# Advanced Signal Processing I

*Ocular Artifacts*

*Digital Filters*

*Time Frequency Approaches*

# 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

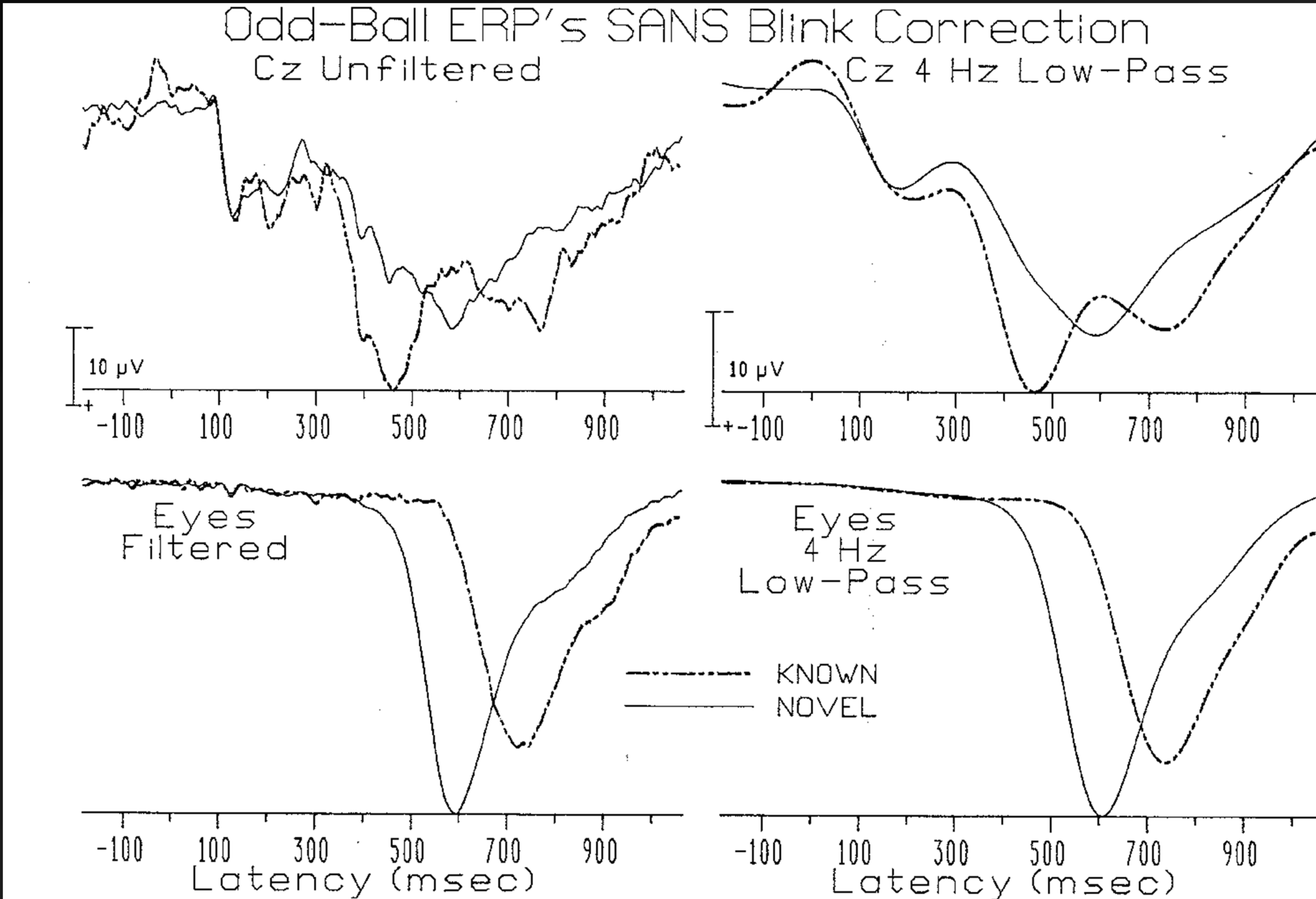
- Signal averaging will not remove this "noise" (noise wrt signal of interest)
- Average waveform a(t) is mixture of timelocked signal s(t) and randomly distributed error (noise)

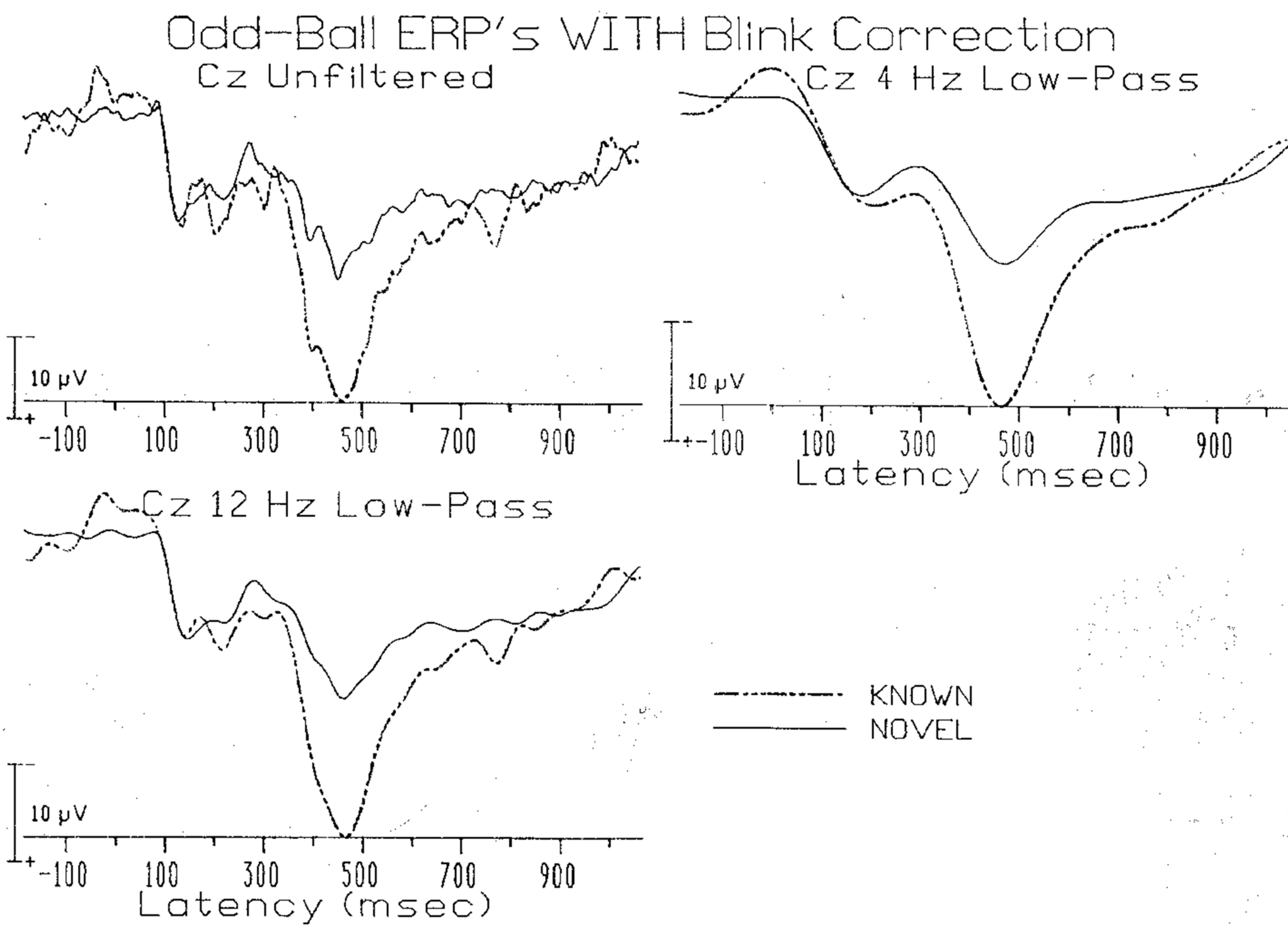
$$a(t) = s(t) + \frac{\sum_{1}^{n} e(t)}{n}$$

- 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

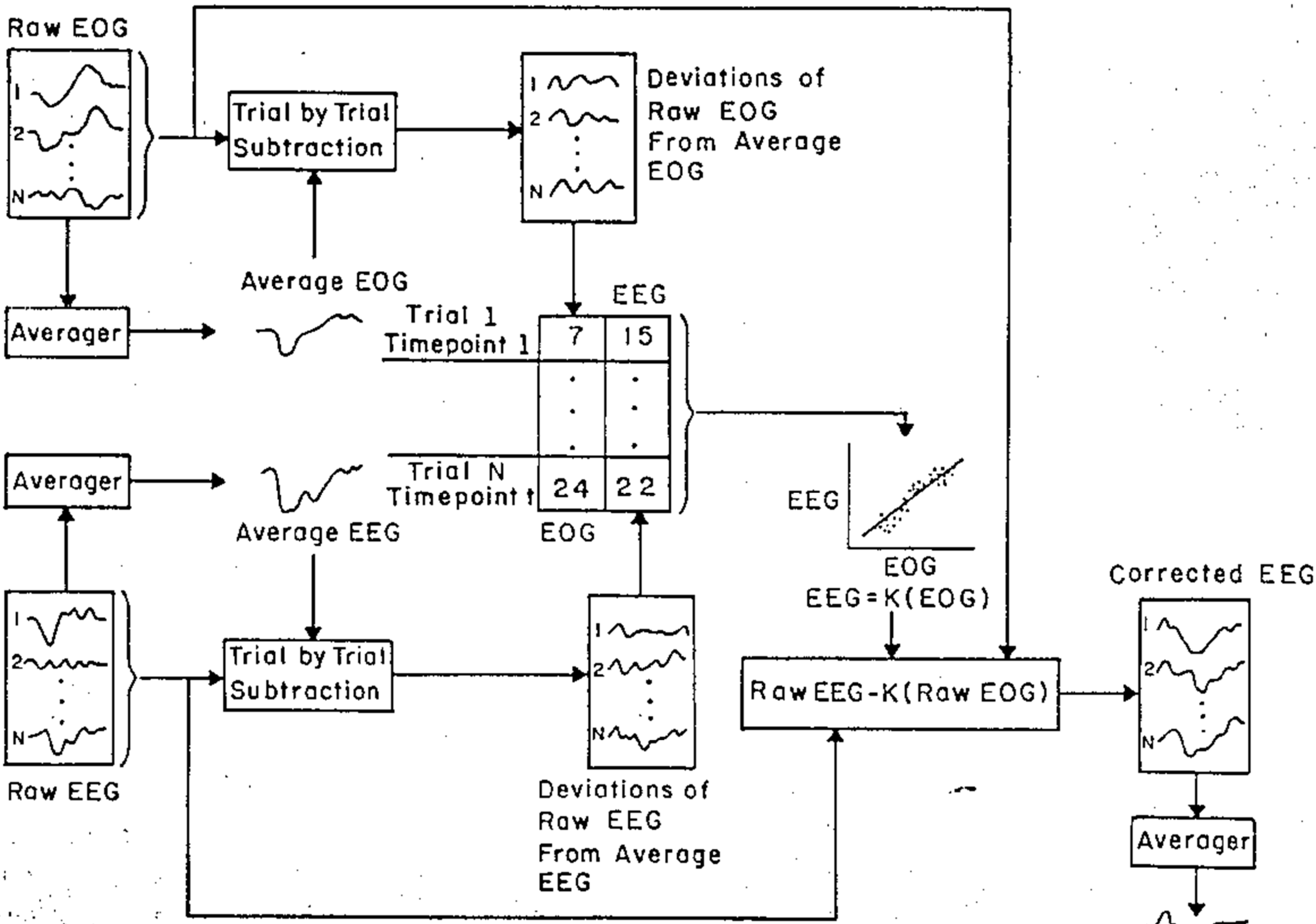
- Eye-blinks tend to occur at the cessation of processing.
  - Recall that the P300 is also a good index of cessation of processing.
- As a result, eye-blink artifact tends to appear as a late P300ish component


Odd-Ball ERP's SANS Blink Correction
Cz Unfiltered
Cz 4 Hz Low-Pass
10 µV
10 µV
-100
100
300
500
700
900
Eyes
Filtered
Eyes
4 Hz
Low-Pass
KNOWN
NOVEL
Latency (msec)
Latency (msec)


Odd-Ball ERP's WITH Blink Correction
Cz Unfiltered
Cz 4 Hz Low-Pass
Cz 12 Hz Low-Pass
10 μV
-100
100
300
500
700
900
Latency (msec)
KNOWN
NOVEL

# 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

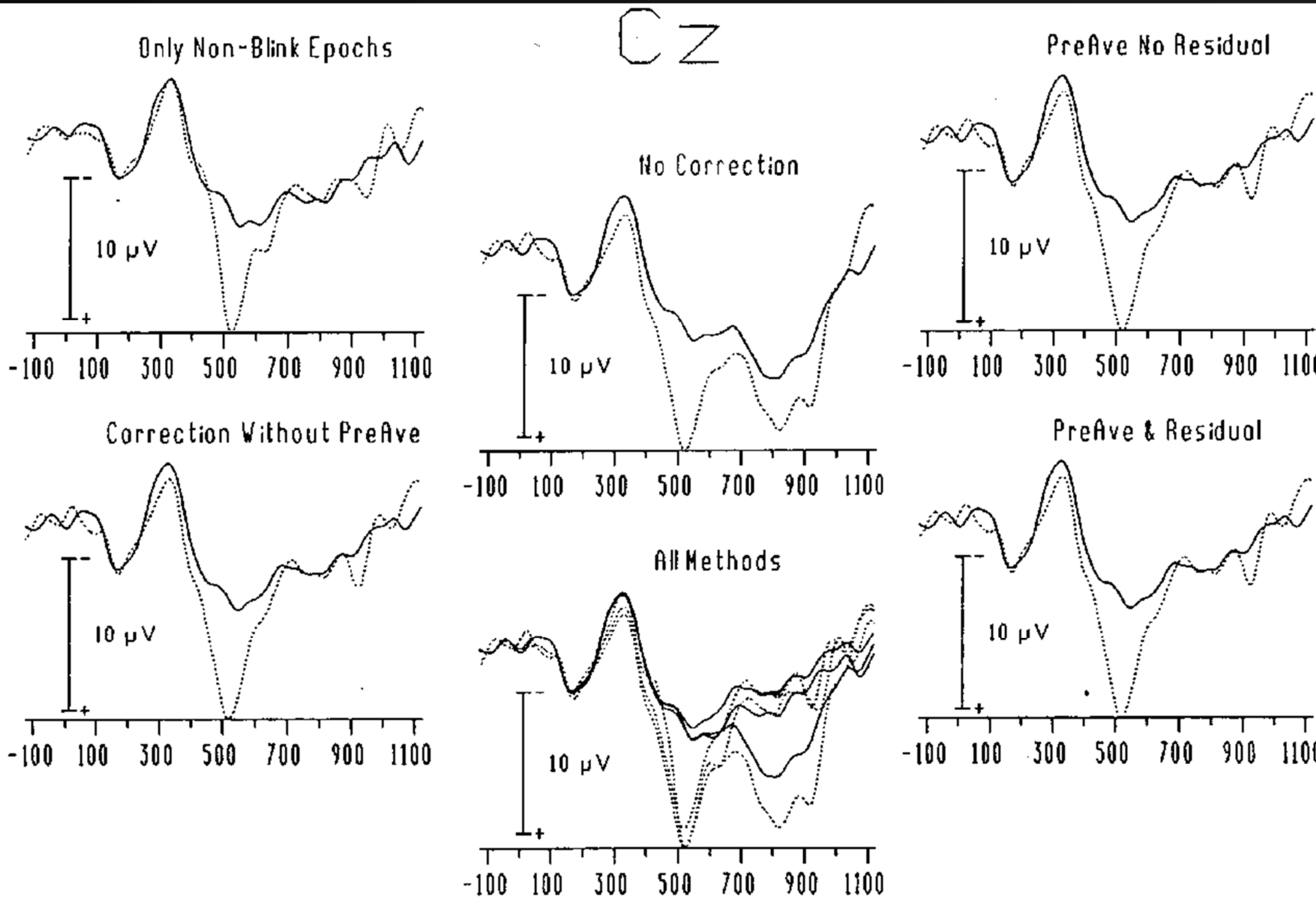
- Must determine extent to which EOG signal propagates to various scalp loci
  - Propagation factors computed only after any event-related activity is removed from both EOG & EEG channels
  - Event related activity in both channels may spuriously inflate estimate of propagation
  - Based upon correlation 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

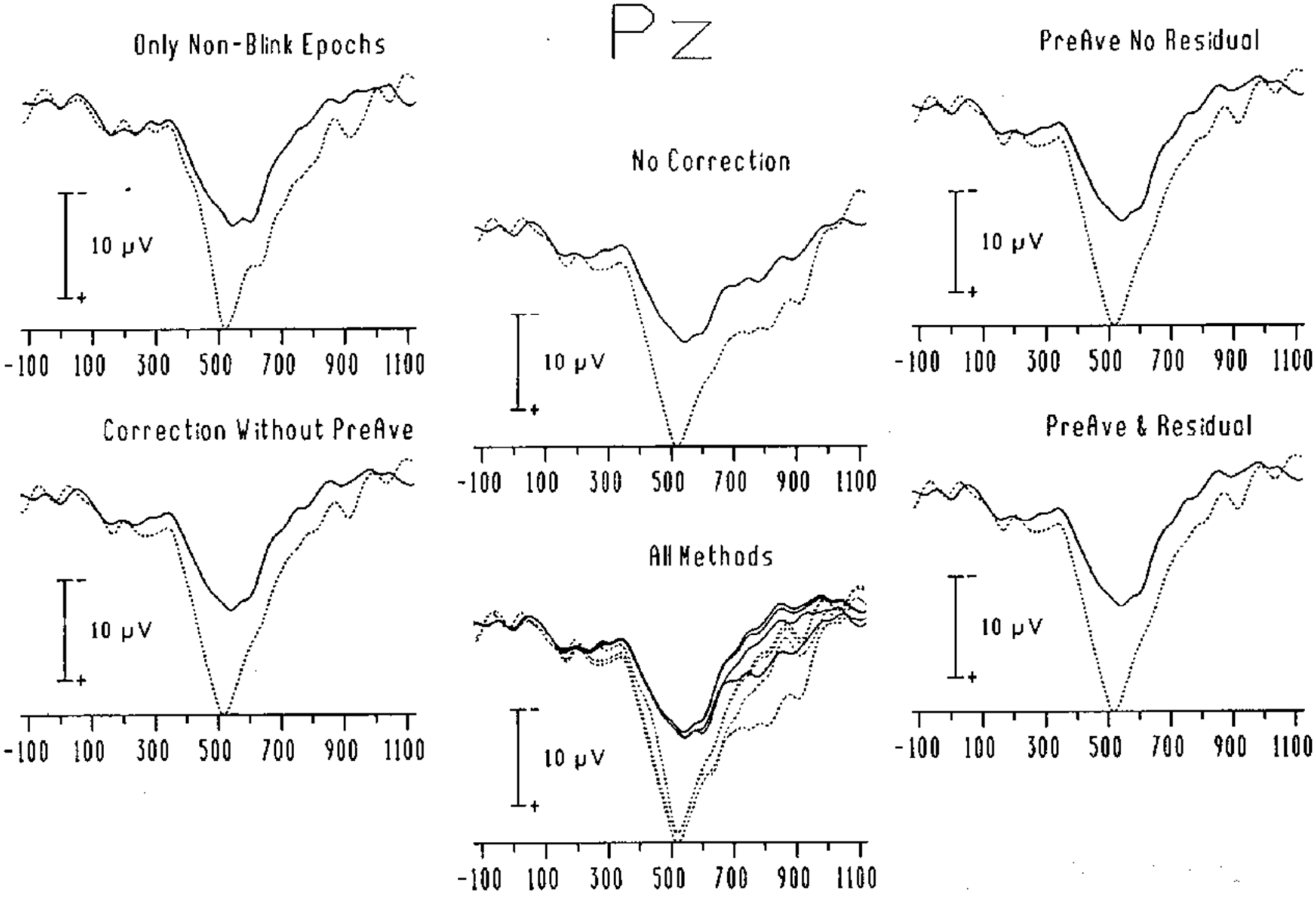
# Validity of Ocular Correction

- 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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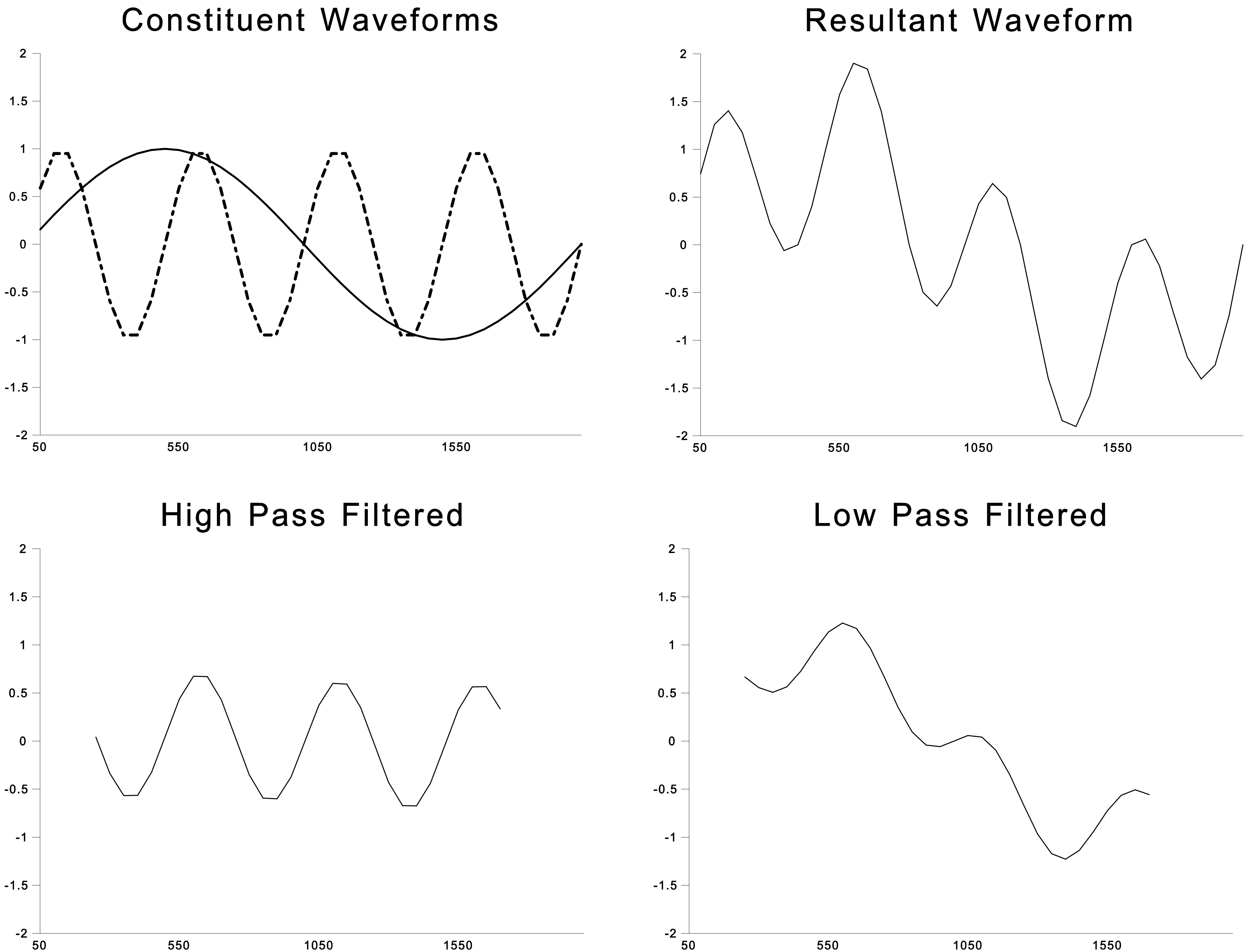
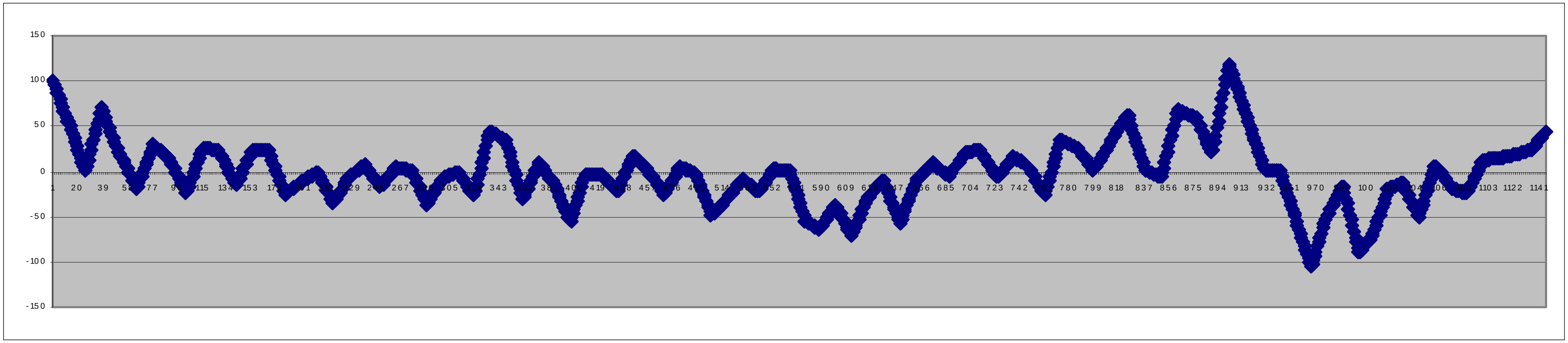
# Other Methods (in brief)

- 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

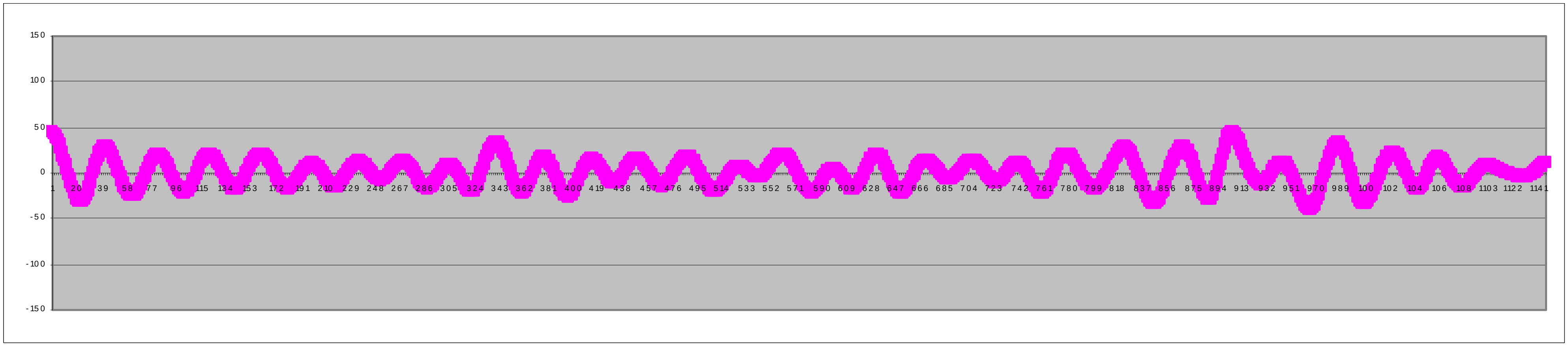
# Digital Vs. Analog Filtering

- Analog filters can introduce the problem of phase shift or lag, with 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
  - this can pose a problem in ERP recording, as some components would be distorted
- Hence, digital filtering is a preferred alternative.
  - No phase shift
  - Is widely used in last several decades

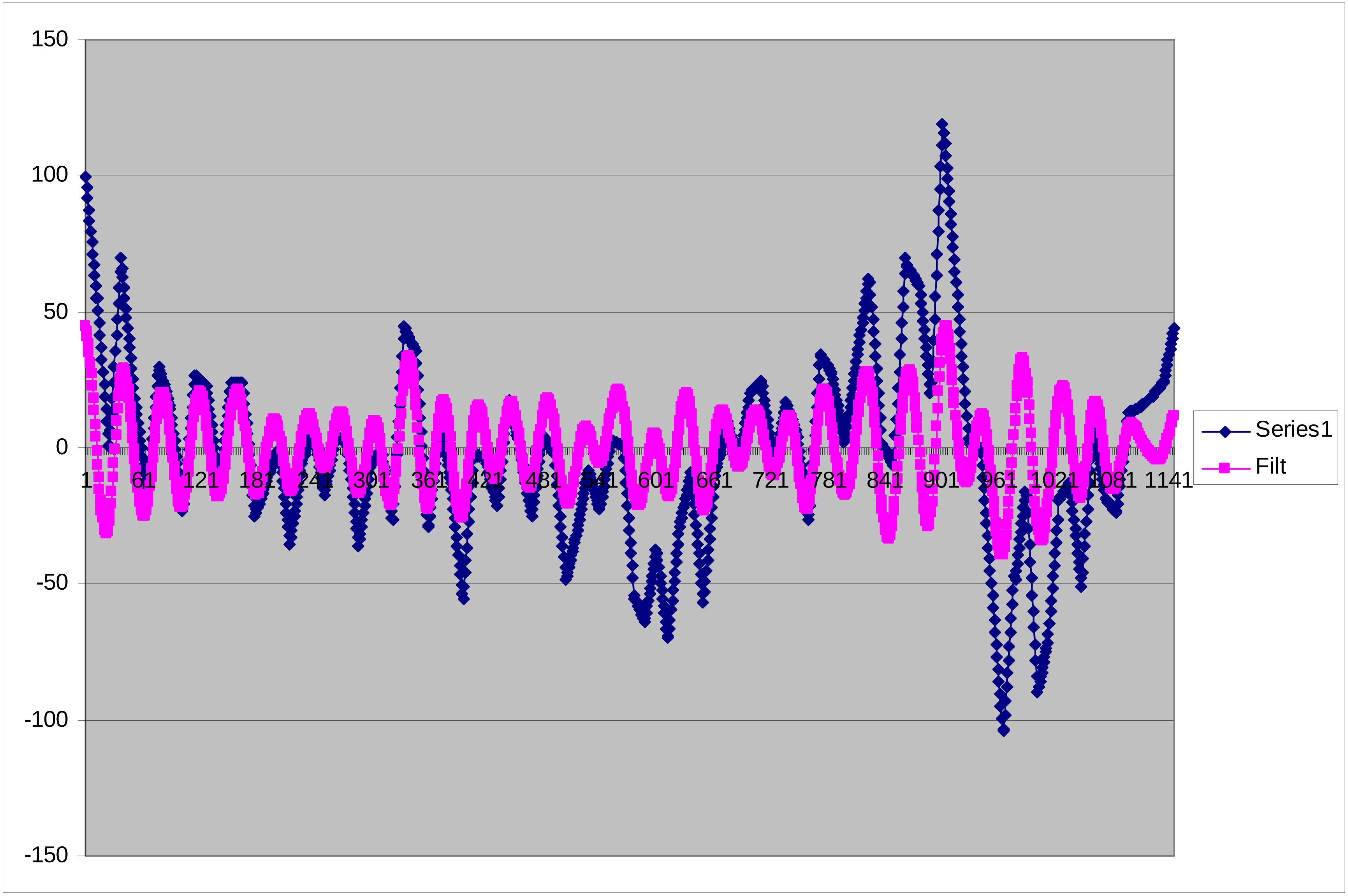

Constituent Waveforms
Resultant Waveform
High Pass Filtered
Low Pass Filtered
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
50
550
1050
1550



150
100
50
0
-50
-100
-150

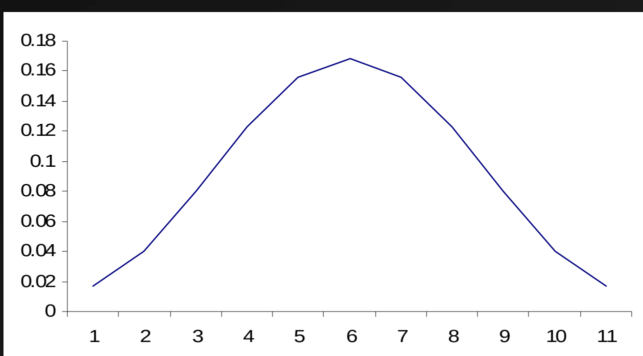



150
100
50
0
-50
-100
-150

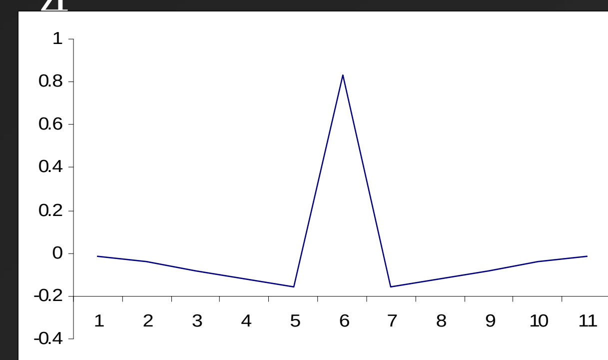

150
100
50
0
-50
-100
-150
1
61
121
181
241
301
361
421
481
541
601
661
721
781
841
901
961
1021
1081
1141
Series1
Filt

# 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 COEFFICIENT | LAG | HIGH PASS 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 <u>non-recursive</u> filter uses raw sample values in the calculations; <u>recursive</u> filters use the already filtered values of preceding samples in the calculations. Non-recursive filters are more straightforward and more commonly used.
- The term <u>linear</u> denotes that the filter involves the computation of <u>weighted sums</u> of the digital sample values. Other filtering algorithms can be devised, but are not 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

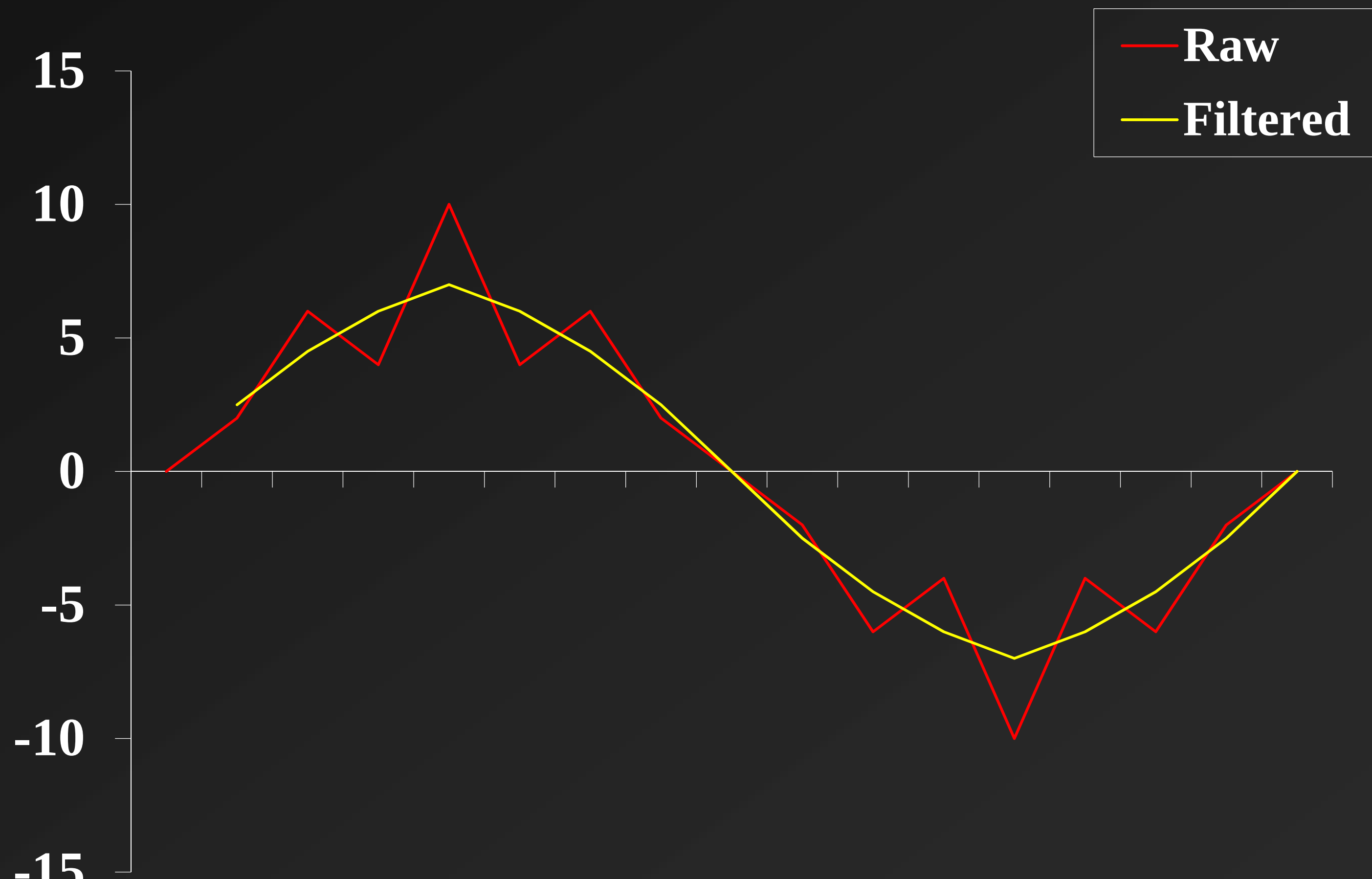
  17.5/200 = x/20 ; x = 1.75 @ 20 Hz Sampling rate

# Muy Simple Filter

[ .25 .5 .25]

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

$filt_{1x3} * segment_{3x1} = filteredpoint$ (scalar)



# Some filters and their Transfer Functions

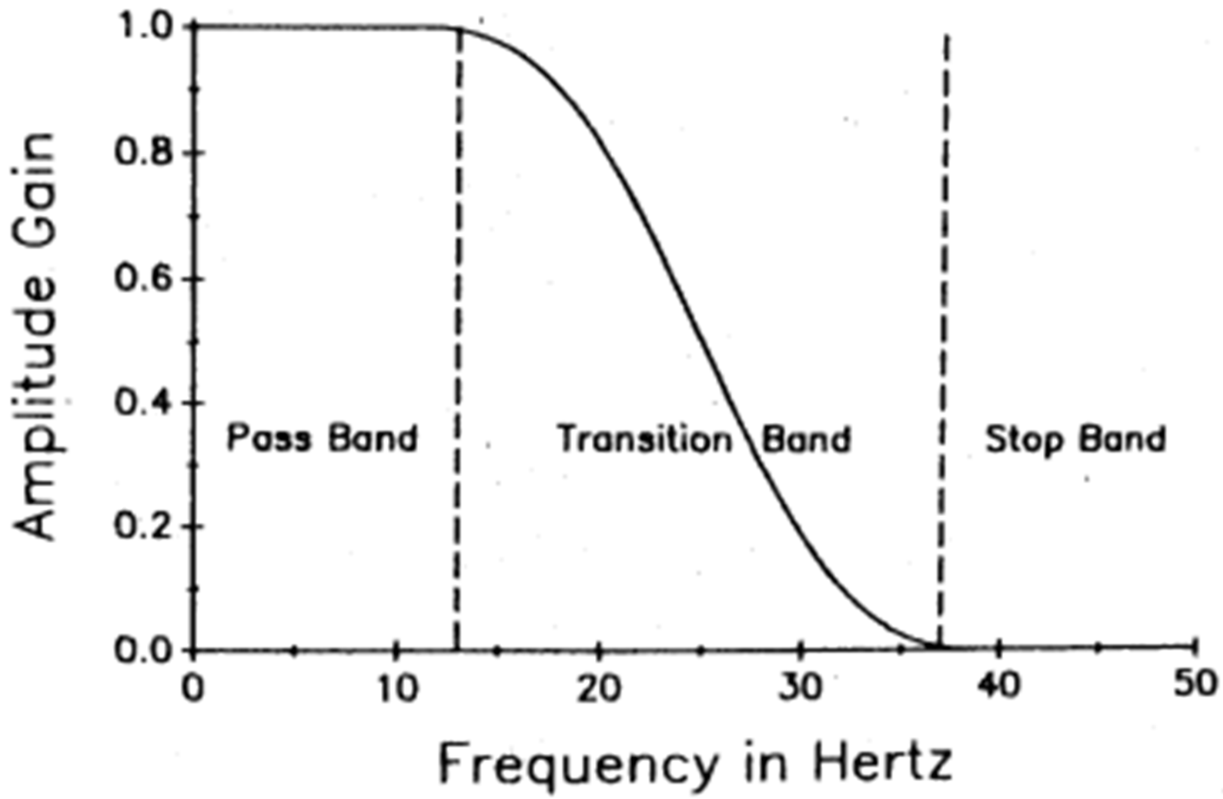
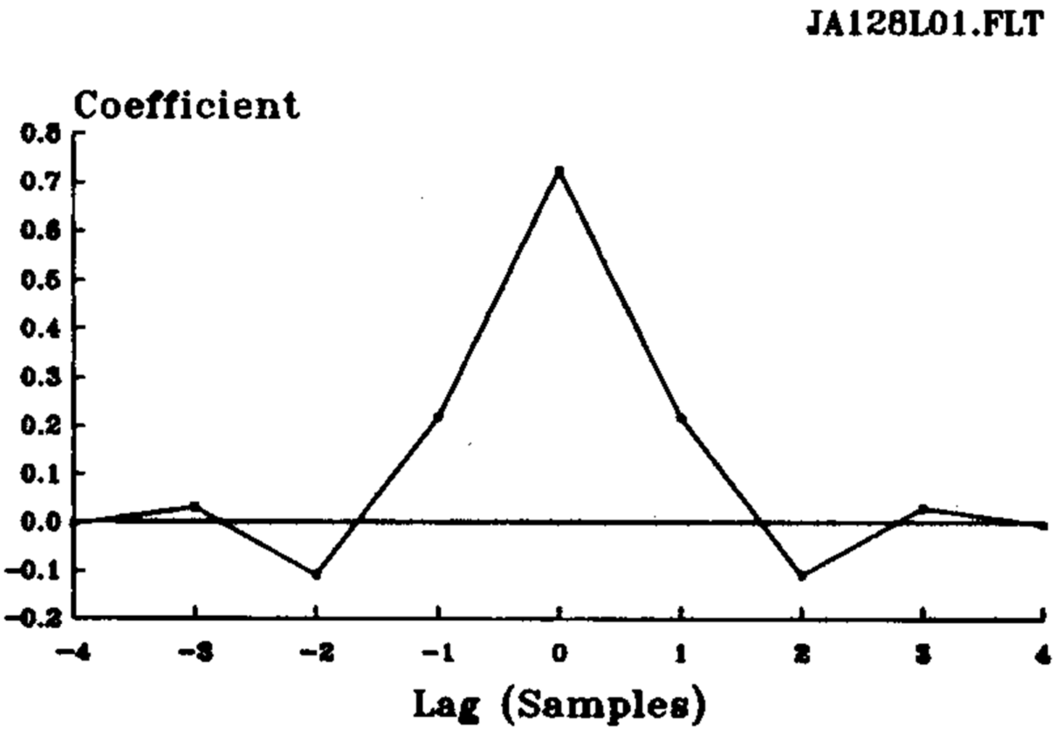



**Figure 1.** The gain function of a filter is divided into the pass band, transition band, and stop band. The gain function shown is for a low-pass filter.

Cook & Miller, 1992

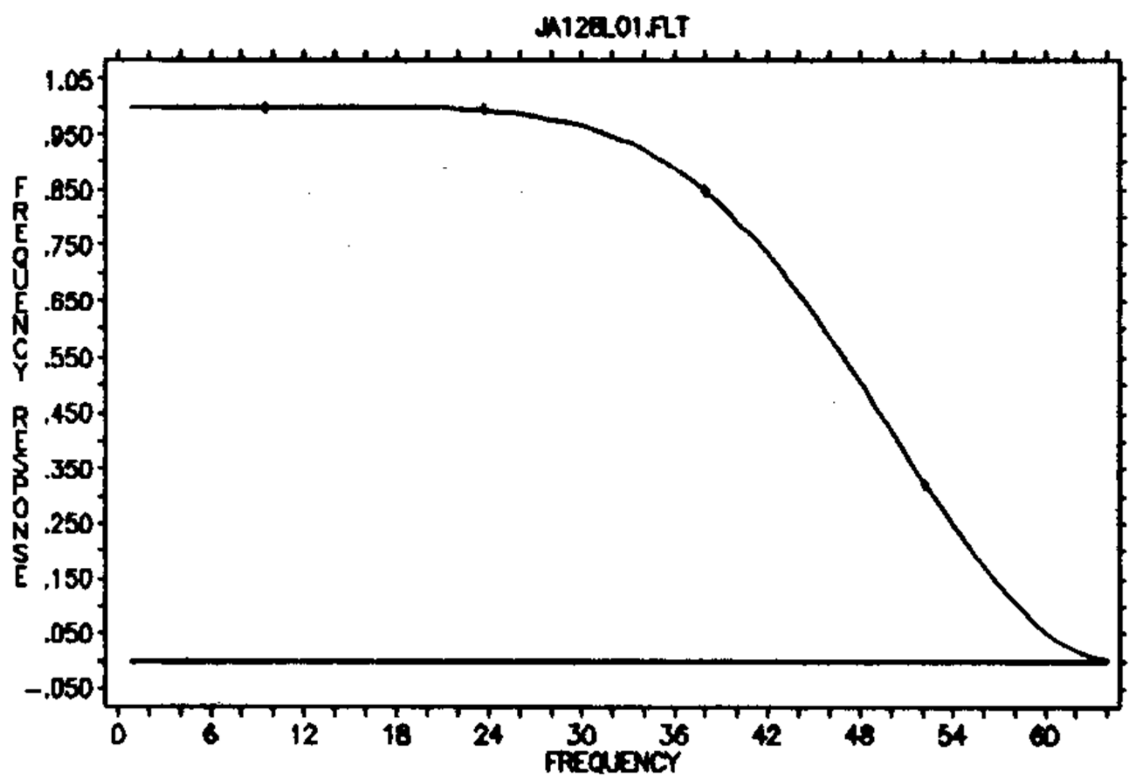


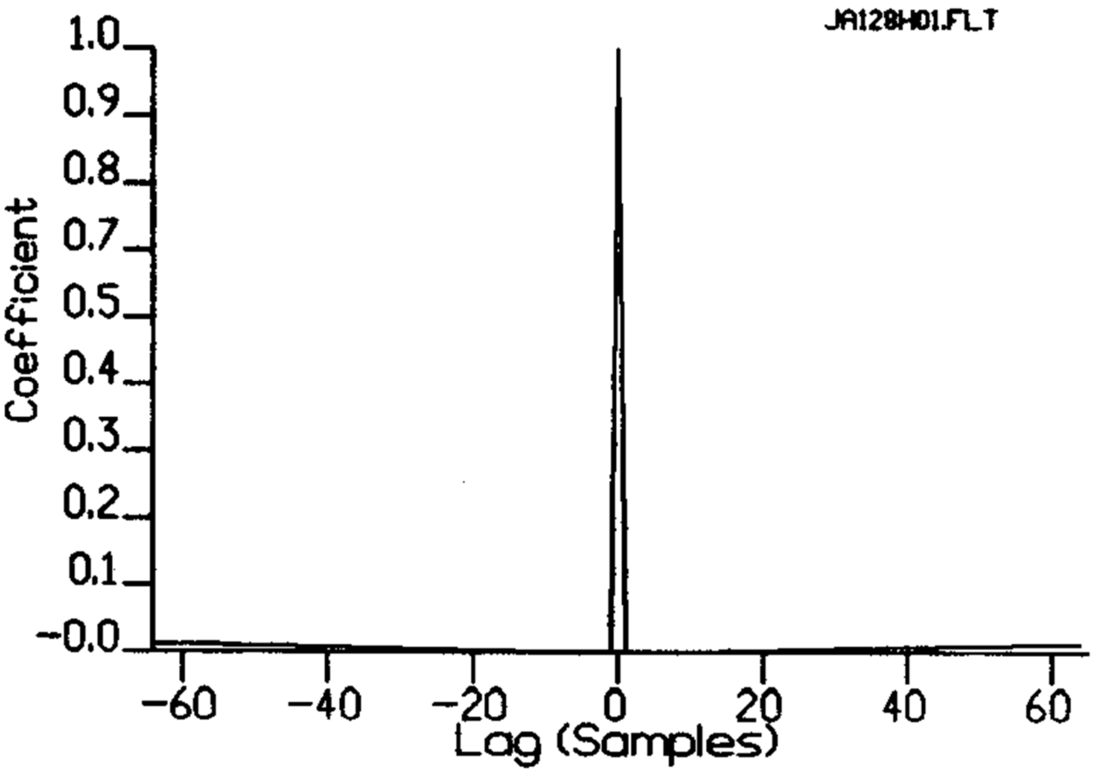

Impulse Response

Note:

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

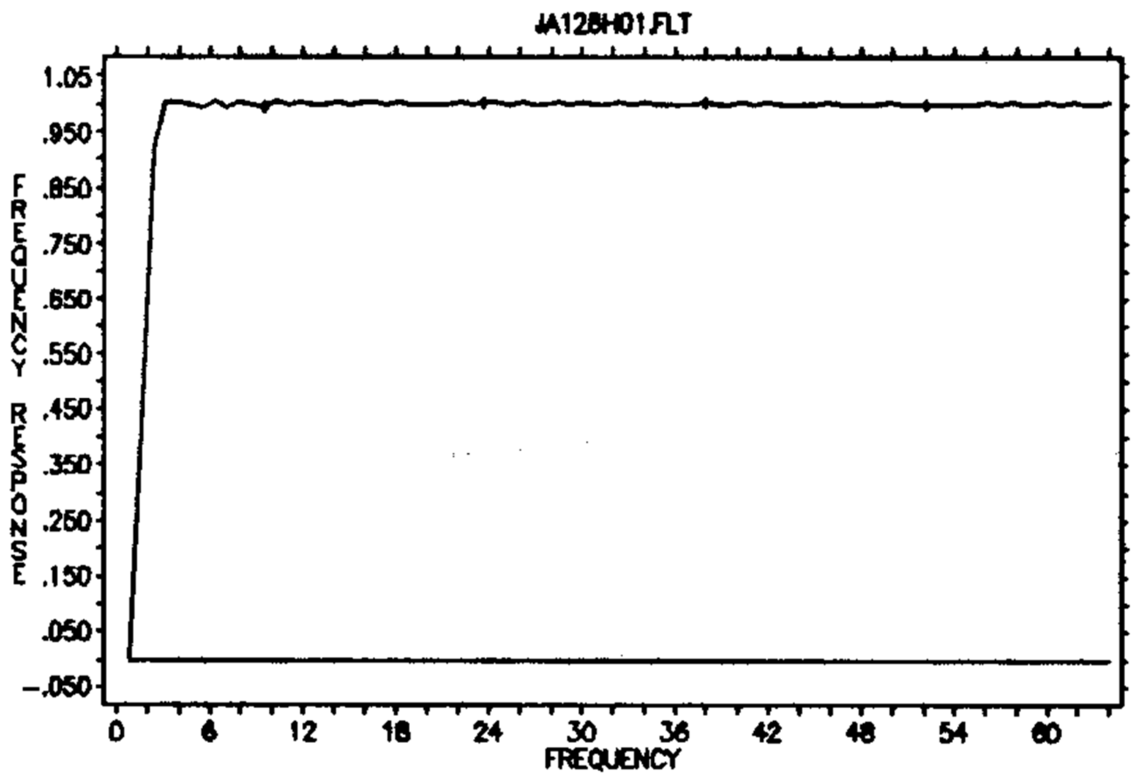
Transfer Function

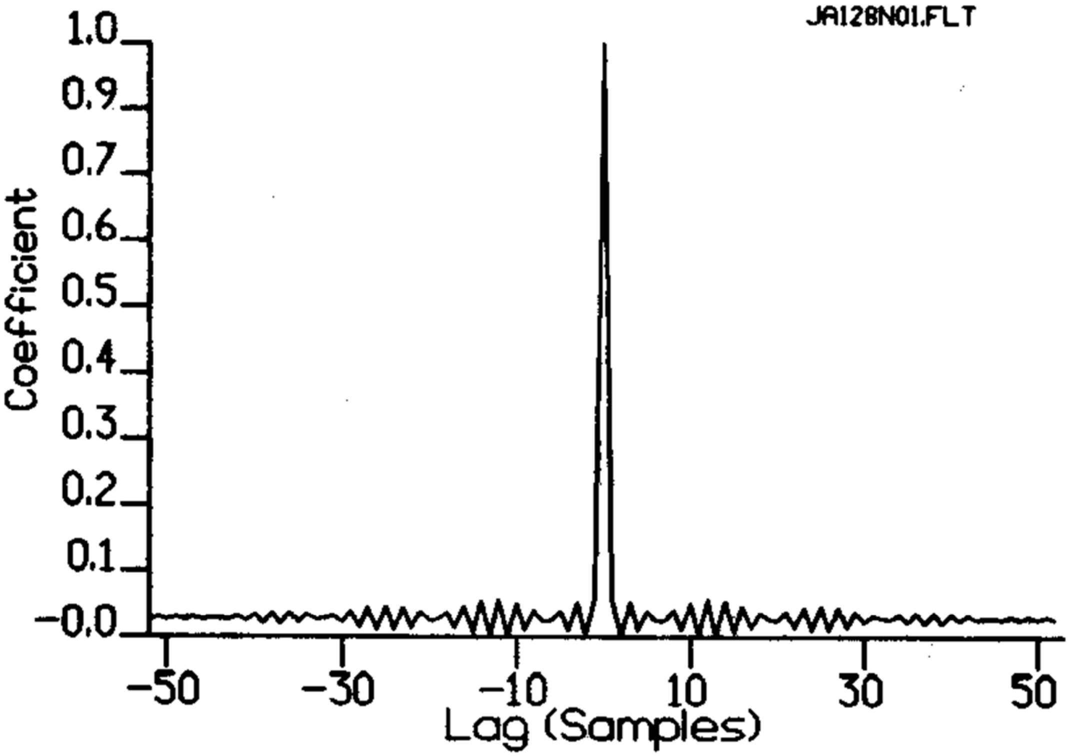





Impulse Response

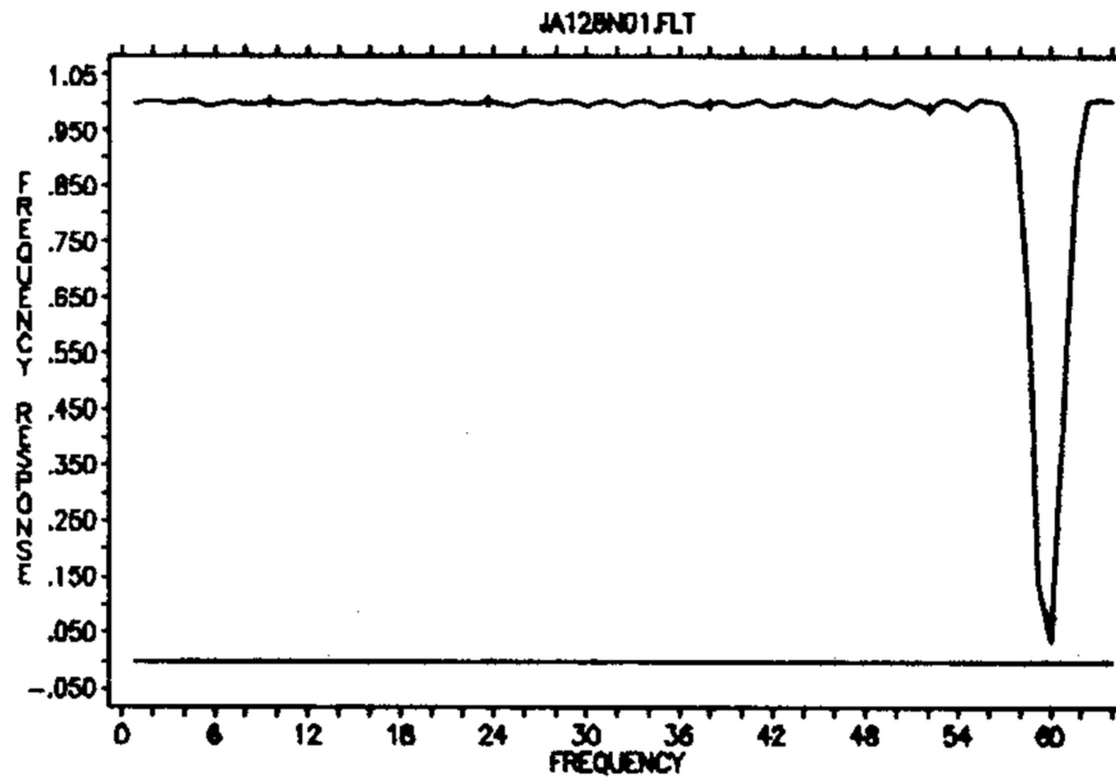
Transfer Function





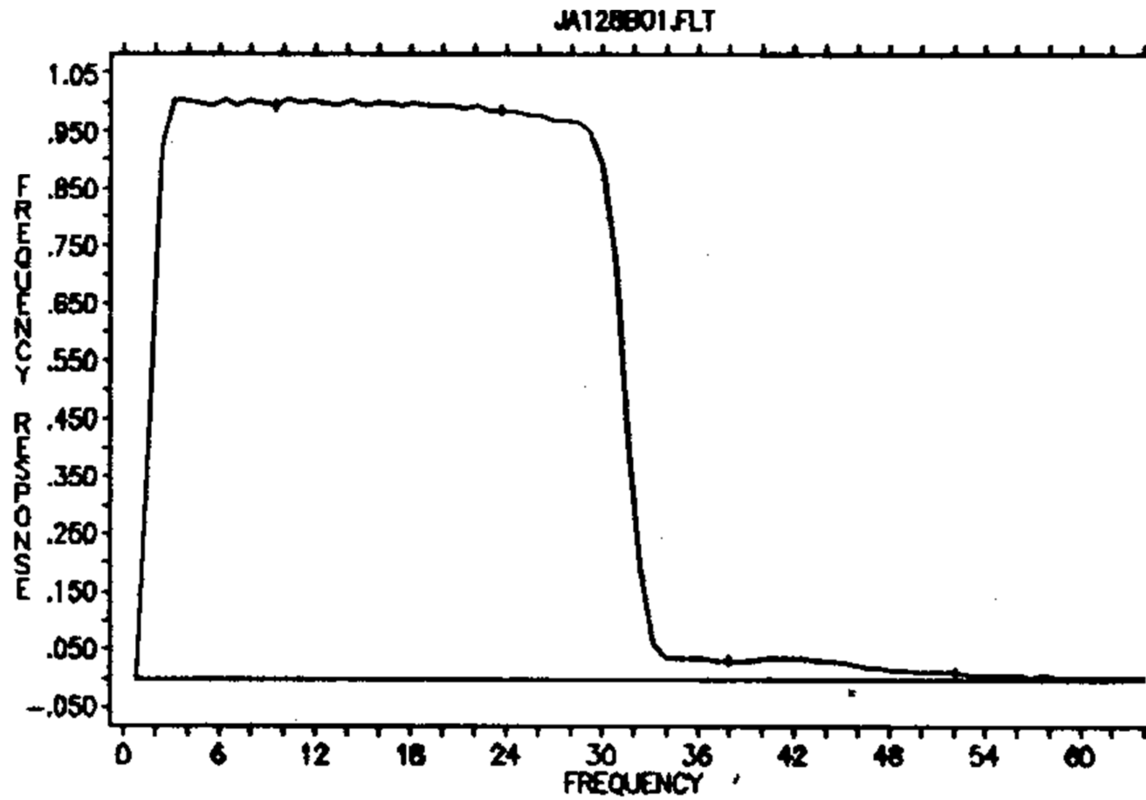

Impulse Response

Transfer Function




Impulse Response

Transfer Function



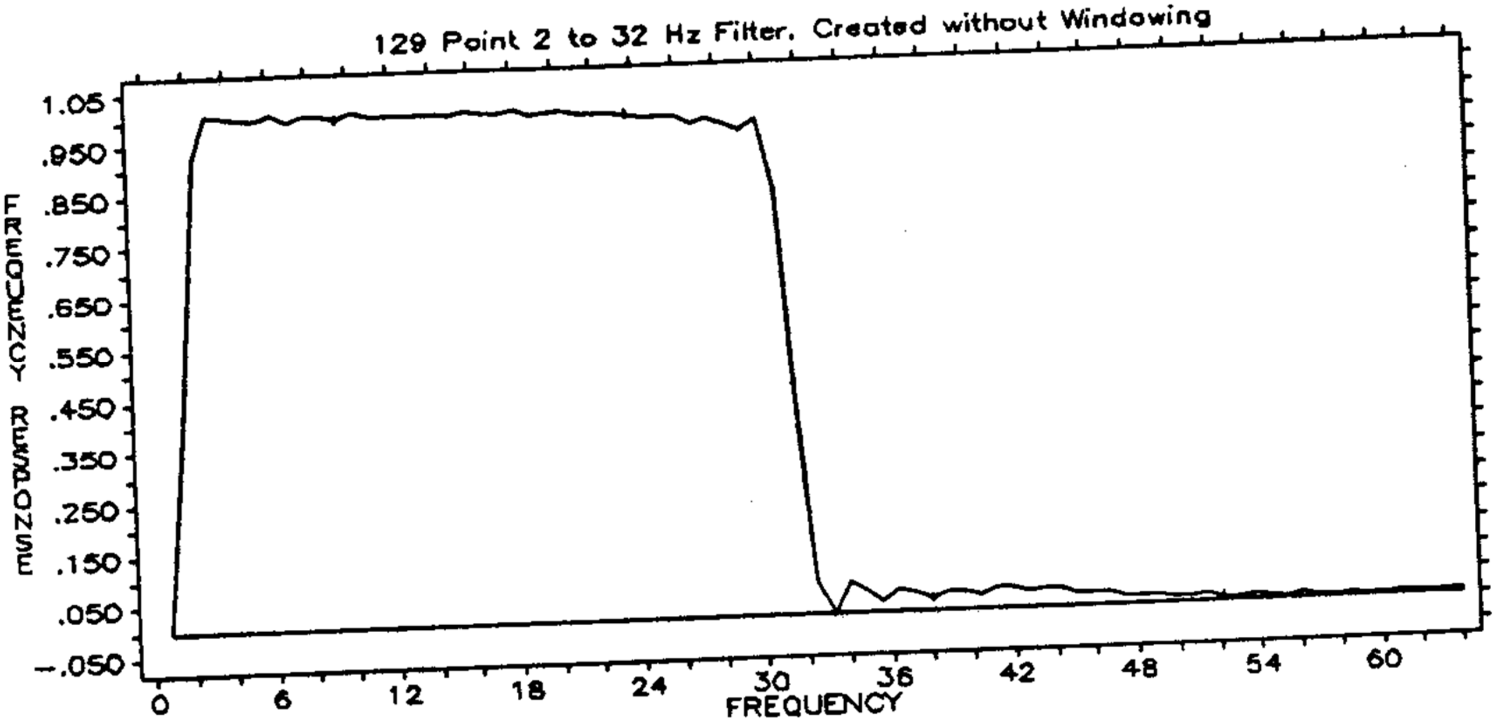
# Pragmatic concerns

- 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

JJBA2

# Convolution of Filters

- If you have filters that do desirable things, but neither does it all, you can convolve filters upon one another
- Since filter's have endpoints near 0, you can "pad" the ends with 0's so as not to lose data points
- Windowing an option




The effects of windowing on broadening the transfer function, but reducing bandpass ripple

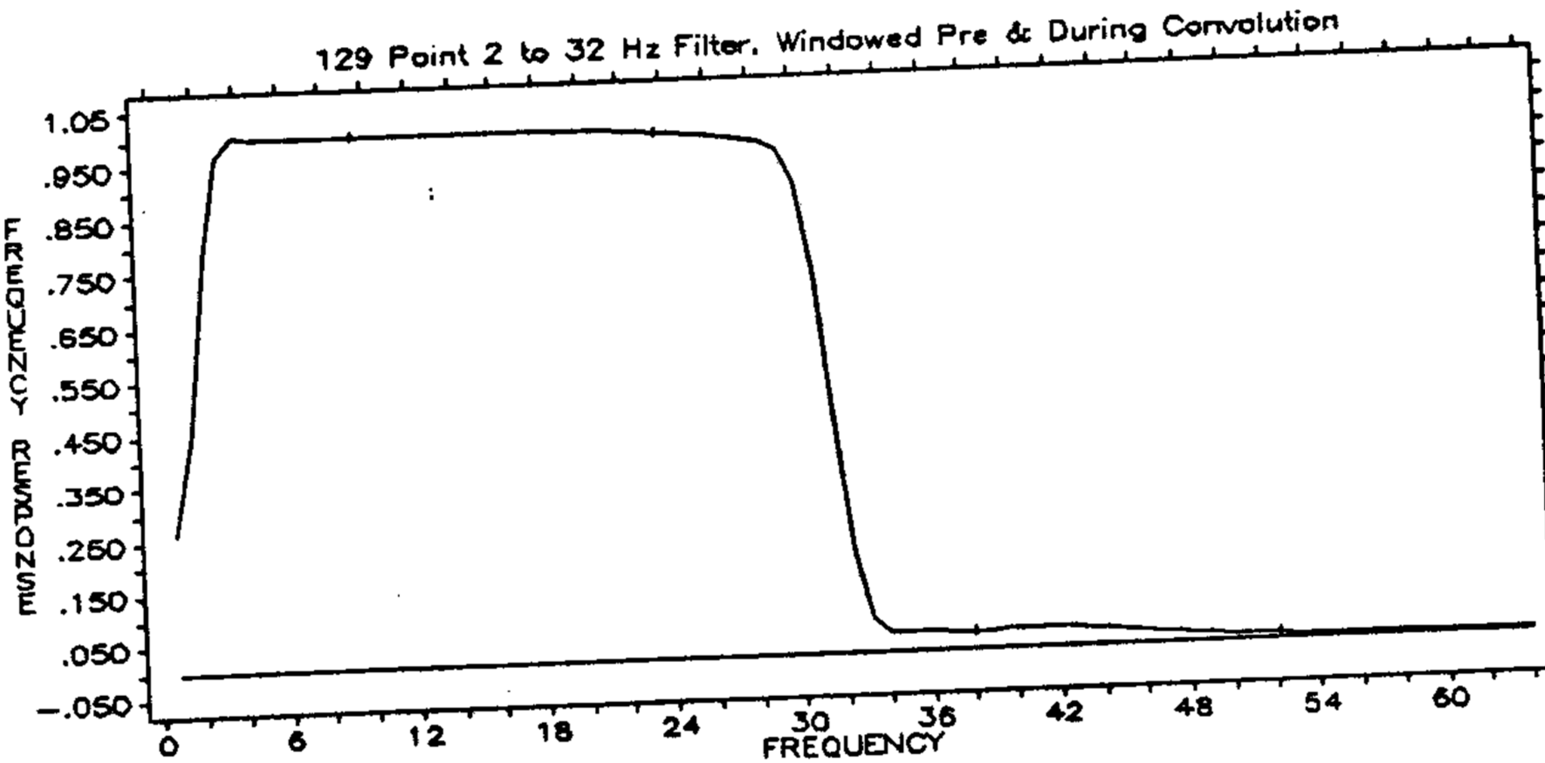
Hamming Taper, for $i$ coefficients $-j$ to $+j$,

WinFilt($i$) = NonWinFilt($i$) * $w_i$

where:

$w_i = .54 + .46 * \cos(\pi p_i)$

$p_i = i/(j+1)$



# Use in Single Trial Analysis

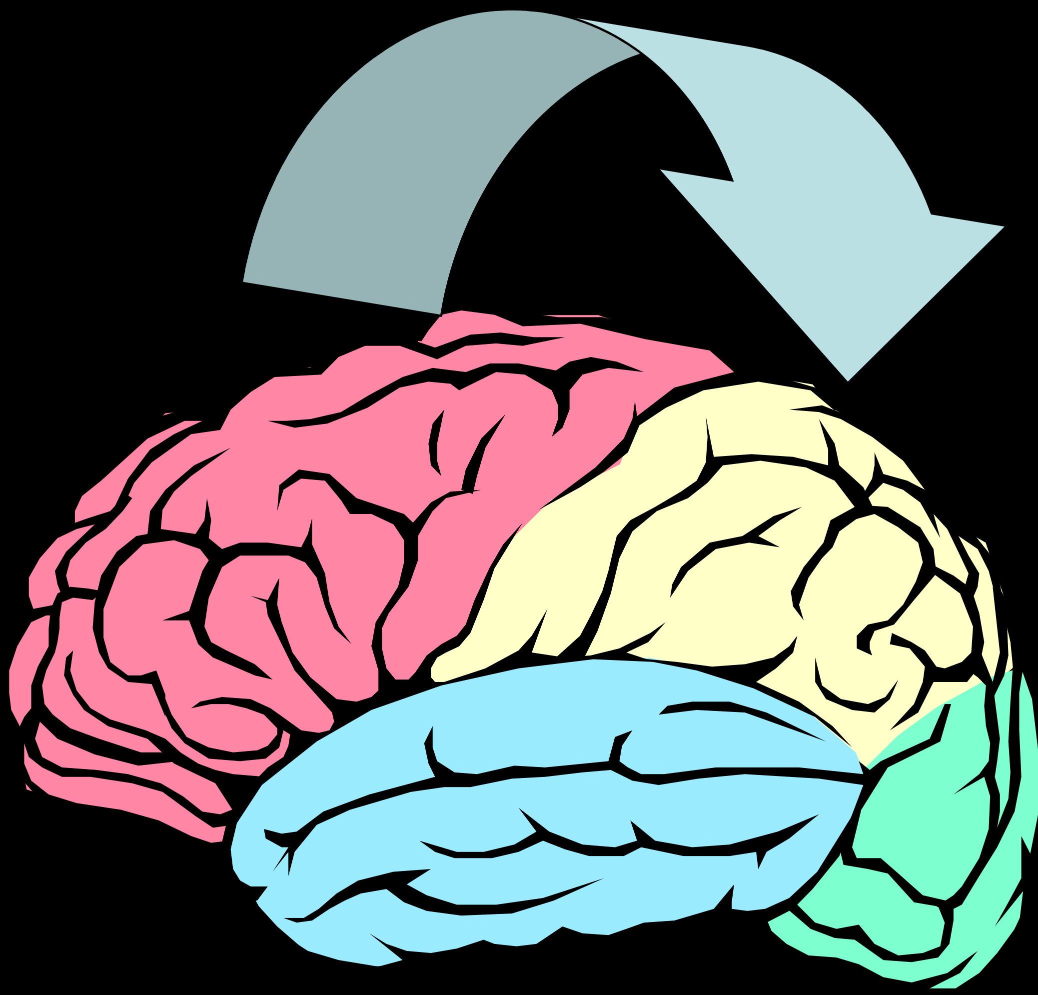
- With stringent digital filtering, you may be able to discern peaks on an individual trial basis

# Digital Filtering and More!

# A bit more on phase and such

**COURTESY OF MIKE COHEN**

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

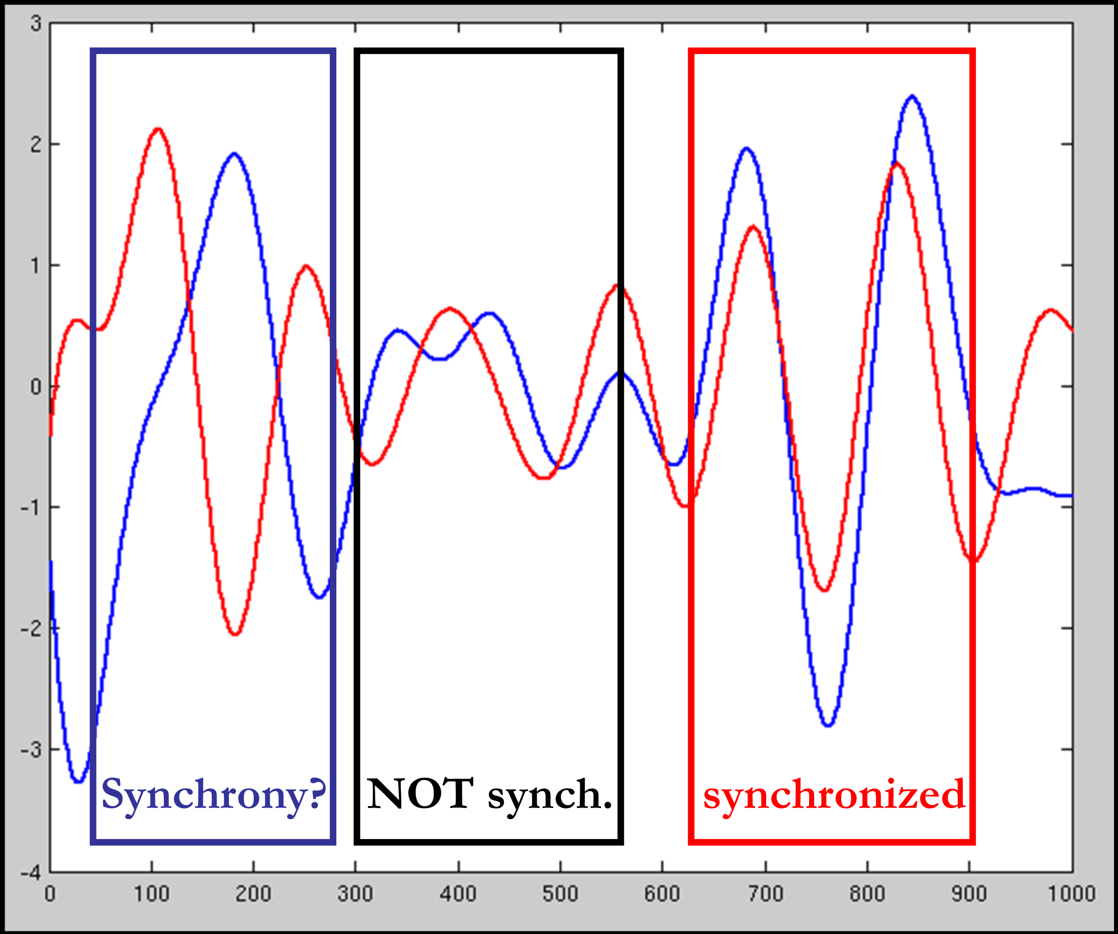


**Perhaps through synchronized oscillations!**

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

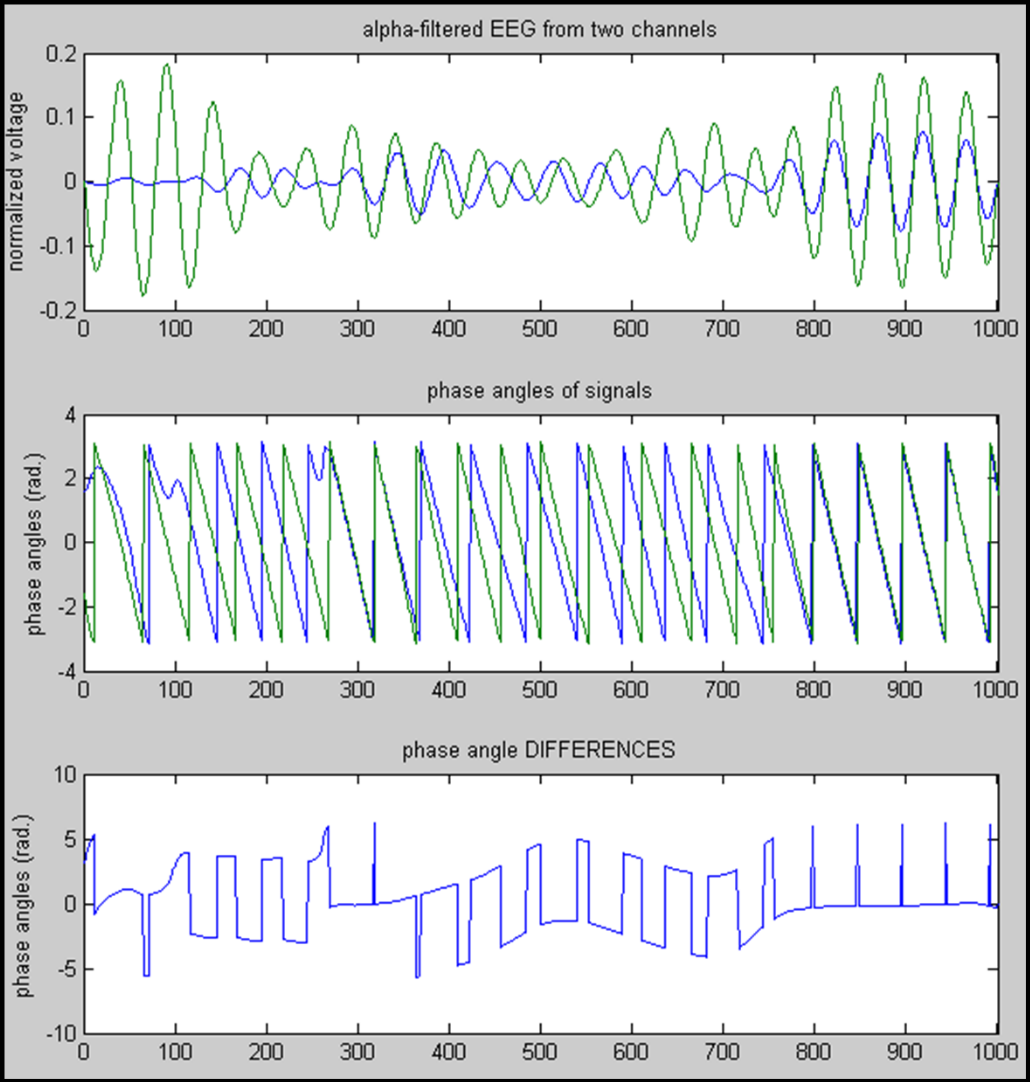
# 2. How do brain regions "talk" to each other?

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

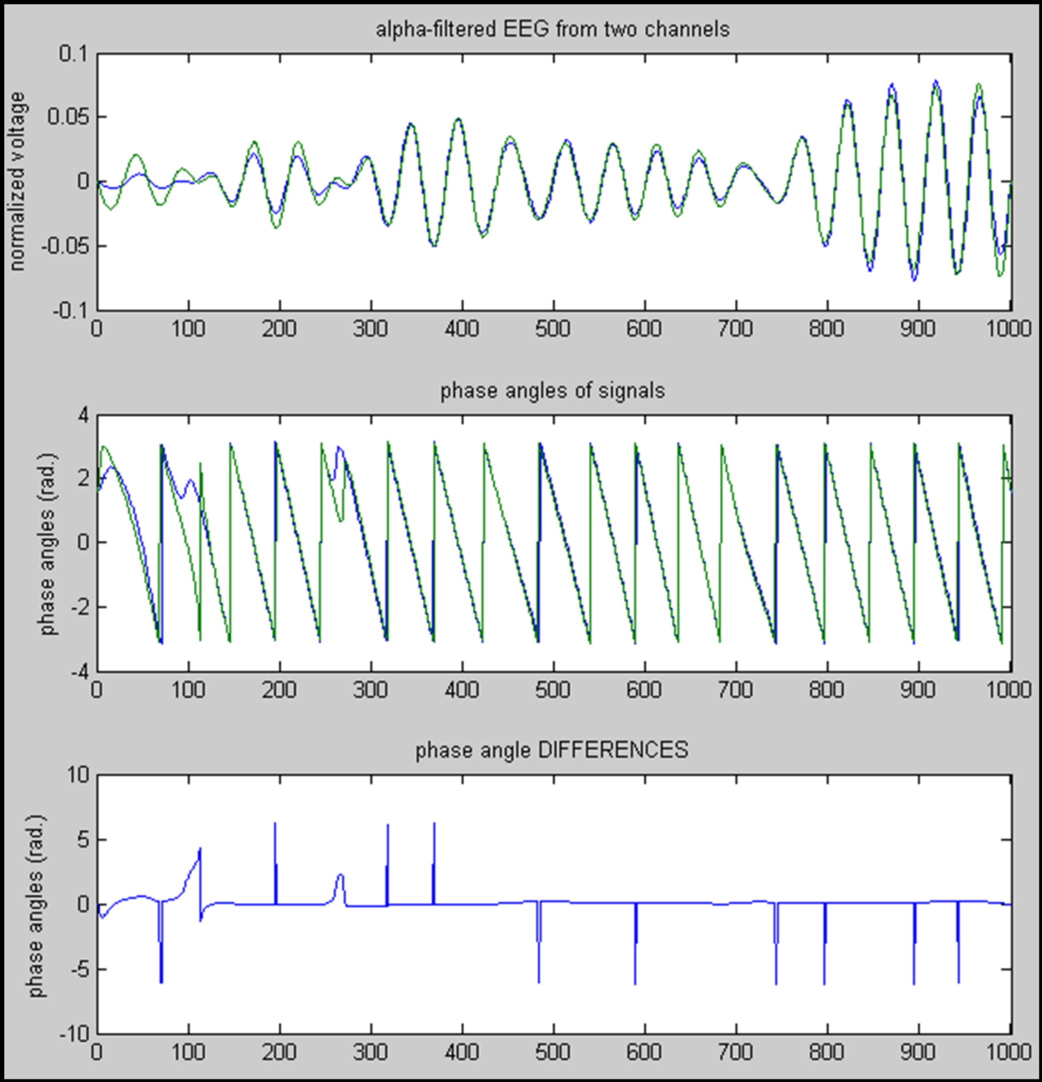


# 2. Inter-site phase coherence.

## Electrodes: Fp1 & C4

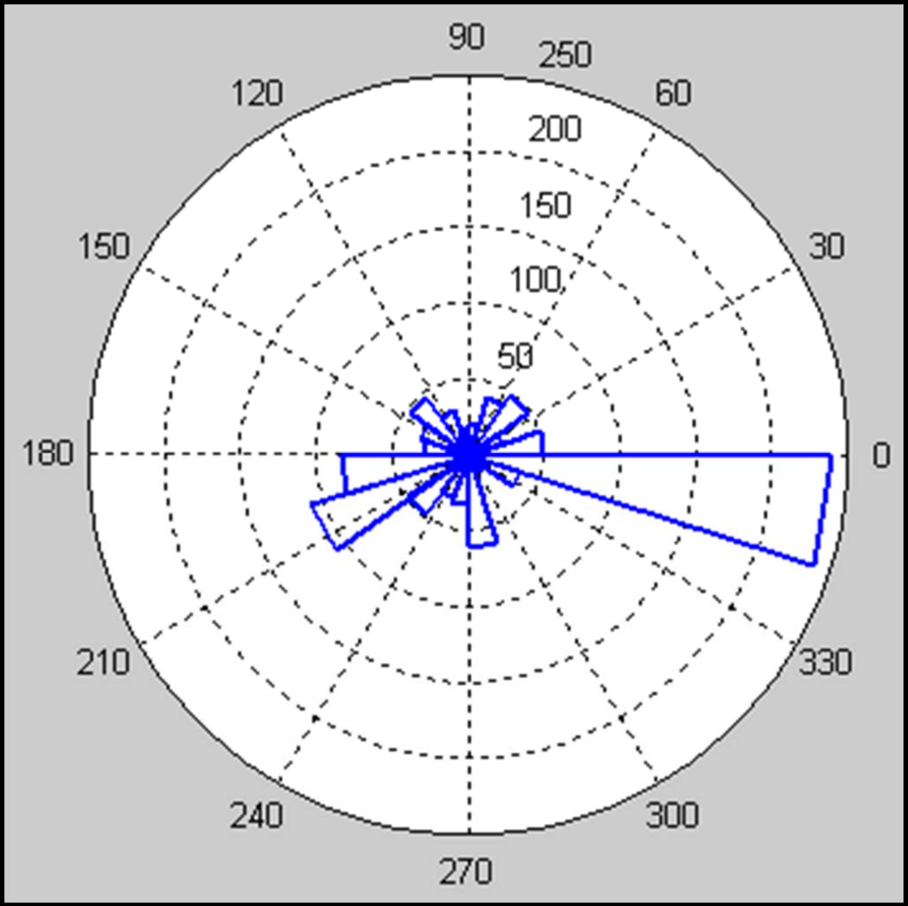


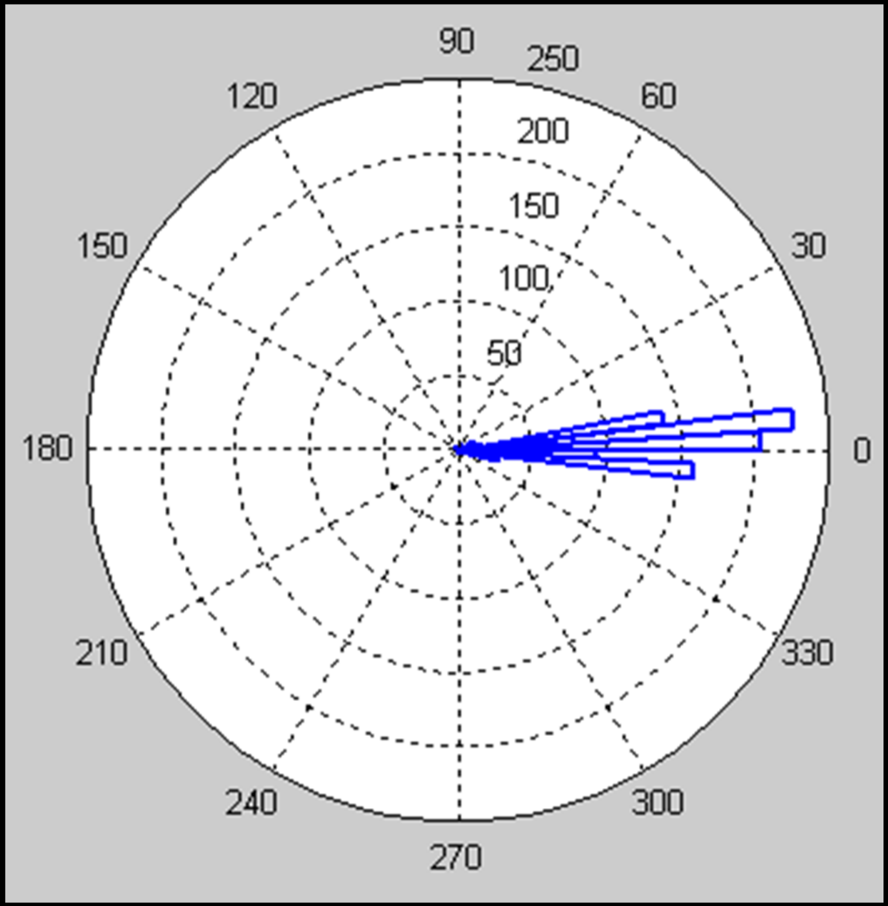

## Electrodes: Fp1 & Fp2



# 2. Inter-site phase coherence?

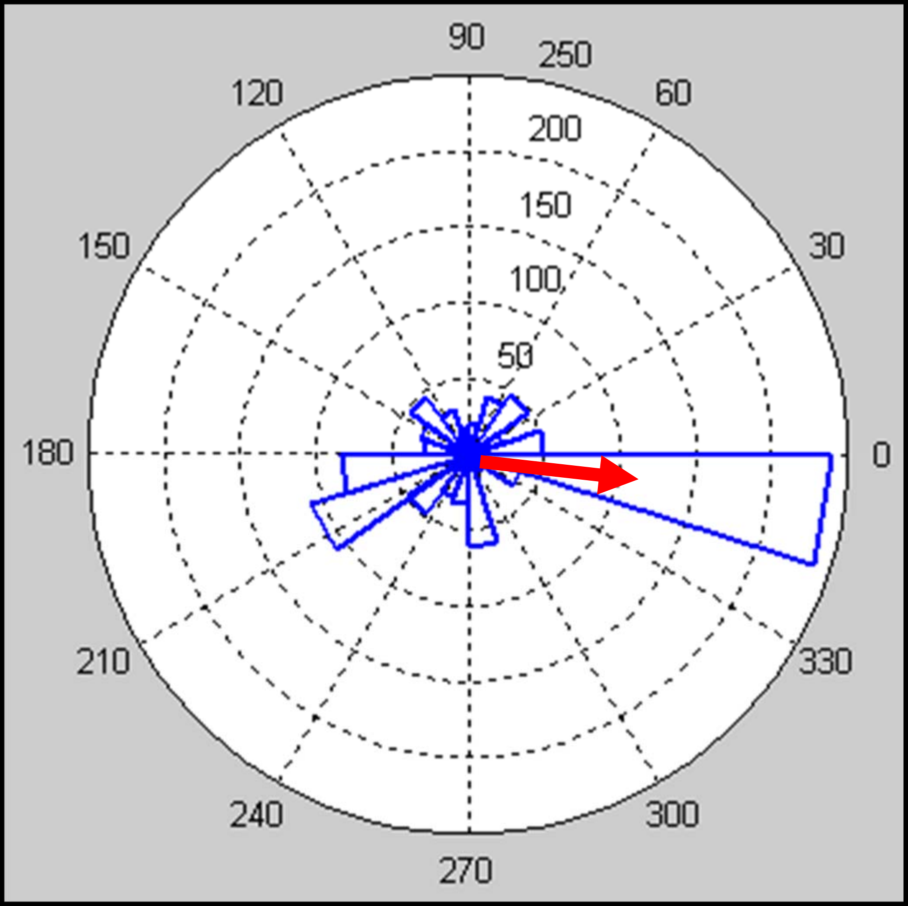
**"Polar plot" of phase angle differences.**

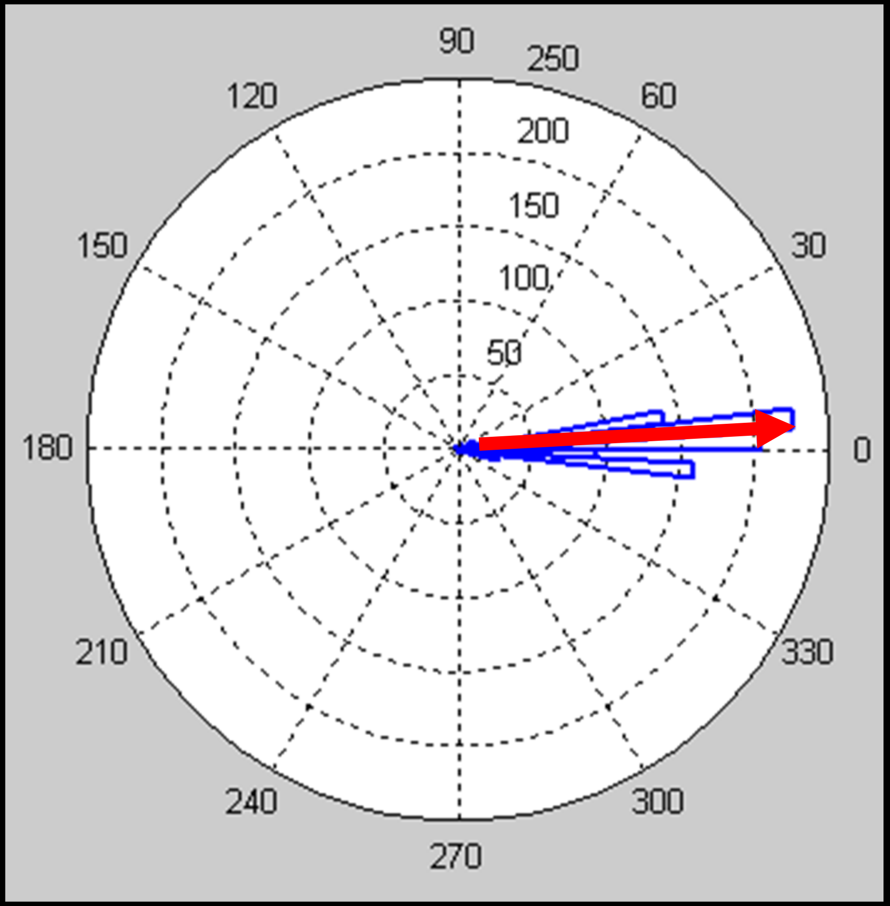


# 2. Circular variance.

**Draw a line through the "average" of vectors.**

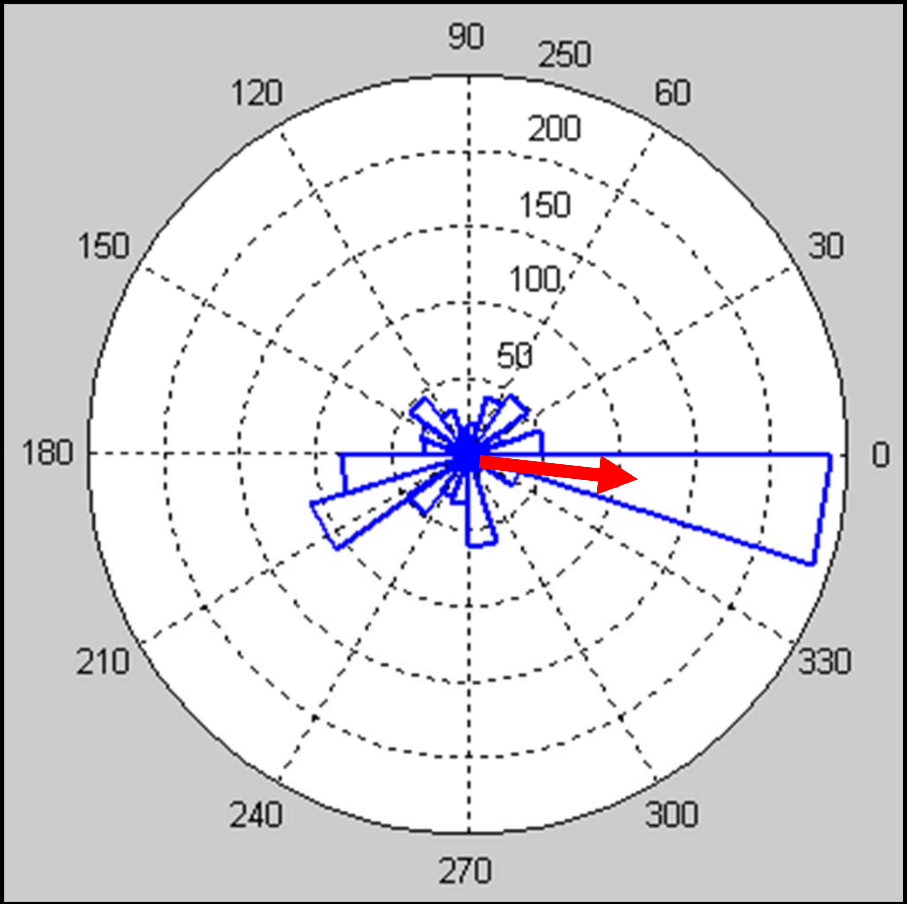


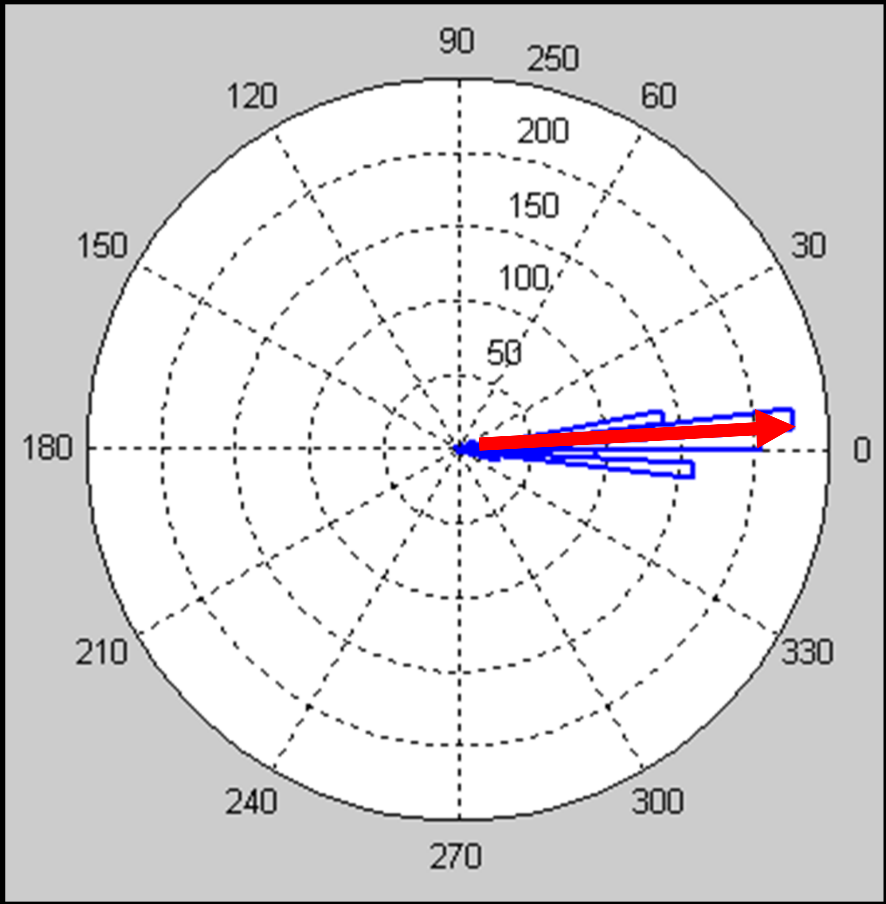
## 2. Circular variance.

**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)));
```

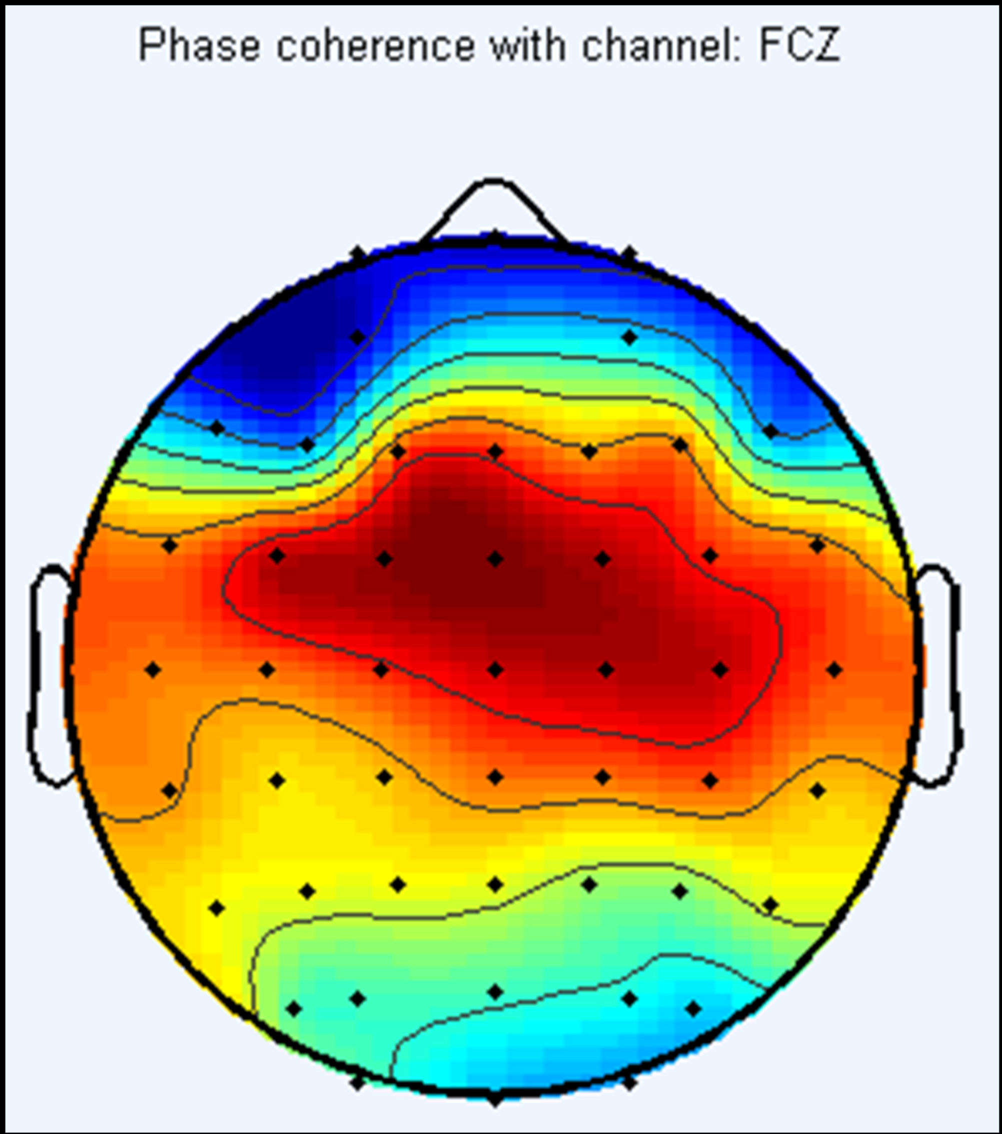
**Magnitude of vector**

**Average across values**

**Transform to complex plane**

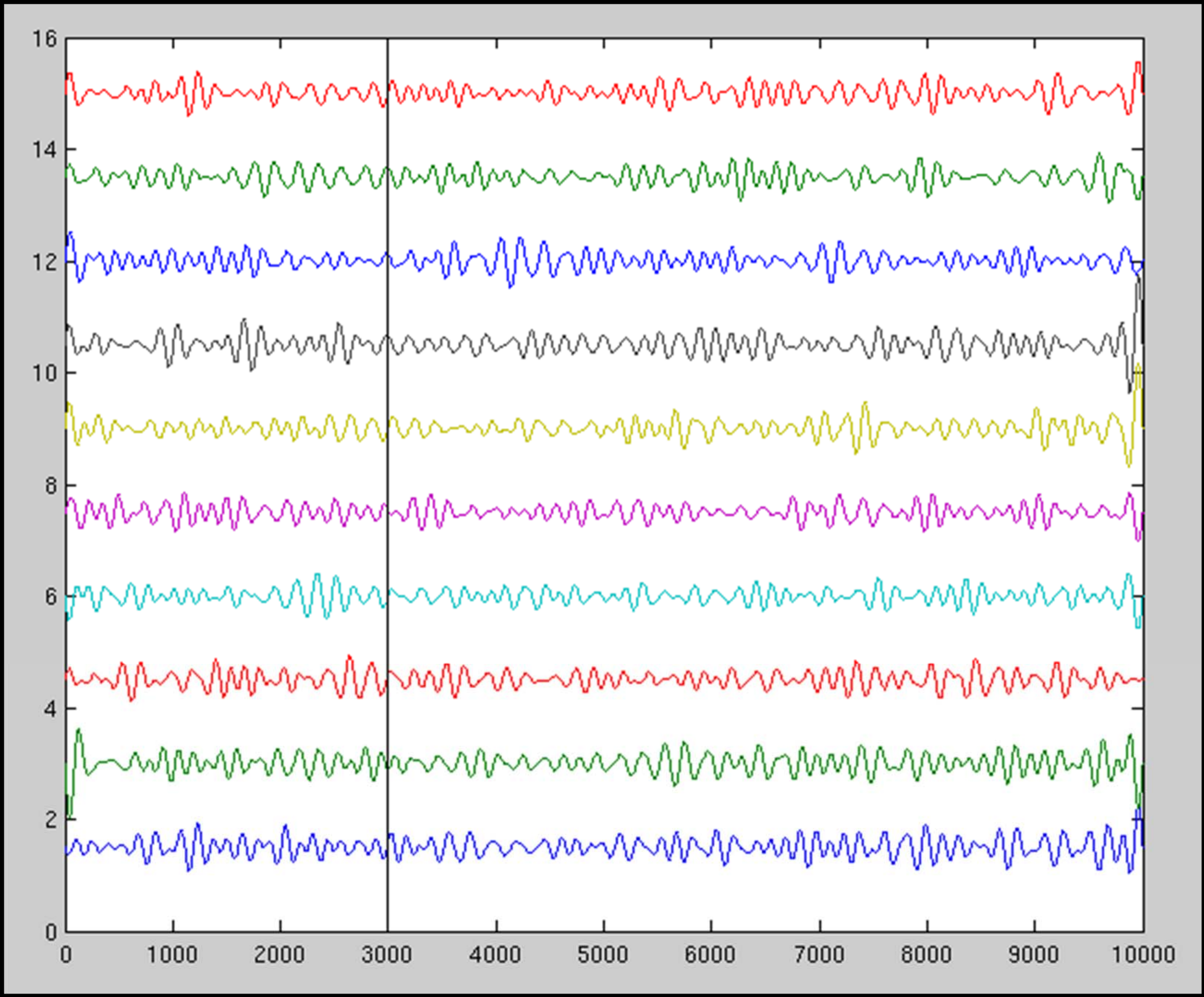
**Phase angle differences between channels**

# 2. Inter-site phase synchrony with one "seed" site.

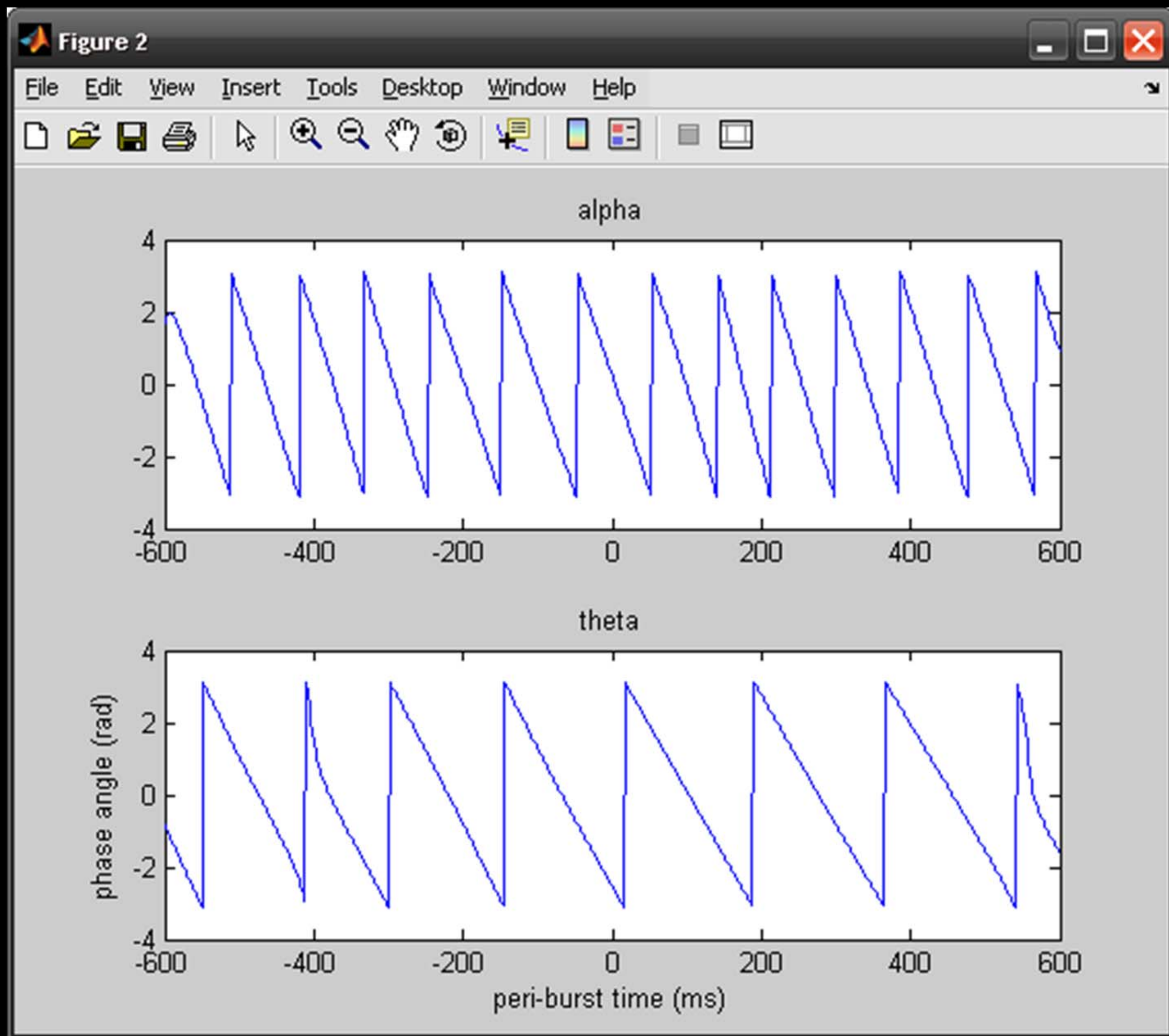


# 2. Inter-trial phase synchrony within one electrode.

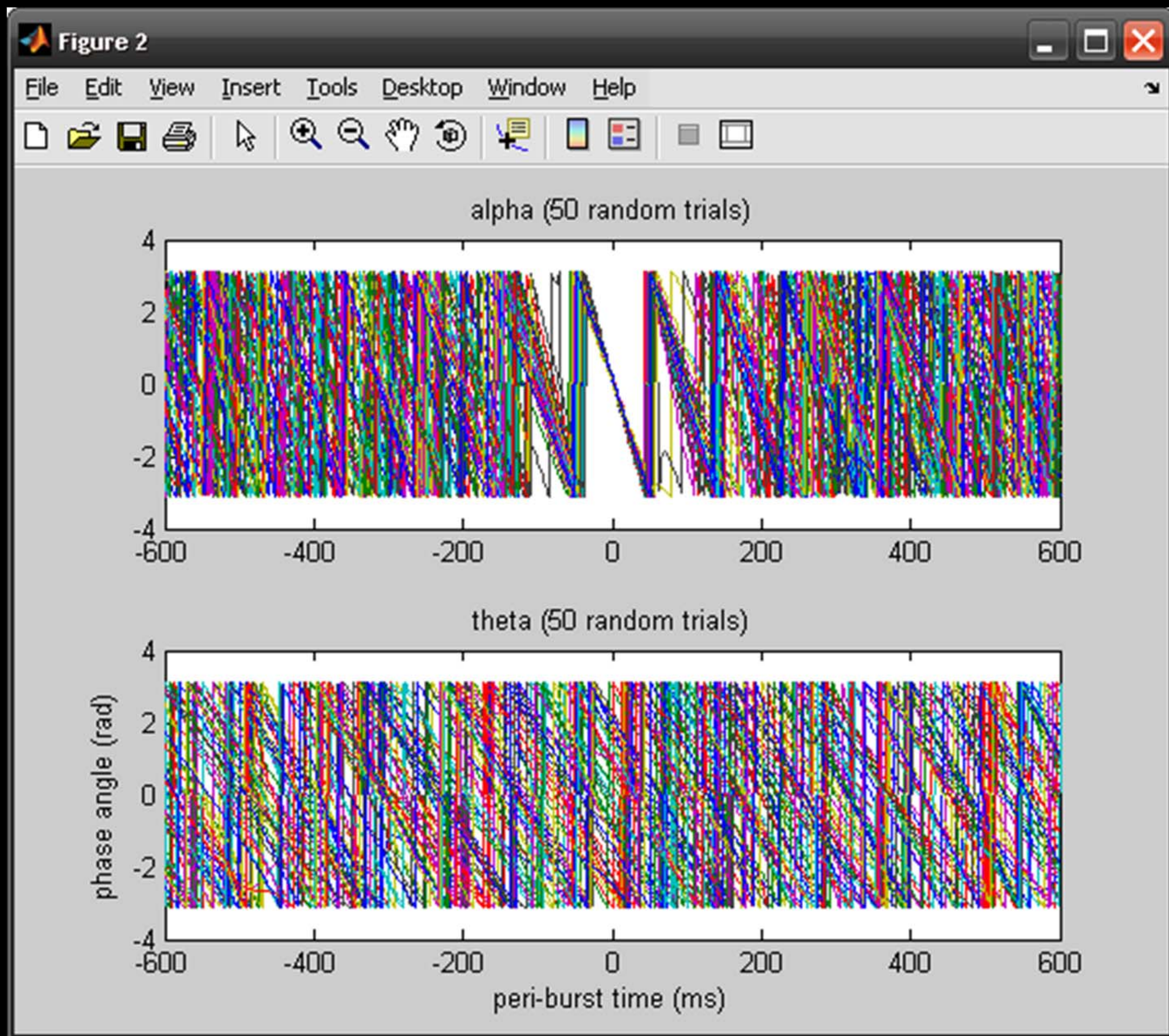
## Many trials from the same electrode:



# 2. Inter-trial phase coherence



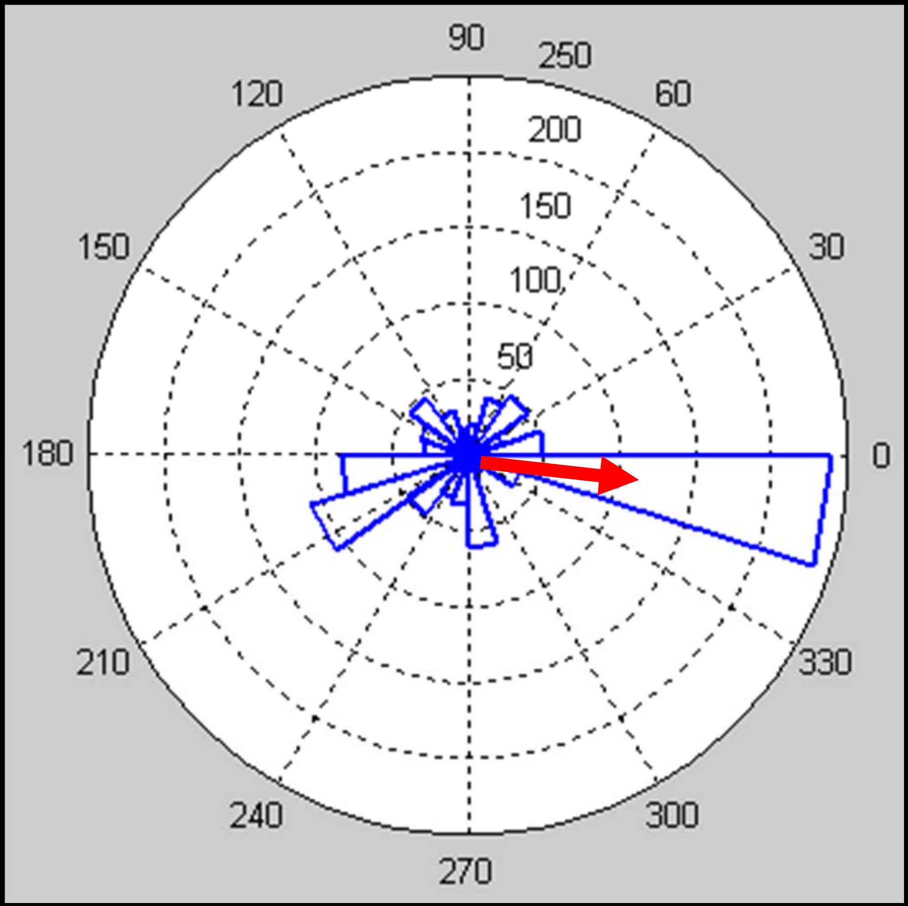
# 2. Inter-trial phase coherence



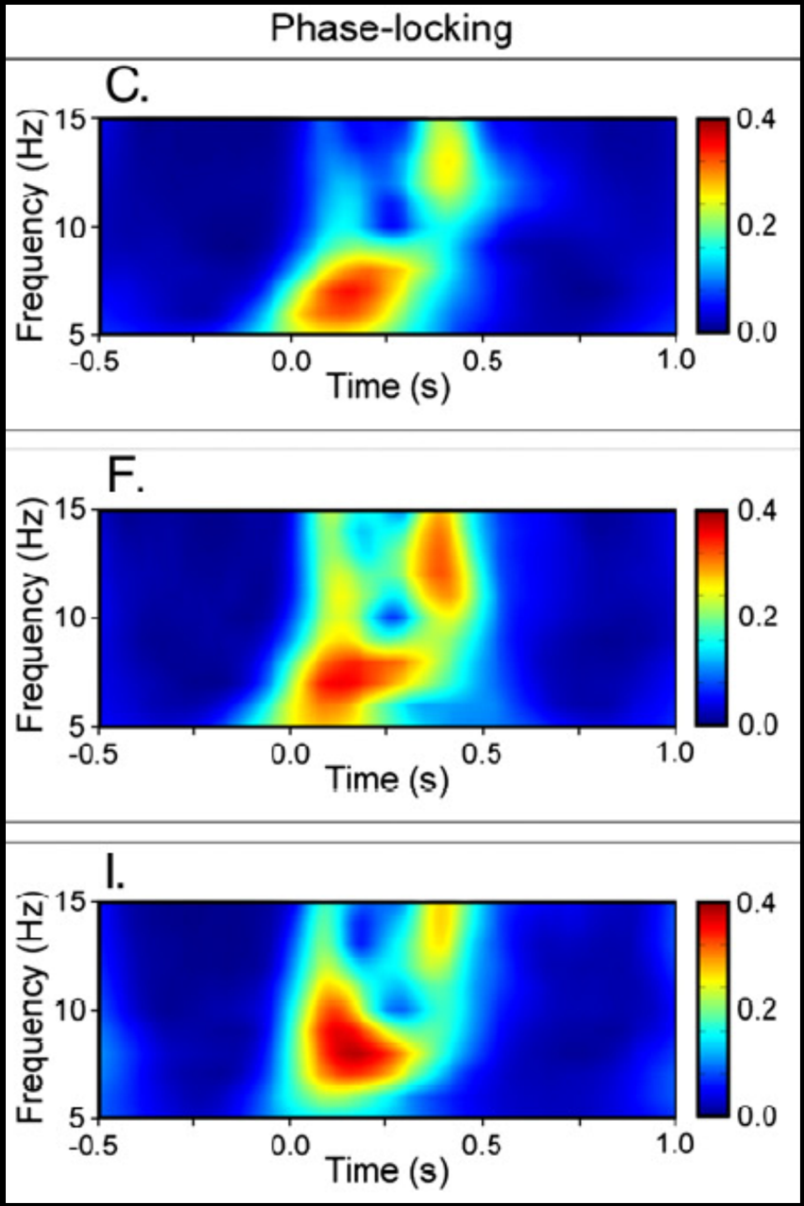
# 2. Inter-trial phase coherence

## Calculate phase coherence across trials at each time point

**Phase coherence, 154 ms: 0.11**



# 2. Inter-trial phase coherence

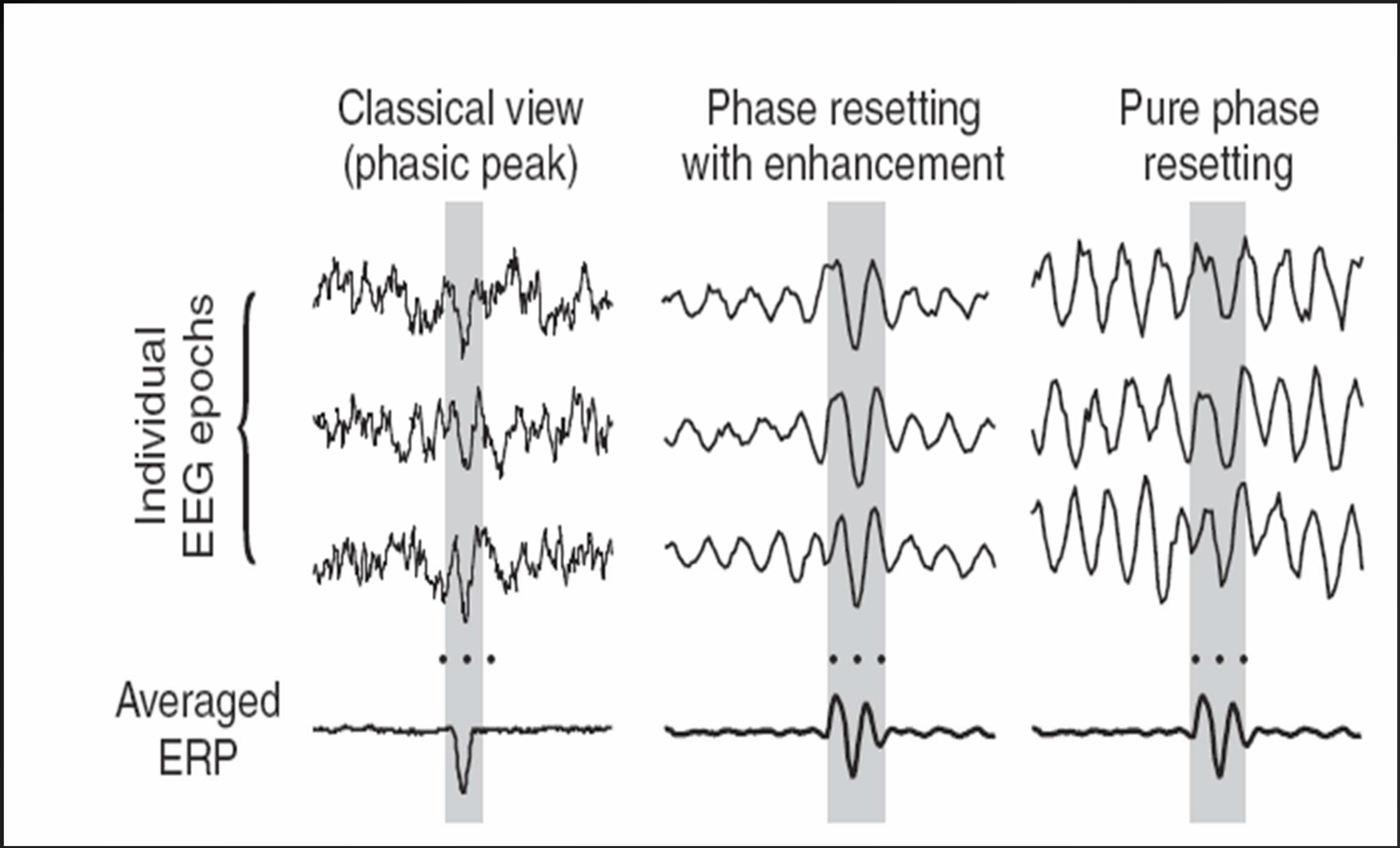



*B.-K. Min et al. / International Journal of Psychophysiology 65 (2007) 58–68*

# Thanks Mike!

## NOW BACK TO JOHN’S SLIDES

# Classic ERPs Vs Phase Resetting




From Yeung et al., *Psychophysiology*, 2004

# Time-Frequency Representations



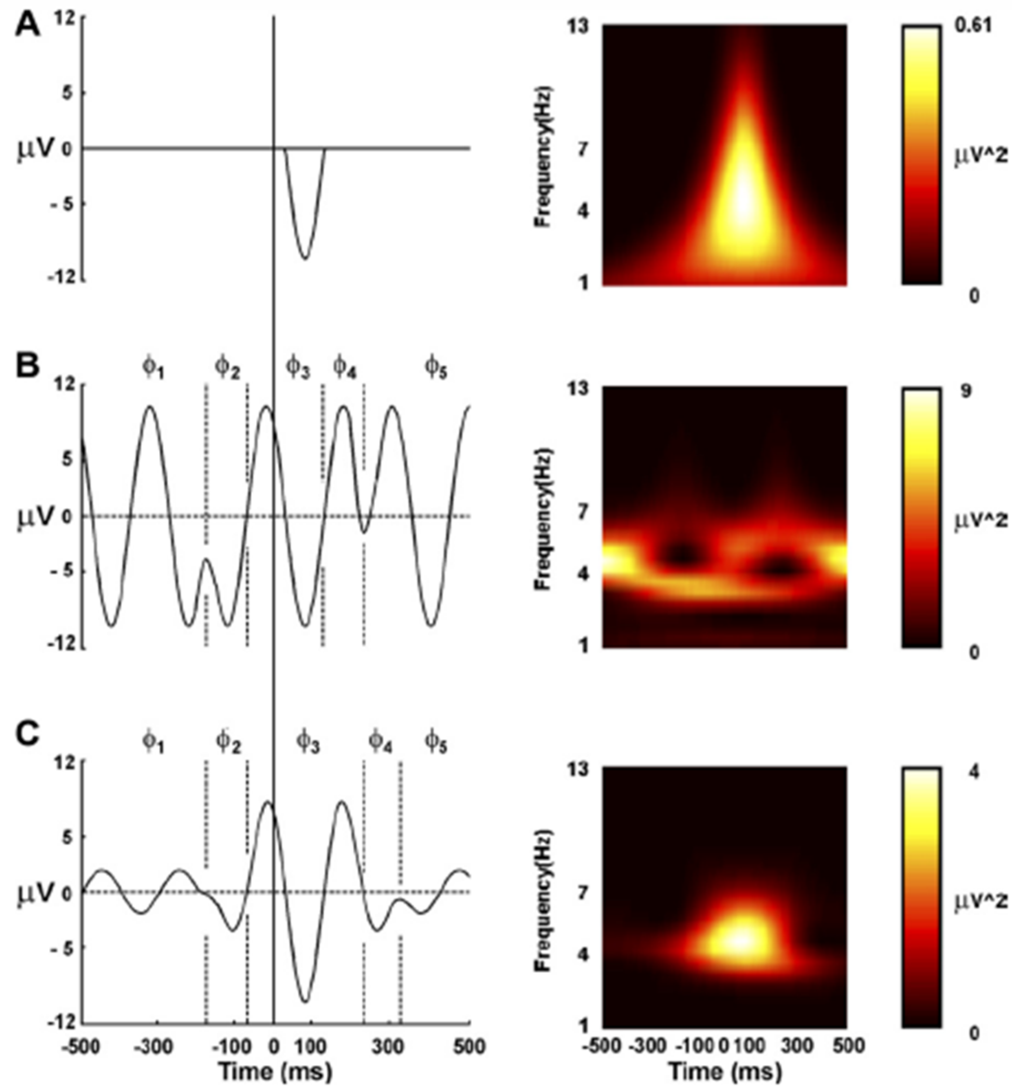
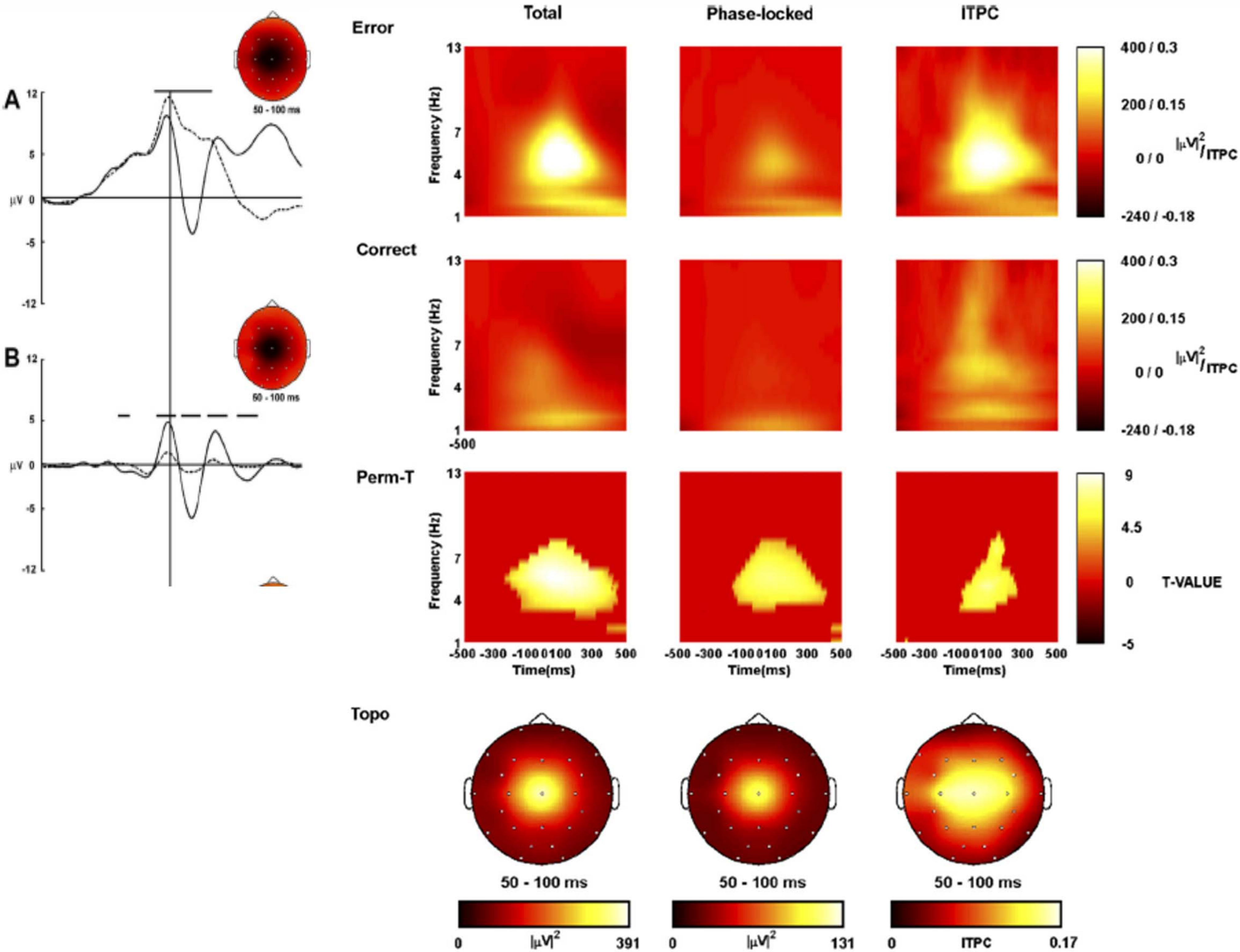
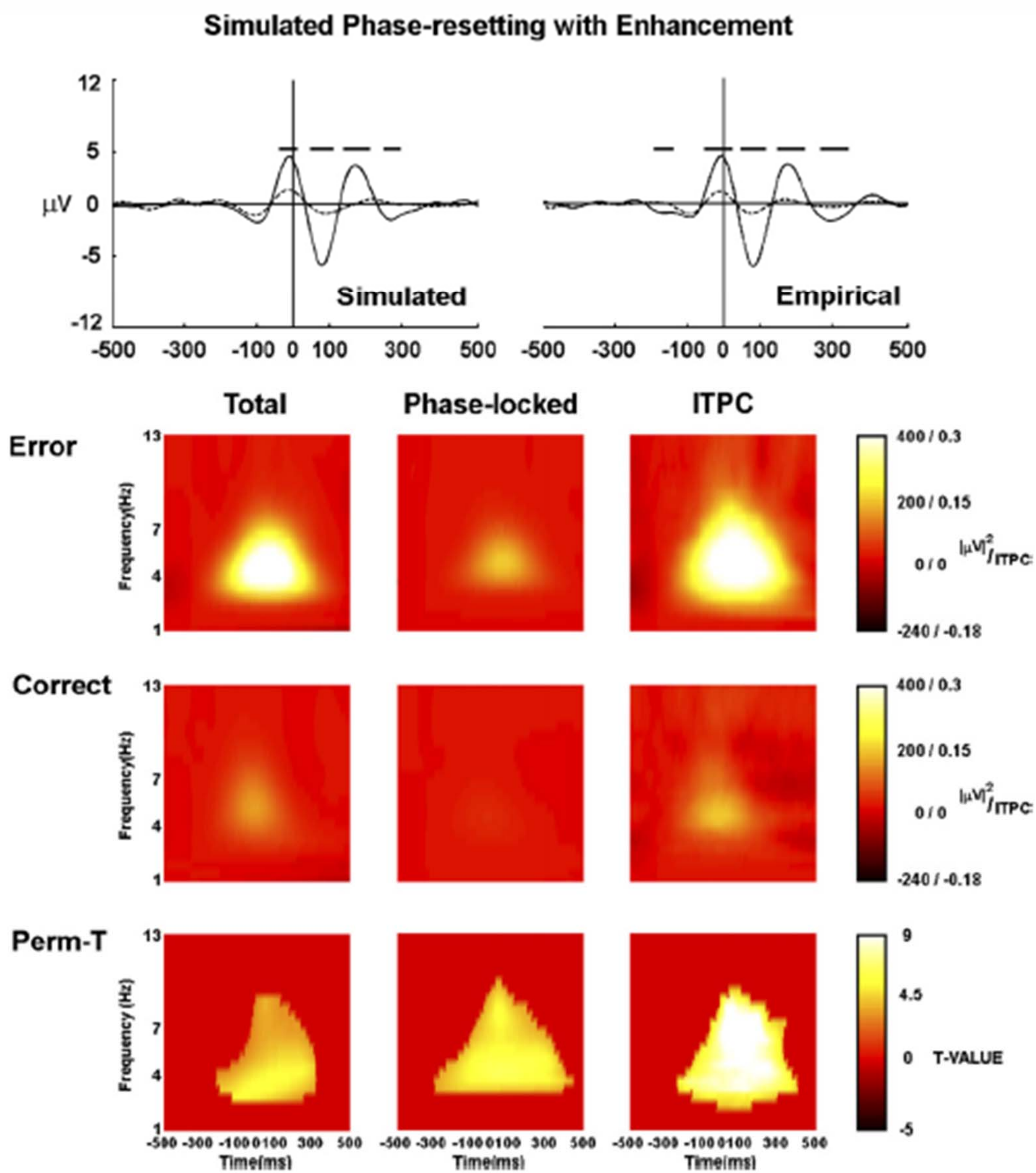


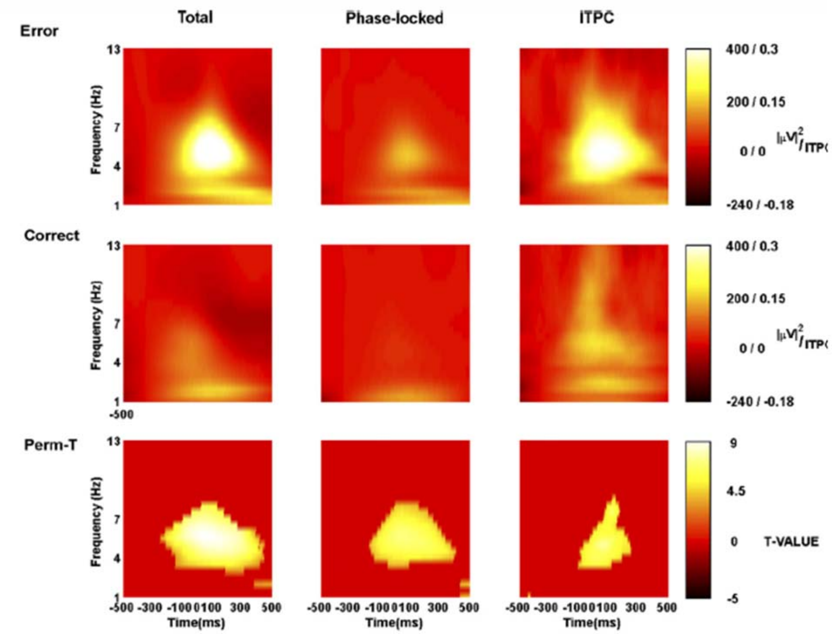

Fig. 1. Left column: Basic oscillatory waveforms used to simulate ERN responses according to the (A) *classic*, (B) *pure phase-resetting*, and (C) *phase-resetting with enhancement* hypotheses of ERN generation. Right column: Corresponding non-baseline-corrected wavelet-based time–frequency representations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



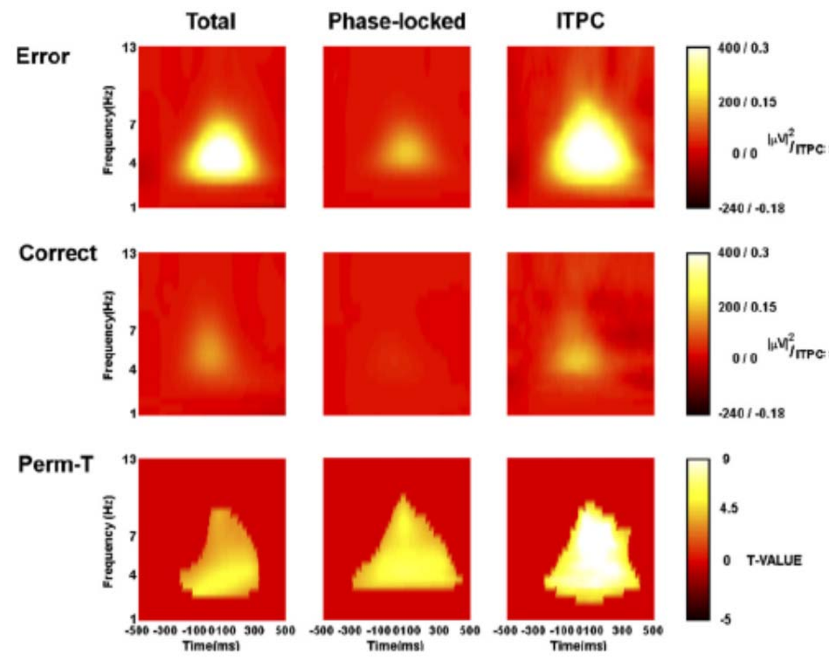
A
B
50 - 100 ms
Error
Correct
Perm-T
Topo
Total
Phase-locked
ITPC
Frequency (Hz)
Time(ms)
400 / 0.3
200 / 0.15
0 / 0
-240 / -0.18
|μV|2/ITPC
9
4.5
0
-5
T-VALUE
0
|μV|2
391
131
ITPC
0.17


Simulated Phase-resetting with Enhancement
μV
12
5
0
-5
-12
-500
-300
-100
0
100
300
500
Simulated
Empirical
Total
Phase-locked
ITPC
Error
Correct
Perm-T
Frequency(Hz)
Frequency (Hz)
13
7
4
1
400 / 0.3
200 / 0.15
0 / 0
-240 / -0.18
9
4.5
0
-5
T-VALUE
Time(ms)

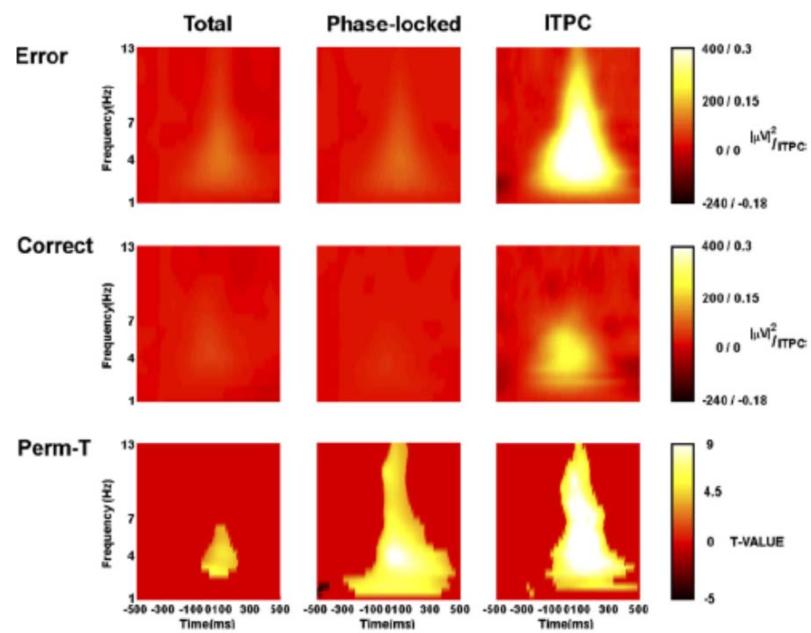
Empirical




Simulated Phase + Amp Enhance




Simulated Classic



JJBA1

# One more advanced topic…

**Slide 59**

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**JJBA1** Note -- added for part 2 of lecture

John JB Allen, 5/1/2006

# The Problem of Latency Jitter

- The averaging assumption of invariance in signal is not always warranted
  - Especially for the later endogenous components
  - To the extent that the signal varies from trial to trial, the average will produce potentially misleading results
- Two common possibilities:
  - Smearing of components;
    - will underestimate amplitude of component (especially a problem if comparing groups, one group with more latency jitter)
  - Bimodal or multi-bumped components

# The Solution

- The Woody Adaptive Filter (Woody, 1967)
- Based on Cross-correlation
  - Assumptions less restrictive than averaging methods
    - Waveform (morphology) must be constant across trials
    - Latency need not be constant

# Details

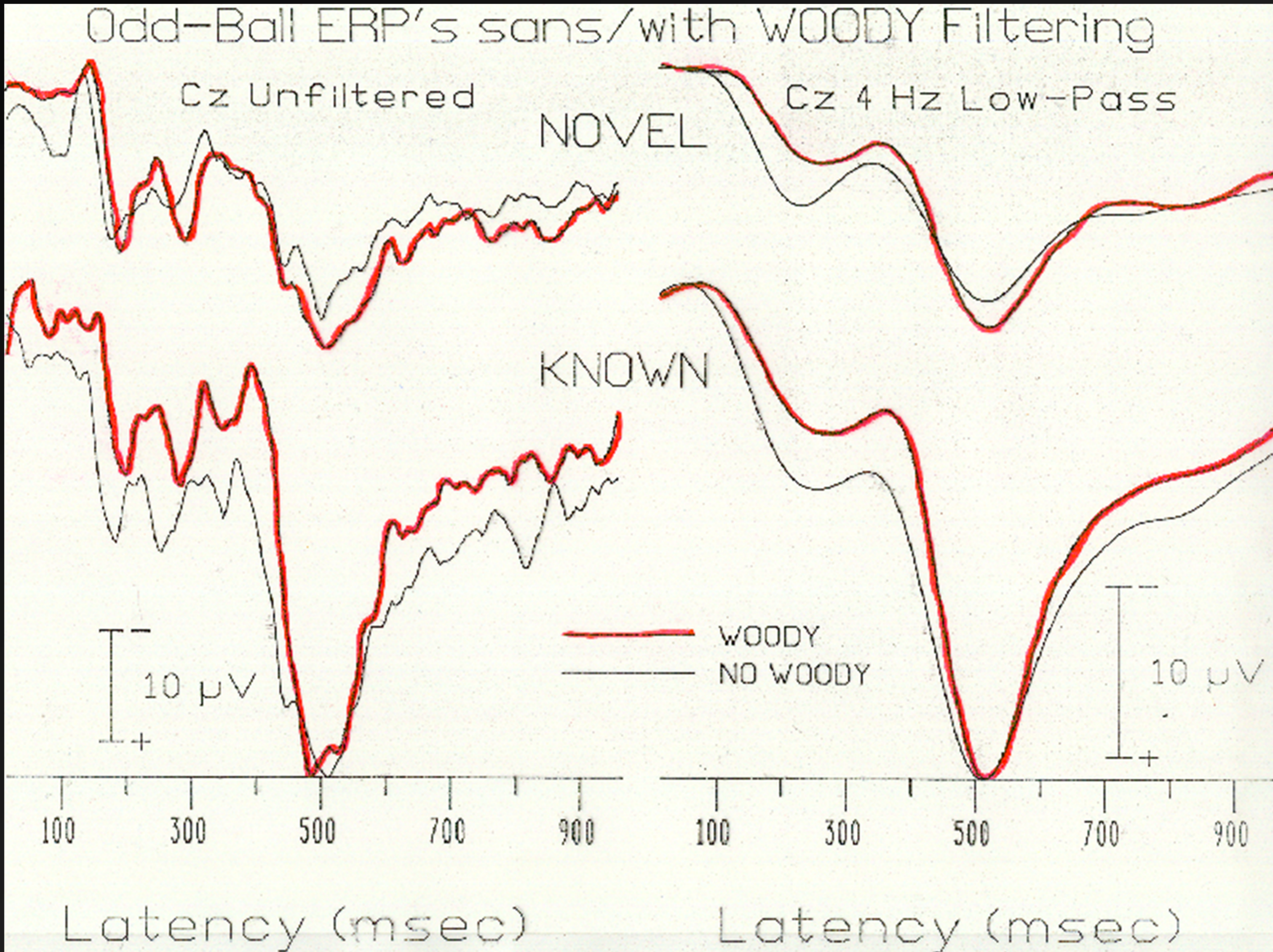
- Cross-correlational series
  - For two waveforms the correlation between each of them is computed
    - first with no lag in time (a1, a2, ..., an with b1, b2, ... bn)
    - then with one lagged with respect to the other (a1, a2, ..., an with b2, b3, ... bn+1)
  - A series of correlation values is obtained by progressively increasing the size of the lag

# More Details

- Can be used as a "template matching" procedure
- Compare running average with raw EEG epochs
- This is a method of single-trial signal detection:
  - First create a template: either predetermined (e.g., sine wave) or empirically determined (e.g., average)
  - Then calculate cross-correlational series between each raw EEG epoch and the template
  - If some maximum correlation achieved, conclude signal is present
  - If correlation not achieved conclude absent
  - This can also be used as a method of determining the latency of a component (by examining the trial-by-trial shifts), or of determining the variability in response for a given individual (again by examining the trial-by-trail shifts)

# Woody's Instantiation

- The Woody Adaptive Filter (Charles Woody, 1967) is a special case and application of cross correlational technique
- The term "adaptive" refers to the fact that the template is not established a priori, but generated and updated by an iterative procedure from the data themselves
- Procedure
  - Initial template is usually either a half cycle of a sine or triangle wave, or the unfiltered average of single trials
  - Cross-lagged correlations (or sometimes covariances) are then computed between each trial and this template **over a limited range of samples** (explain, e.g., region of P300, not over "invariant" components)
  - Each trial is then shifted to align it with the template at the value which yields the maximum cross correlation (or covariance)
  - A new template is then generated by averaging together these time-shifted epochs
  - Procedure is repeated using this new average as the template
  - repeated until the maximal values of the cross correlation become stable
  - often, average cross-correlation value increment monitored; if r increases < .005 or .001, then stability achieved
- Some implementations, trials which do not reach a minimum criterion (e.g., .30-.50) are discarded from subsequent template construction and perhaps from subsequent analysis altogether



Odd-Ball ERP's sans/with WOODY Filtering
Cz Unfiltered
Cz 4 Hz Low-Pass
NOVEL
KNOWN
10 μV
WOODY
NO WOODY
10 μV
100
300
500
700
900
100
300
500
700
900
Latency (msec)
Latency (msec)

# Validity

- Seems to do a fair job of improving signal extraction if a few iterations are used and if the original signal itself is singly peaked
- Wastell(1977) reports a decline in the validity of the procedure if numerous iterations are used
- Therefore, unlike averaging, Woody filtering can only improve signal-to-noise ratio over a definite limit
- Suggests also that Woody may not be the solution under conditions of very low signal-to-noise ratio