Artwork by Mayumi and Makoto Miyakoshi

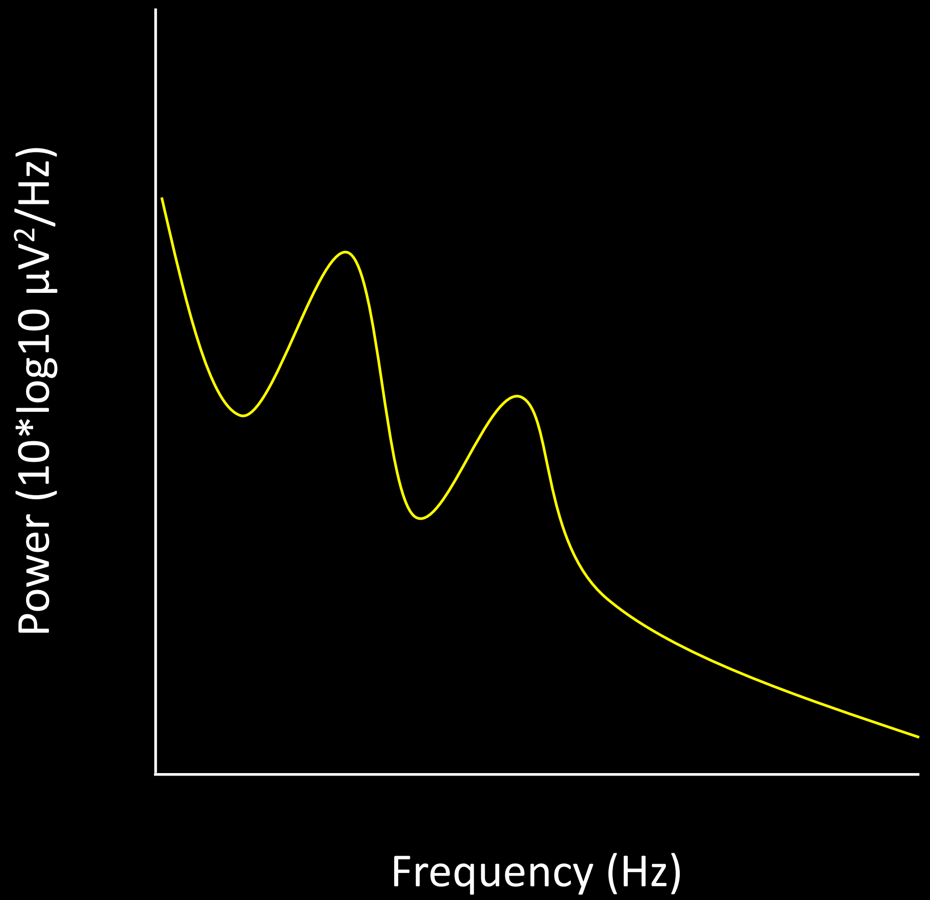
Cross-frequency power-power coupling analysis toolbox (PowPowCAT)

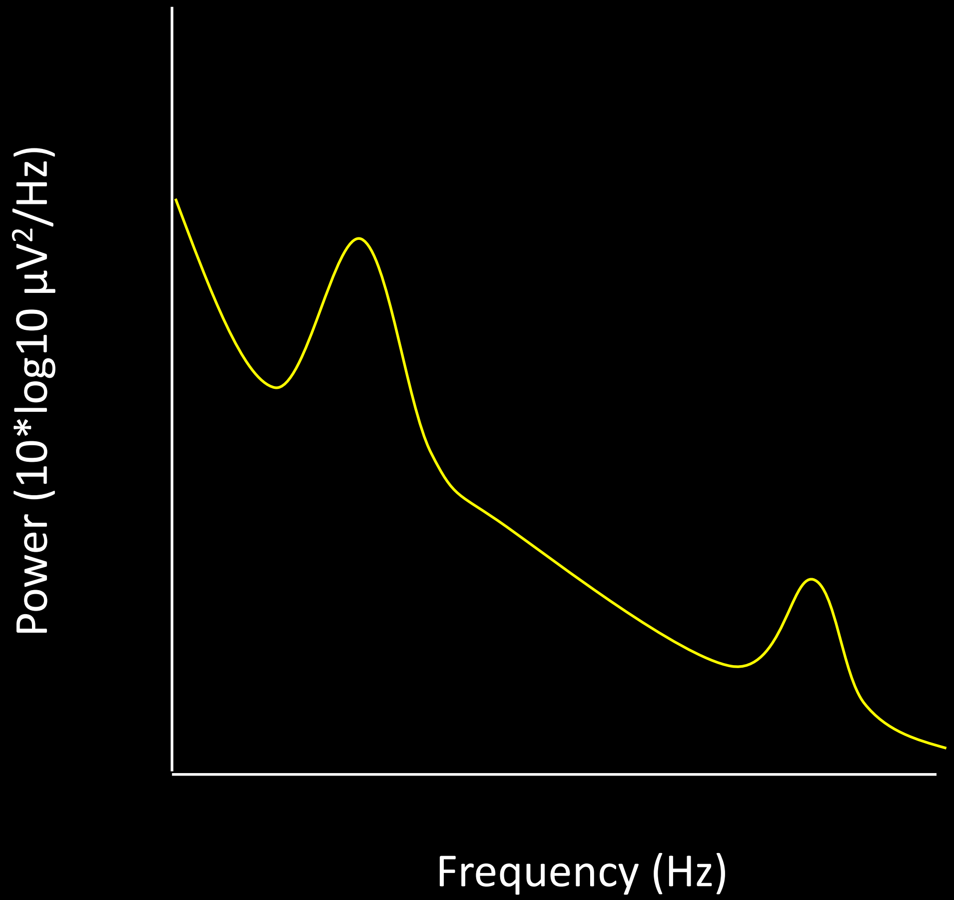
Makoto Miyakoshi

Advanced Topics in The 30th EEGLAB workshop

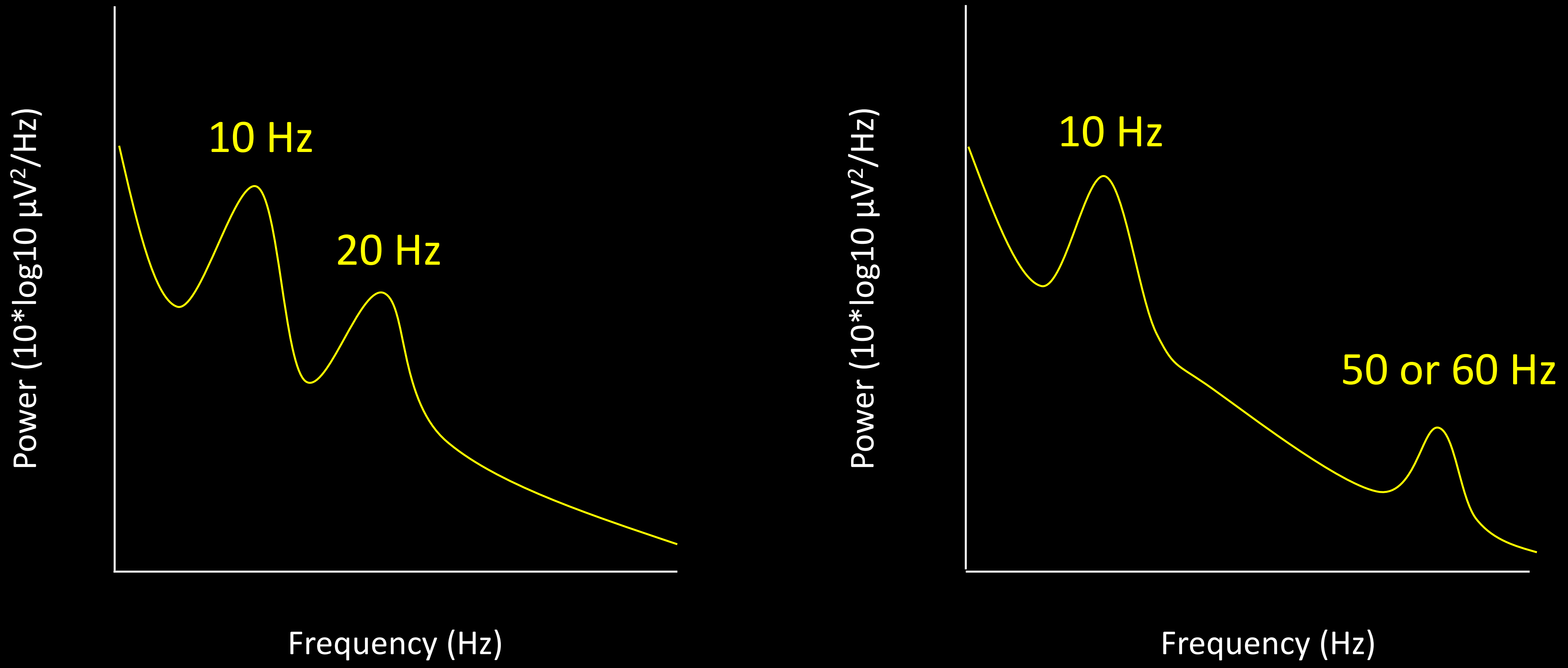
June 15, 2021 12:00-12:45 pm

What’s the difference?

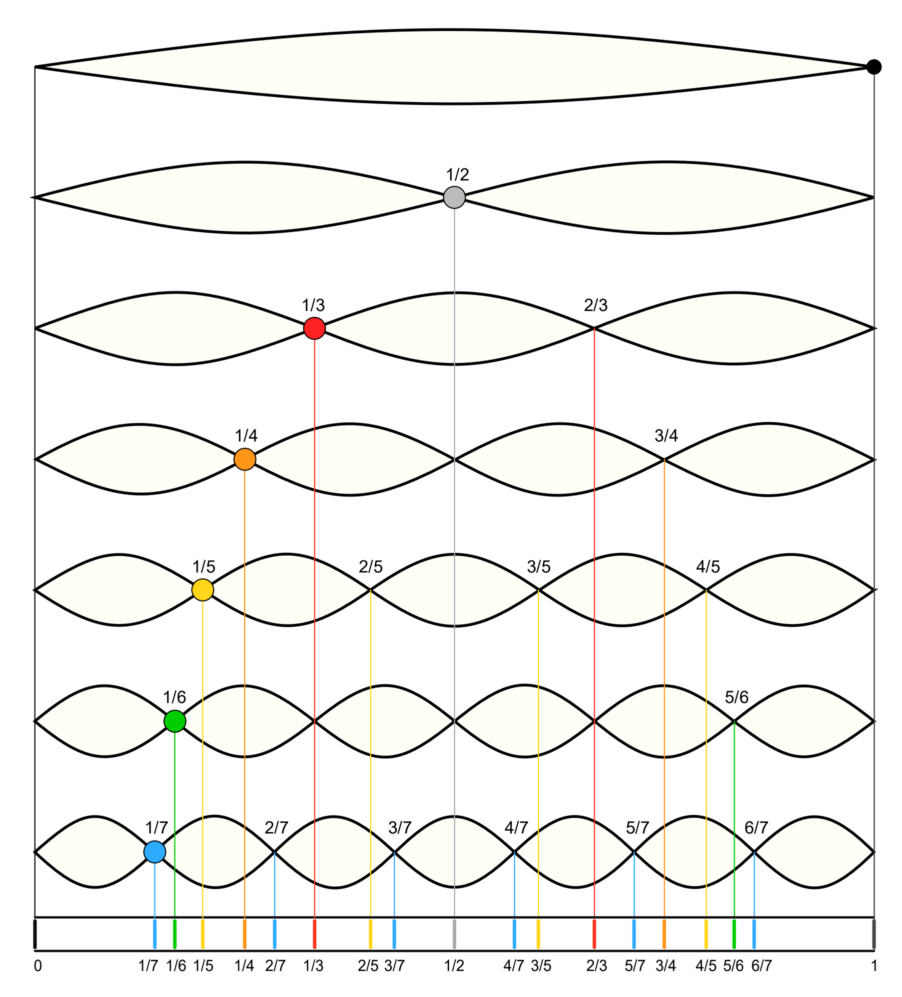




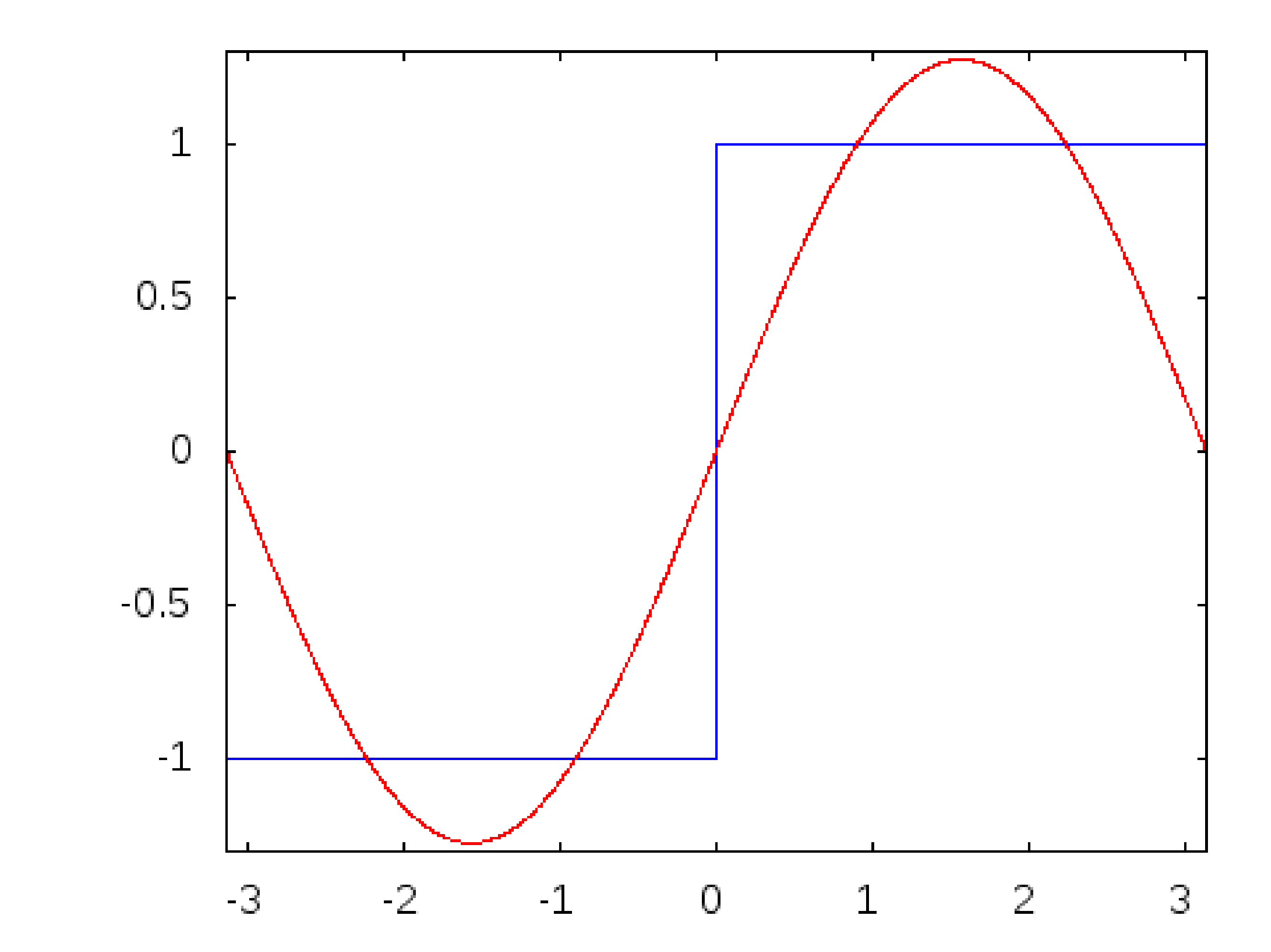
How about this?



What is harmonics?

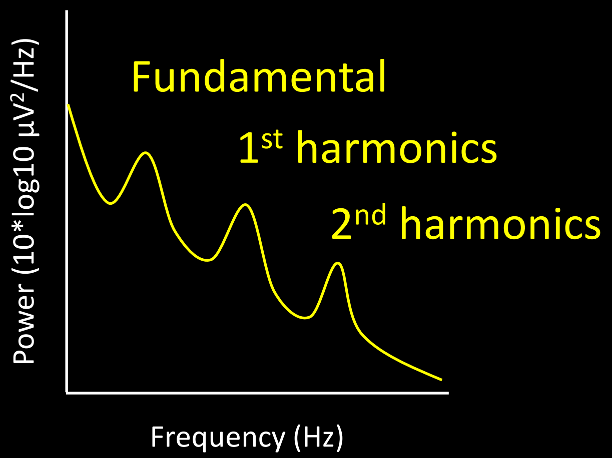


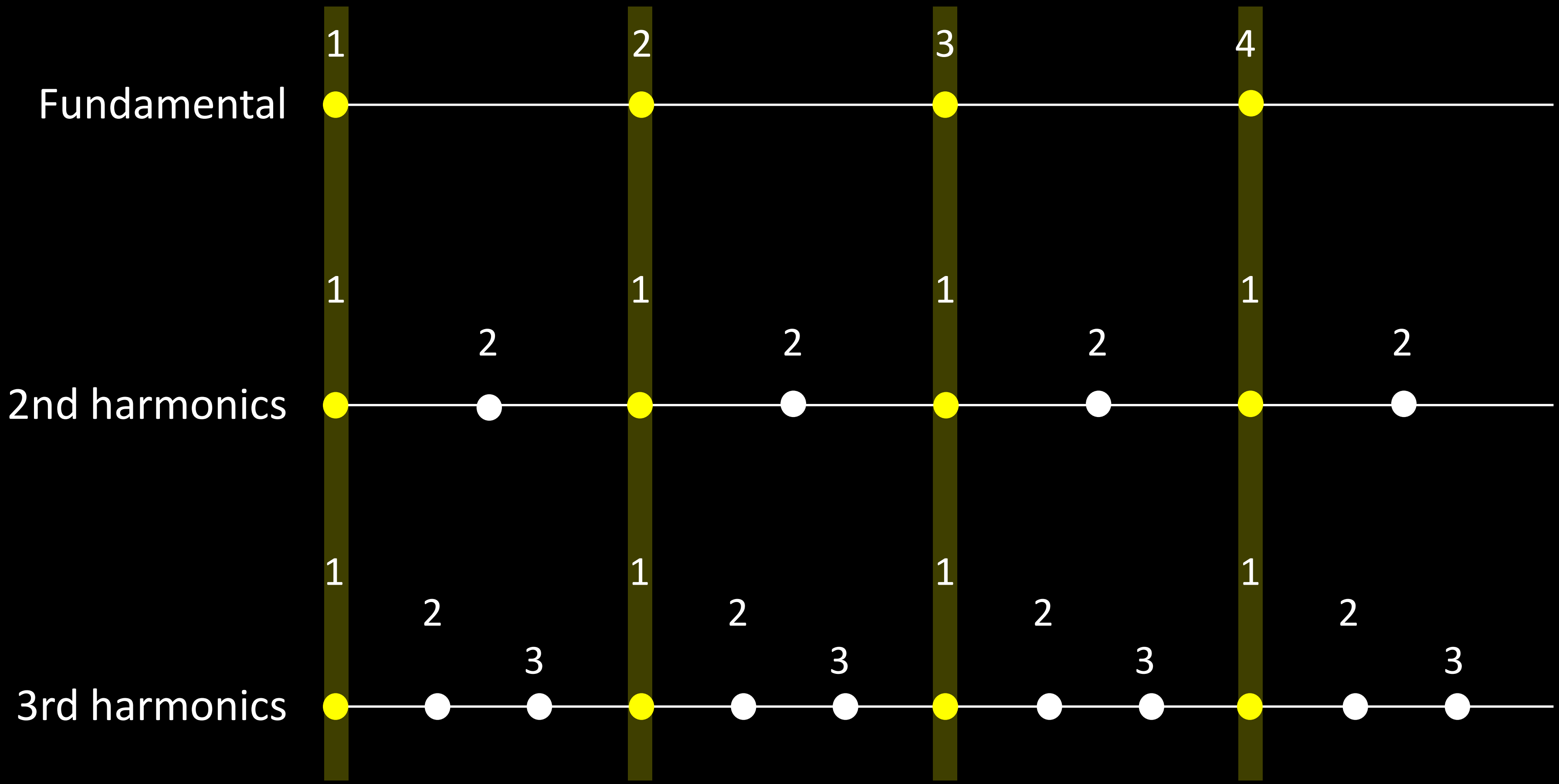
Wikipedia ‘harmonics’



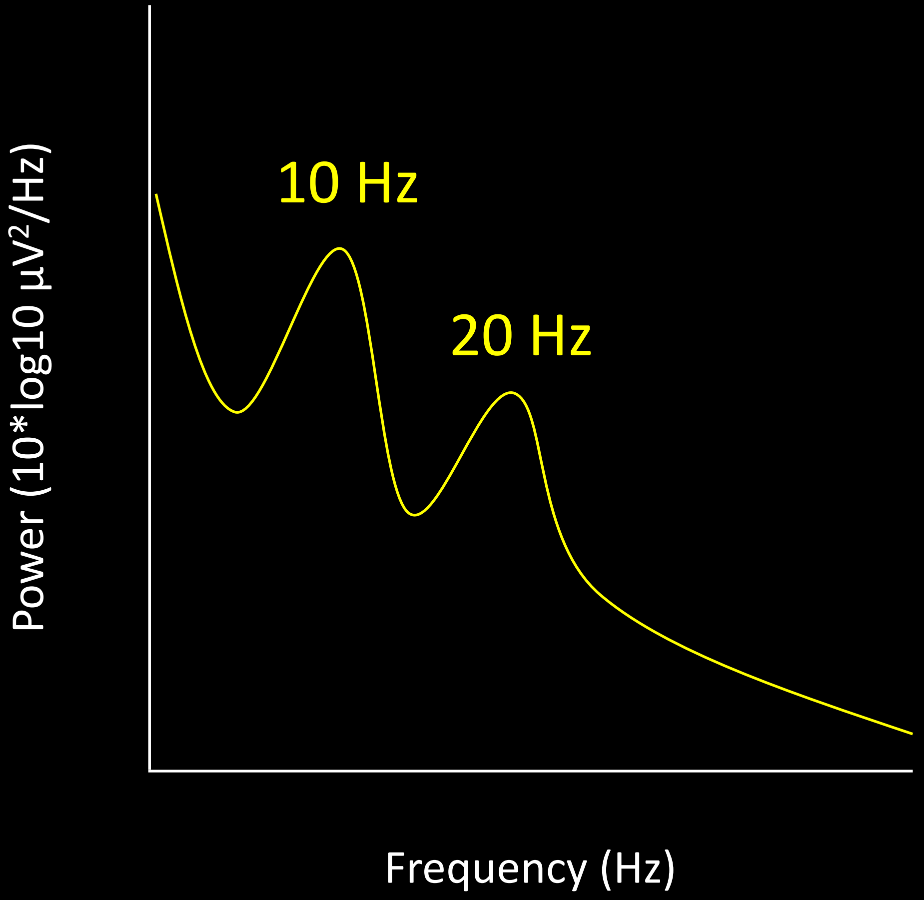
Wikipedia ‘square wave’

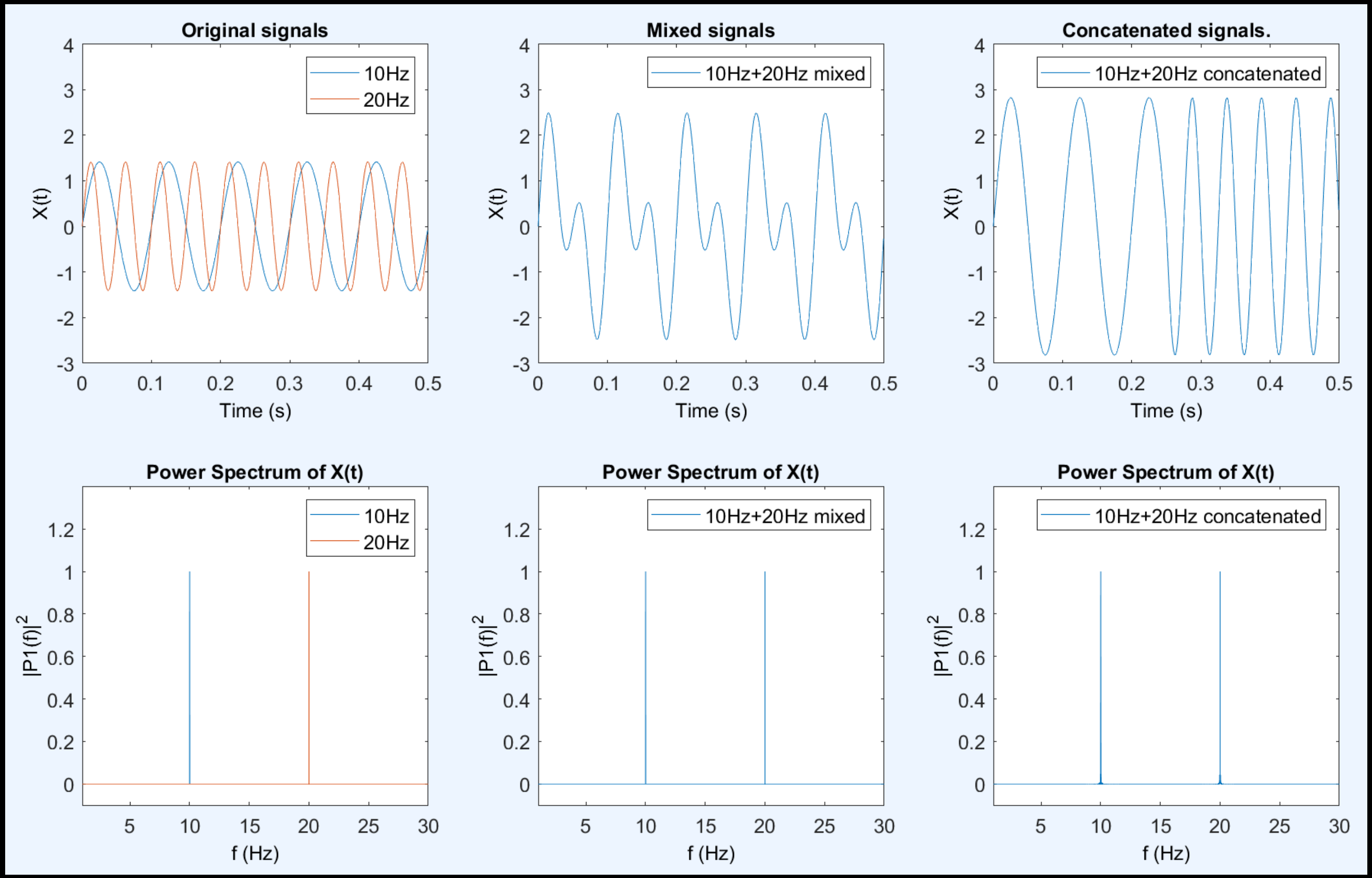
Virtual John Iversen’s explanation





Double peaks does not guarantee cross-frequency coupling

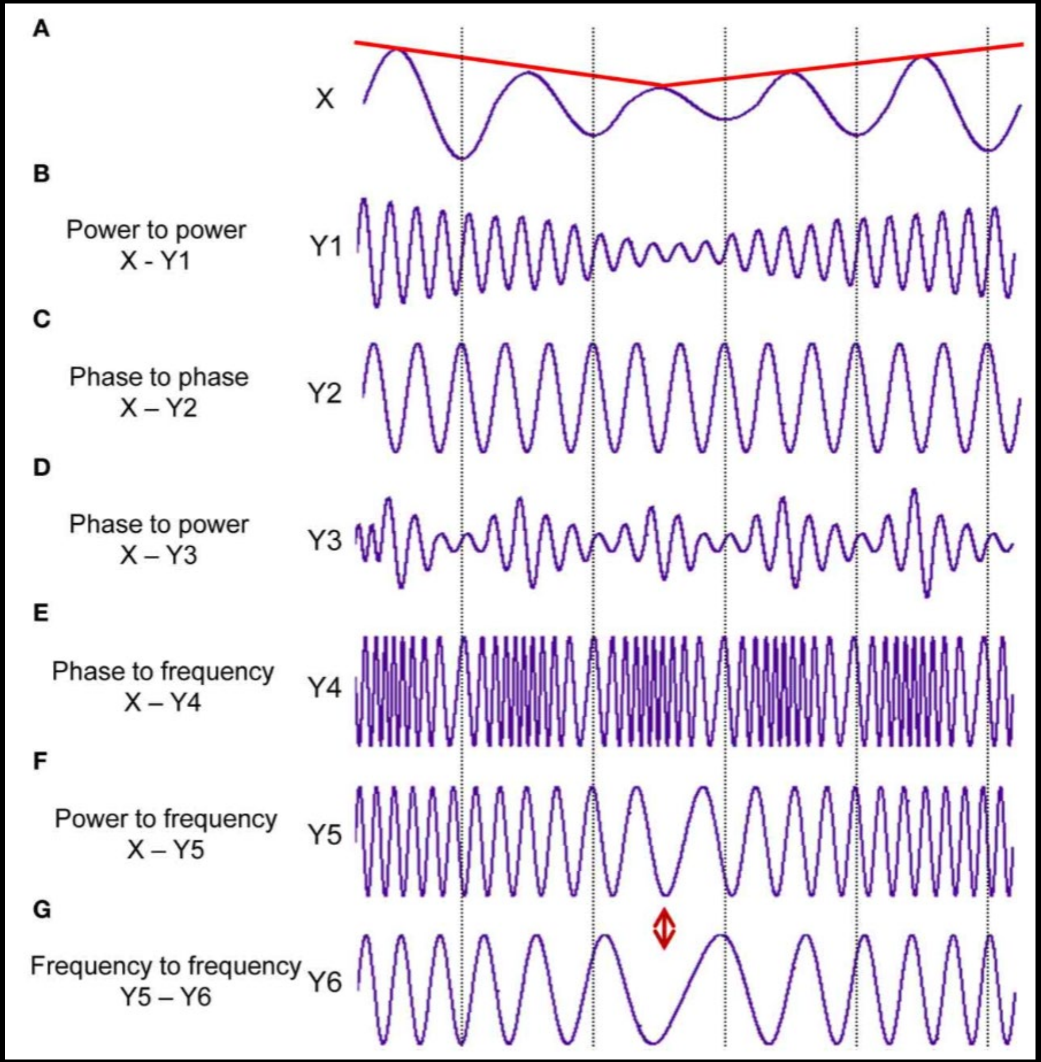




Thammasan and Miyakoshi (2020)

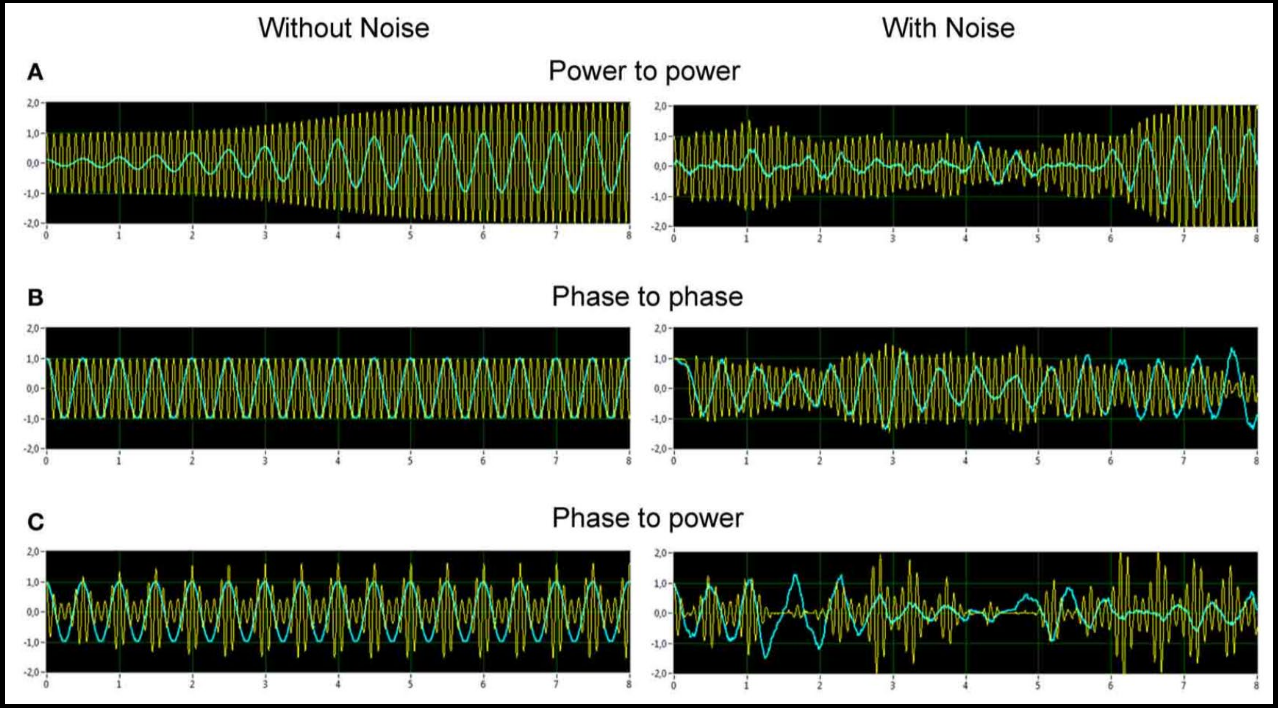
Why do I like power-power coupling?

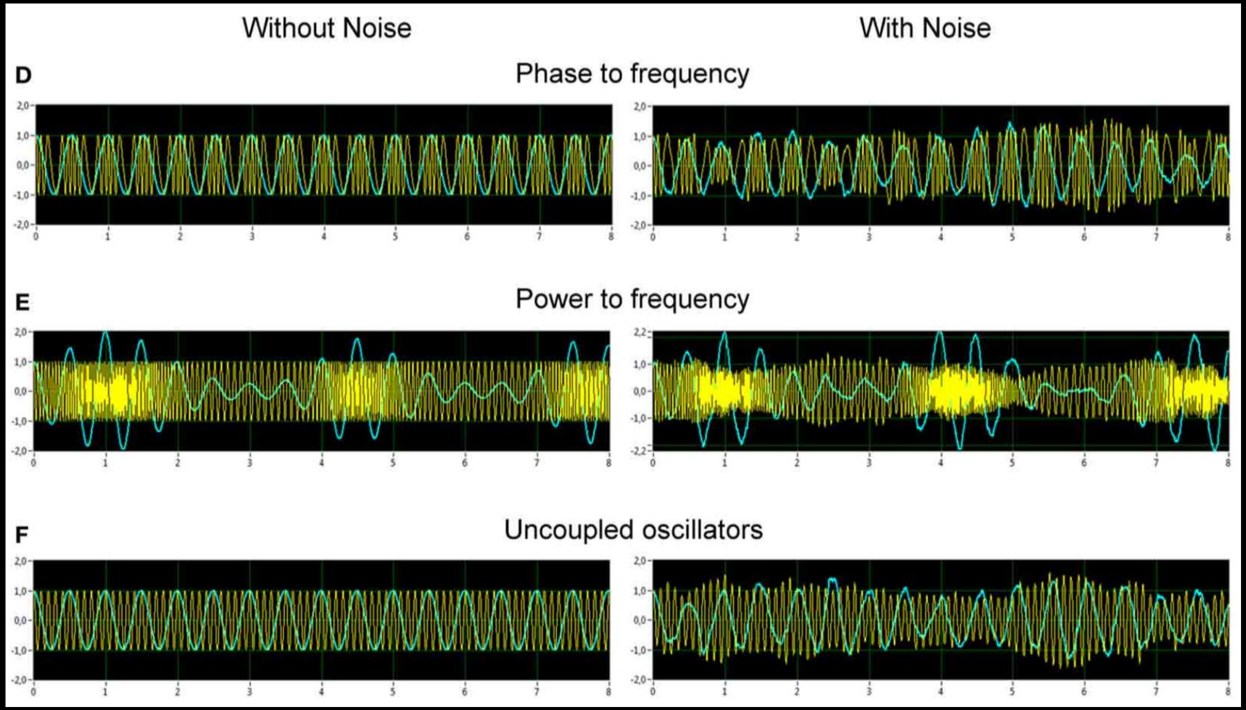
List of cross-frequency relations 1



Jirsa and Müller (2013)

List of cross-frequency relations 2

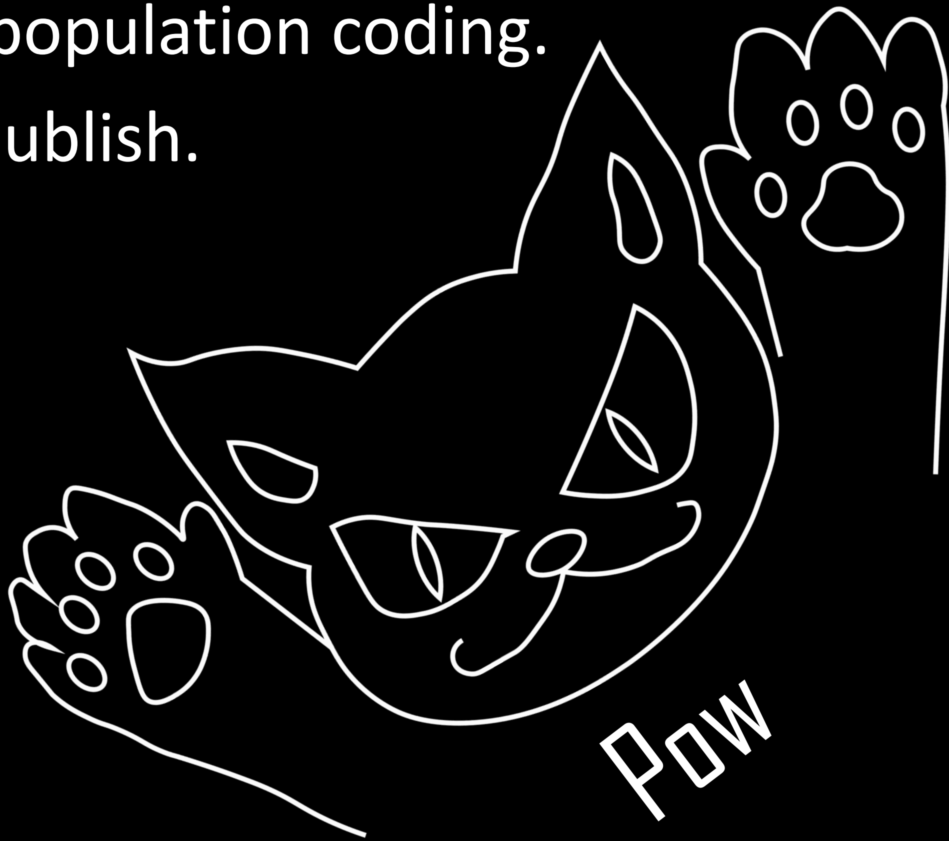




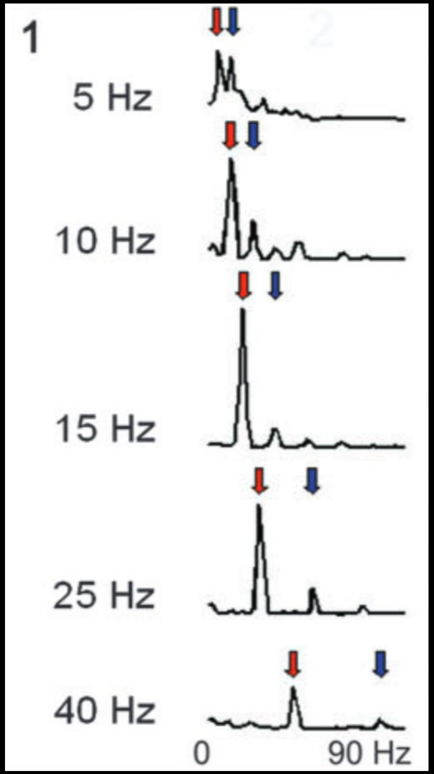
Jirsa and Müller (2013)

Reasons to analyze EEG power rather than phase

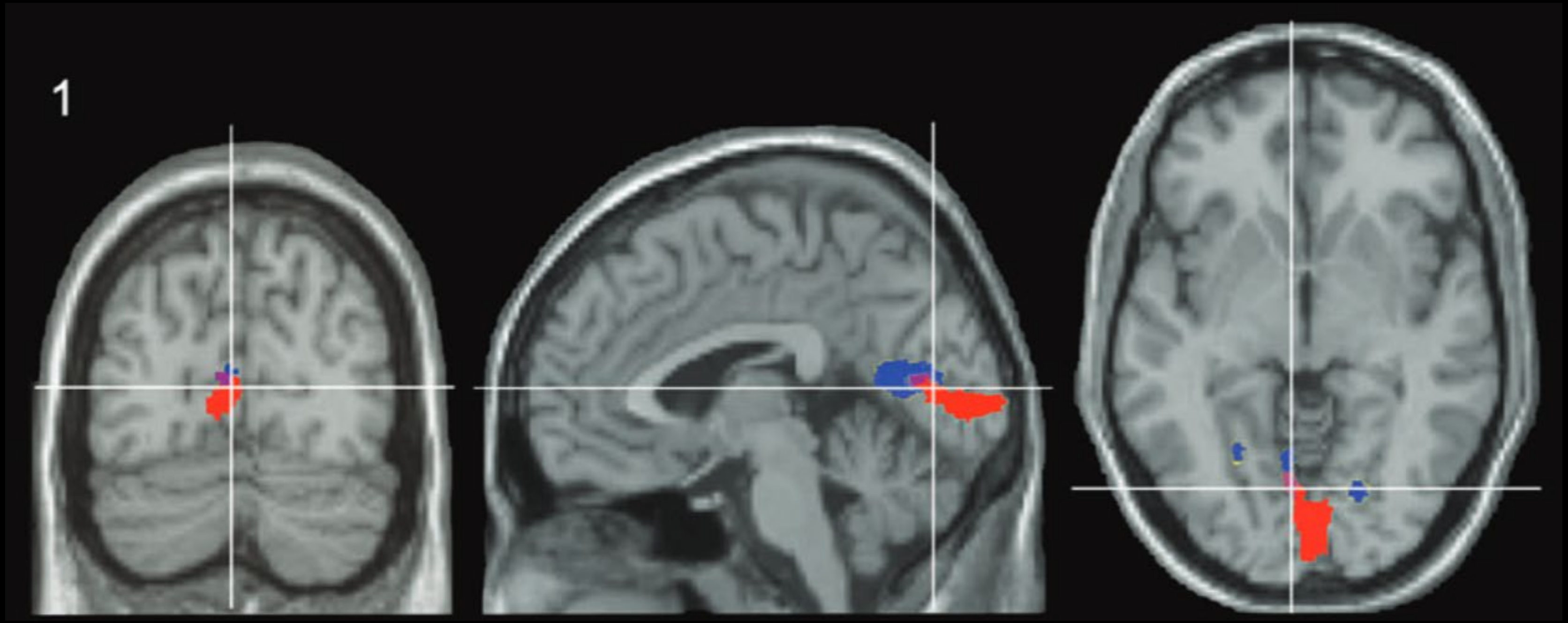
- Phase is a noisy metric, has weird dependency on amplitude contrary to the intuition, etc.
- Power metric has good biological evidence: population coding.
- ‘PowPowCAT’ is a good name which I must publish.



Why is harmonics important in EEG? 1



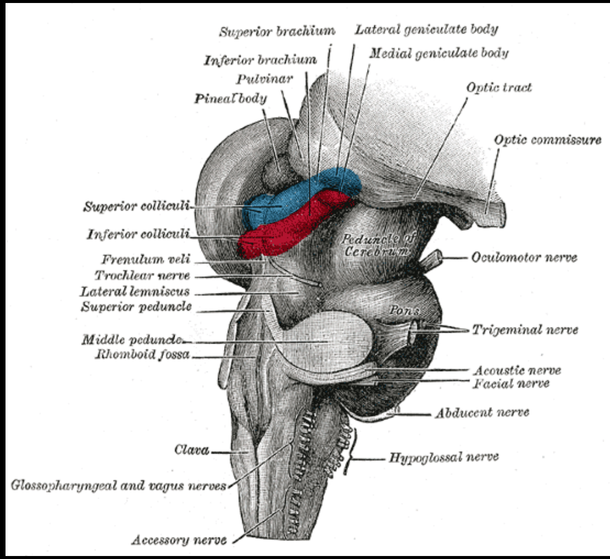
Power Spectral Density of averaged Steady-State Visual Evoked Potential (SSVEP) at Oz, O1, O2.

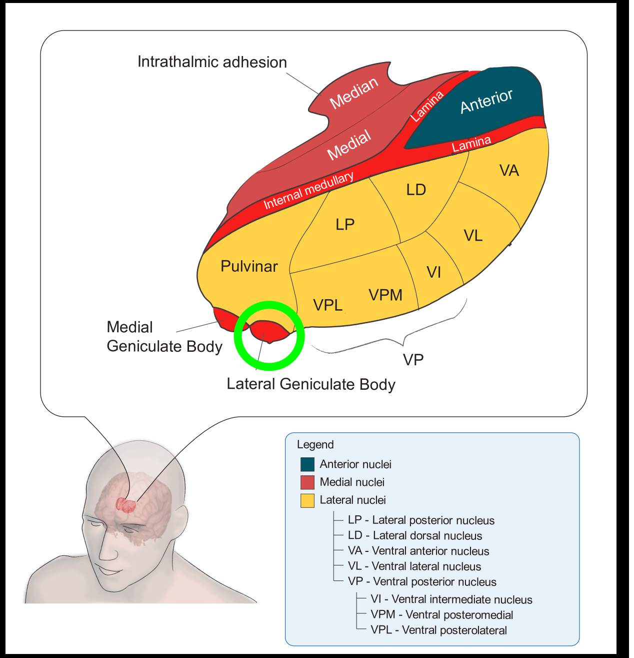


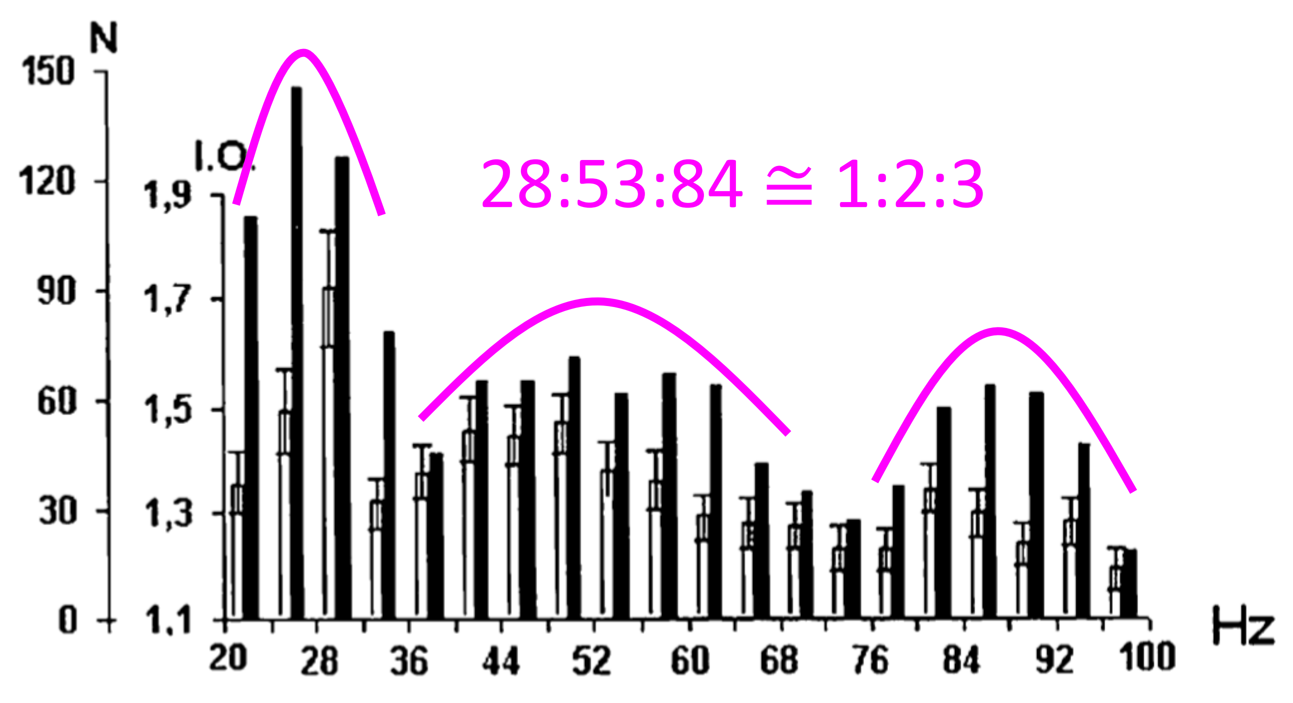
Regional cerebral blood flow (rCBF) measured with $\mathrm{H}_2^{15}\mathrm{O}$ PET. Red, fundamental freq-weighted. Blue, first harmonics-weighted.

Pastor et al. (2006)

Why is harmonics important in EEG? 2







Wikipedia 'lateral geniculate nucleus'

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

Podvigin et al. (2004)

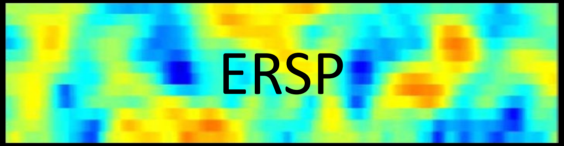
How to calculate power-power coupling

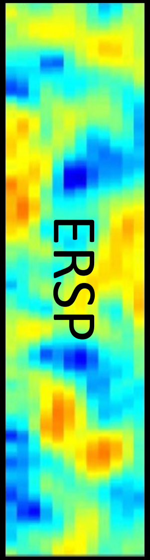
Comodulogram as spectral covariance

When X is the time-frequency decomposed single-channel/component power,

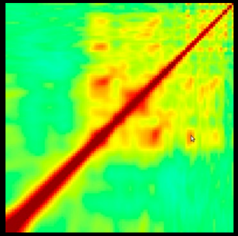
$$\mathrm{Comodulogram(X)} = \frac{\mathrm{cov}(X,X)}{\sigma^2}$$

This calculation is the same as Pearson's correlation coefficient!

$=$ 

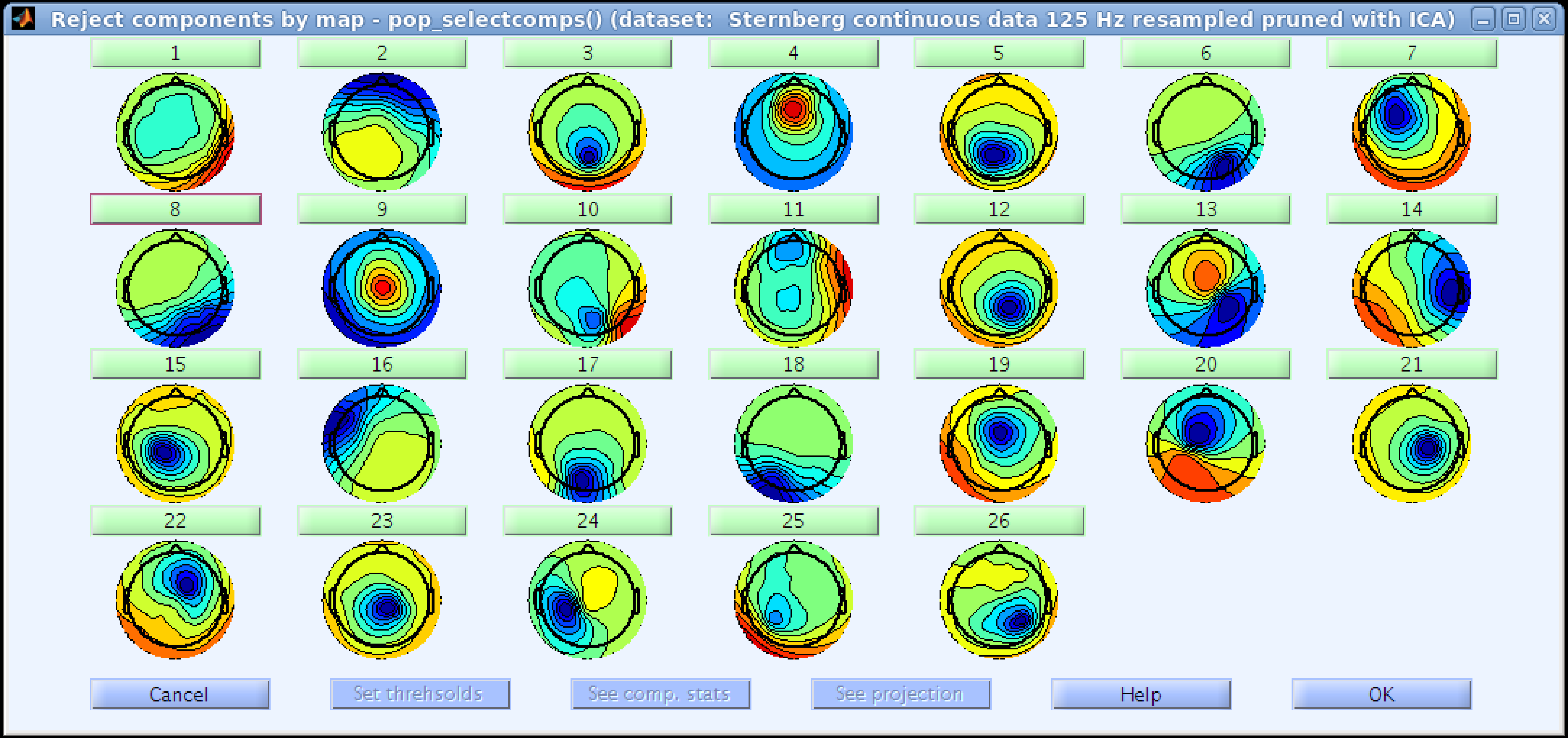
$\times$ 

$\div\ \sigma^2$

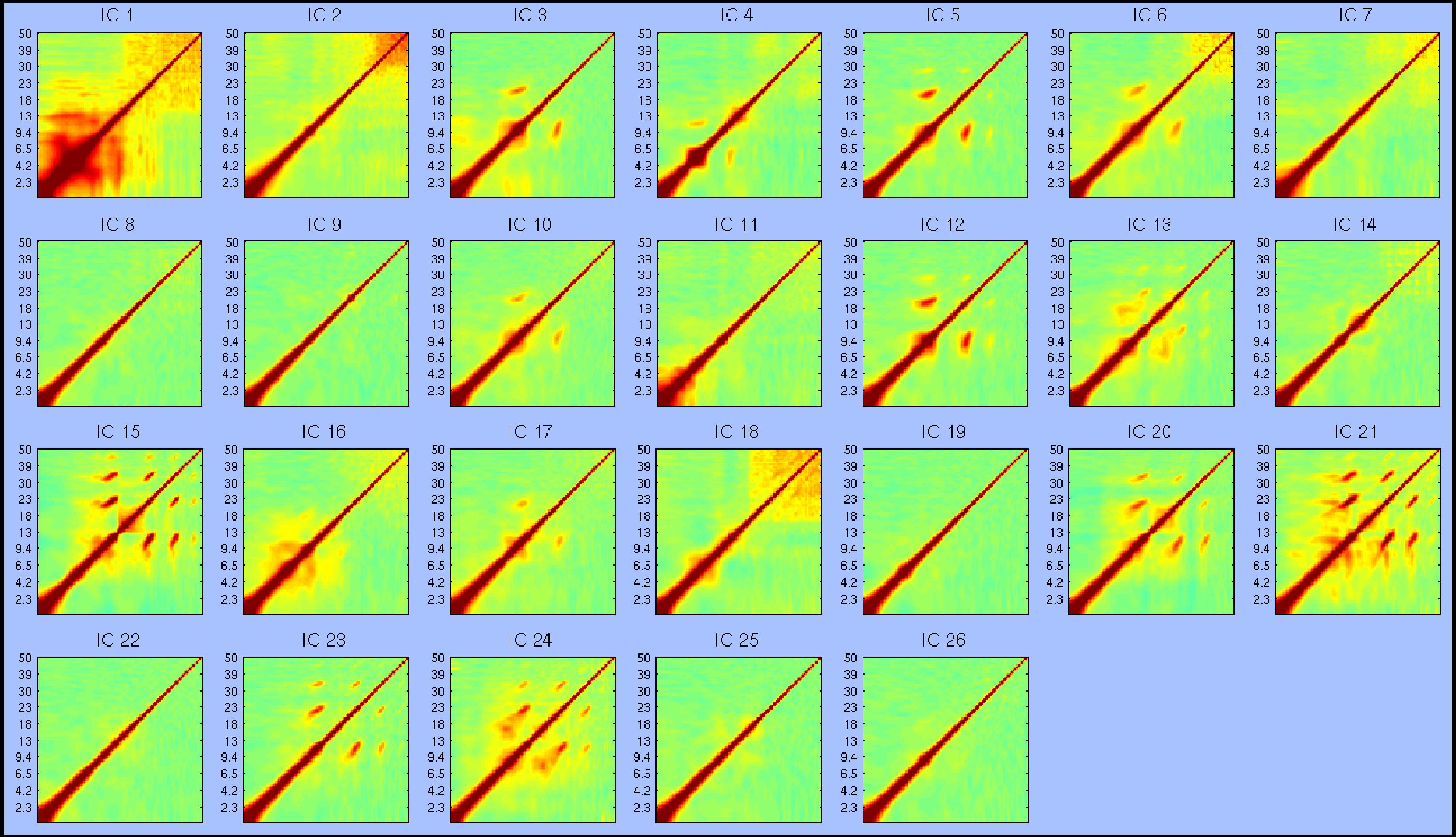
$=$ 

Demonstration of PowPowCAT

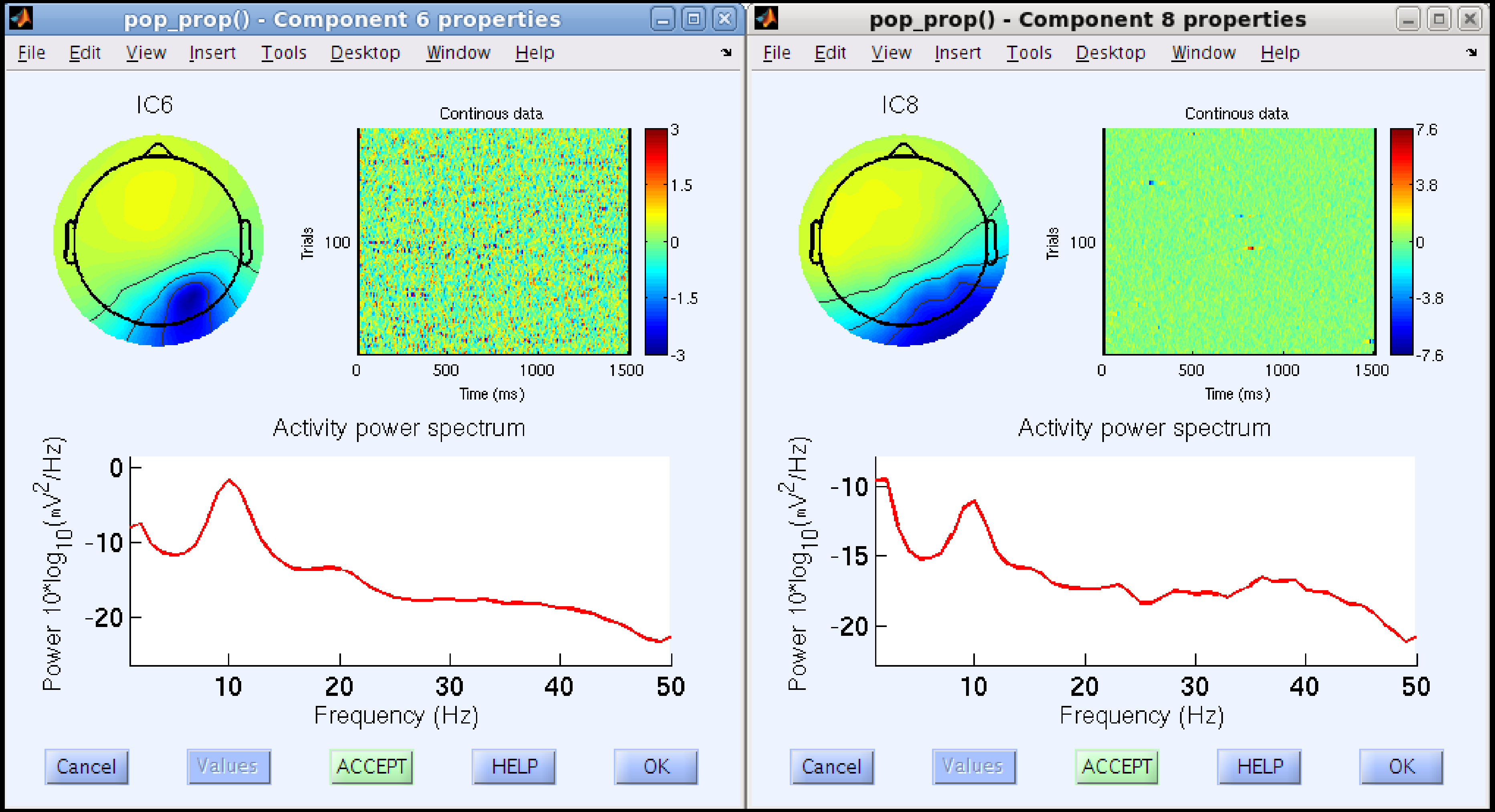
‘stern_125.set’ (tutorial dataset) IC scalp topos



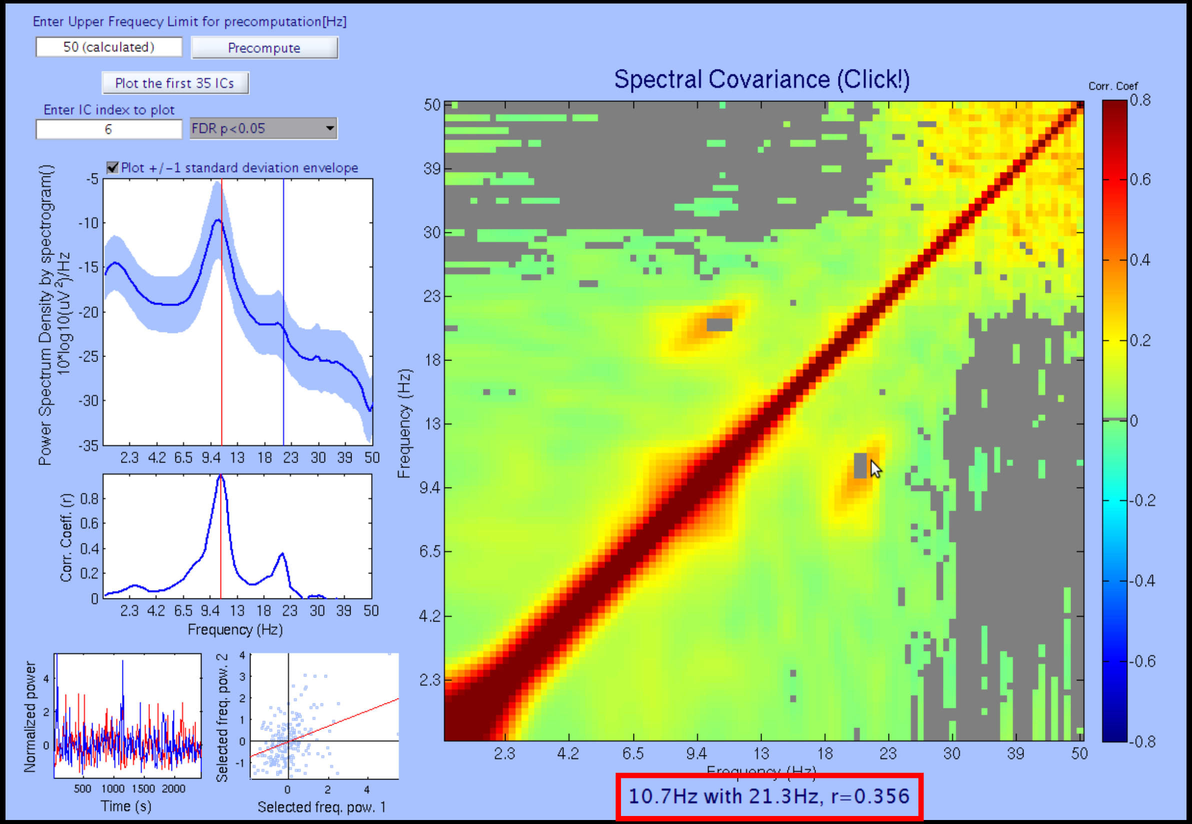
‘stern_125.set’ Comodulogram

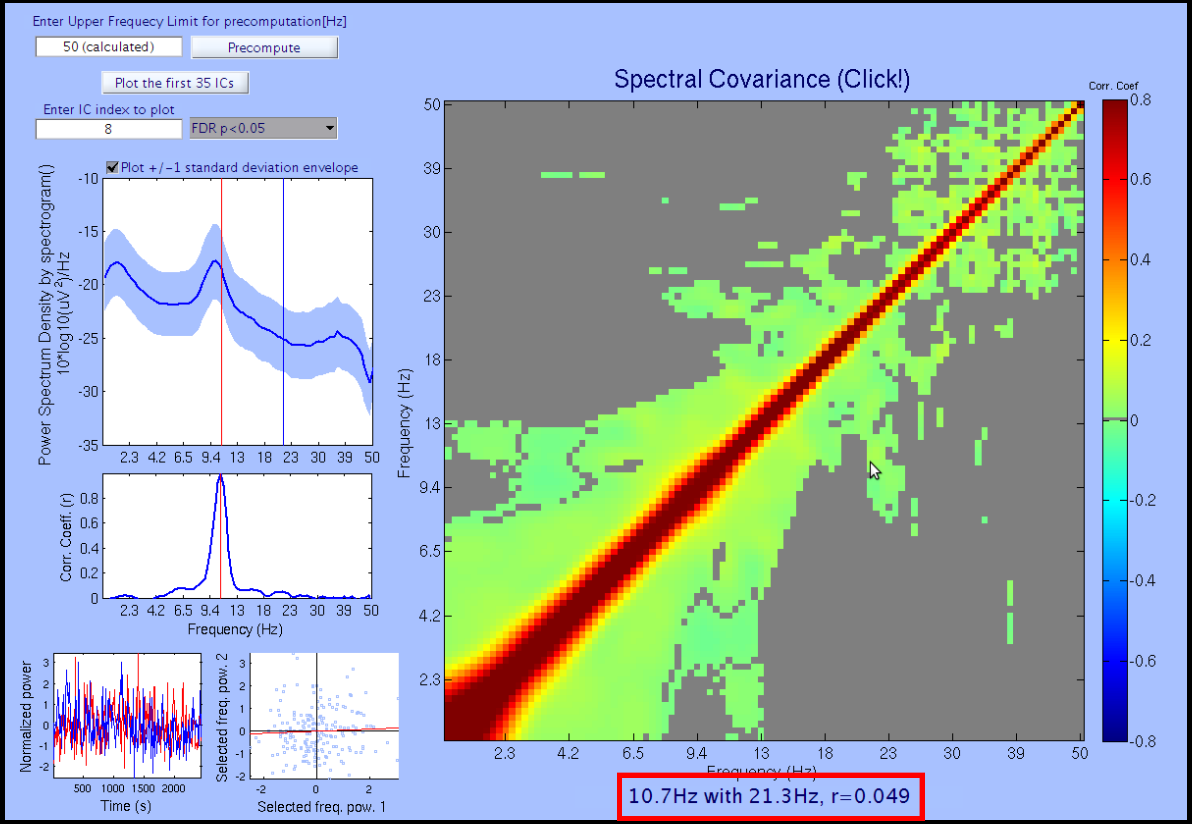


IC6 vs. IC8—What's the best description of the difference?

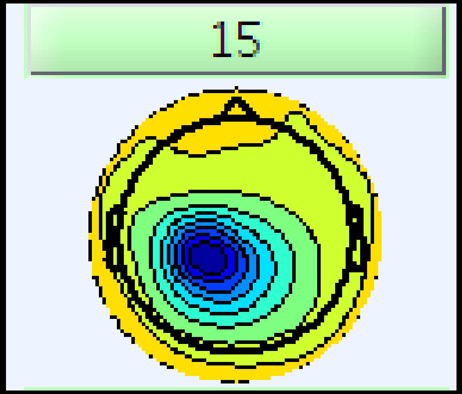


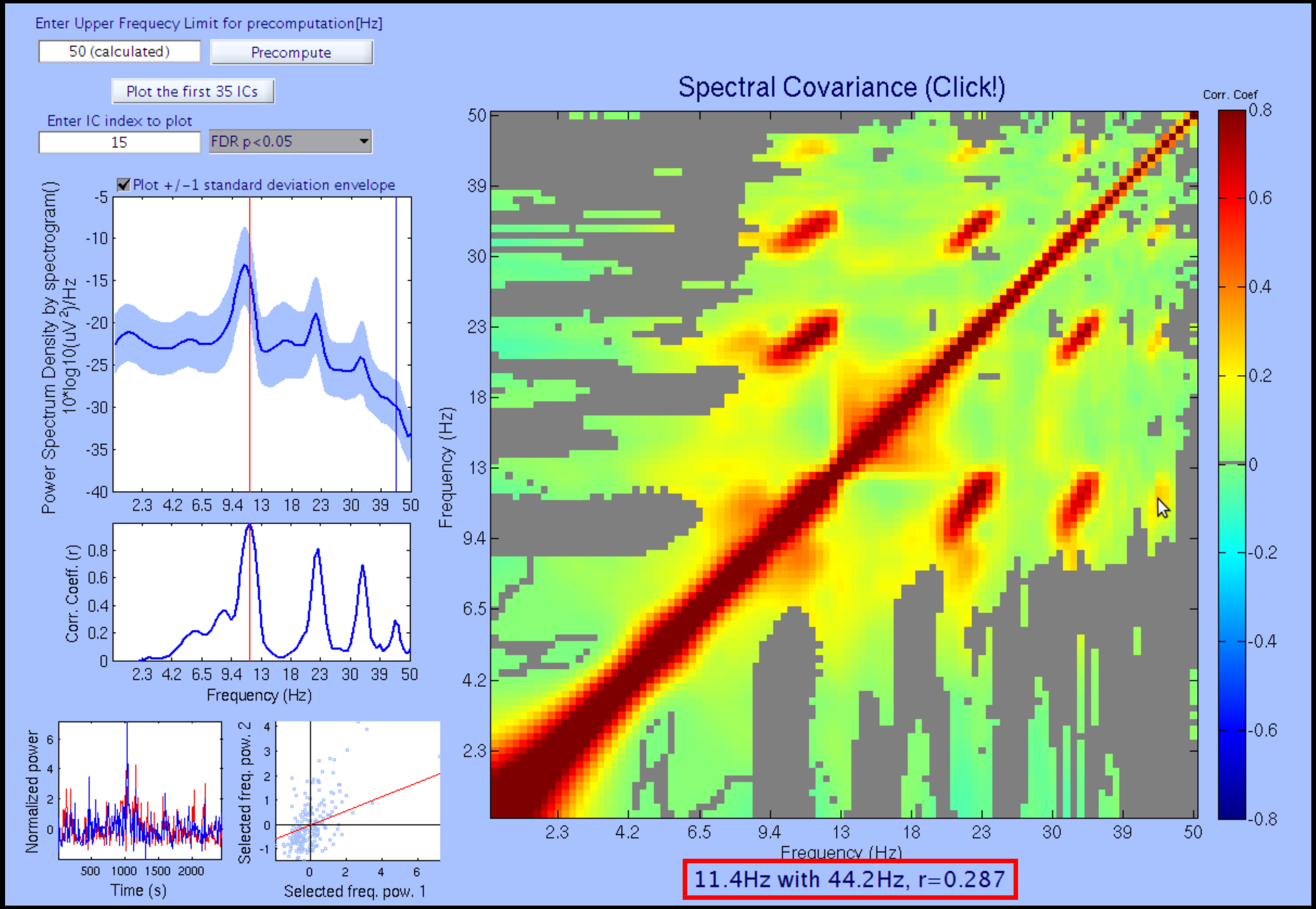
IC6 shows a nice second harmonics (r=0.356)



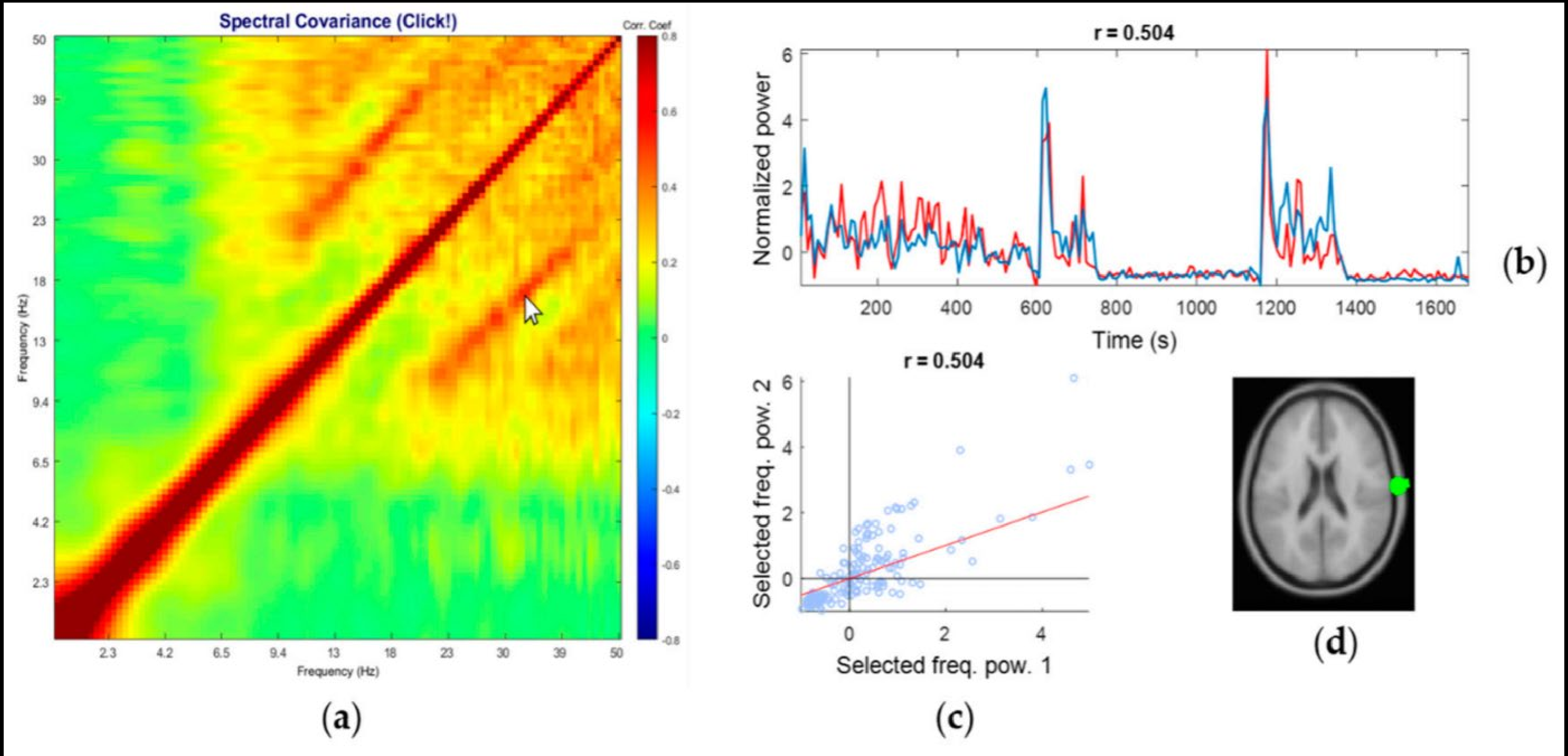


4TH harmonics captured!



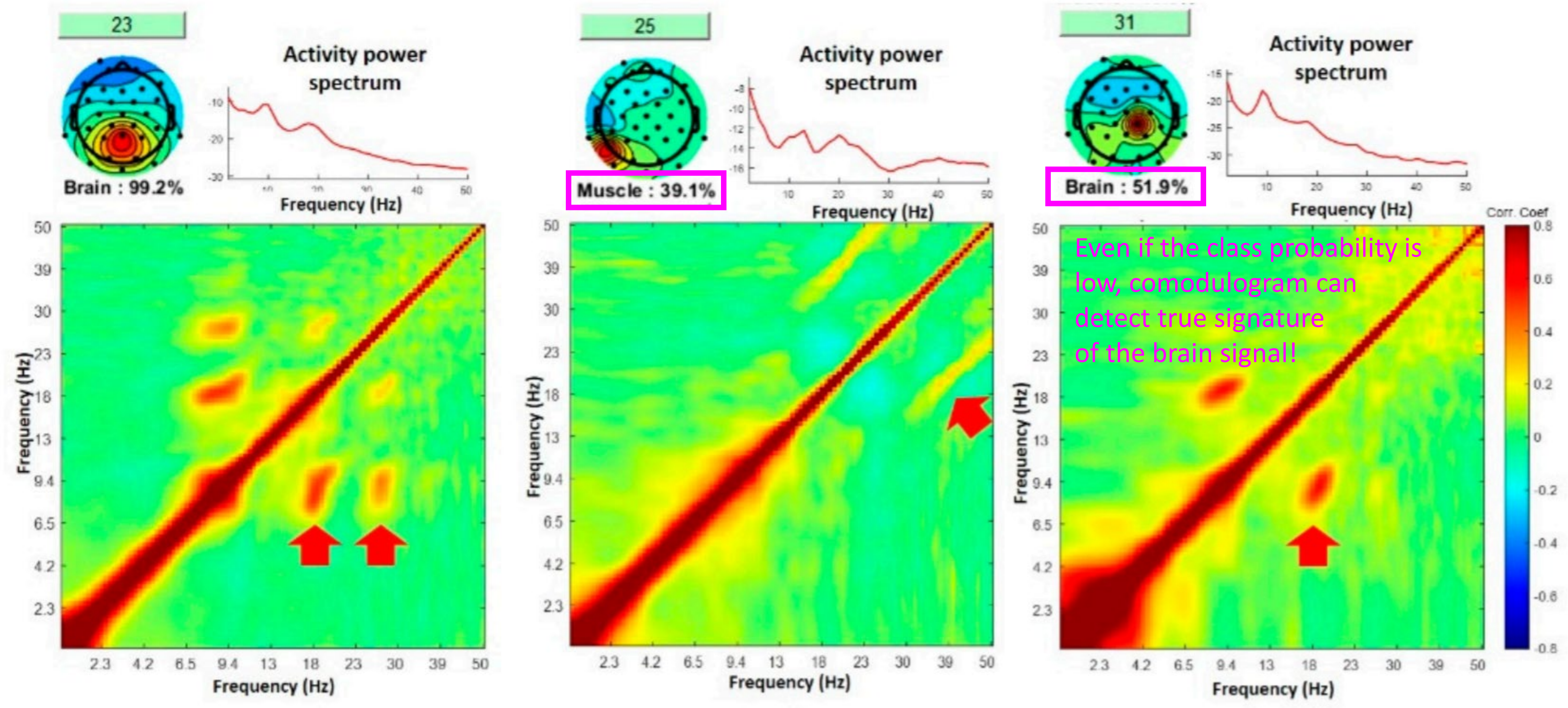


How a muscle IC is nicely represented



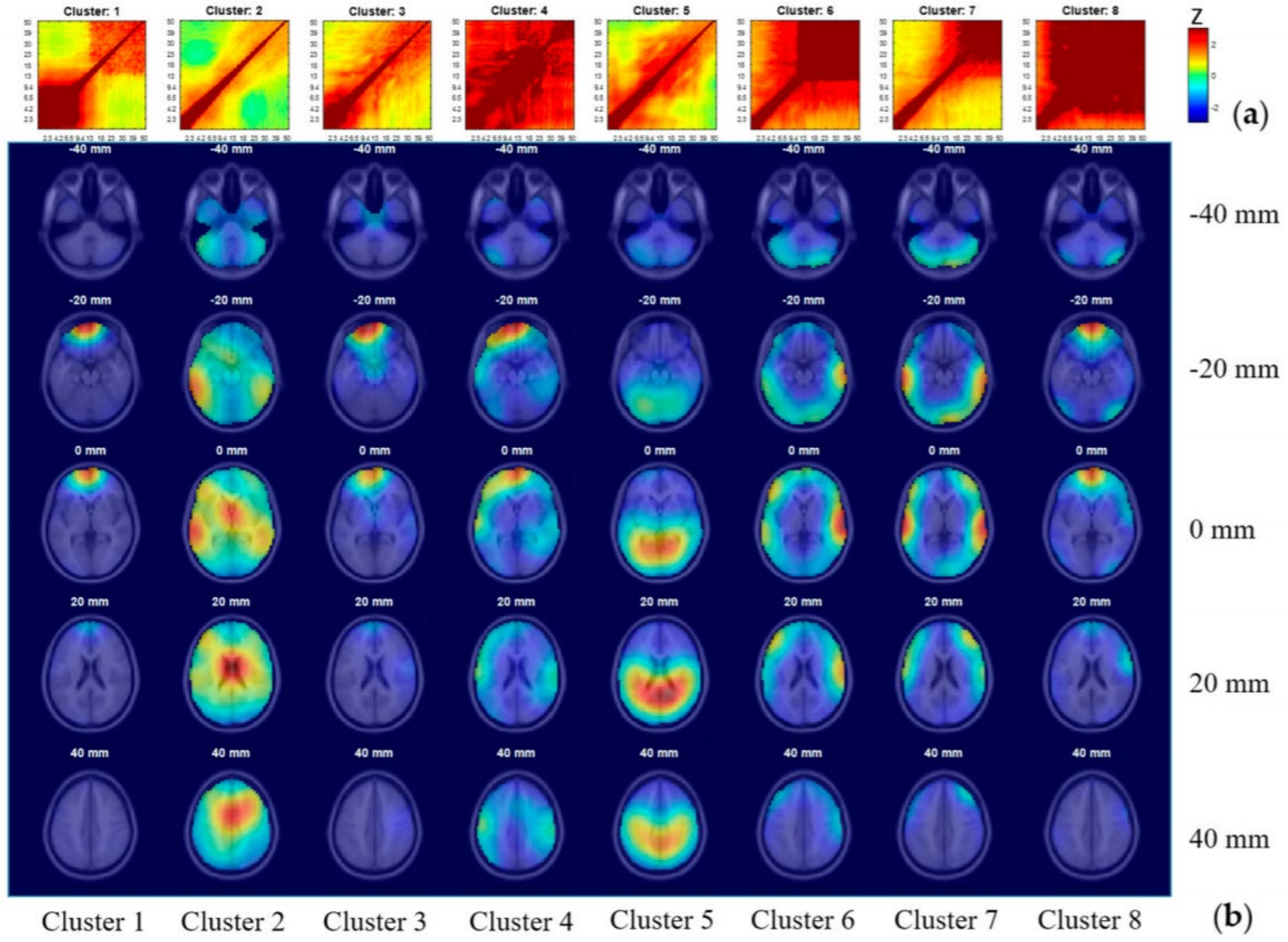
Thammasan and Miyakoshi (2020)

Comodulogram helps classify the ICs



Thammasan and Miyakoshi (2020)

Comodulogram for IC classification



Thammasan and Miyakoshi (2020)

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.’

Luca Pion-Tonachini

Conclusion

- Cross-frequency power-power coupling plot is called *comodulogram*.
- Comodulogram is an extension of power spectral density (PSD) which tells us temporal correlations across time series of power fluctuations in different frequency bands.
- Comodulogram provides additional information about the independent components (ICs) that has been neglected but now proven to classify them.
- PowPowCAT has been available since 2017 to calculate the comodulogram.
    - Recently batch mode is supported upon request of Pål from Oslo.

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 (University of Twente)

Envelope-Envelope Coupling

Bekisz & Wróbel, 1999

Neuroreport
Cross-correlation between envelopes of filtered beta and gamma oscillatory signals

Bruns et al., 2000

Neuroreport
Amplitude-envelope correlation (AEC) of filtered signals

Bruns & Eckhorn, 2004

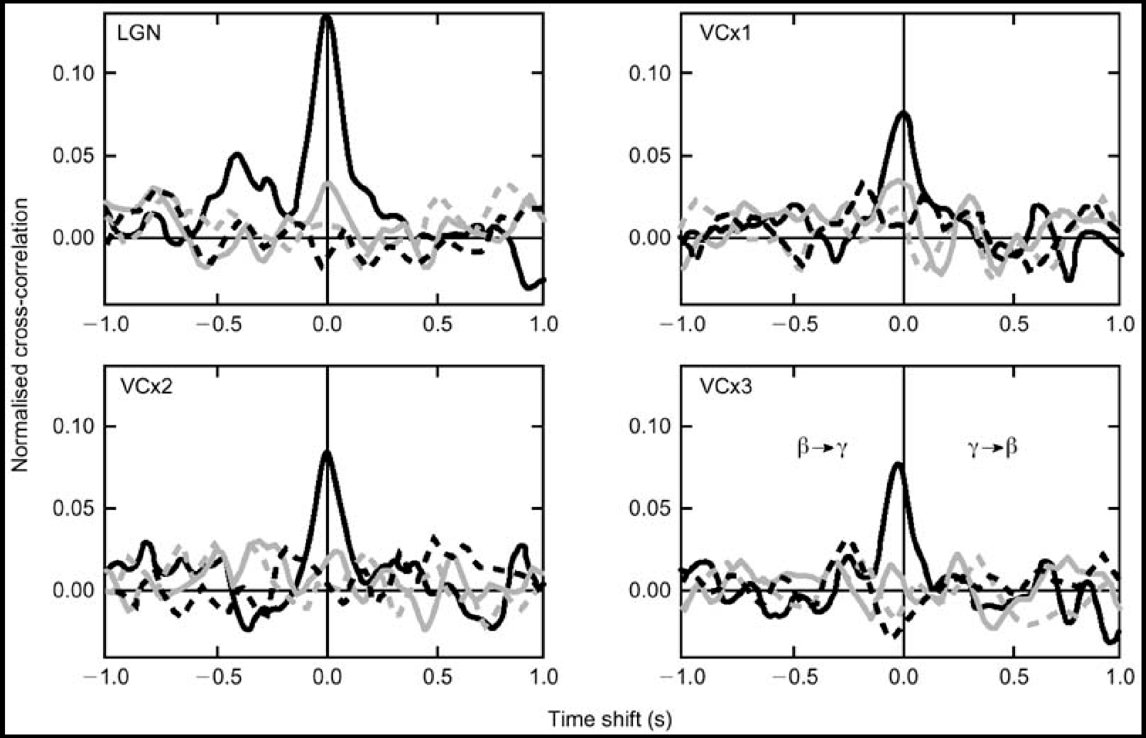
Int. J. Psychophysiol
Correlation between corresponding envelope segments

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

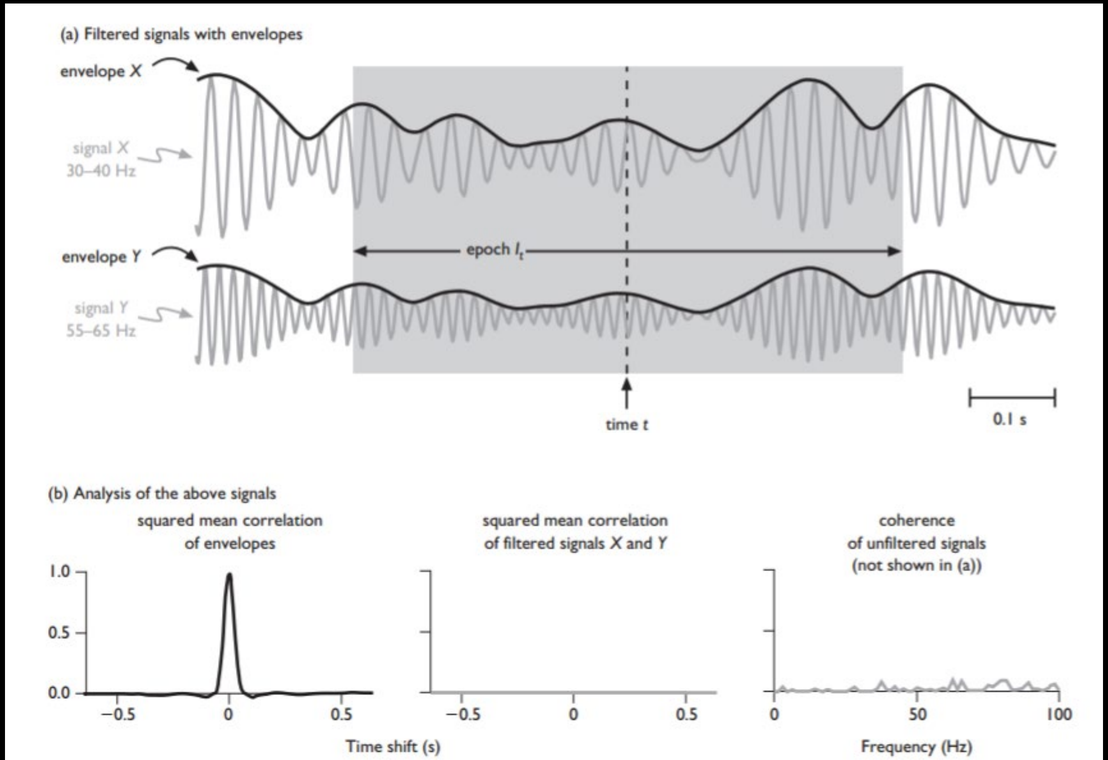
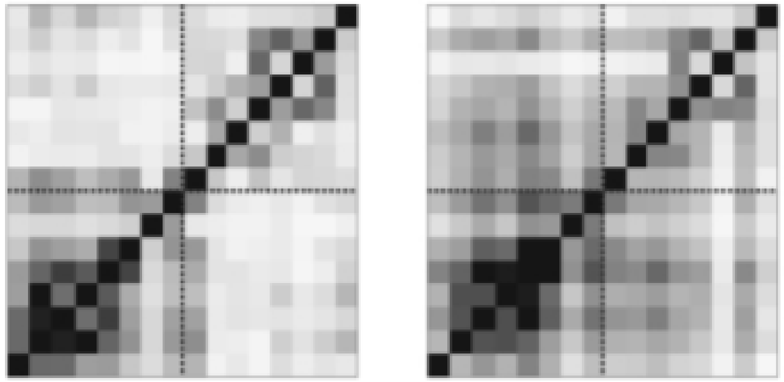
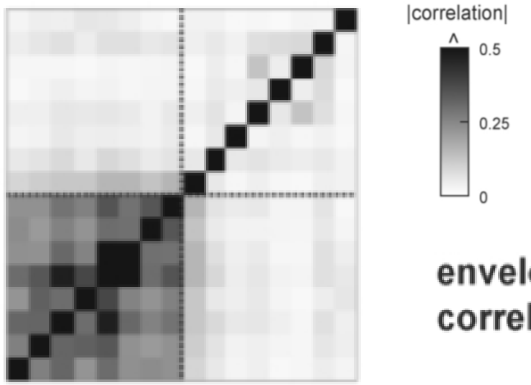


Illustration of AEC method

Envelope-Envelope Coupling

Bruns & Eckhorn, 2004





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

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

envelope-to-envelope correlation

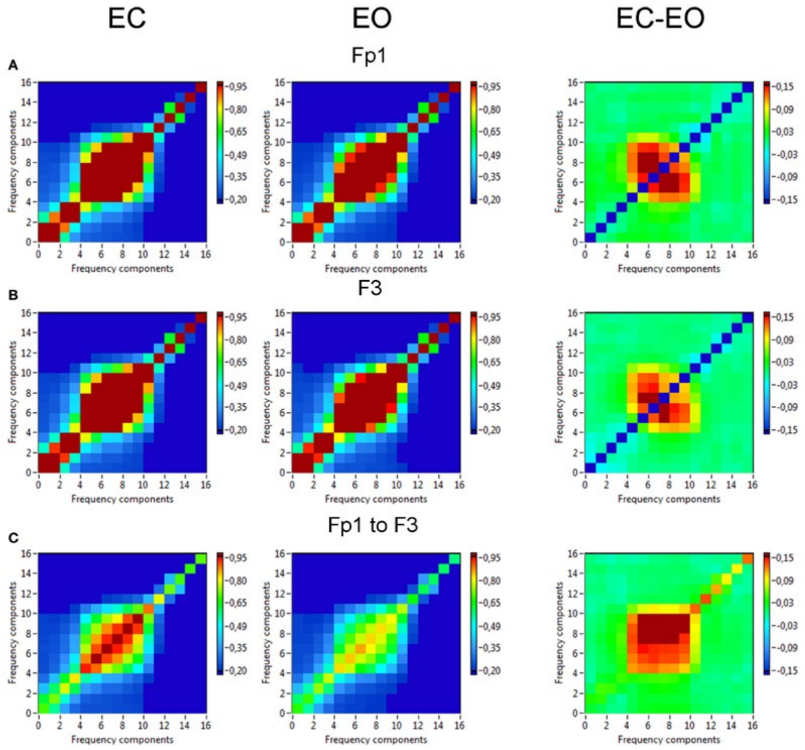
Pronounced task-related increase of gamma-delta envelope-to-signal correlation between superior and inferior occipital visual area → possibly reflecting a short-term memory encoding process

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