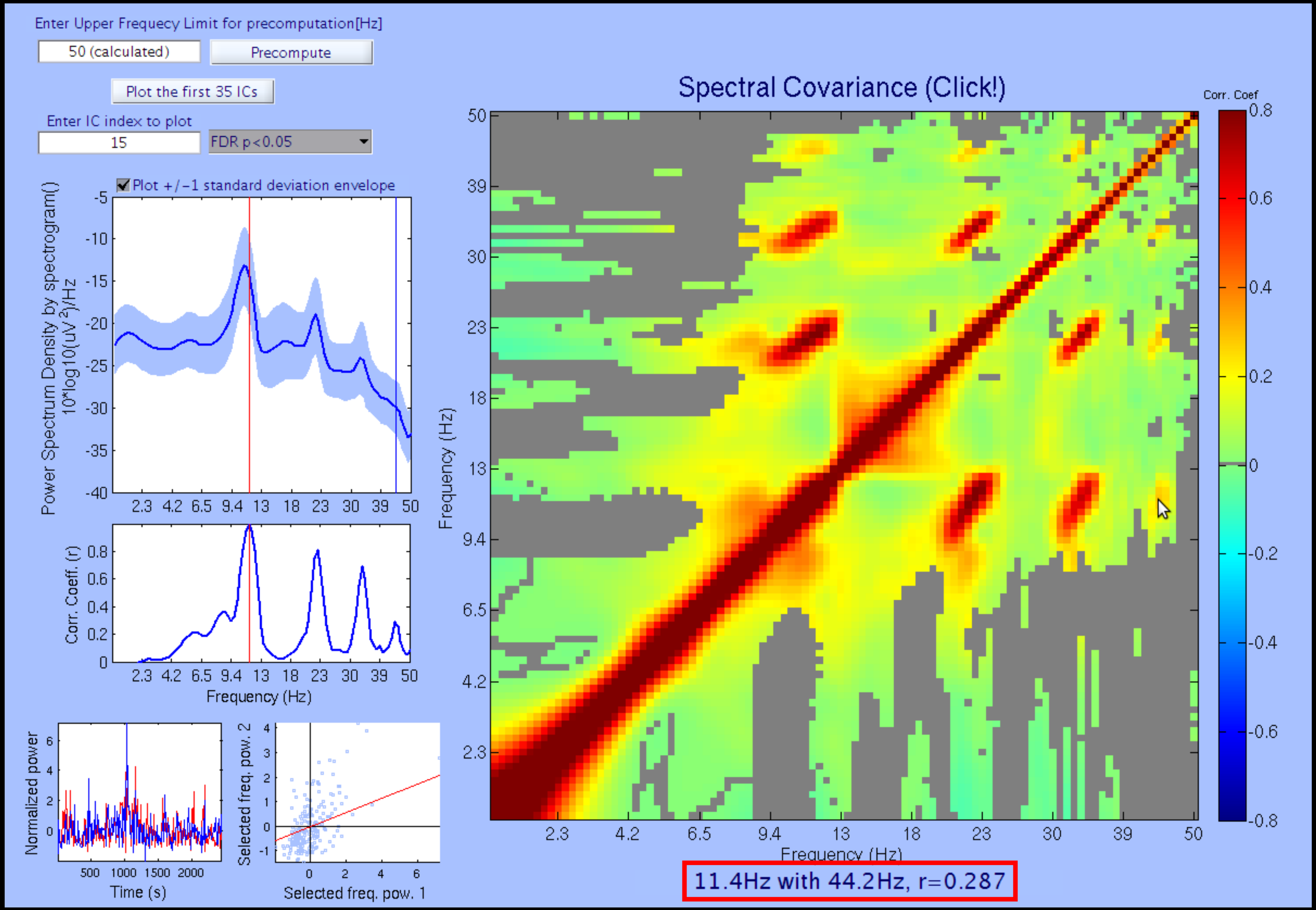
IC6 shows a nice second harmonics (r=0.356)



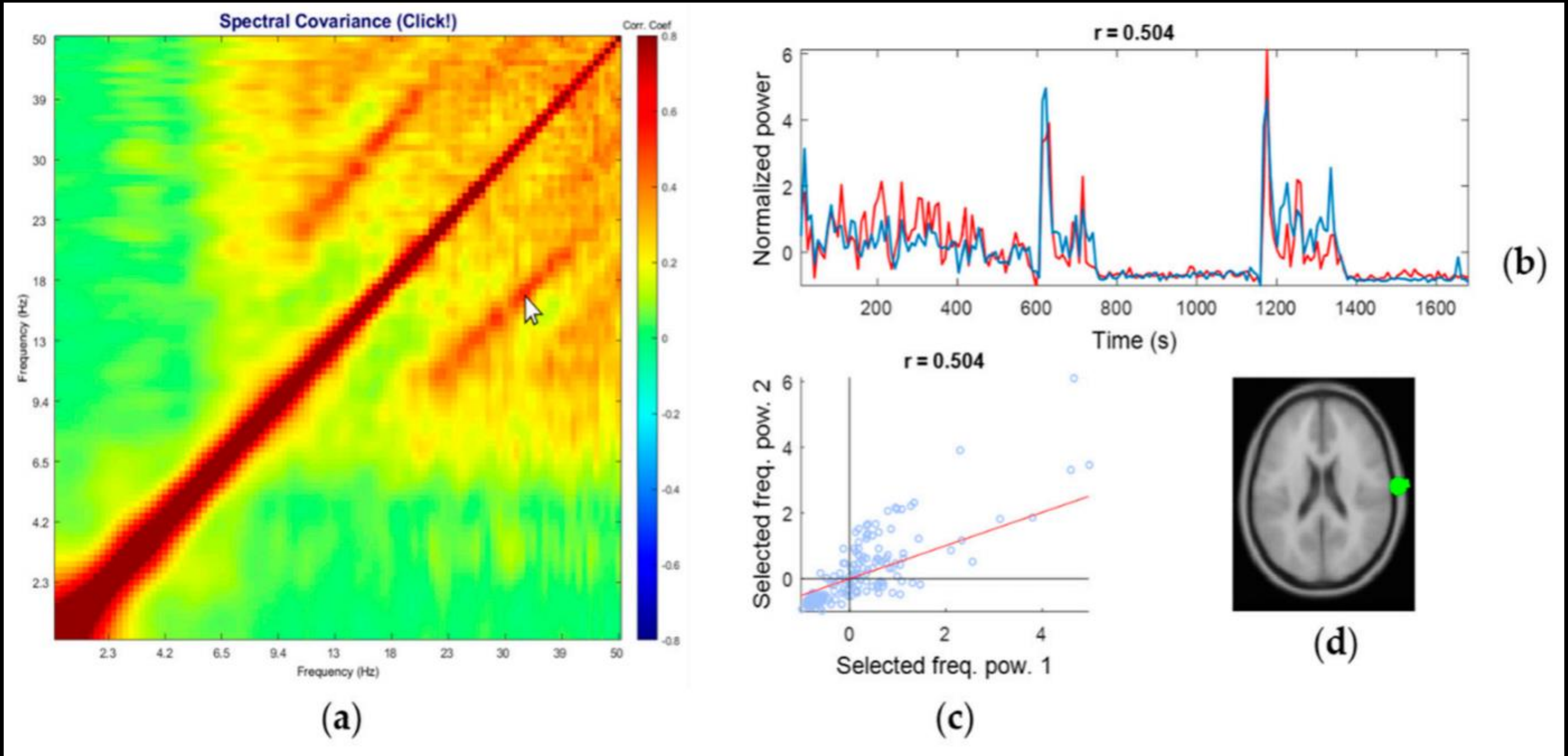


4TH harmonics captured!



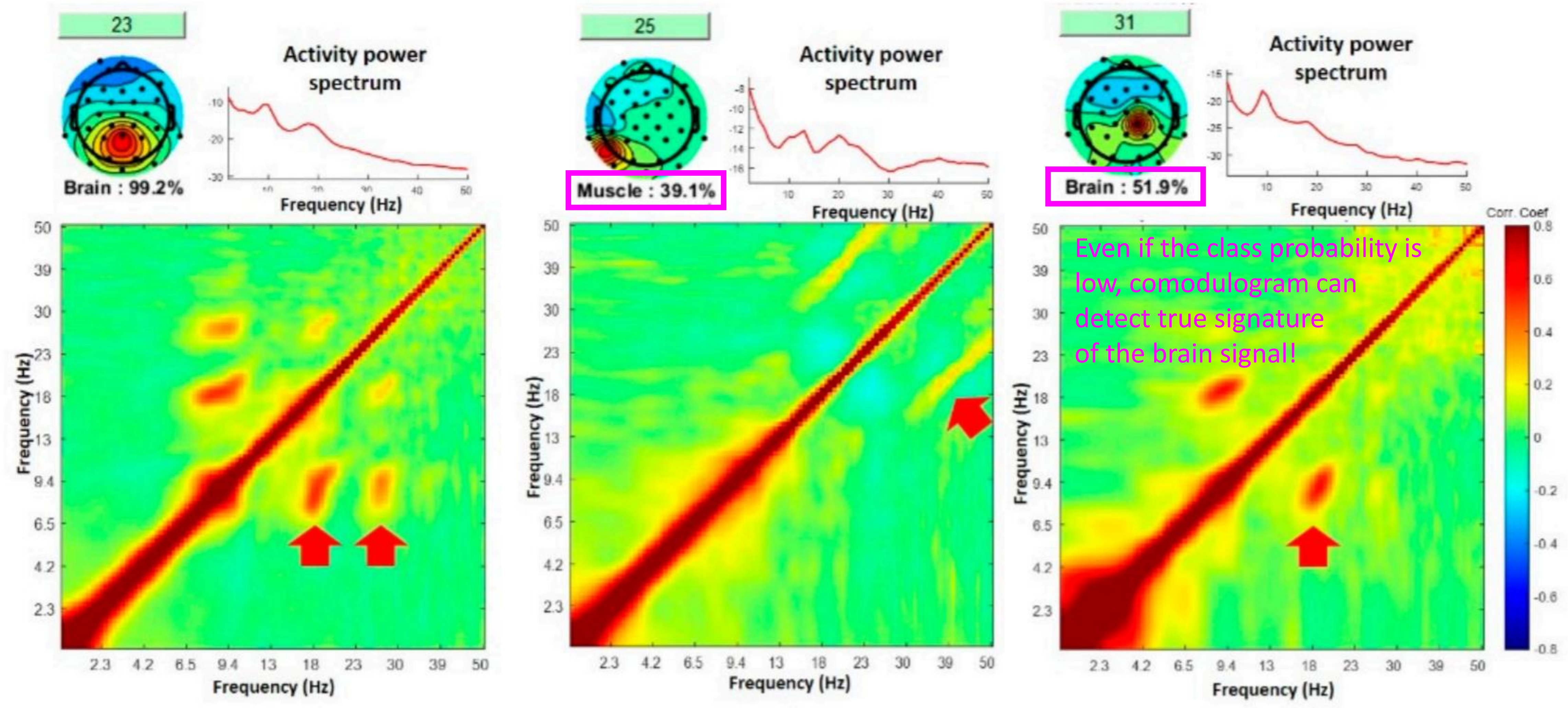


How a muscle IC is nicely represented



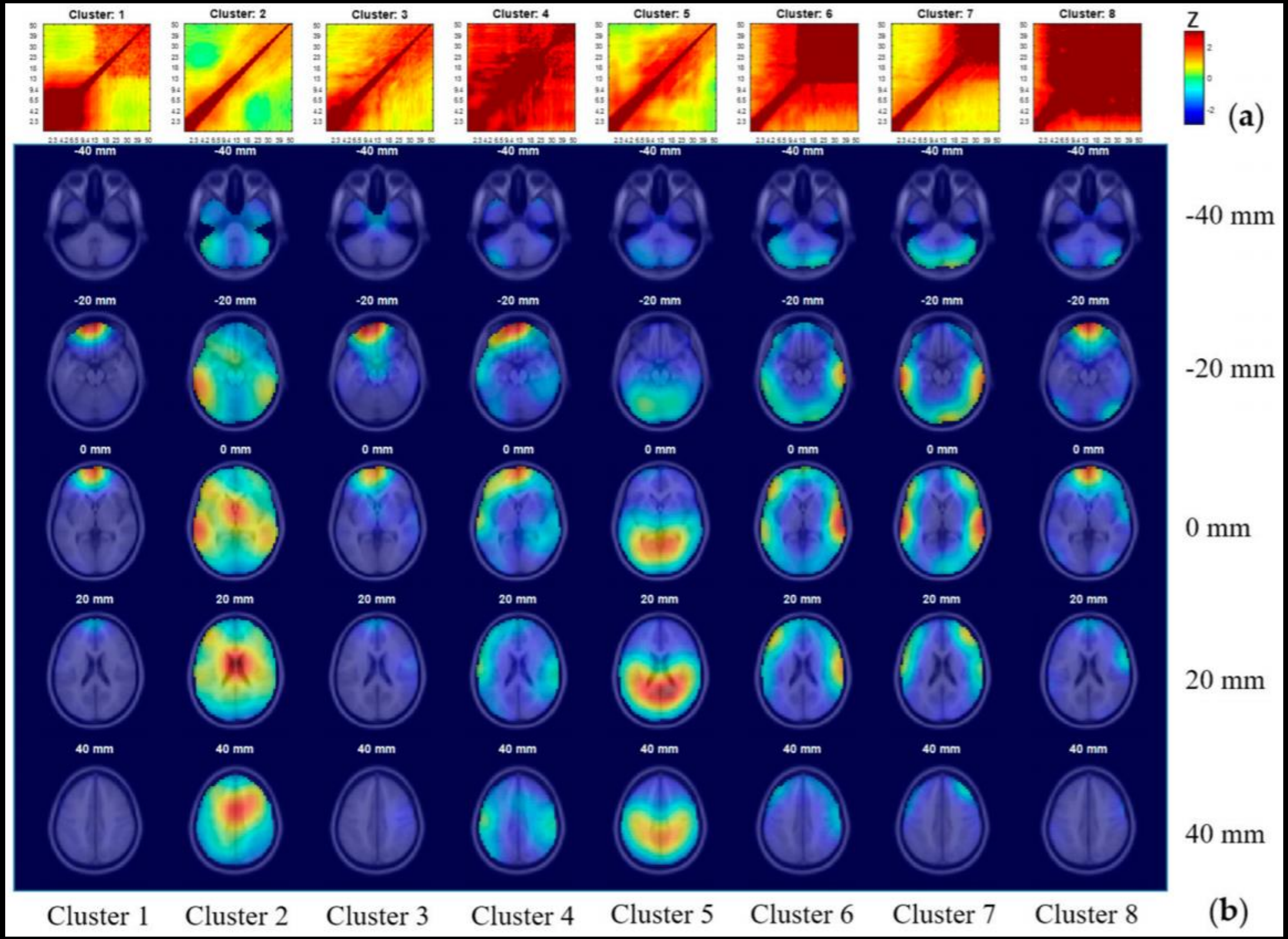
Thammasan and Miyakoshi (2020)

Comodulogram helps classify the ICs



Thammasan and Miyakoshi (2020)

Comodulogram for IC classification



Clusters	Our Interpretation	Percentage of ICs in Each Class as Labeled by ICLabel							Total Number of ICs
		Brain	Muscle	Eye	Heart	Line Noise	Channel Noise	Other	
2	Brain	52.5	23.0	1.8	0.0	13.5	0.0	9.2	282
3	Brain	23.2	26.8	16.1	0.0	25.0	0.0	8.9	56
5	Brain	82.0	8.7	0.0	0.0	8.7	0.0	0.7	150
6	Muscle	10.4	83.1	0.0	0.0	2.6	0.0	3.9	77
7	Muscle	27.6	51.5	2.2	0.0	5.2	0.0	13.4	134
8	Muscle	3.3	53.3	26.7	0.0	10.0	0.0	6.7	30
1	Eye	3.2	0.0	83.9	0.0	6.5	0.0	6.5	31
4	Noise	16.7	20.0	56.7	0.0	3.3	3.3	0.0	30
	Total	42.5	31.4	8.6	0.0	10.1	0.1	7.2	790

‘The diagonal line of comodulogram is the power spectral density (PSD). When used in machine learning, comodulogram could be more informative than PSD.’

Thammasan and Miyakoshi (2020)

Luca Pion-Tonachini

Conclusion

- Cross-frequency (power-power) coupling plot is called *comodulogram*.
  - The diagonal of the comodulogram is *power spectral density (PSD)*.
- It is a 2-D representation of power-power coupling across frequencies over time .
- Comodulogram can classify ICs into categories.
  - Can be added to *ICLabel*?

Mini history of PowPowCAT

Nattapong Thammasan
Visiting scholar at SCCN
Jan-Mar 2017

- The prototype of PowPowCAT was developed as ‘re-inventing the wheel’.

> in the final revision. PPC was ad hoc re-invented by MM to convince Michael that the 44-Hz peak in the PSD of his EEG data was not related to other brain signals.

- The original EEGLAB plugin was published on January 3, 2017.
- I continued to develop it *during* the 23rd EEGLAB workshop in January 2017 at Mysuru, India.
- Proposed to Nattapong from Osaka University as a ‘souvenir project’.
    - E-mail discussion with György, Daniel, Dion, and Brendon.
    - First submitted in 2017 (rejected).
    - The second submission accepted in 2020.

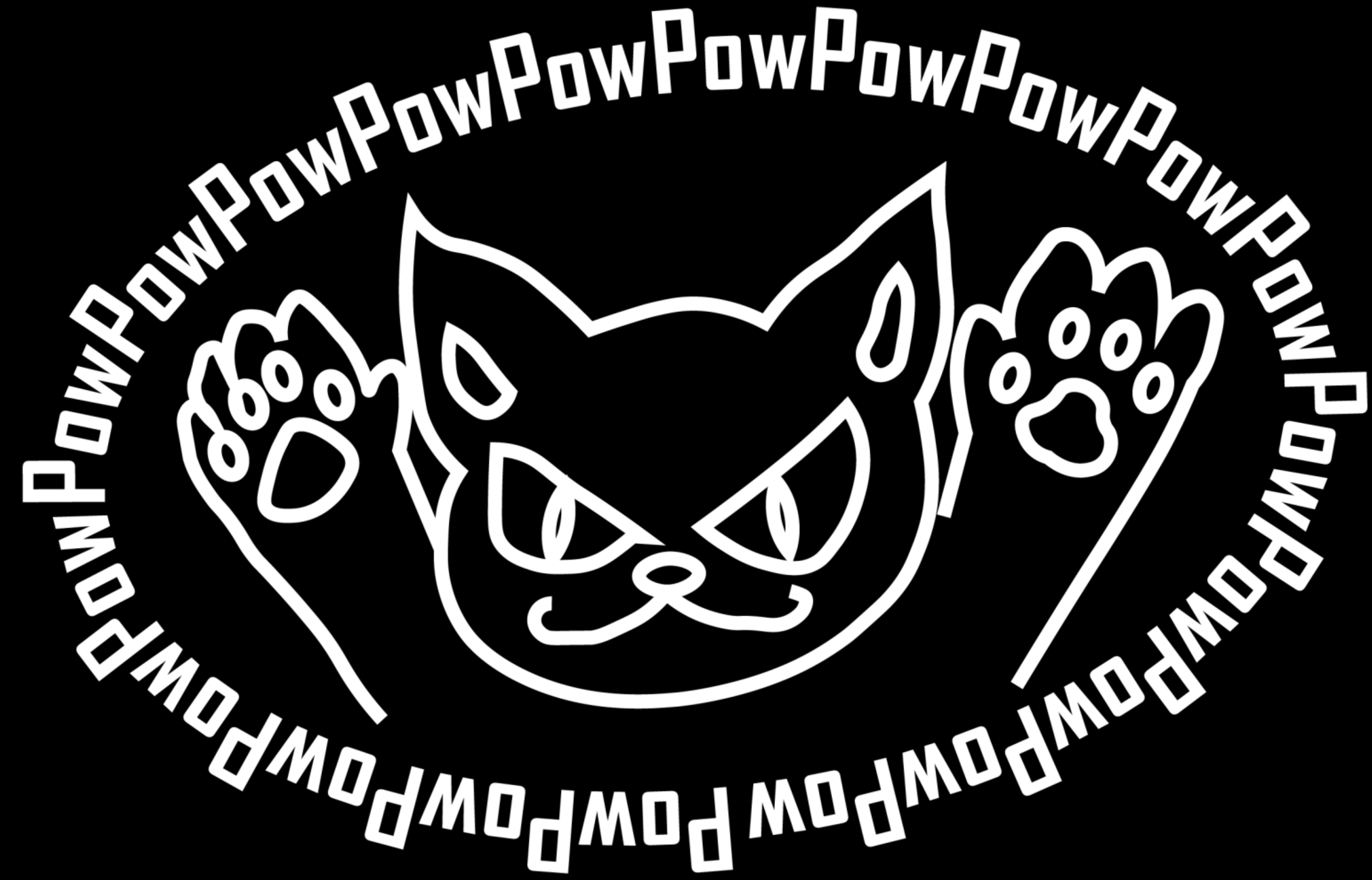
sensors MDPI

Article

Cross-Frequency Power-Power Coupling Analysis: A Useful Cross-Frequency Measure to Classify ICA-Decomposed EEG

Nattapong Thammasan [1] and Makoto Miyakoshi [2,*]

Thank you for your attention



Artwork by Mayumi and Makoto Miyakoshi

A mini review of the power-power coupling analysis

by Nattapong Thammasan

(imec the Netherlands, Arnhem, Gelderland, Netherland)

Envelope-Envelope Coupling

Bekisz & Wróbel, 1999
Neuroreport
Cross-correlation between envelopes of <u>filtered</u> beta and gamma oscillatory signals

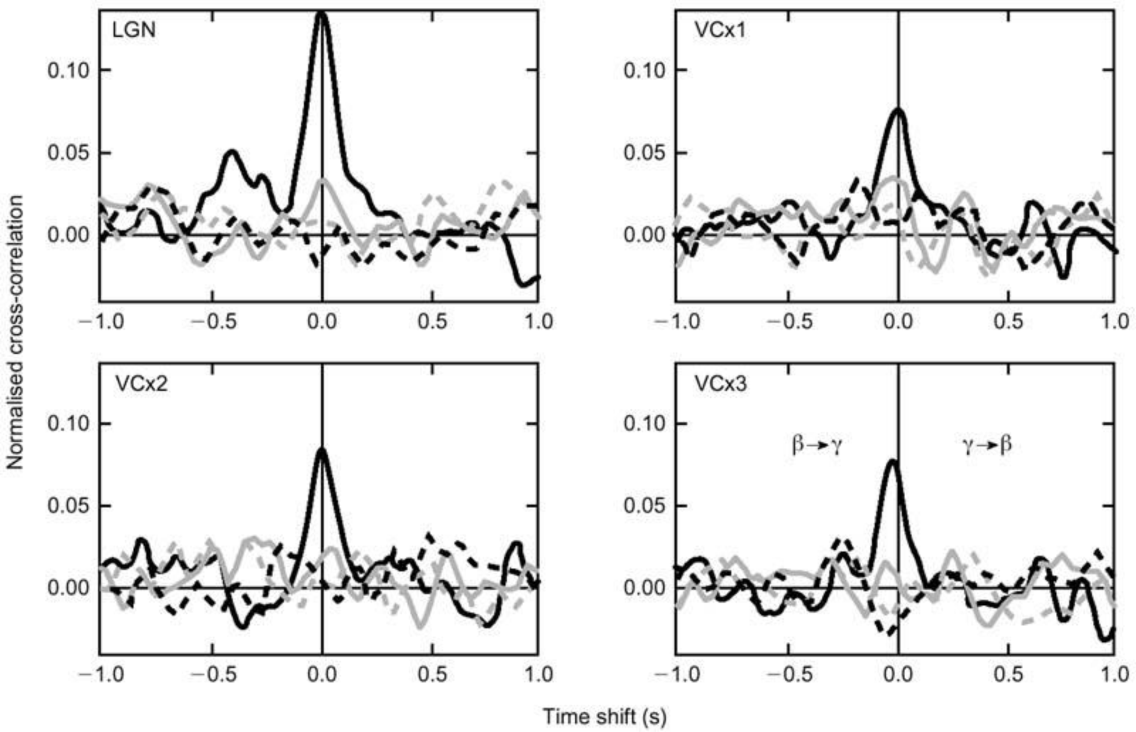
Bruns et al., 2000
Neuroreport
Amplitude-envelope correlation (AEC) of <u>filtered</u> signals

Bruns & Eckhorn, 2004
Int. J. Psychophysiol
Correlation between corresponding envelope segments

Jirsa & Müller, 2013
Front. Comput. Neurosci.
Review paper
Envelope-Envelope Coupling

Envelope-Envelope Coupling

Bekisz & Wróbel, 1999



Cross-correlation function between envelopes of beta and gamma signals

Bruns et al., 2000

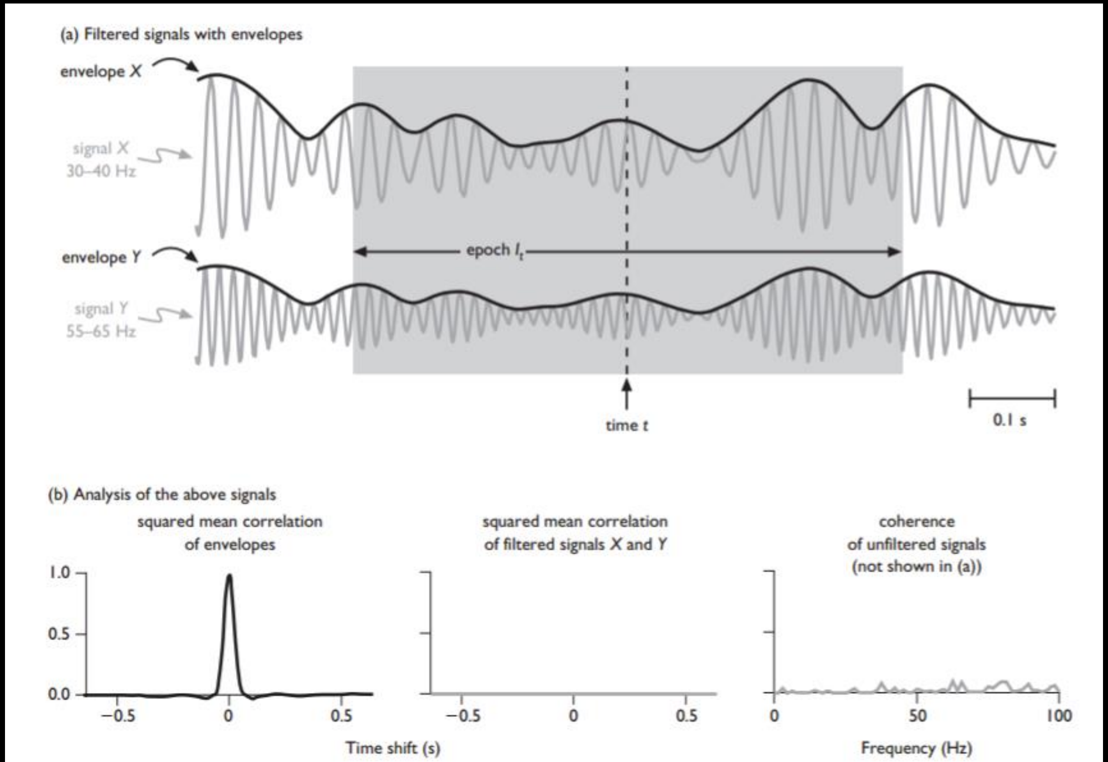
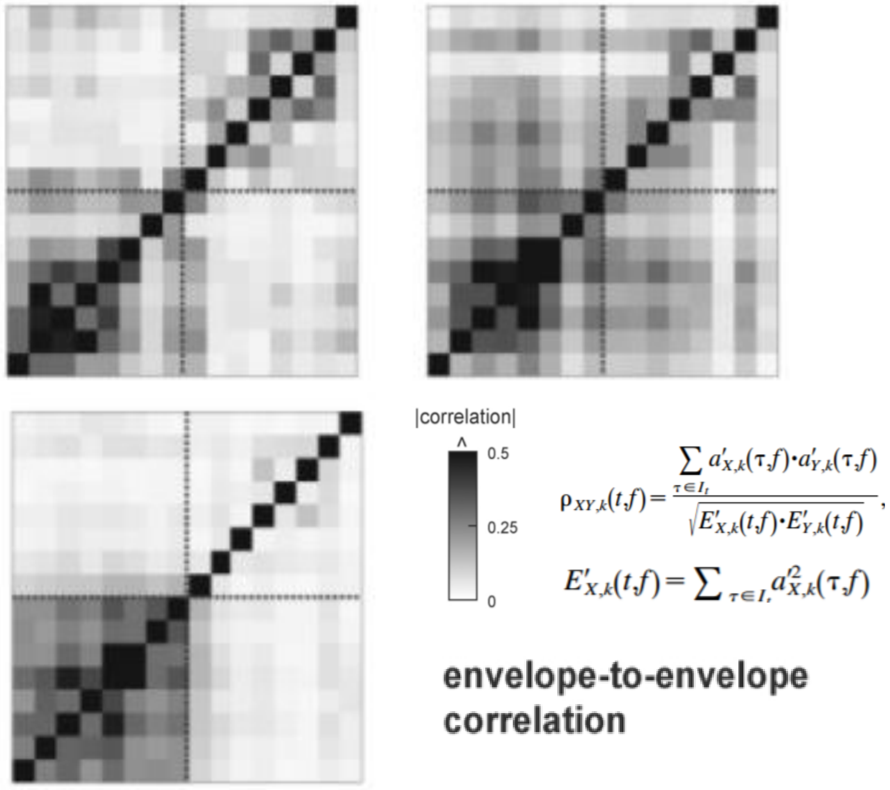


Illustration of AEC method

Envelope-Envelope Coupling

Bruns & Eckhorn, 2004



$$\rho_{XY,k}(t,f)=\frac{\sum_{\tau\in I_t} a'_{X,k}(\tau,f)\cdot a'_{Y,k}(\tau,f)}{\sqrt{E'_{X,k}(t,f)\cdot E'_{Y,k}(t,f)}},$$

$$E'_{X,k}(t,f)=\sum_{\tau\in I_t} a'^{2}_{X,k}(\tau,f)$$

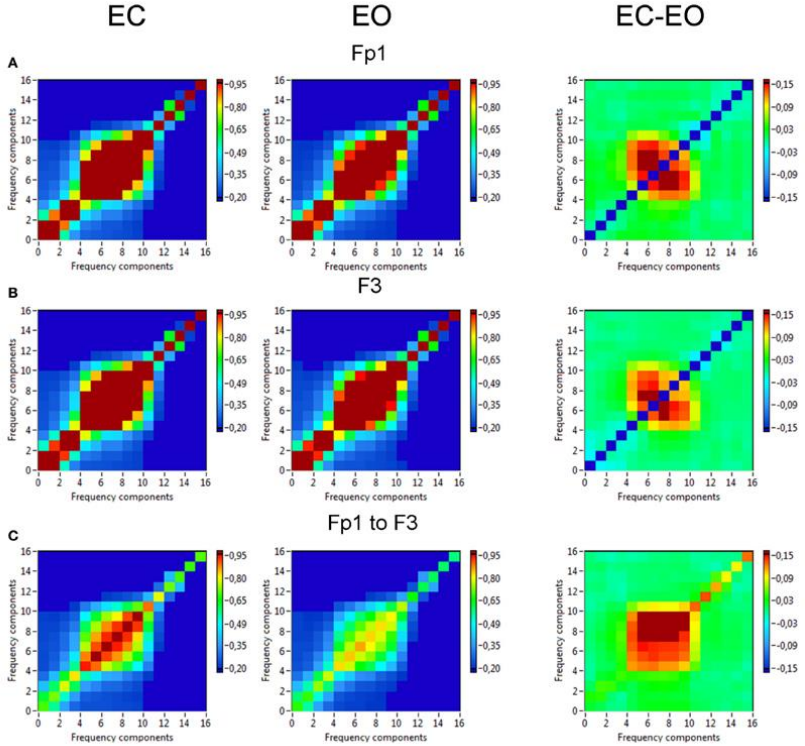
Pronounced task-related increase of gamma-delta envelope-to-signal correlation between superior and inferior occipital visual area → possibly reflecting a short-term memory encoding process

Jirsa & Müller, 2013

$$\rho_X^{(k)}(f_m,f_n,t)=\frac{\sum\left(A_X^{(k)}(f_m,\tau)\cdot A_Y^{(k)}(f_n,\tau)\right)}{\sqrt{E_X^{(k)}(f_m,\tau)\cdot E_Y^{(k)}(f_n,\tau)}}$$

Eye Closed

Eye Open



Strongest in 5-14 Hz, Coupling in EC > in EO

Envelope-Envelope Coupling

- Bruns & Eckhorn, *Int. J. Psychophysiol*, 2004
  - correlation between corresponding envelope segments was determined after subtracting the segments' means and correlation values were normalized to segment energies:

$$\rho_{XY,k}(t,f) = \frac{\sum_{\tau \in I_t} a'_{X,k}(\tau,f) \cdot a'_{Y,k}(\tau,f)}{\sqrt{E'_{X,k}(t,f) \cdot E'_{Y,k}(t,f)}},$$

where $a'_{X,k}(\tau,f) = a_{X,k}(\tau,f) - \overline{a_{X,k}}(t,f)$ $(\tau \in I_t)$ denotes an envelope segment with its mean subtracted, and $E'_{X,k}(t,f) = \sum_{\tau \in I_t} a'^2_{X,k}(\tau,f)$ is the energy of that segment. Finally, correlation values were averaged across trials, using Fisher's Z transform $\mathrm{FZT}(\rho) = \tanh^{-1}(\rho)$:

$$\rho_{XY}(t,f) = \mathrm{FZT}^{-1}\left(\frac{1}{N}\sum_{k=1}^{N} \mathrm{FZT}(\rho_{XY,k}(t,f))\right). \qquad (8)$$

envelope-to-envelope correlation