Advanced Signal Processing I

Digital Filters

Time Frequency Approaches

Ocular Artifacts

Announcements

- Research Proposals due next Monday (May 2) no later than 2 pm via email to instructor
  - Word format (DOCX or DOC) preferred
  - Use the stipulated format (check website for details)
  - Look at the relevant “guidelines” paper(s) (link on website)
- Take home final distributed next week, due May 9 at noon (hardcopy in my mailbox).
- 3x5s x 2

Advanced Signal Processing I

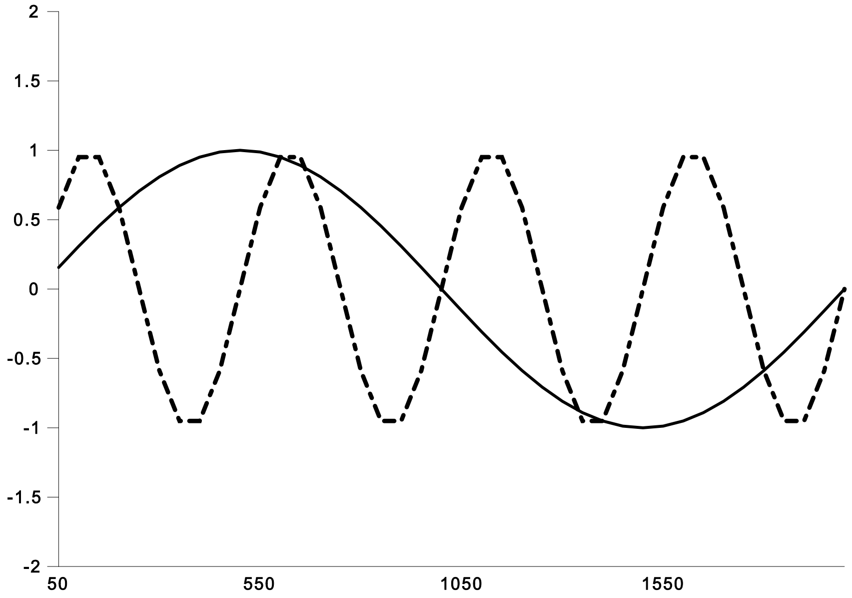
Digital Filters

Time Frequency Approaches

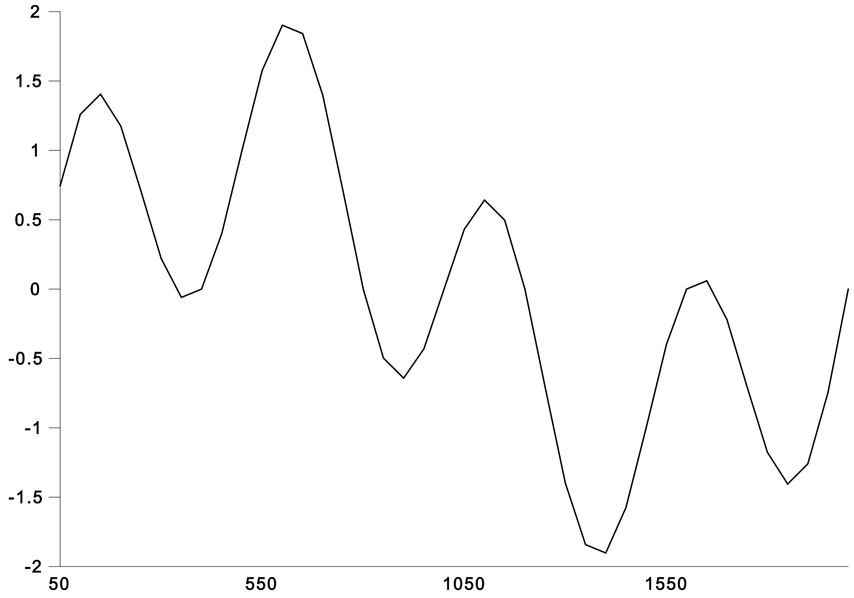
Ocular Artifacts

Digital Vs. Analog Filtering

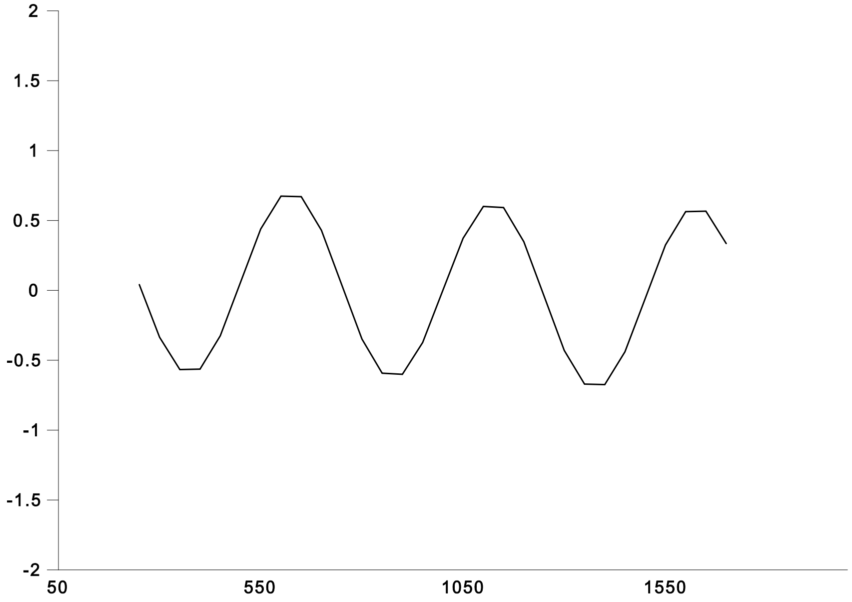
- Analog filters can introduce phase shift or lag
  - Certain frequency components "lagging" behind the others
  - This is the effect of a capacitor literally slowing a signal
  - Some frequencies are slowed more than others
  - Problem: some ERP components could be distorted
- Hence, digital filtering is a preferred alternative.
  - No phase shift
  - Is widely used in last several decades
- If digitized signal has minimal filtering, nearly infinite possibilities exist for digital filtering later



Constituent Waveforms

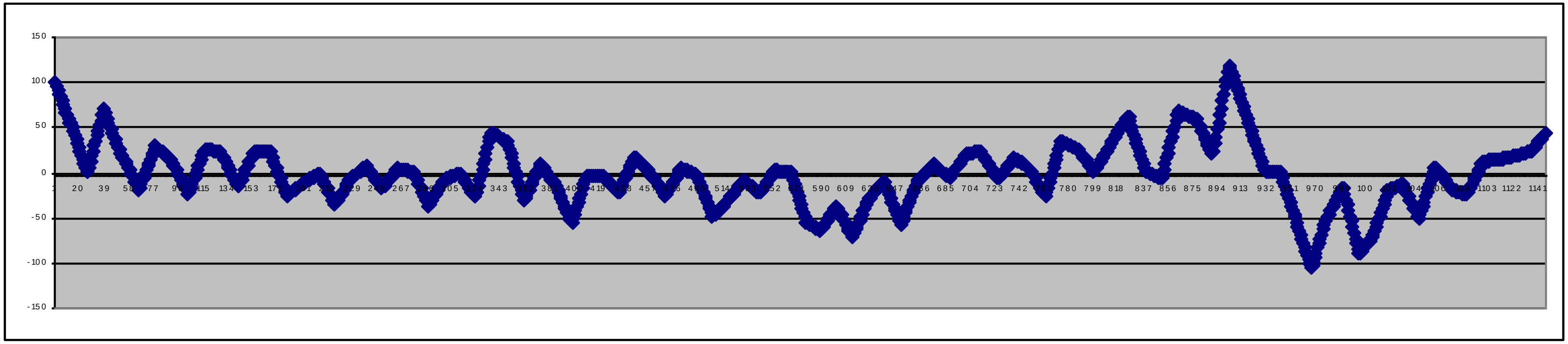


Resultant Waveform



High Pass Filtered

Low Pass Filtered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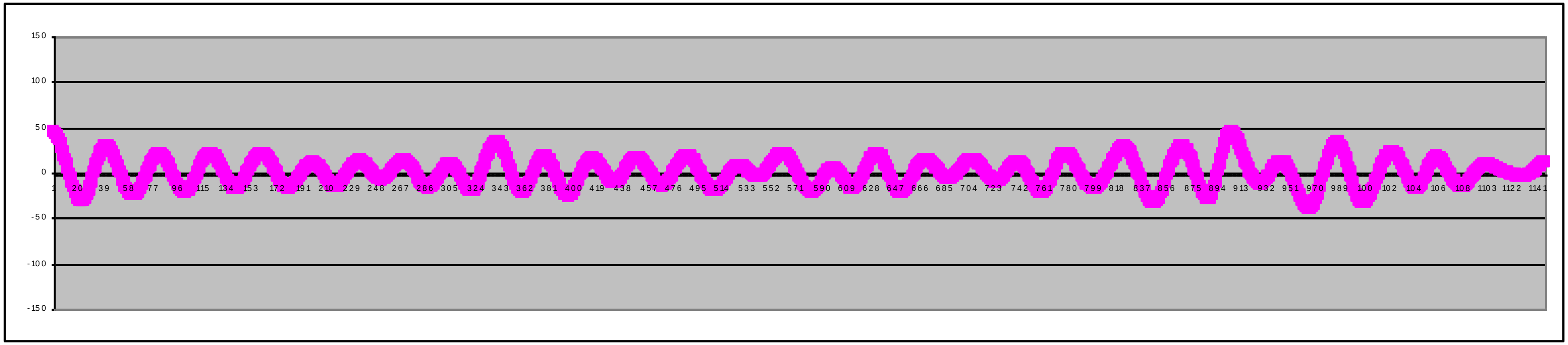
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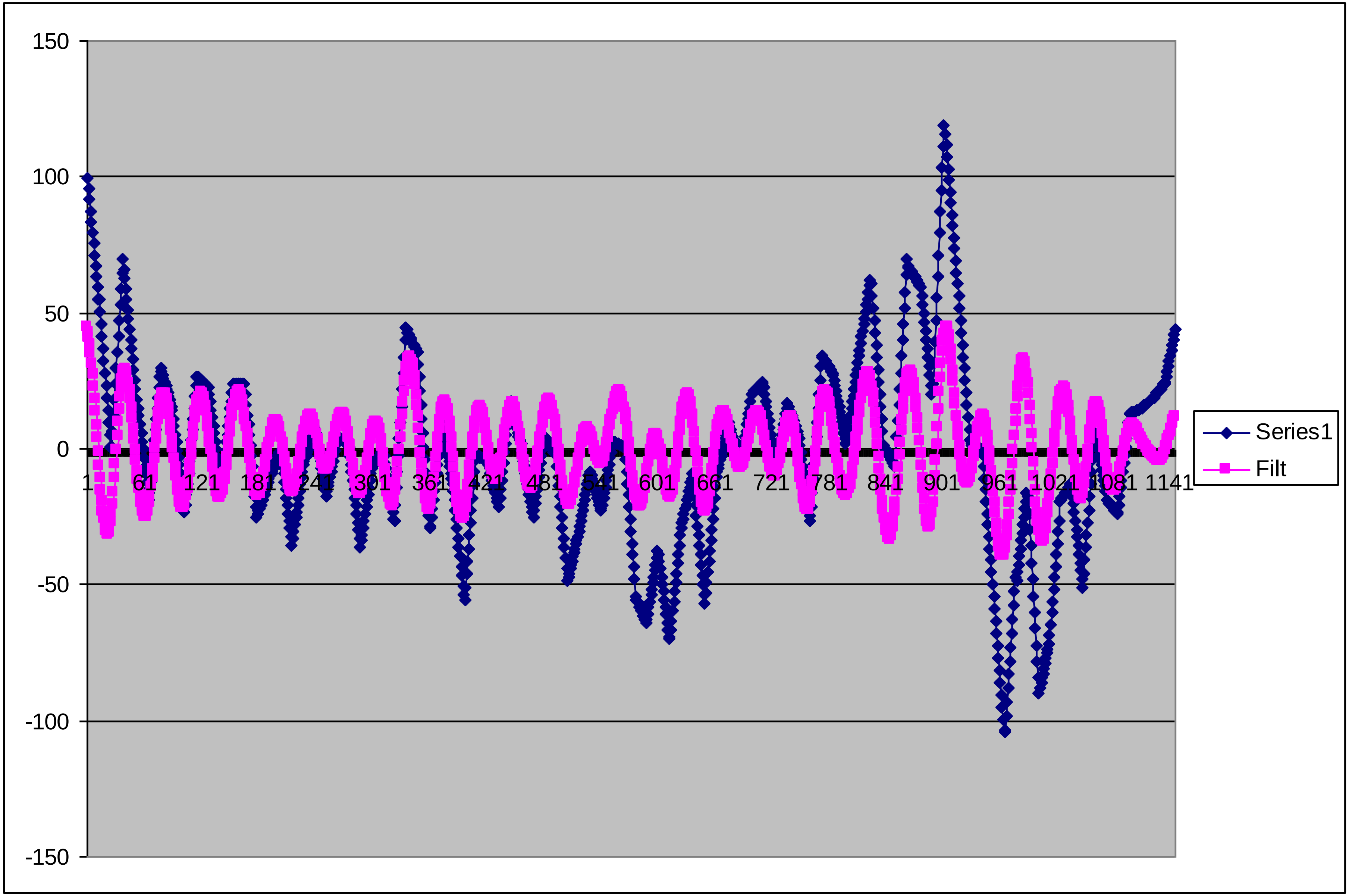
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841
901
961
1021
1081
1141
Series1
Filt

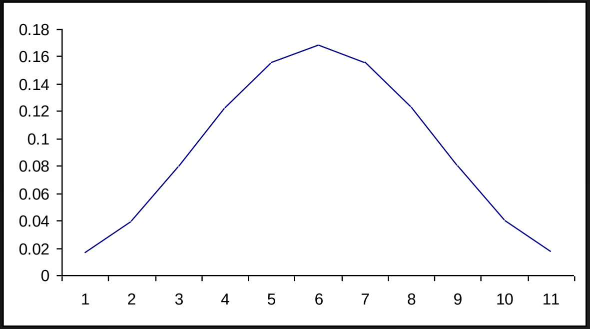
The Details!

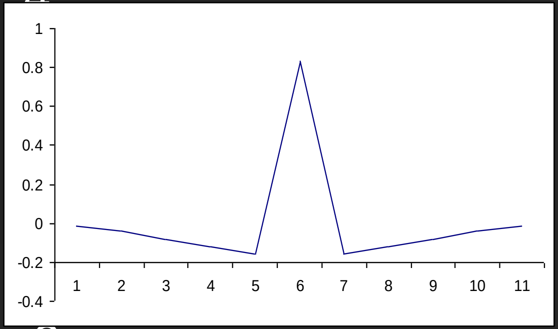
- Handout on Digital Filtering

Filter Details

A. Linear digital filters may be conceived of as vectors of weights that are to be multiplied by the digitally sampled values from a waveform. The filters given below are both 11 point digital filters with a half-amplitude frequency cutoff of approximately 17.5 Hz for data sampled at 200 Hz.

LOW PASS		HIGH PASS	
COEFFICIENT	LAG	COEFFICIENT	LAG
0.0166	5	-0.0166	5
0.0402	4	-0.0402	4
0.0799	3	-0.0799	
0.1231	2	-0.1231	
0.1561	1	-0.1561	
0.1684	0	0.8316	
0.1561	-1	-0.1561	
0.1231	-2	-0.1231	-2
0.0799	-3	-0.0799	-3
0.0402	-4	-0.0402	-4
0.0166	-5	-0.0166	-5





More Details

- 11 point filters indicates that 11 sample points are used in the determination of the new filtered value of any one sample point
- Middle (sixth) sample point is a weighted sum of the first 11 samples.
- The non-recursive filter uses raw sample values in the calculations; recursive filters use the already filtered values of preceding samples in the calculations. Non-recursive filters are more straightforward and more commonly used.
- The term linear denotes that the filter involves the computation of weighted sums of the digital sample values. Other filtering algorithms can be devised, but are less often applied to psychophysiological signals.

More Details (cont')

- Digital filters have characteristics that are sampling-rate dependent.
- These same filters would have a different cutoff frequency for data sampled at different sampling rates.
- Once you know the characteristics of a digital filter at a given frequency, it is a simple matter to convert the filter to another sampling rate as follows:

  17.5/200 = x/1000 ; x = 87.5 @ 1000 Hz Sampling rate

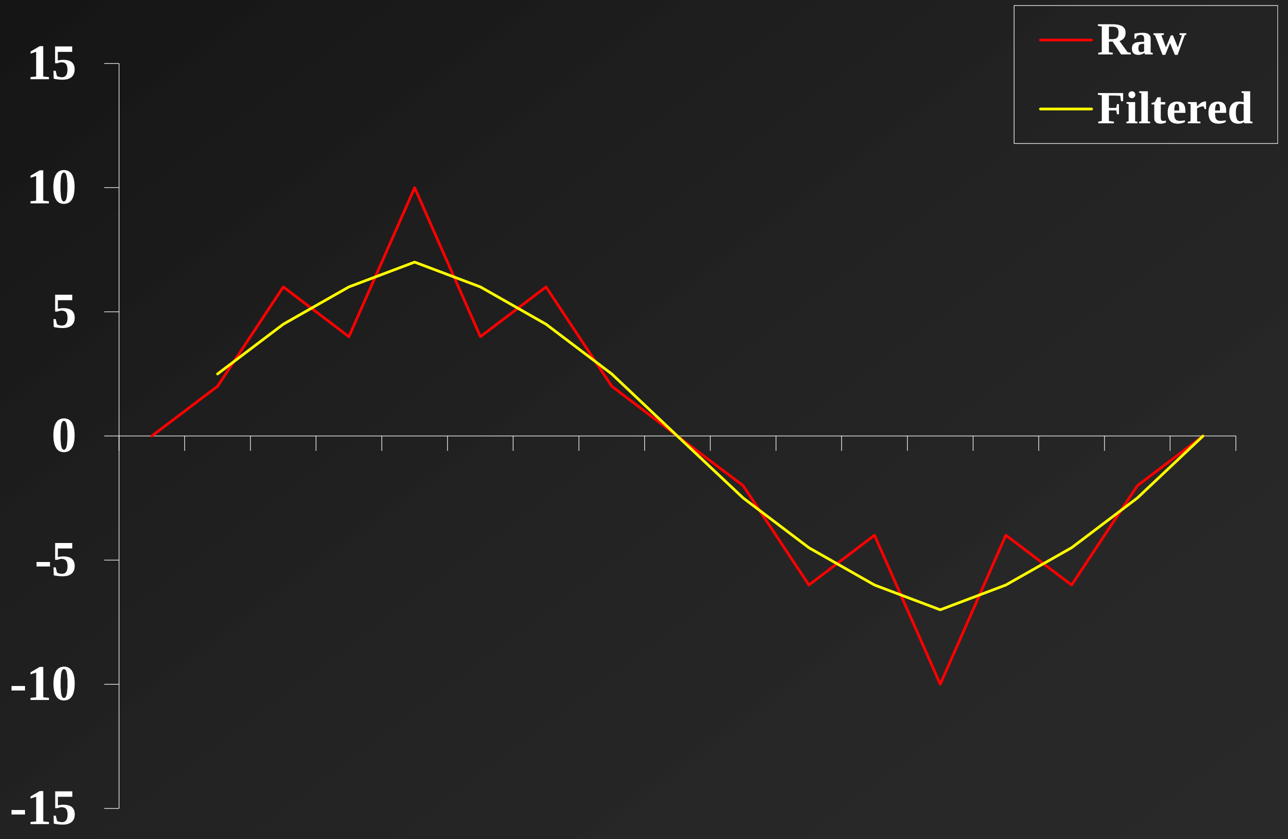
  17.5/200 = x/20 ; x = 1.75 @ 20 Hz Sampling rate

Muy Simple Filter

[.25 .5 .25]

To apply: Iterate through data segments the size of the filter

$\text{filt}_{1x3}*\text{segment}_{3x1}=\text{filteredpoint (scalar)}$



Some filters and their Transfer Functions

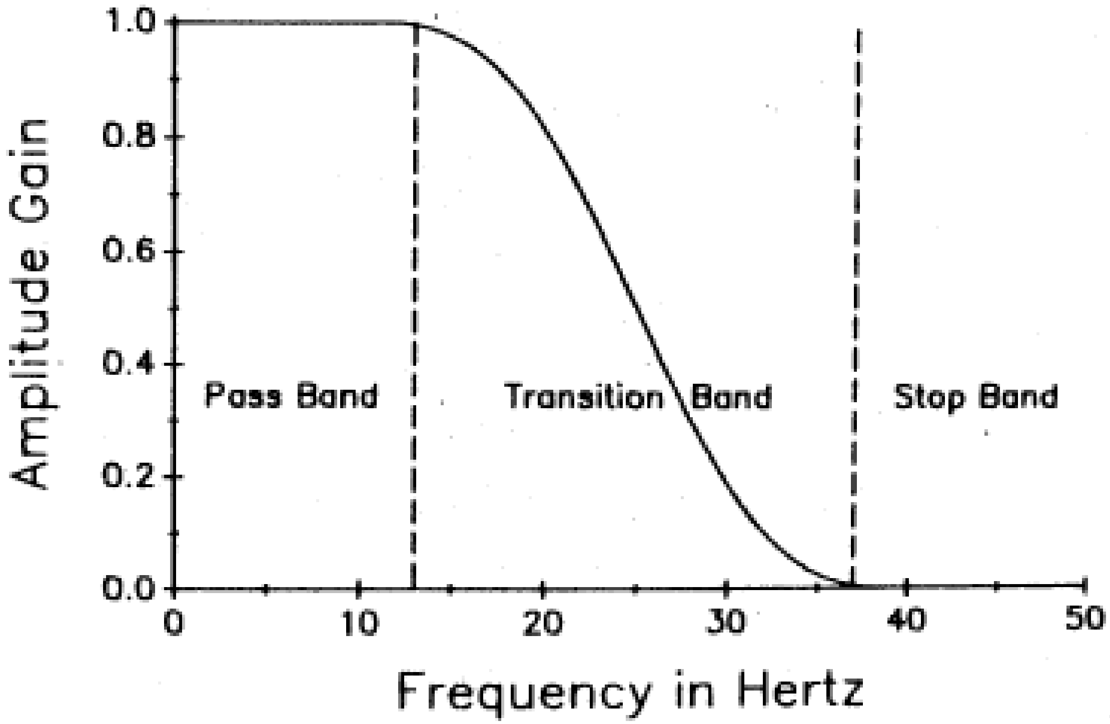
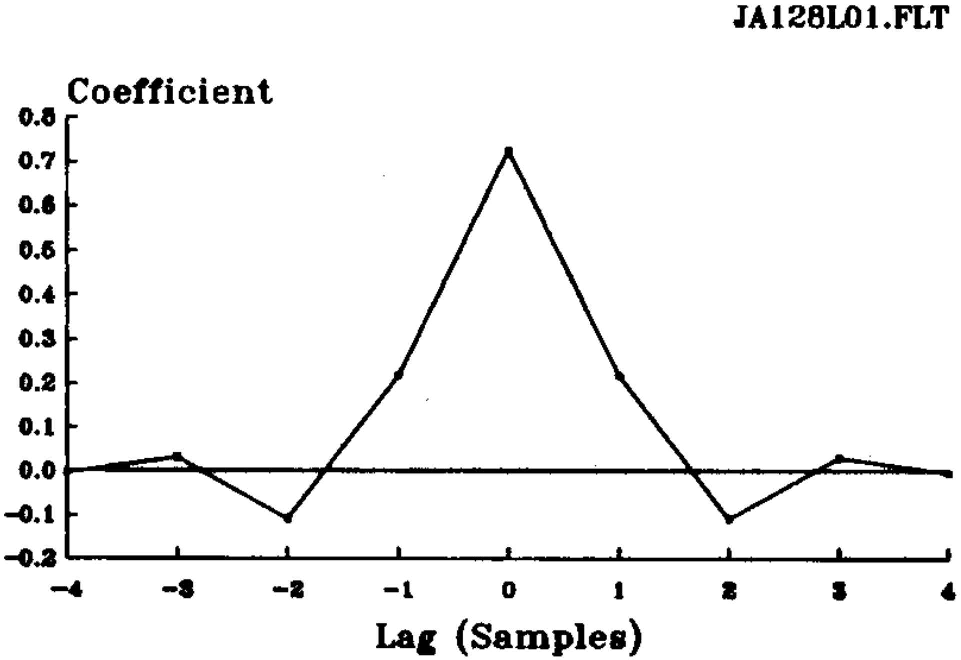


Figure 1. The gain function of a filter is divided into the pass band, transition band, and stop band. The gain function shown is for a low-pass filter.

Cook & Miller, 1992

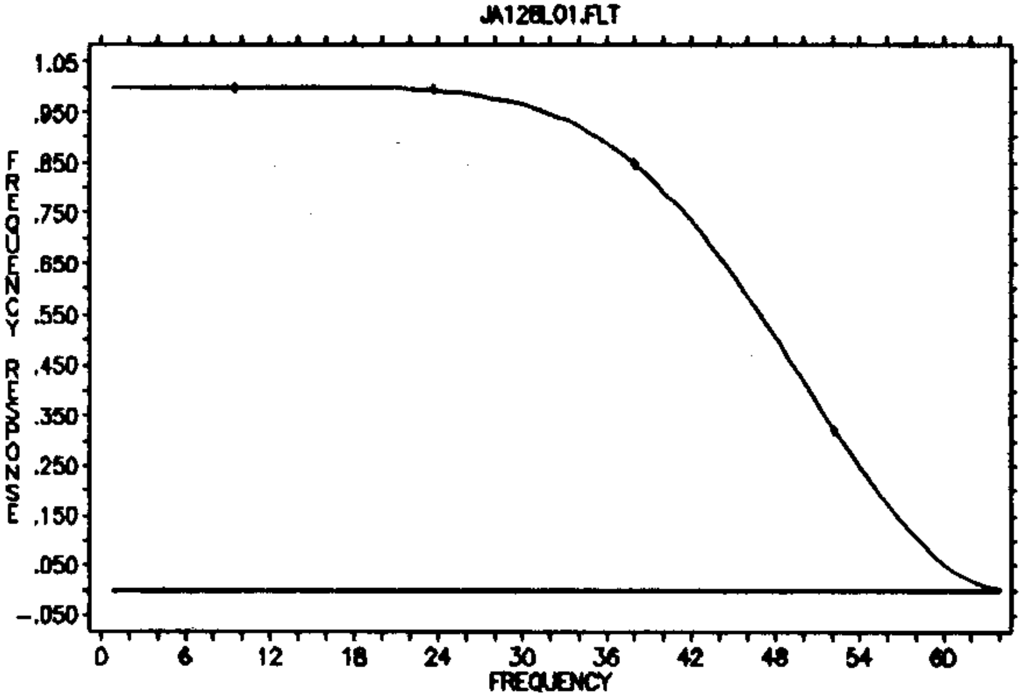


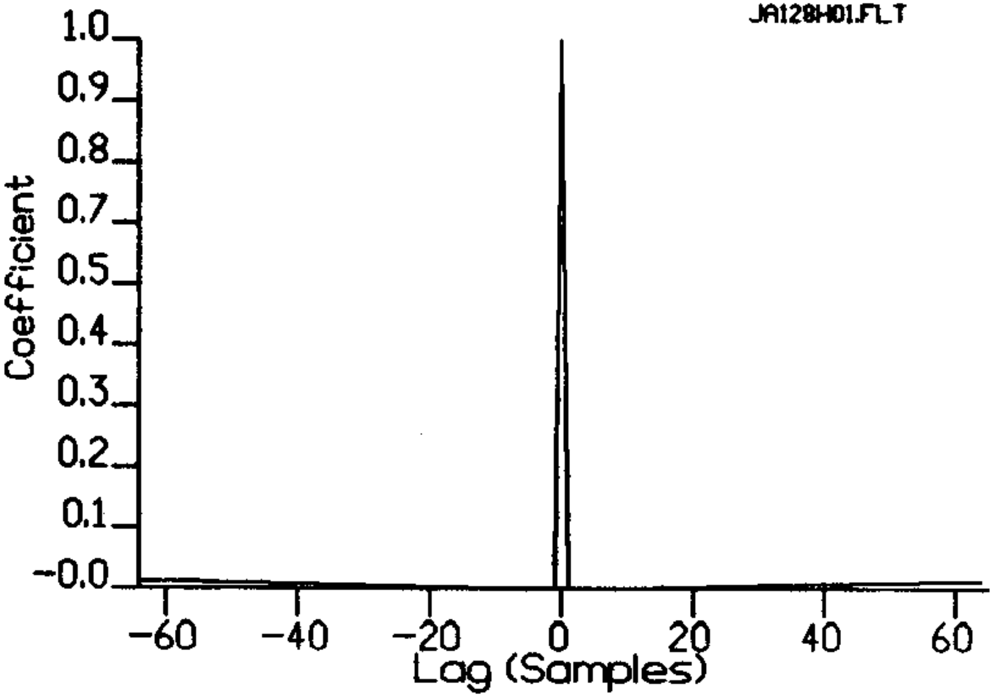
Impulse Response

Note:

- ➢ FFT of Impulse Response (filter) gives transfer function
- ➢ Inverse FFT of transfer function yields impulse response (filter coefficients)

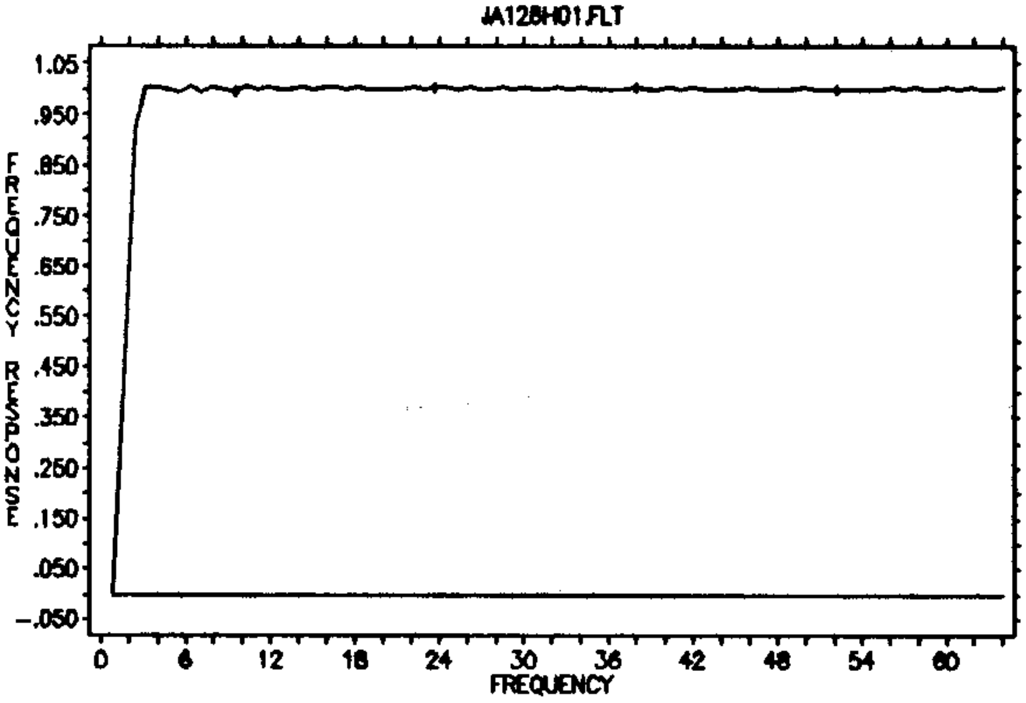
Transfer Function

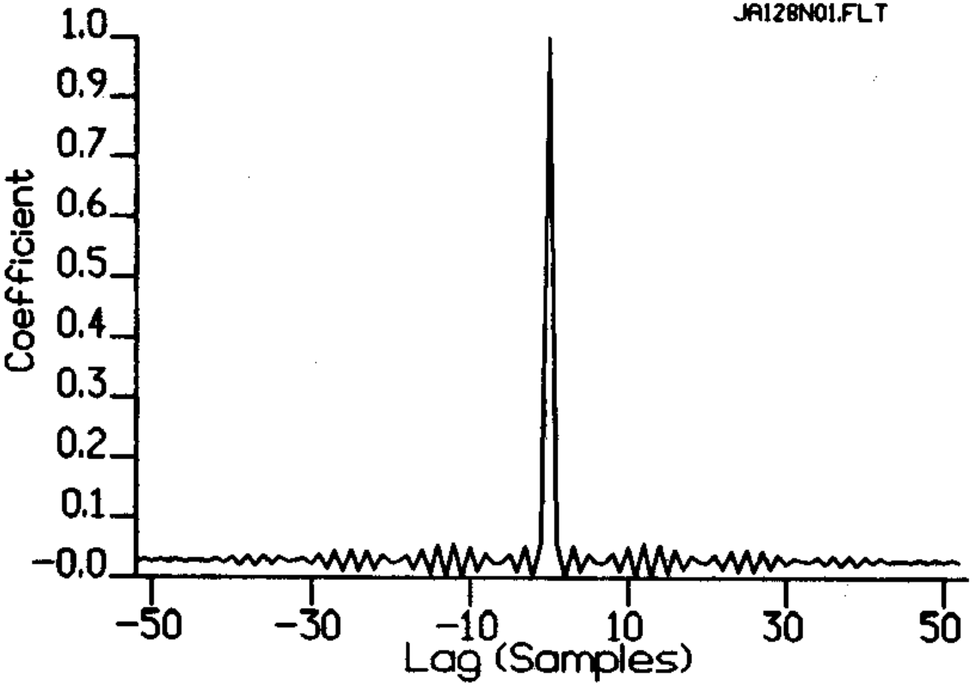




Impulse Response

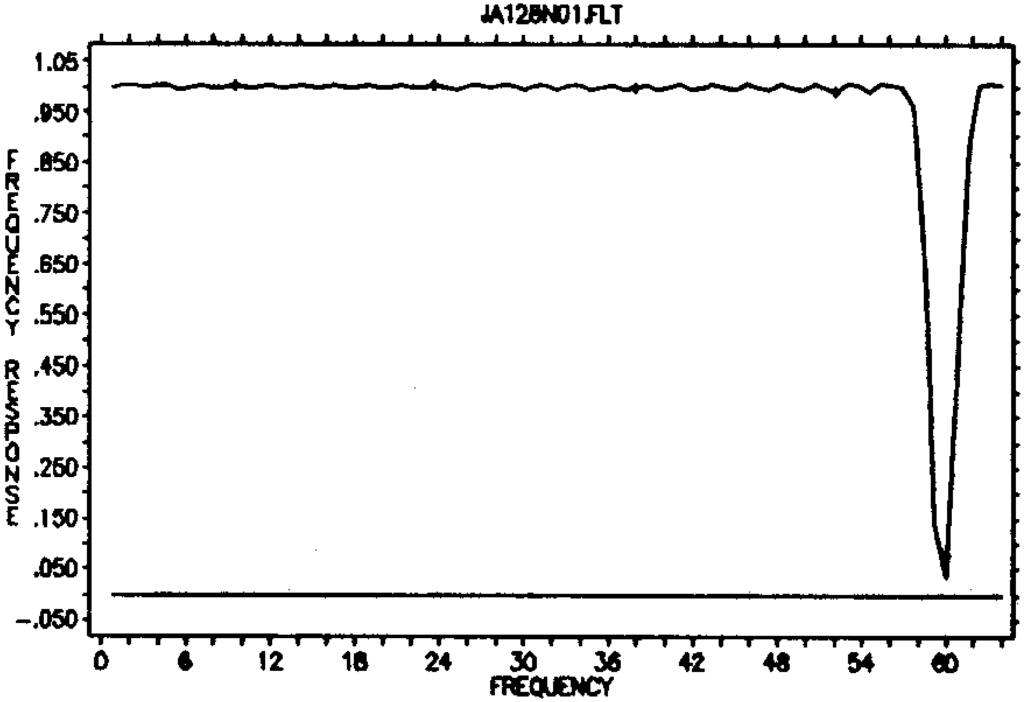
Transfer Function





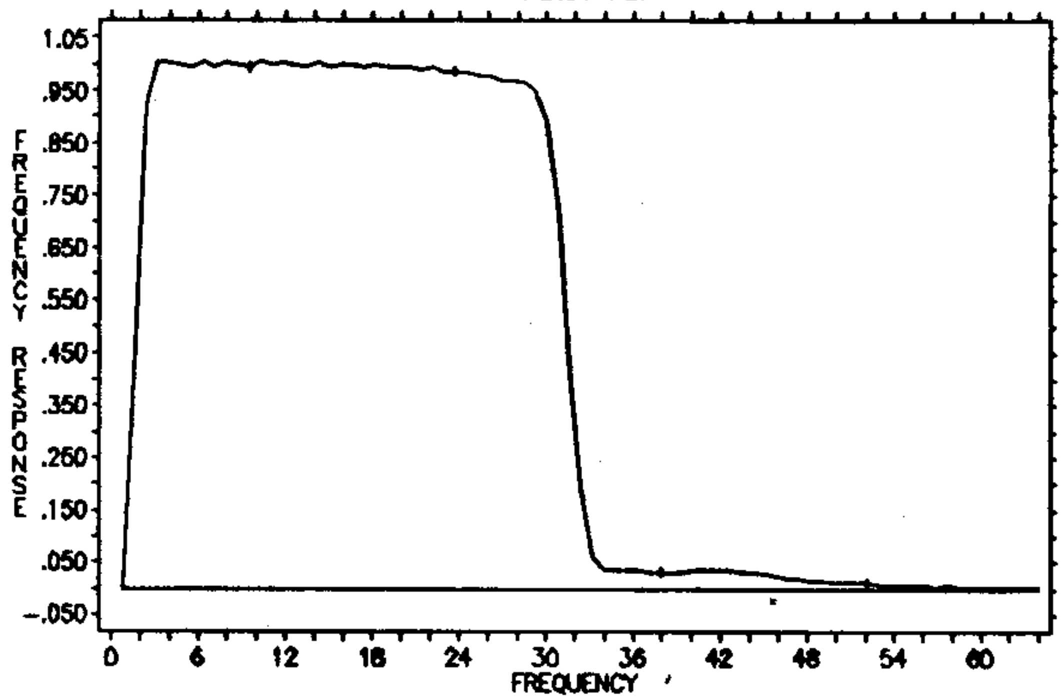
Impulse Response

Transfer Function



Impulse Response

Transfer Function



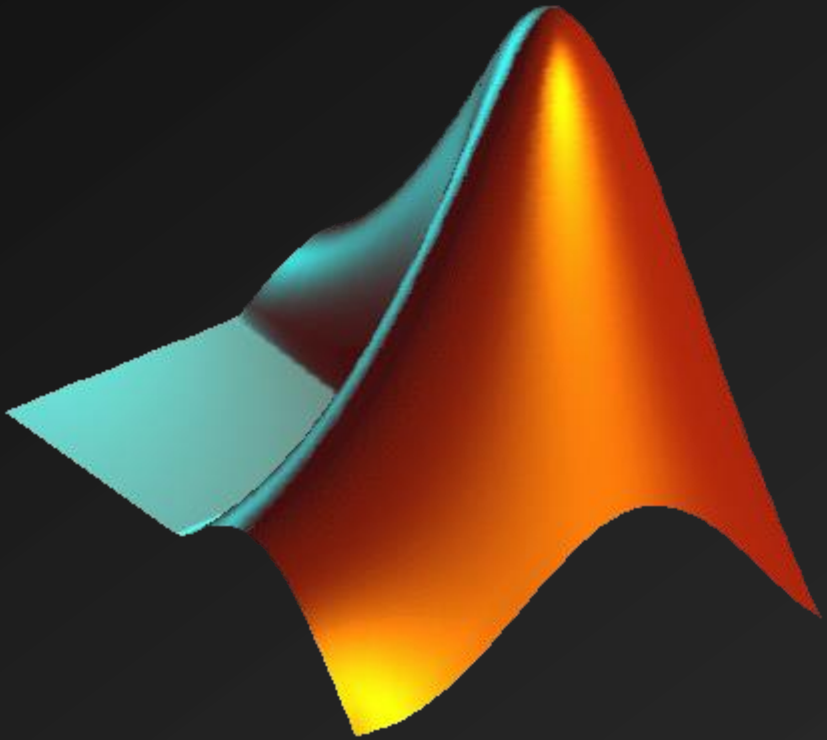
Pragmatic concerns

- Sample extra data points; many if you want sharp roll-off
  - The filter cannot filter the first (n-1)/2 points for filter length n
- Try out your filter via FFT analysis or via derivation of the transfer function before you apply it routinely

Use in Single Trial Analysis

- With stringent digital filtering, you may be able to discern peaks on an individual trial basis

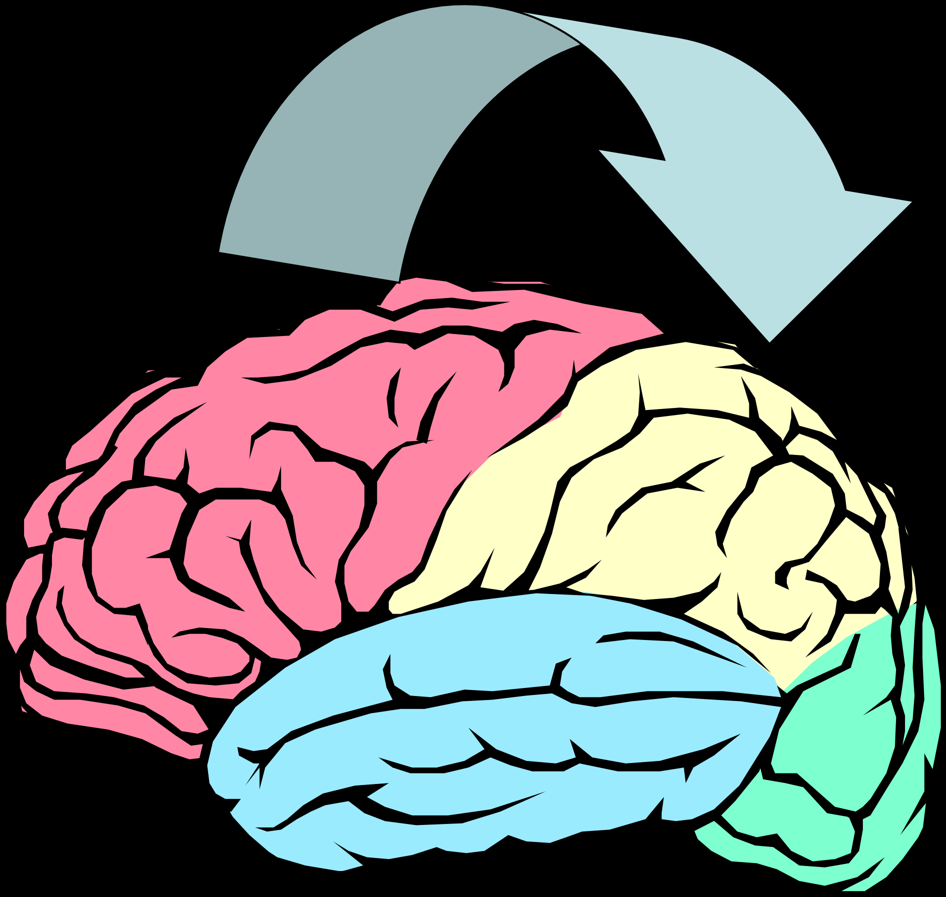
Digital Filtering and More!



A bit more on phase and such

COURTESY OF MIKE COHEN

2. How do brain regions "talk" to each other?

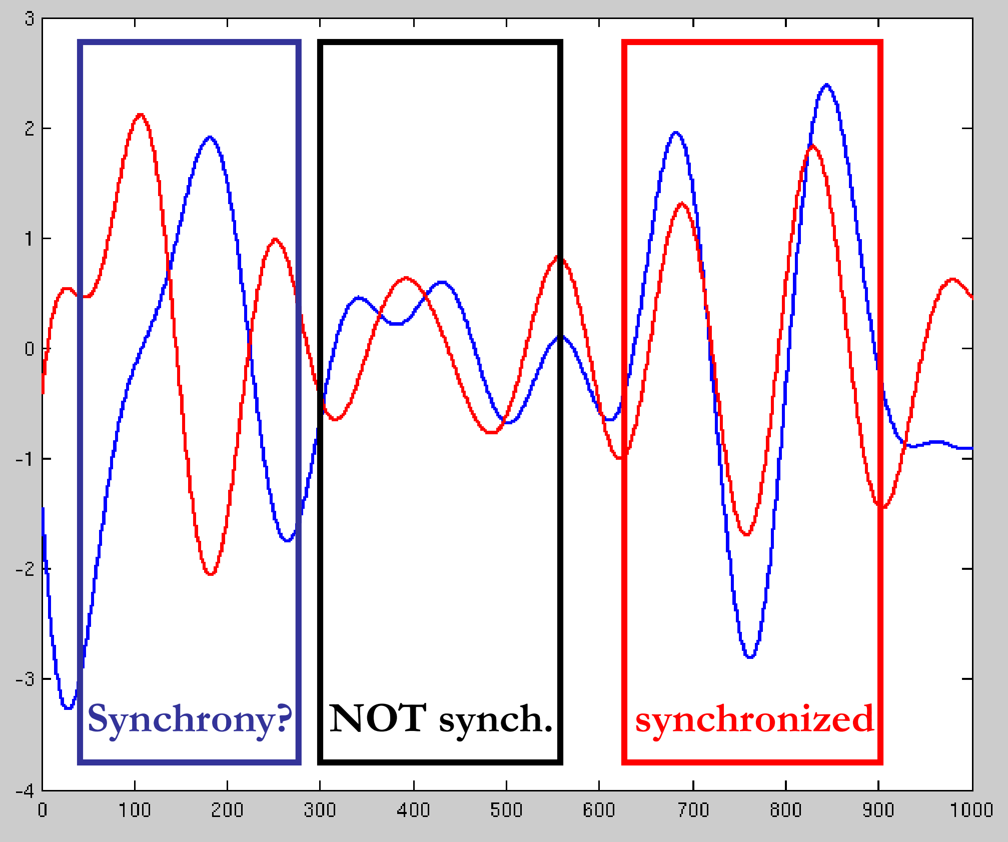


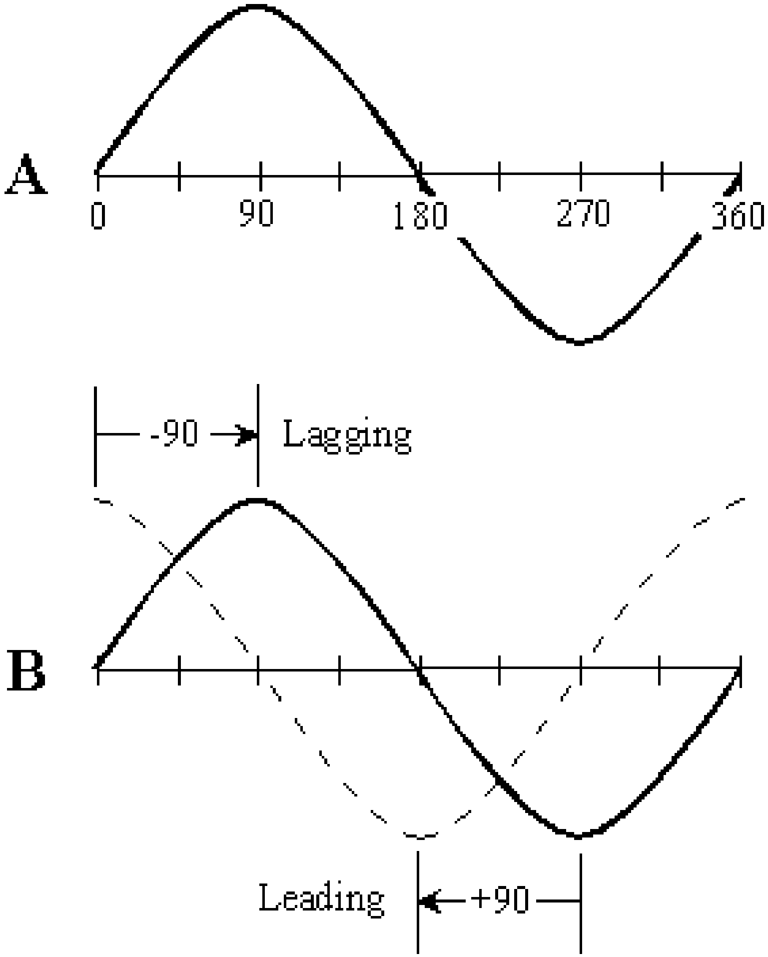
Perhaps through synchronized oscillations!

See empirical work and reviews by:
Rubino, Lisman, Singer, Engels, etc.

2. How do brain regions "talk" to each other?

Synchronized oscillations is an intuitive concept, but how to measure it quantitatively?





- The time interval for one degree of phase is inversely proportional to the frequency.

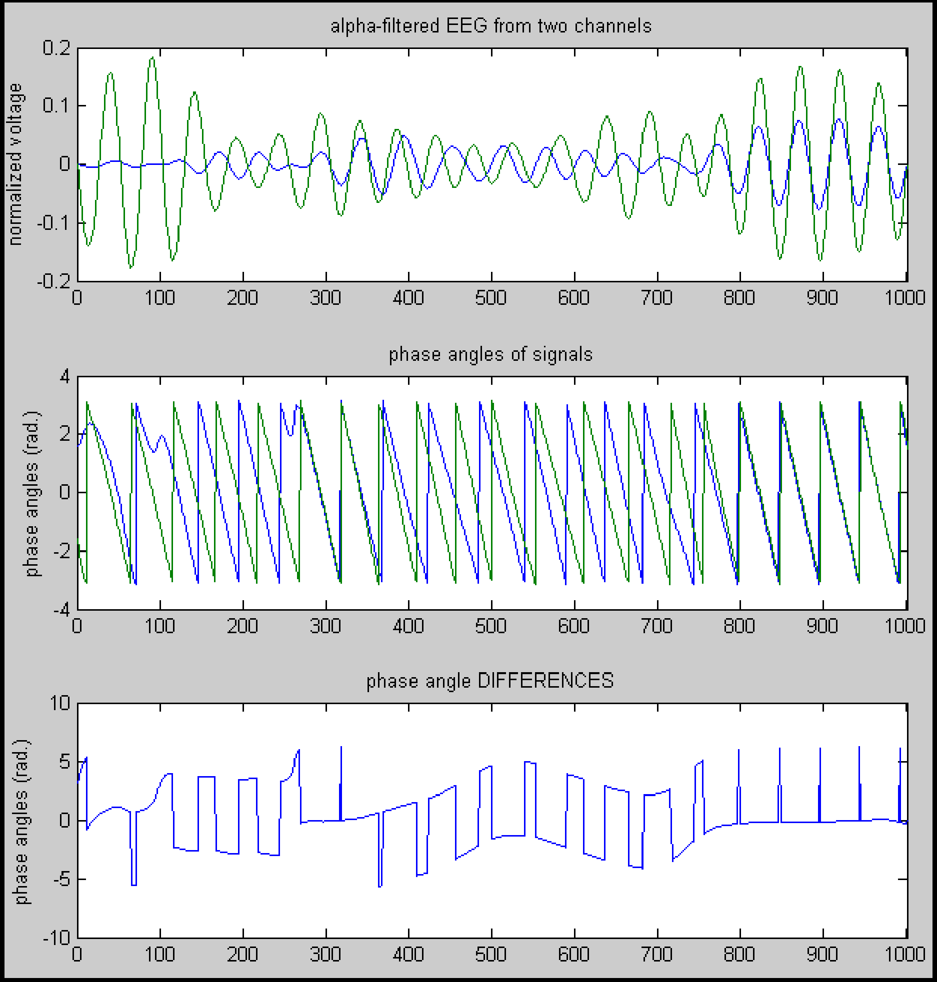
- You know…. the frequency of a signal f is expressed in Hz)

- The time *t* (in seconds) corresponding to:
  - one degree of phase is: $t_{\text{deg}} = 1 / (360 f)$
  - one radian of phase is approximately: $t_{\text{rad}} = 1 / (6.28 f)$

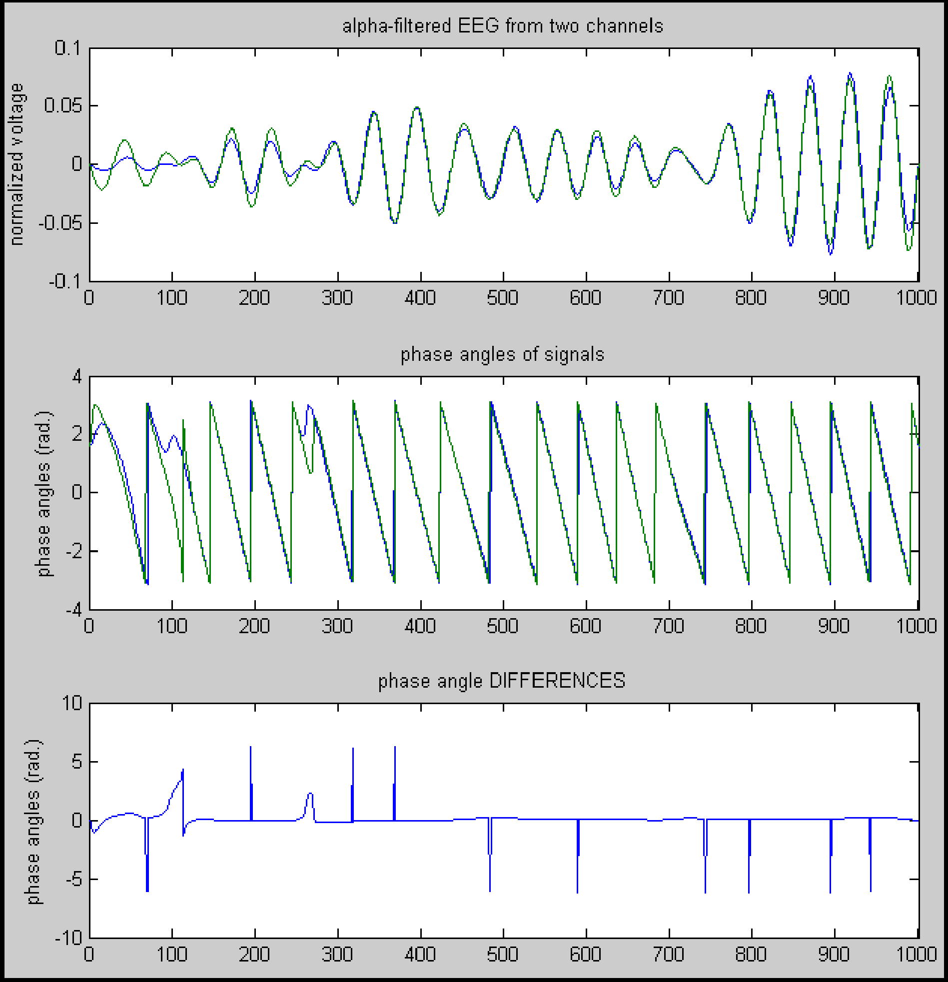
Adapted from http://whatis.techtarget.com/

2. Inter-site phase coherence.

Electrodes: Fp1 & C4

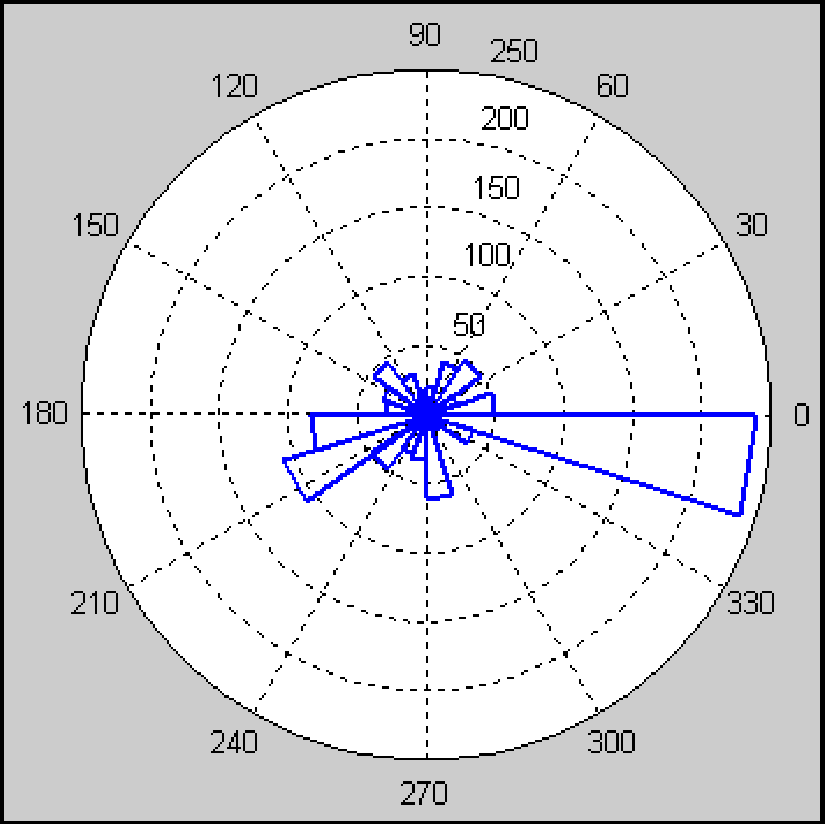


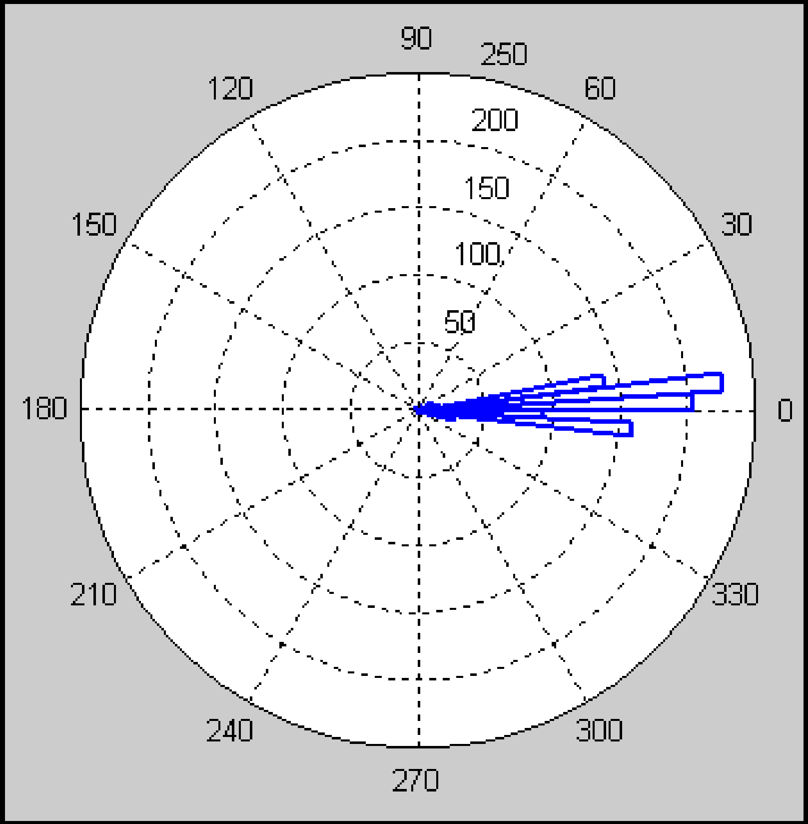
Electrodes: Fp1 & Fp2



2. Inter-site phase coherence?

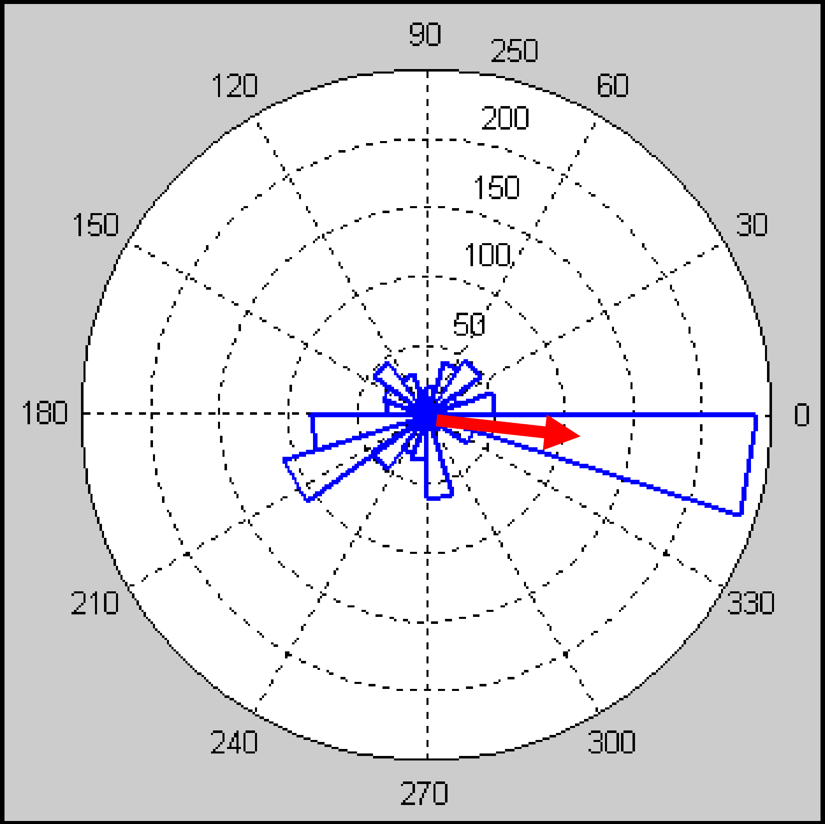
“Polar plot” of phase angle differences.

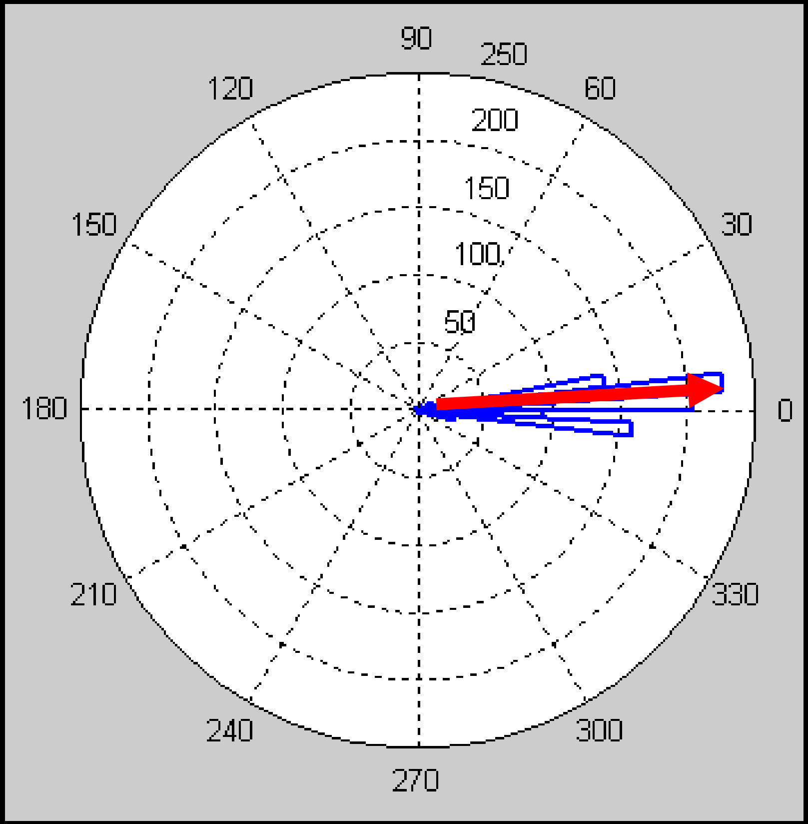




2. Circular variance.

Draw a line through the “average” of vectors.

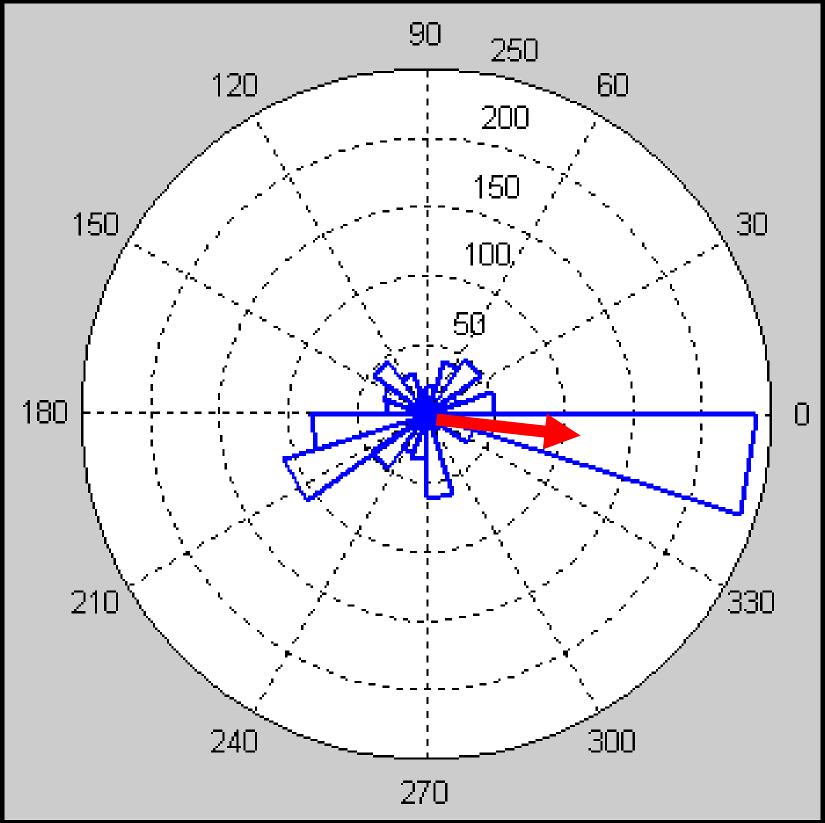




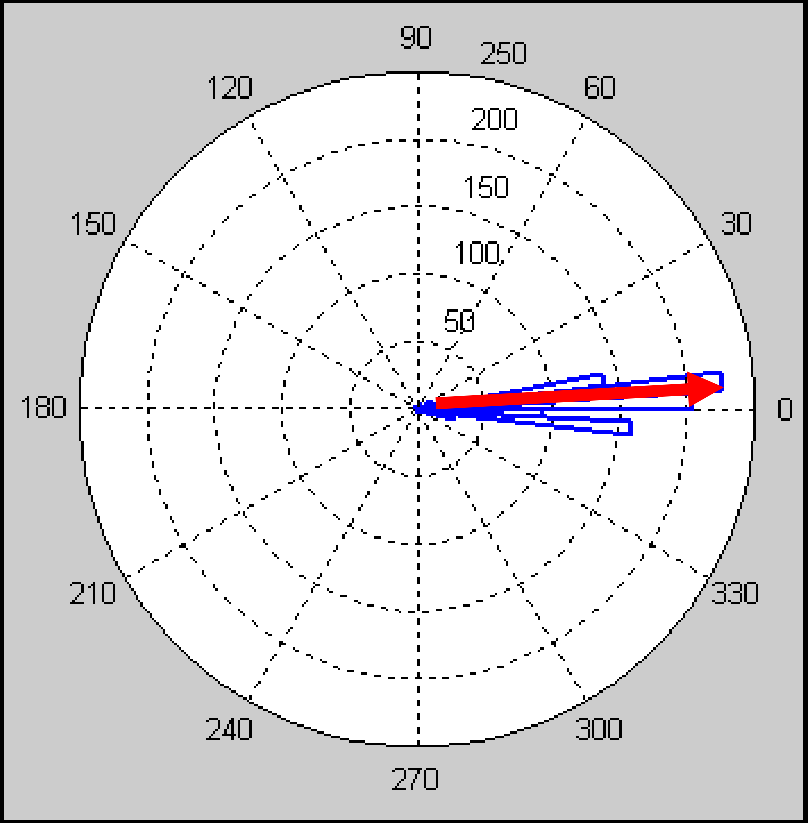
2. Circular variance.

The length (magnitude) of that vector varies from 0 to 1, and is the phase coherence.

Phase coherence: 0.11



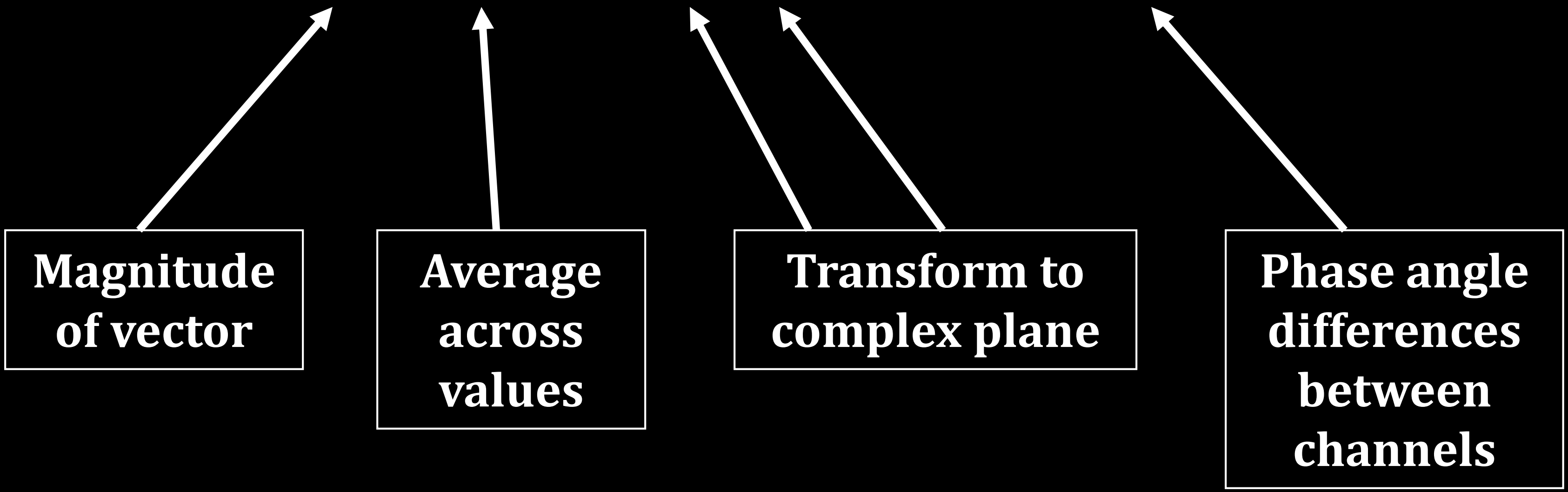
Phase coherence: 0.94



2. Circular variance.

The equation for phase coherence is simple:

```
> abs(mean(exp(i*angle_differences)));
```



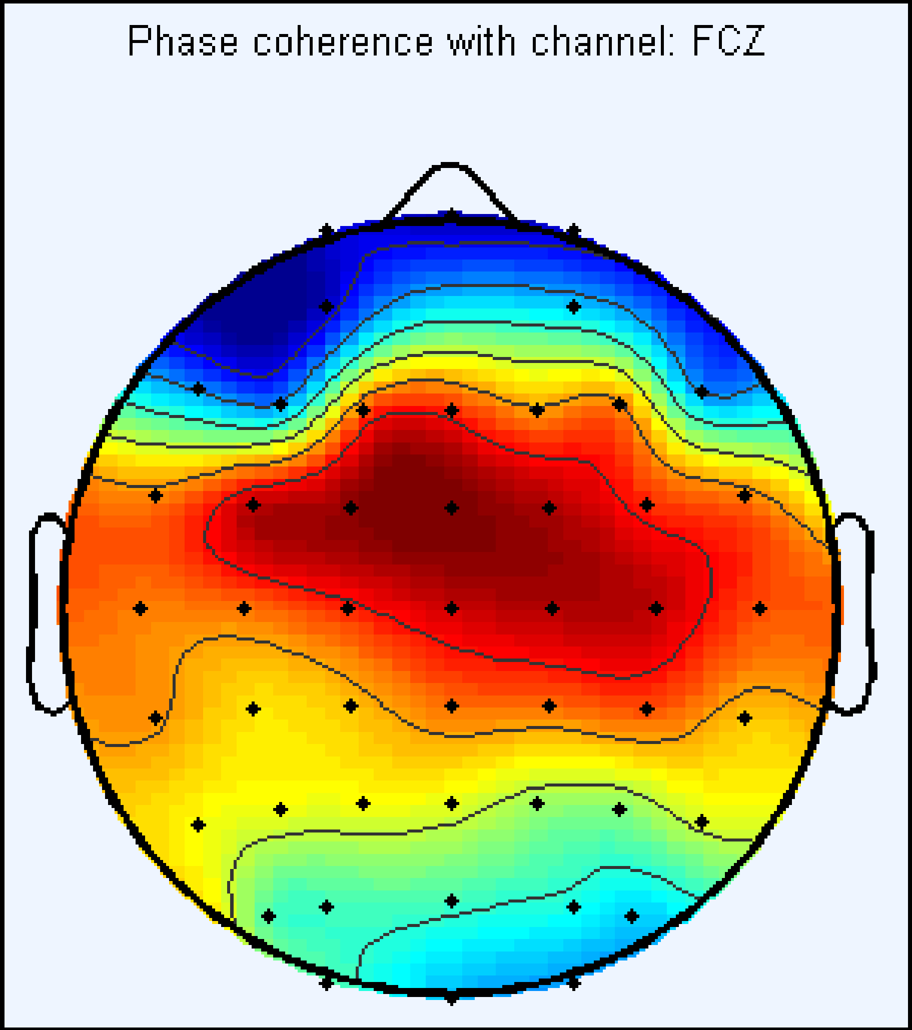
Magnitude of vector

Average across values

Transform to complex plane

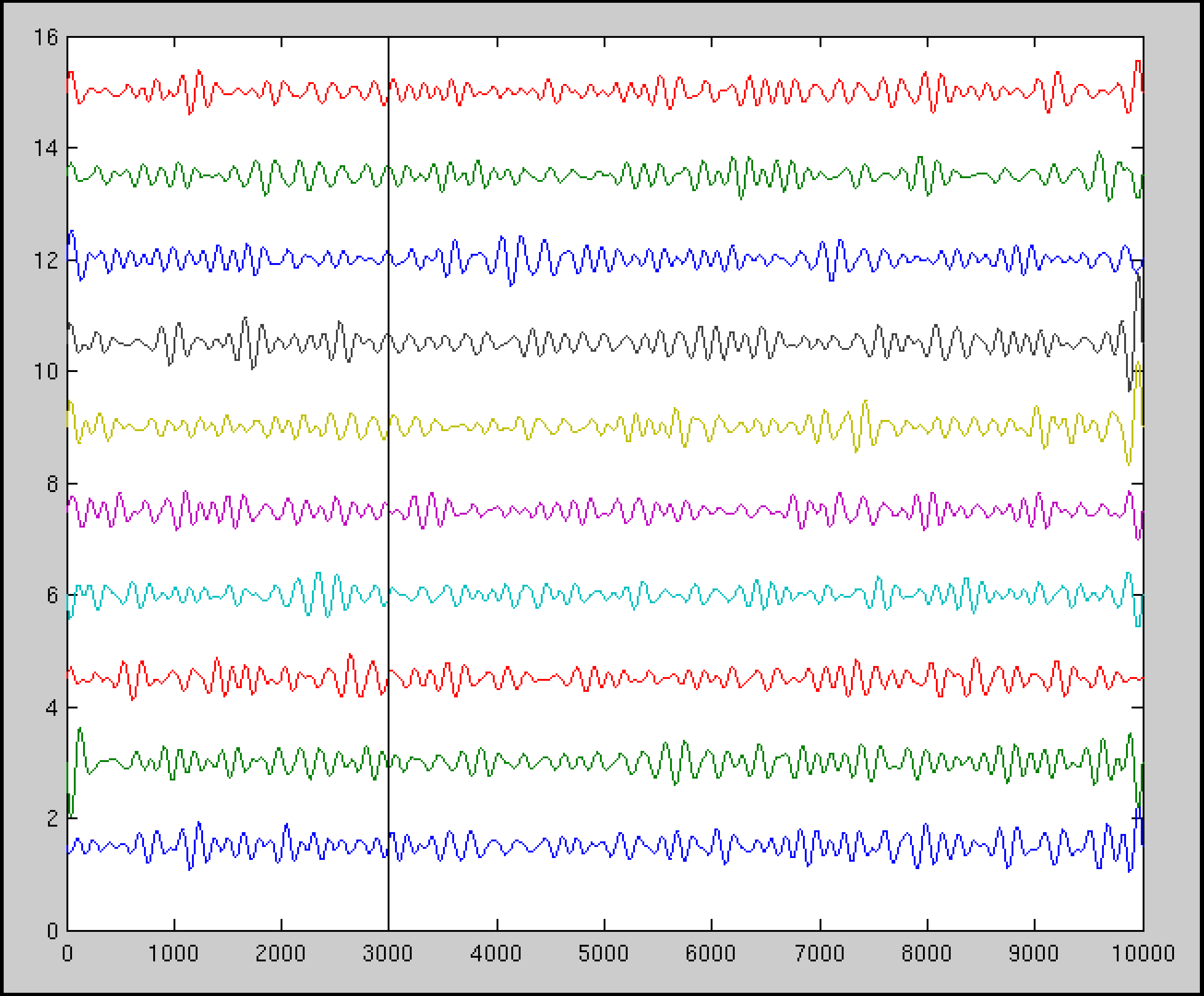
Phase angle differences between channels

2. Inter-site phase synchrony with one “seed” site.

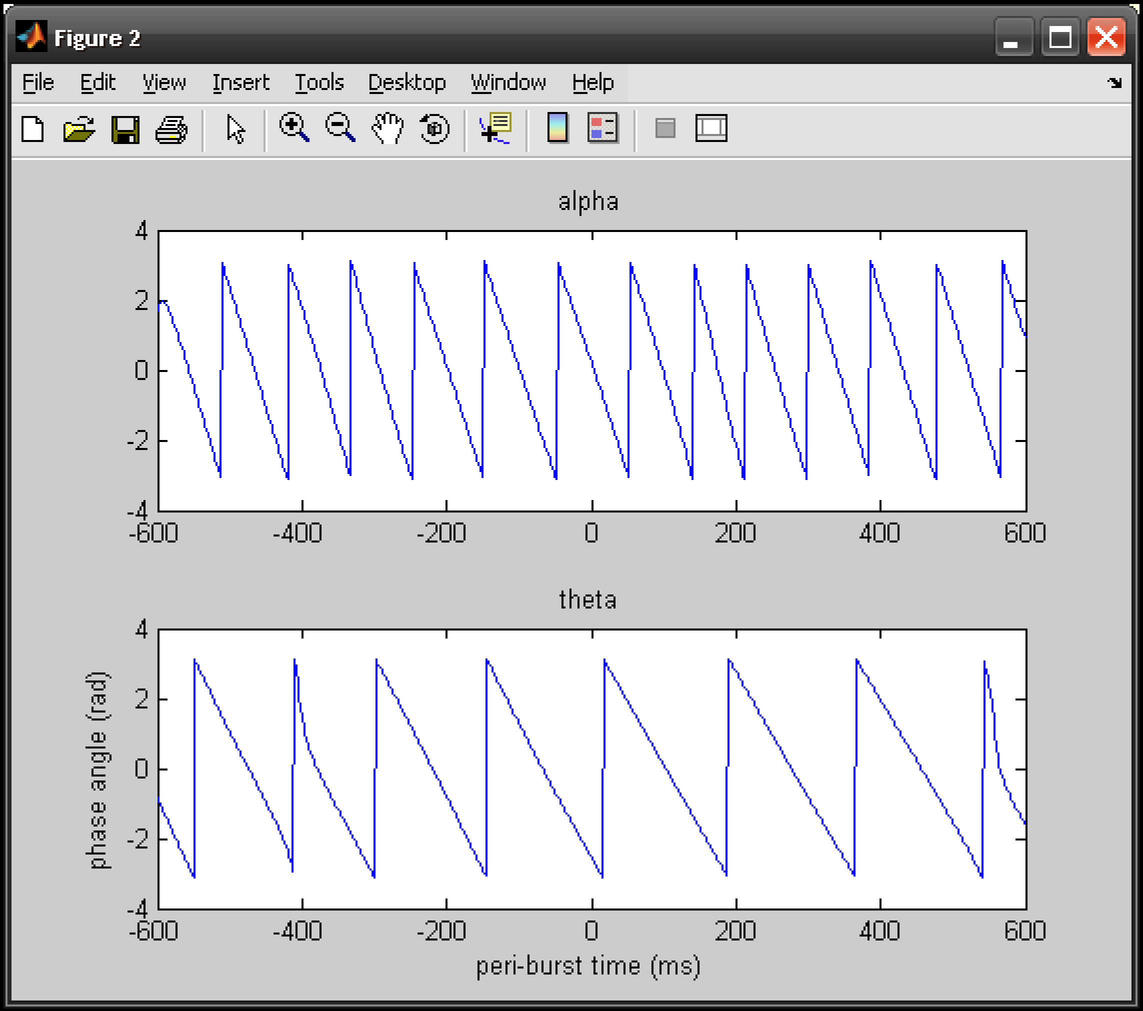


2. Inter-trial phase synchrony within one electrode.

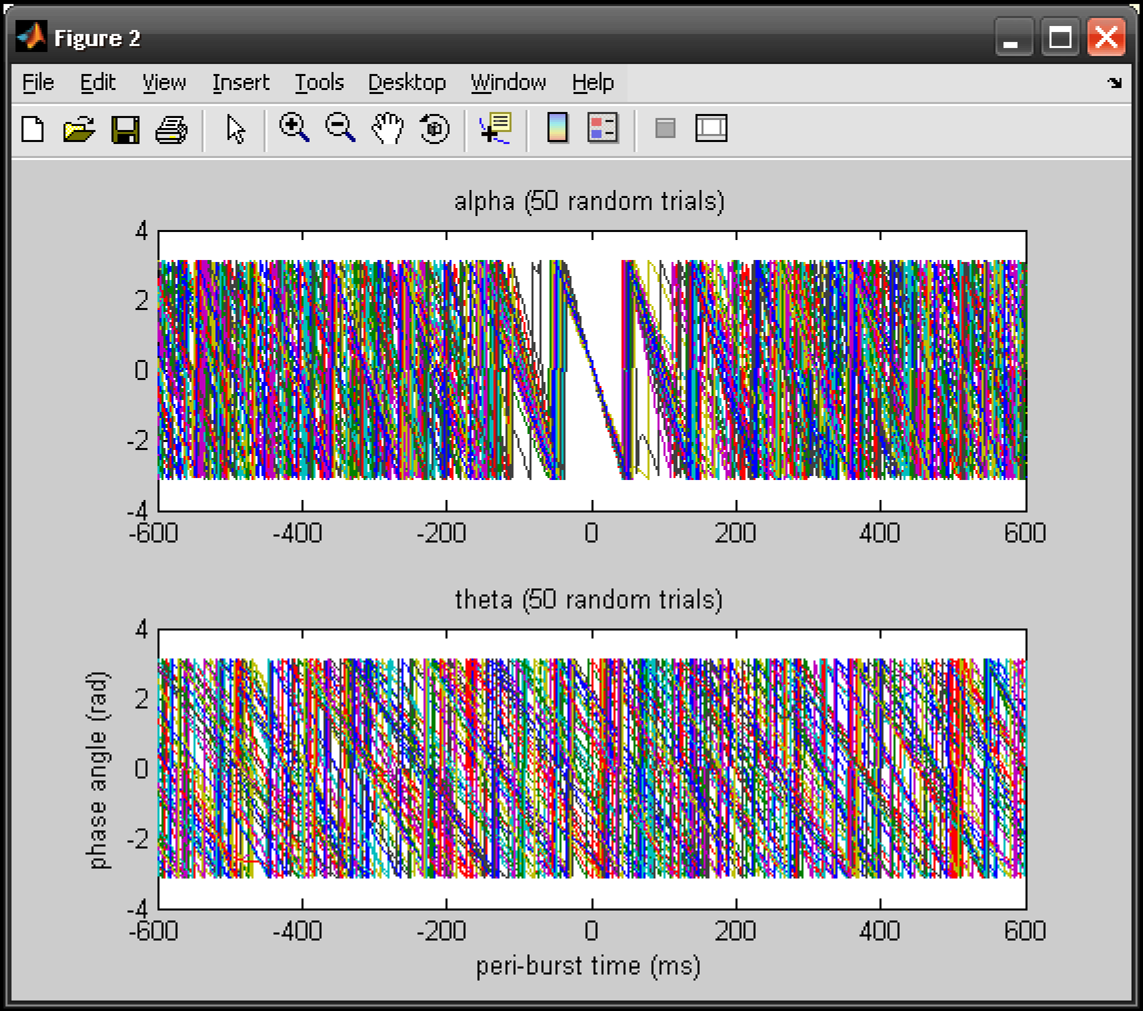
Many trials from the same electrode:



2. Inter-trial phase coherence



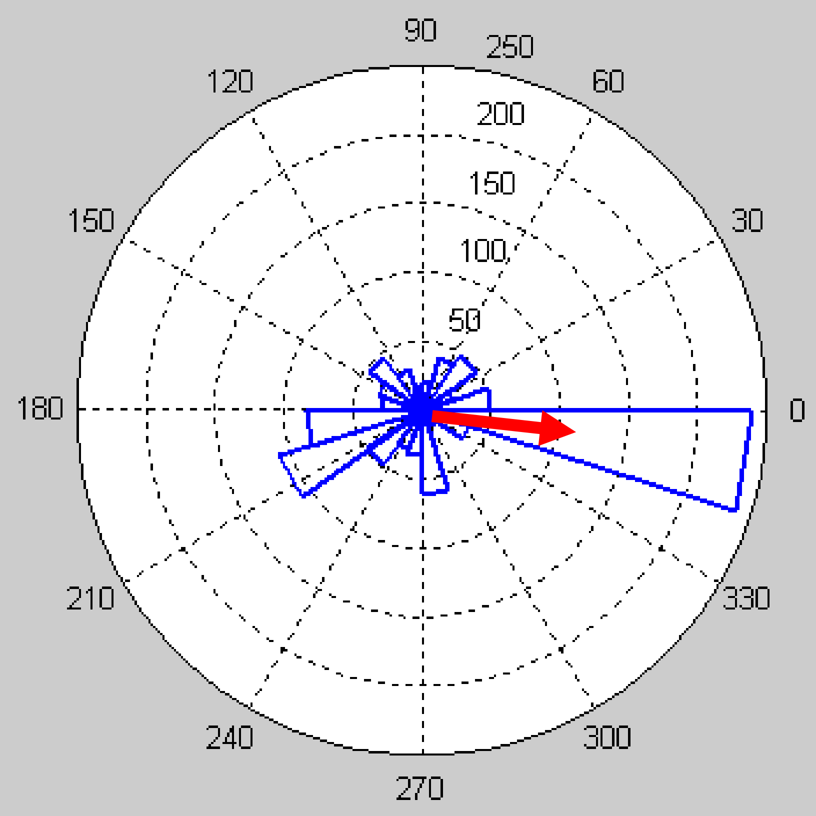
2. Inter-trial phase coherence



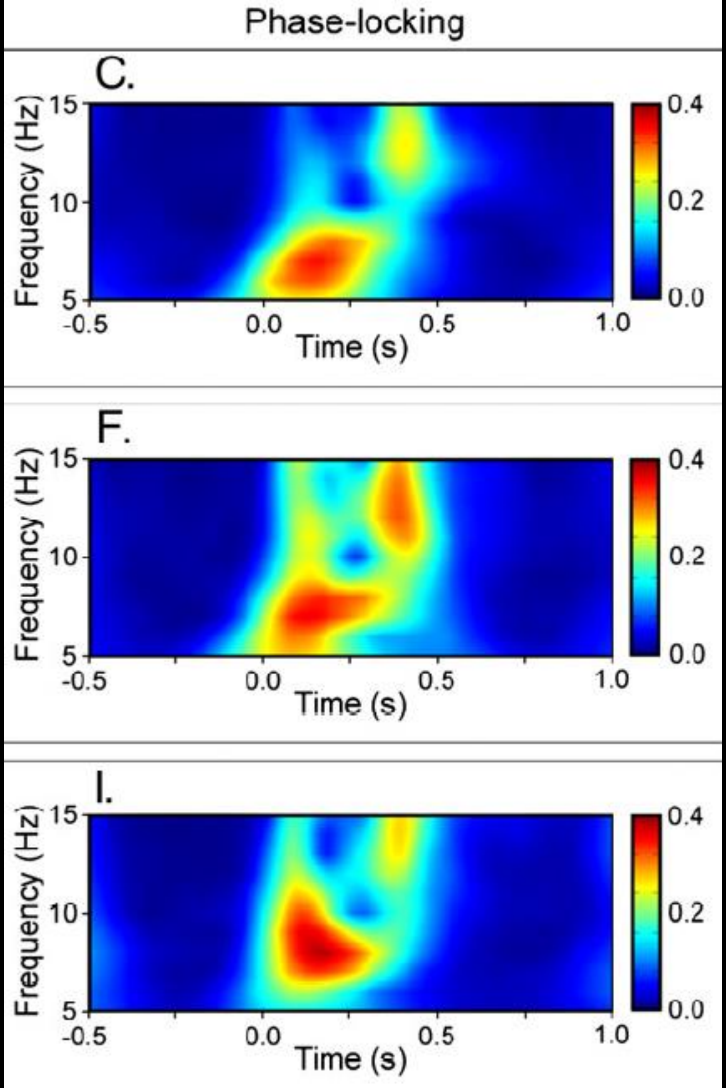
2. Inter-trial phase coherence

Calculate phase coherence across trials at each time point

Phase coherence, 154 ms: 0.11



2. Inter-trial phase coherence



3 different electrodes

B.-K. Min et al. / International Journal of Psychophysiology 65 (2007) 58–68

Thanks Mike!

NOW BACK TO JOHN’S SLIDES

Power increase in the absence of any phase locking

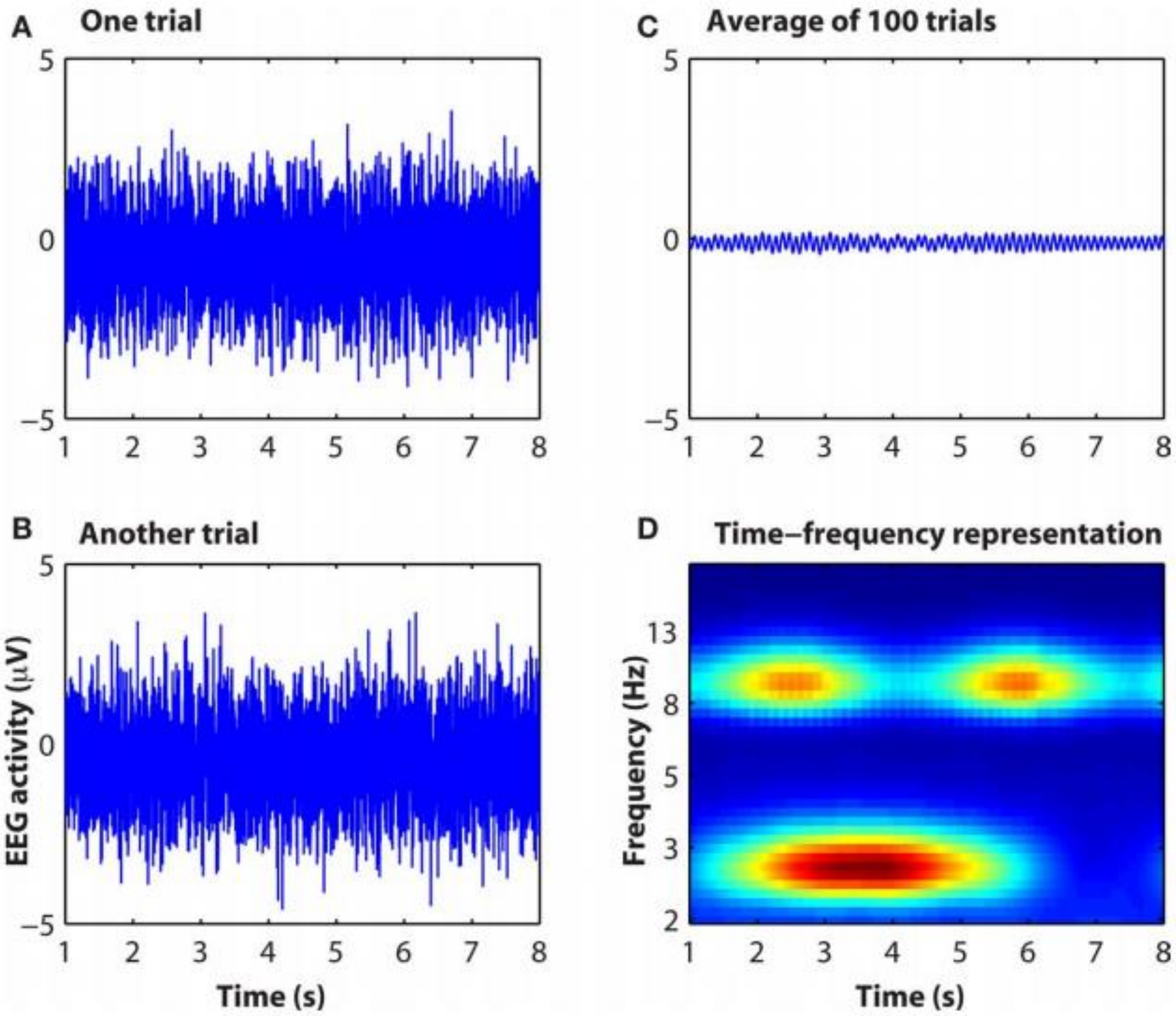
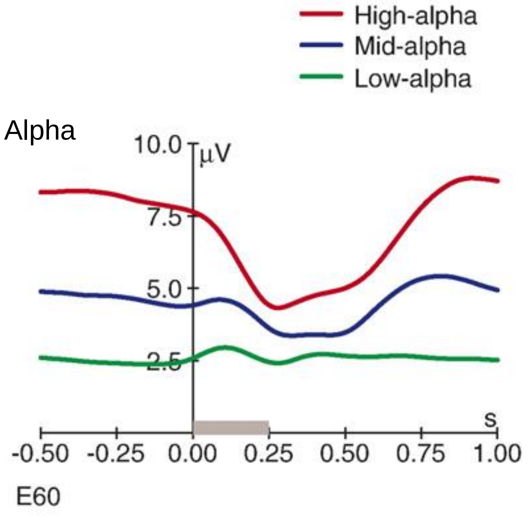


FIGURE 3 | Simulated data showing how information contained in raw EEG data [(A,B): single "trials"] is not apparent in the event-related potential **(C)** but is readily observable in the time–frequency representation **(D)**. Matlab code to run this simulation is available from the author.

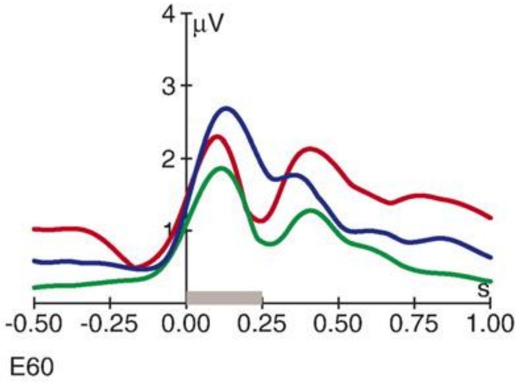
Cohen, 2011, *Frontiers in Human Neuroscience*

Power, Phase, ERPs

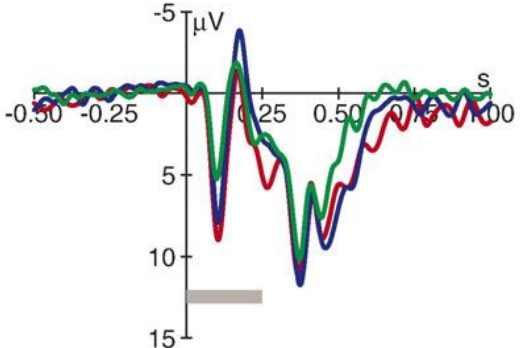
Total Alpha

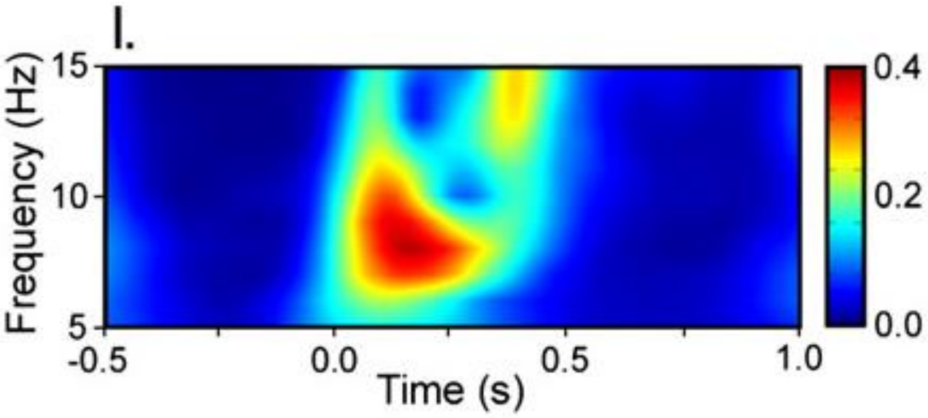


Evoked Alpha



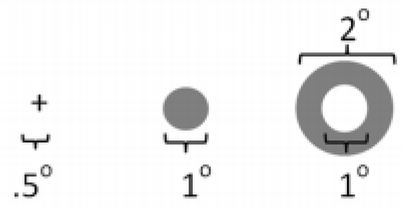
ERPs





B.-K. Min et al. / International Journal of Psychophysiology 65 (2007) 58–68

The Importance of Phase!



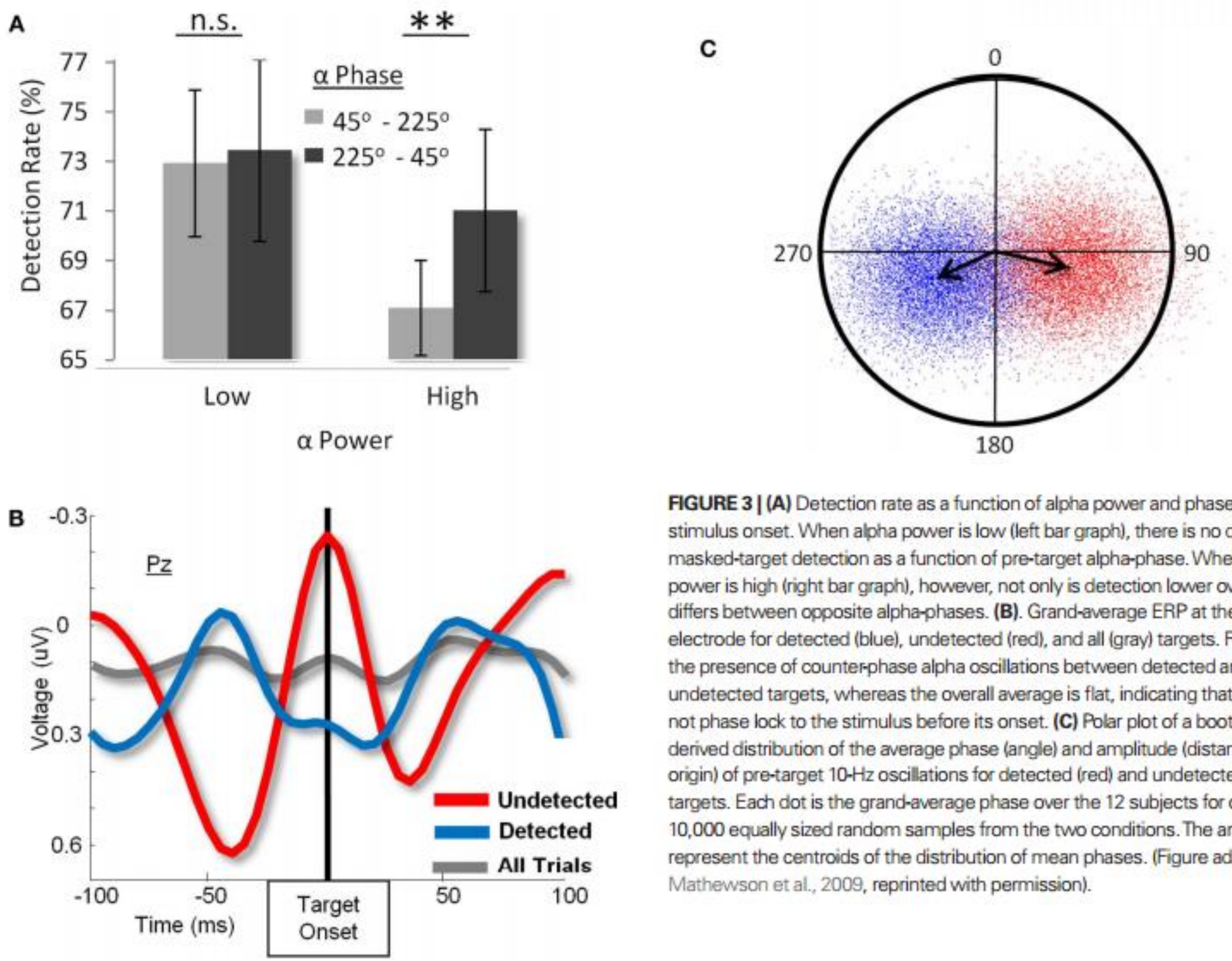
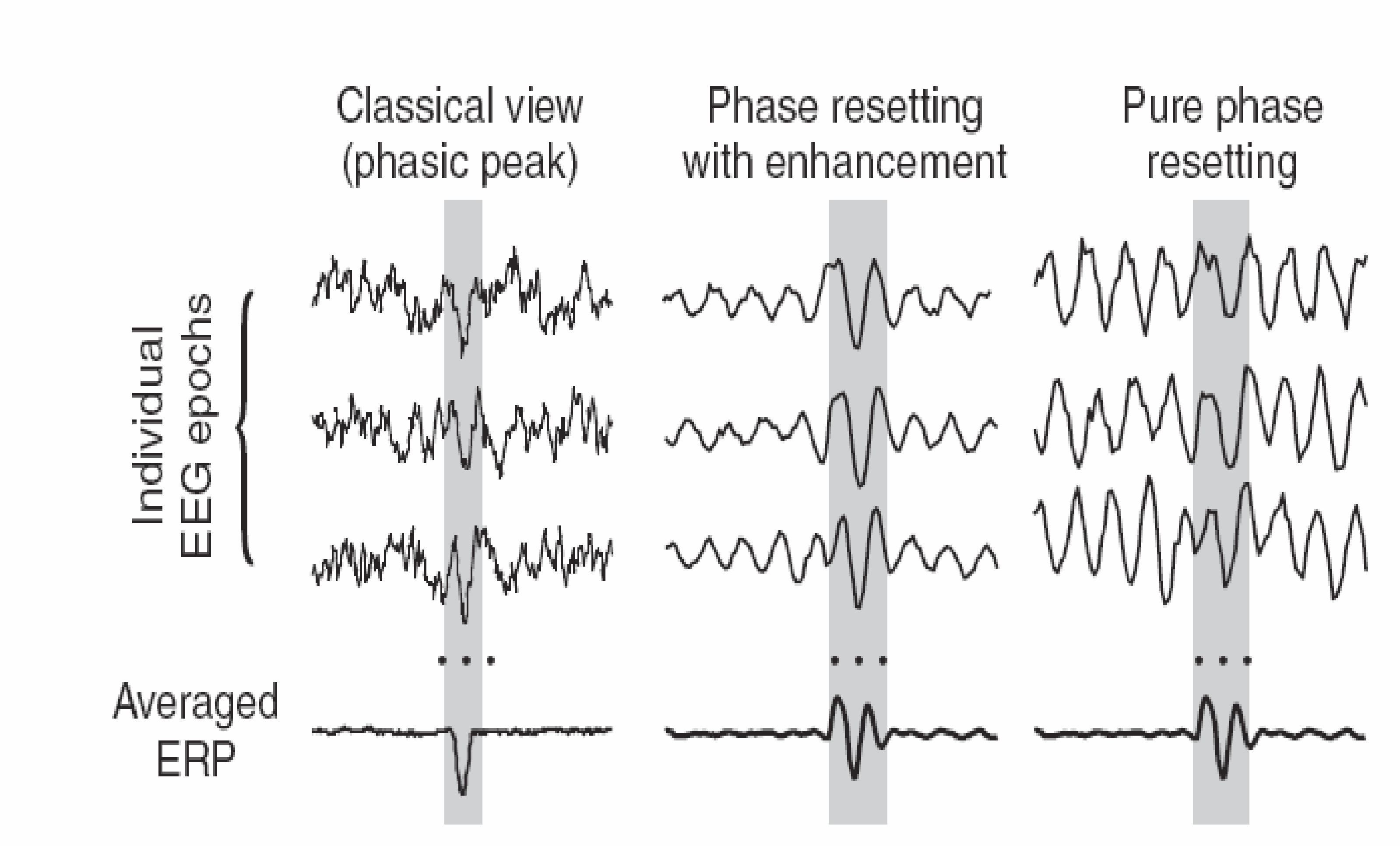


FIGURE 3 | (A) Detection rate as a function of alpha power and phase before stimulus onset. When alpha power is low (left bar graph), there is no difference in masked-target detection as a function of pre-target alpha-phase. When alpha power is high (right bar graph), however, not only is detection lower overall, but it differs between opposite alpha-phases. **(B)**. Grand-average ERP at the Pz electrode for detected (blue), undetected (red), and all (gray) targets. Results show the presence of counter-phase alpha oscillations between detected and undetected targets, whereas the overall average is flat, indicating that subjects did not phase lock to the stimulus before its onset. **(C)** Polar plot of a bootstrap-derived distribution of the average phase (angle) and amplitude (distance from origin) of pre-target 10-Hz oscillations for detected (red) and undetected (blue) targets. Each dot is the grand-average phase over the 12 subjects for one of 10,000 equally sized random samples from the two conditions. The arrows represent the centroids of the distribution of mean phases. (Figure adapted from Mathewson et al., 2009, reprinted with permission).

Matthewson, 2011, *Frontiers in Psychology*

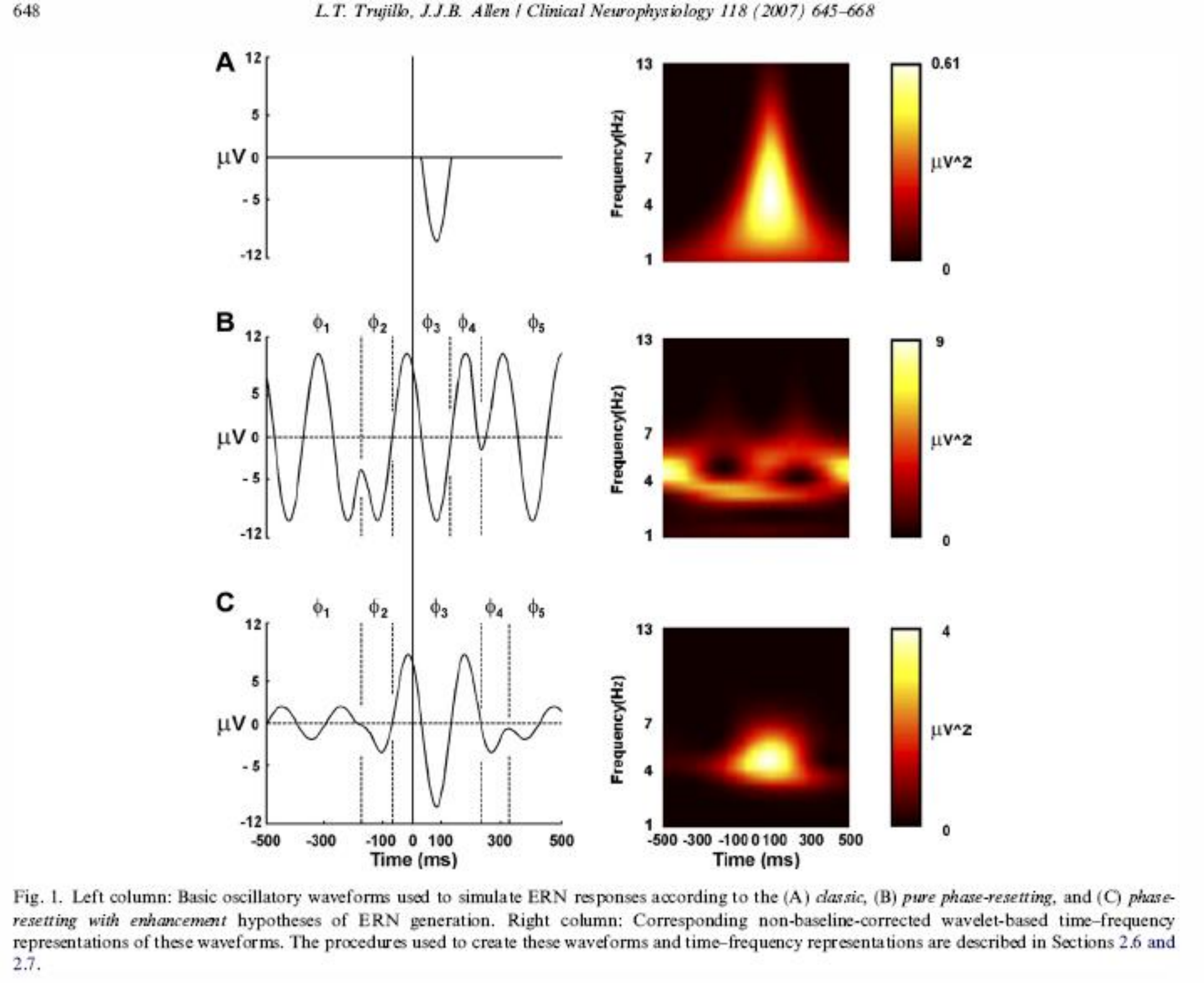
Time-Frequency Approaches to Error Monitoring

Classic ERPs Vs Phase Resetting



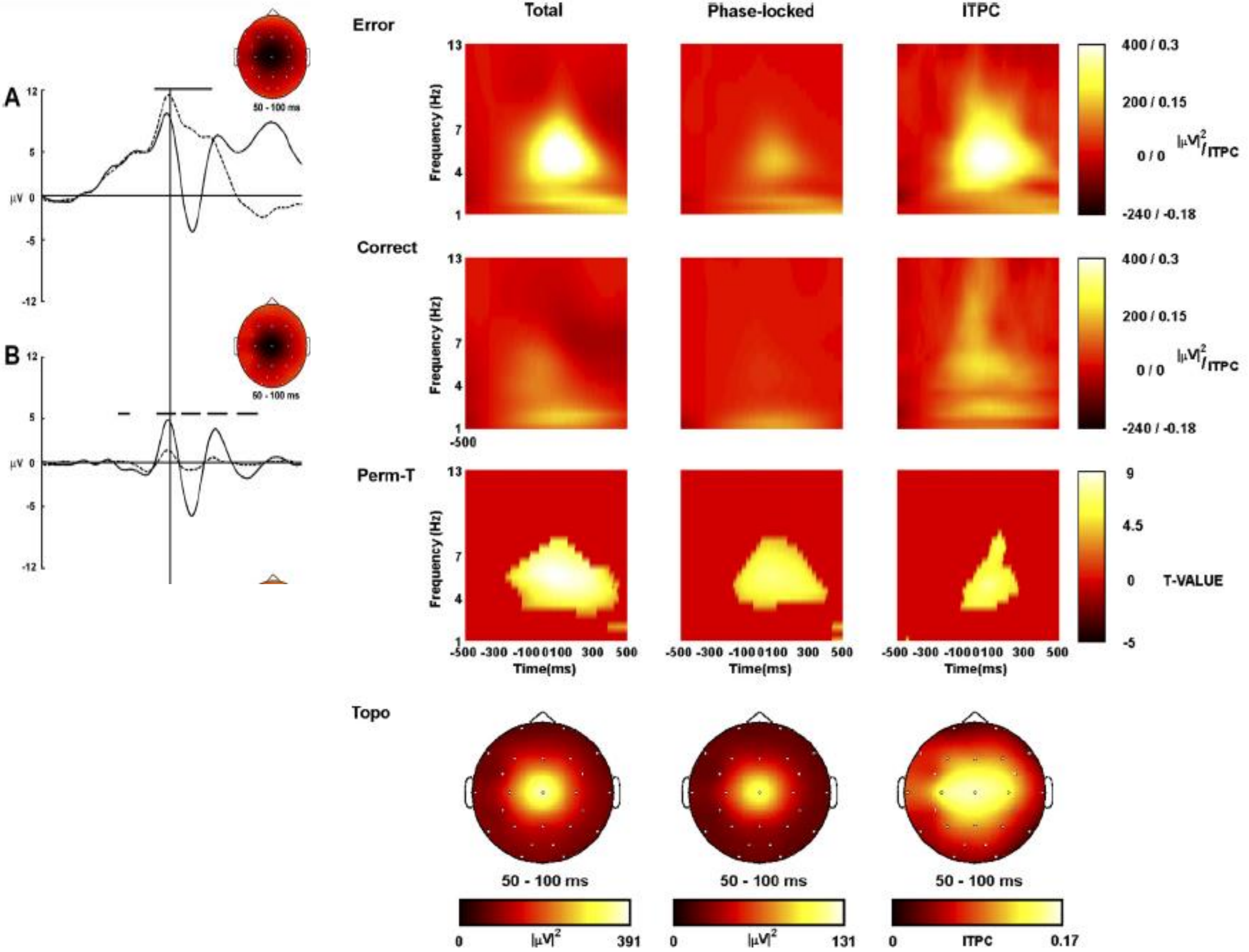
From Yeung et al., *Psychophysiology*, 2004

Time-Frequency Representations

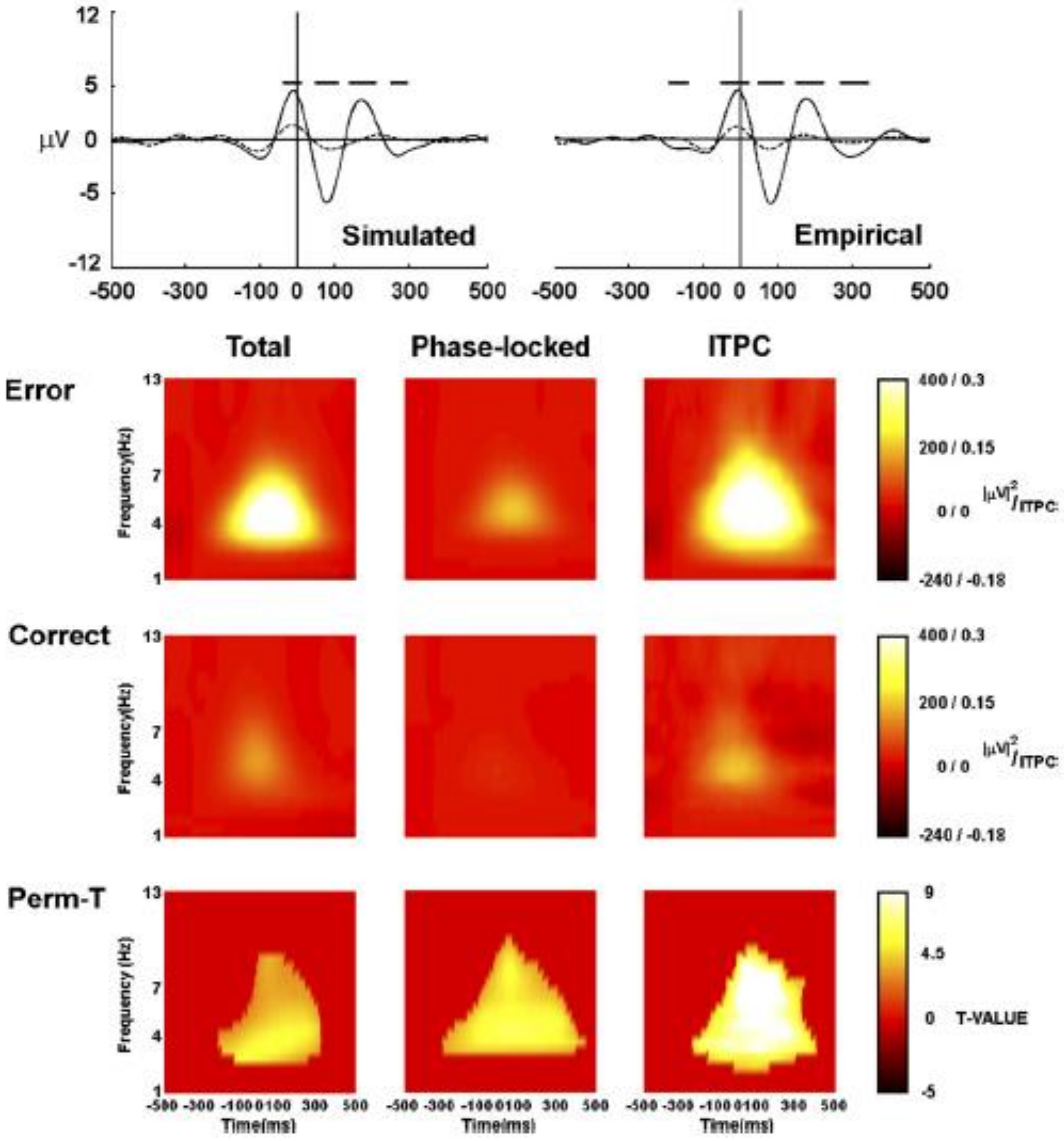


648 *L.T. Trujillo, J.J.B. Allen / Clinical Neurophysiology 118 (2007) 645–668*

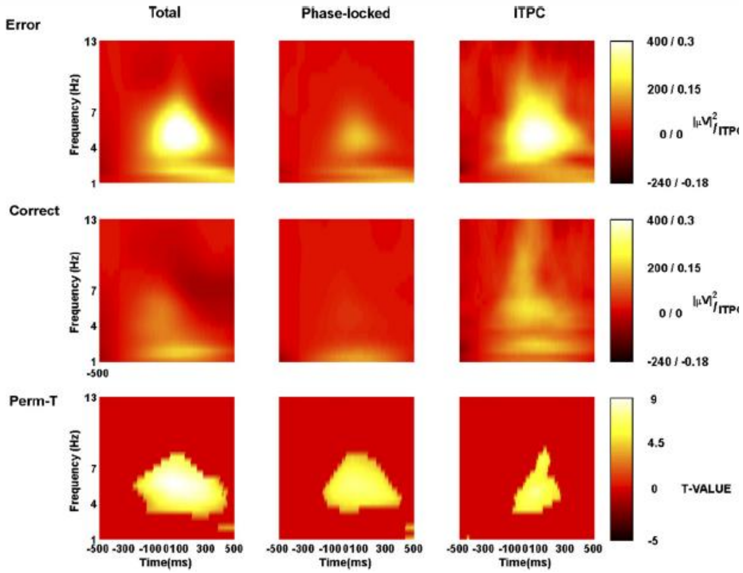
Fig. 1. Left column: Basic oscillatory waveforms used to simulate ERN responses according to the (A) *classic*, (B) *pure phase-resetting*, and (C) *phase-resetting with enhancement* hypotheses of ERN generation. Right column: Corresponding non-baseline-corrected wavelet-based time–frequency representations of these waveforms. The procedures used to create these waveforms and time–frequency representations are described in Sections 2.6 and 2.7.


A
12
5
µV 0
-5
-12
50 - 100 ms
B
12
5
µV 0
-5
-12
50 - 100 ms
Total
Phase-locked
ITPC
Error
Correct
Perm-T
Topo
Frequency (Hz)
13
7
4
1
-500
400 / 0.3
200 / 0.15
0 / 0
-240 / -0.18
|µV|²/ITPC
9
4.5
0
-5
T-VALUE
-500 -300 -100 0 100 300 500
Time(ms)
50 - 100 ms
0
|µV|²
391
0
|µV|²
131
0
ITPC
0.17

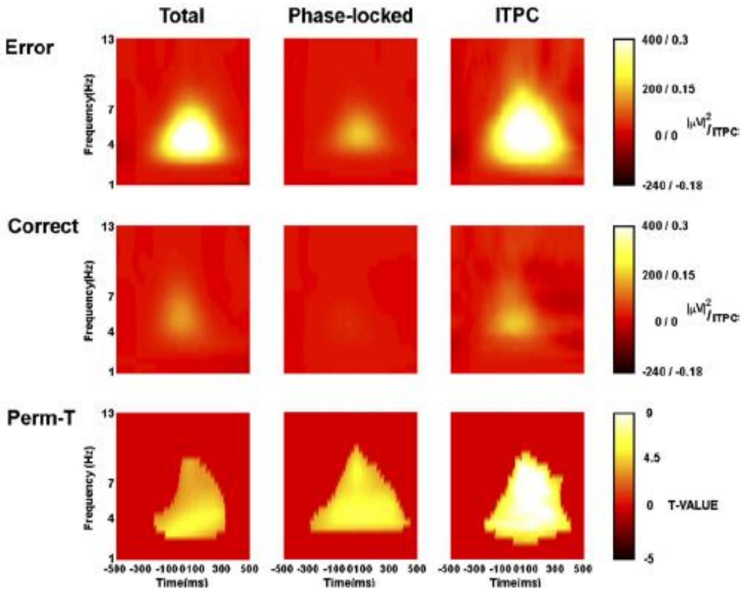
Simulated Phase-resetting with Enhancement



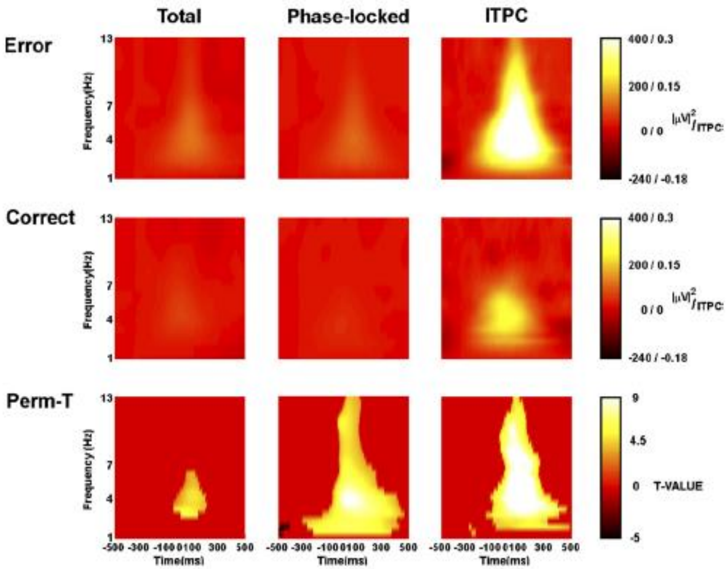
Empirical



Simulated Phase + Amp Enhance



Simulated Classic



Dealing with Ocular Artifacts

Ocular Artifacts

- The problem
  - Eye movements and blinks create a potential that is propagated in volume conducted fashion
  - Manifests in recorded EEG
- Why?
  - Eye not spherical; more rounded in back
  - Potential is therefore positive in front with respect to rear of eye
  - Movements = Moving dipole
  - Blinks = sliding variable resistor

Ocular Arifacts

- Eye-blinks are ***systematic*** noise with respect to the ERP signal
  - Occur at predictable latencies (Stim-Resp-Blink)
  - Are meaningful variables in and of themselves:
    - John Stern: Information processing and blink latency
    - Peter Lang: Blink Amplitude and affectively modulated startle response

Ocular Artifacts

- Signal averaging will not remove this "noise" (noise wrt signal of interest)
- Average waveform a(t) is mixture of timelocked signal s(t) and randomly distributed error (noise)

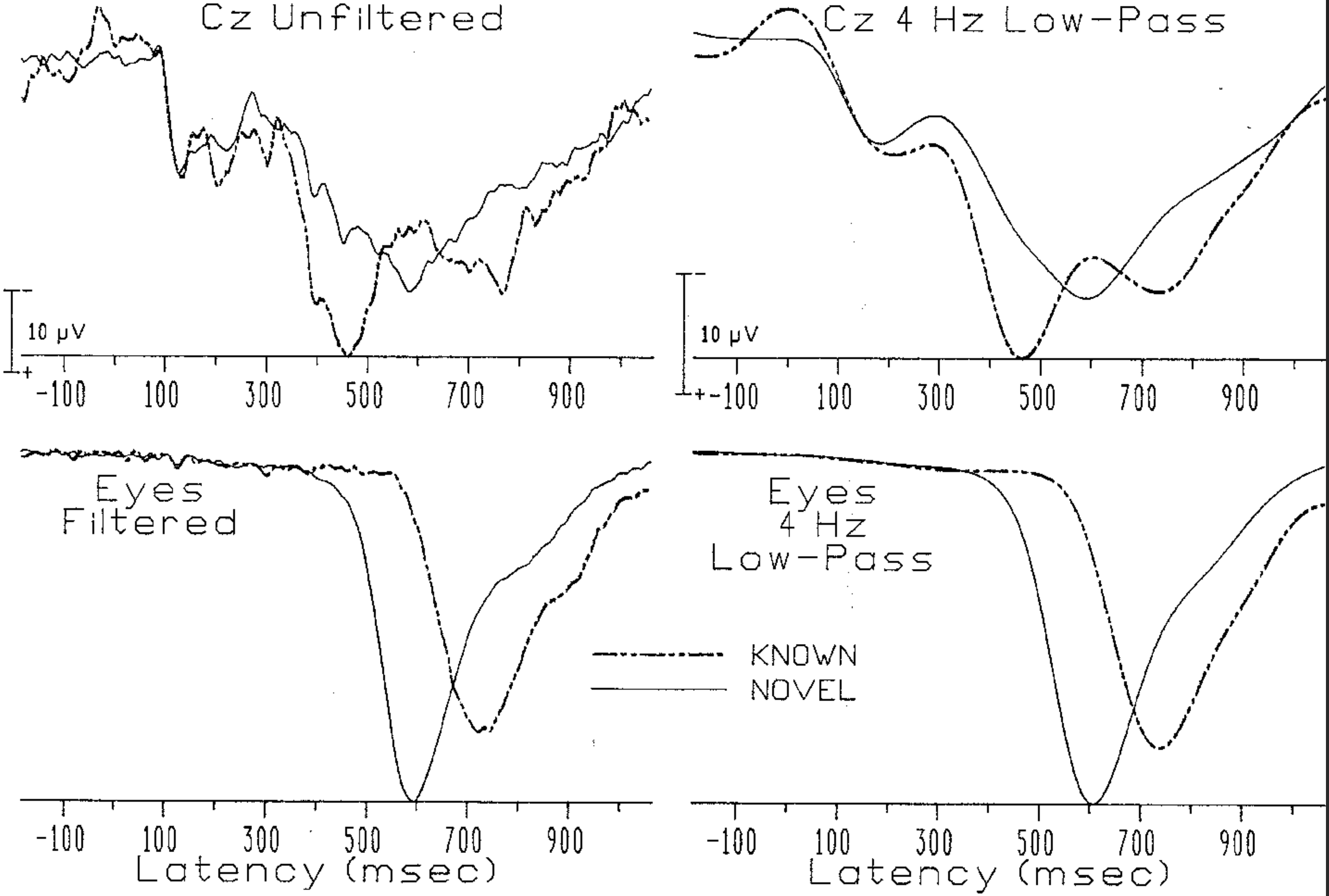
$$a(t) = s(t) + \frac{\sum_{1}^{n} e(t)}{n}$$

- If non-ERP signals are random with respect to stimulus onset, then the latter term will approach zero with sufficient trials (n)
- If not, the latter term will not sum to zero, but will include time-locked noise
- Noise will therefore average IN, not average OUT

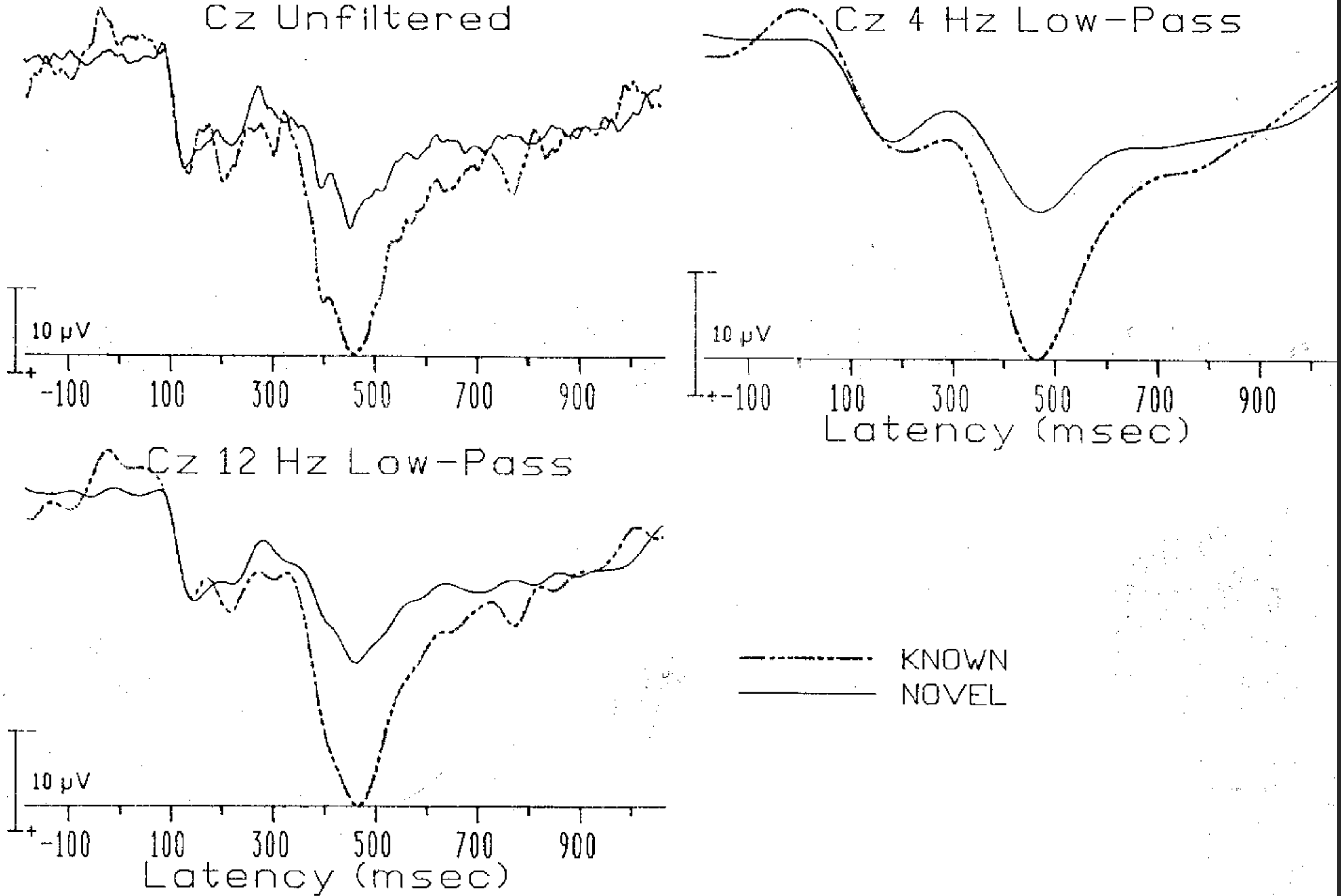
Ocular Artifacts

- Eye-blinks tend to occur at the cessation of processing.
    - Recall that the P300 is also a good index of cessation of processing.
- As a result, eye-blink artifact tends to appear as a late P300ish component

Odd-Ball ERP's SANS Blink Correction

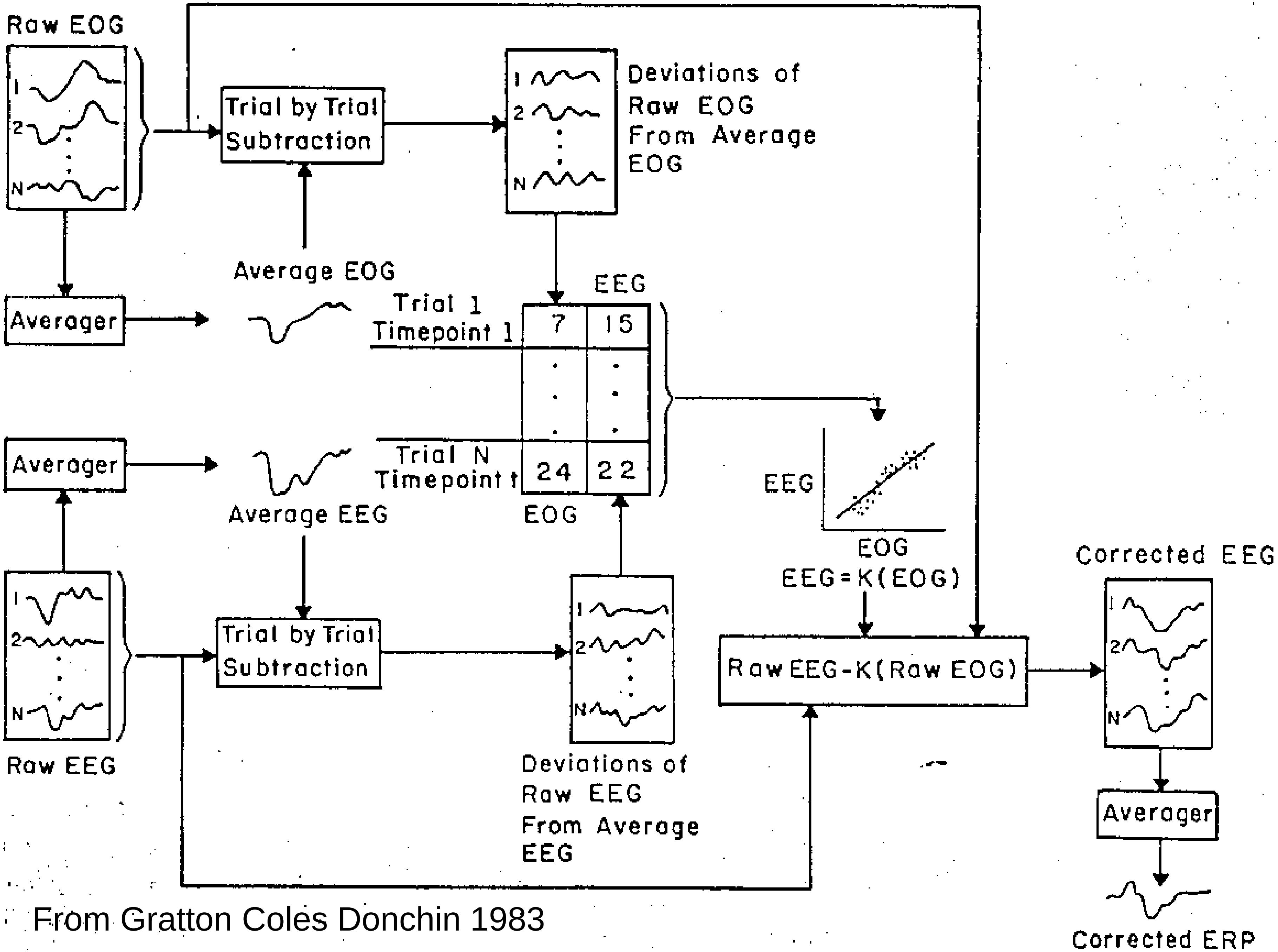


Odd-Ball ERP's WITH Blink Correction



What to Do?!

- Reject trials during which eye-blink occurred.
  - Problems:
    - Trials which elicit blinks may not be equivalent to those which do not.
    - Large data loss, may be unable to get usable average
    - Telling subjects not to blink creates dual task
- Eye-blink correction (Gratton, Coles, & Donchin, 1983)
  - Assumes that the effect of an eye-movement or blink on the recorded EEG can be inferred from activity recorded near the source of the artifact (top and bottom of eye, e.g.)
- Model ocular potentials as a source, and remove from scalp sites (more later)



From Gratton Coles Donchin 1983

The Details

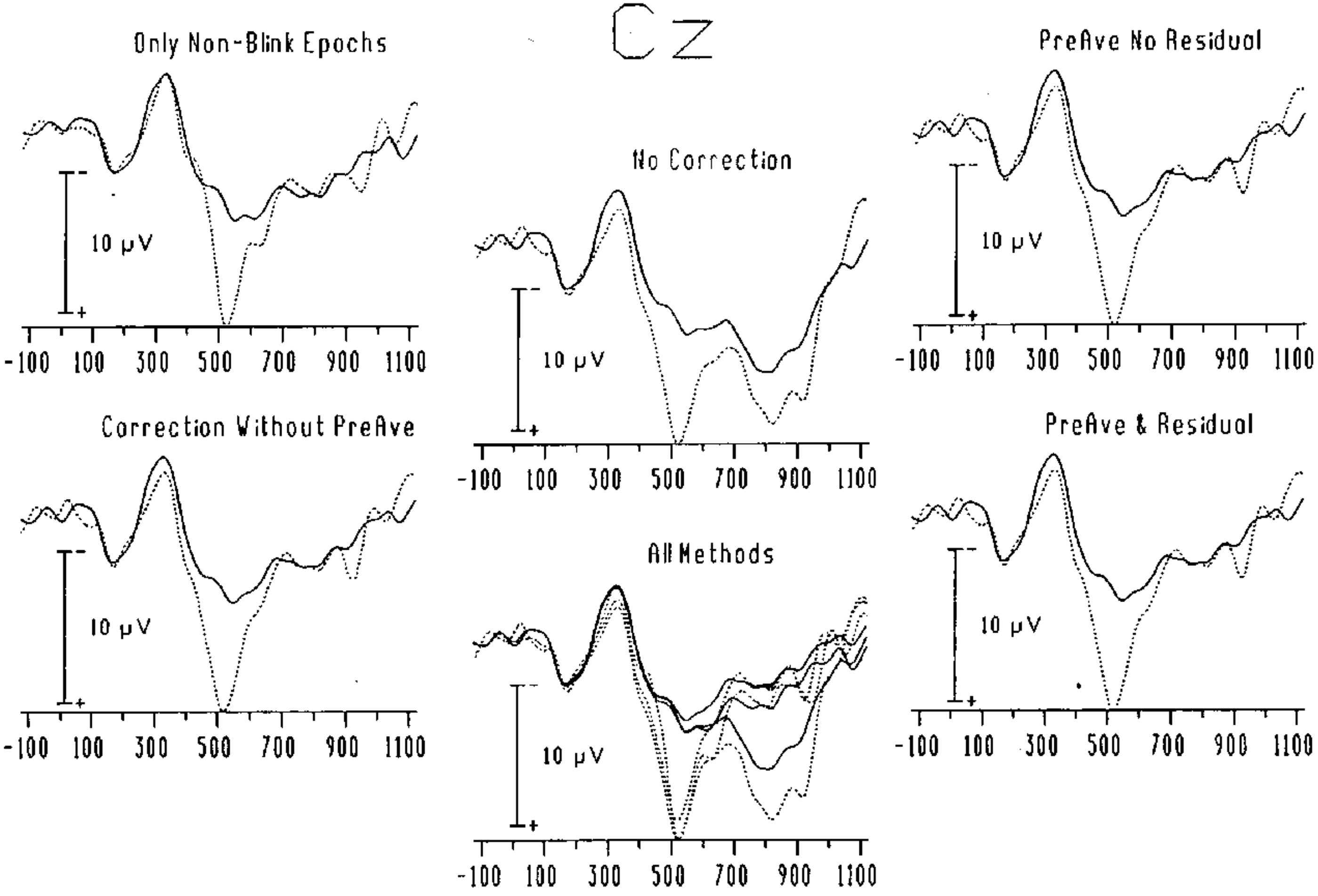
- Must determine extent to which EOG signal propagates to various scalp loci
  - Propagation factors computed only after any event-related activity is removed from both EOG & EEG channels
  - Event related activity in both channels may spuriously inflate estimate of propagation
  - Based upon correlation and relative amplitudes of EEG & EOG, a scaling factor is computed. The scaling factor is then applied on a trial by trial basis as follows:

Corrected EEG = Raw EEG - K*(Raw EOG)

- Corrected EEG epochs then averaged together to get blink-corrected ERP

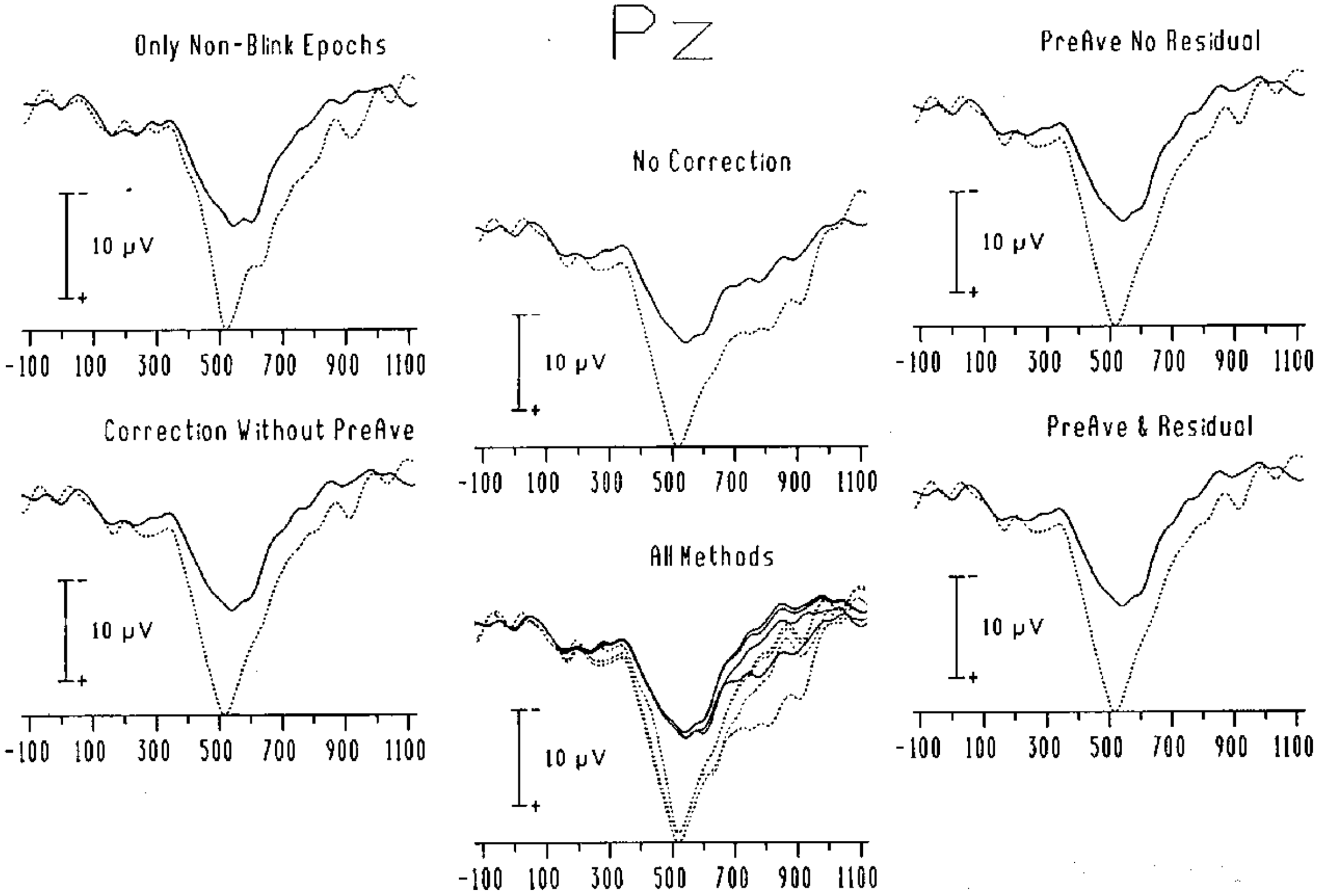
Validity of Ocular Correction

- Can produce valid results, but important to examine data to ascertain how well procedure worked.
- Variant of Gratton et al devised by Semlitsch, Anderer, Schuster, and Presslich (1986).
  - Creates blink-locked averages
  - Should reduce event-related contributions to correction estimate
  - Produces highly similar results



Four methods of undetermined validity for dealing with Blink Artifact in an Oddball Paradigm. Solid lines represent frequent novel items, and dotted lines represent rare learned items.

"Only Non-Blink Epochs" = excluding blink-contaminated epochs (28/60 Learned, 34/150 Unlearned)
"Correction without PreAve" = Gratton et al. method without the preliminary subtraction of event-related activity
"PreAve No Residual" = Gratton et al. method, event-related activity extracted prior to correction, no residual correction
"PreAve & Residual" = Gratton et al. method, event-related activity extracted prior to correction, with residual correction
For comparison, non-corrected data and all methods are presented in the center column. Abscissa is latency (msec).



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Other Methods (in brief)

- Most other methods also depend upon subtraction of a proportion of the EOG signal or some transformation of the EOG signal
  - Frequency-domain methods recognize that not all frequencies in the EOG channel propagate equally to scalp sites
  - Source localization methods attempt to derive a source that represents the equivalent of the origin of the eye potentials, and then compute the extent to which these sources would project onto scalp
    - BESA
    - ICA

Demonstration of Ocular Correction