Advanced Signal Processing I

Digital Filters

Time Frequency Approaches

Ocular Artifacts

International Trans Day of Visibility,
International Trans Day of Visibility,

Announcements 4/28/25

- Paper/Proposal new due date: May 7, 11:59 pm
  - Be sure to review the Guidelines (On course webpage, Link in D2L)
  - Pay special attention to methods
    - Tasks
    - Recording parameters
    - Signal processing to obtain metrics
    - Analysis plan related to hypotheses
- Student Course Surveys – complete by last day of class (May 5)
- 501B Lab Section
  - Apr 30 End of Day EEG frequency domain report due
  - May 2 End of Day ERP Analysis done (Email Kelly)
  - May 9 End of Day ERP Report Due

International Trans Day of Visibility,
International Trans Day of Visibility,

Announcements 4/28/25 (continued)

- Office hour this week: Wednesday 2:30-3:30 pm
- Last class session next week
  - Need to adjust the time 3:30-6:00 pm

Feedback and Questions

Since you can use ERPs to detect hearing impairments in infants, I was wondering if the same was true for visual impairments? If you could catch conditions like amblyopia early treatment is much more effective.

Simple screening using photorefraction can detect:

- Nearsightedness
- Farsightedness
- Astigmatism
- Anisometropia (unequal refractive power between eyes)
- Strabismus (misalignment of the eyes)
- Media opacities (e.g., cataract)

VEPs used for known/suspected lesions in visual pathway (but not routine acuity screening). Can detect:

- Optic nerve problems
- Severe retinal issues
- Cortical visual impairment
- Delayed visual maturation (normal outcome but initially slow VEP responses)

Feedback and Questions

The P300 response occurs when the brain perceives something important or unexpected. Knowing this, how do researchers study the P300 in people with different mental disorders like ADHD or Alzheimer's Disease?

Feature	Healthy Controls	Alzheimer's Disease
P300 Latency	Normal (~300–380 ms)	Prolonged (~400–500+ ms)
P300 Amplitude	Higher	Reduced
Topography	Maximal at parietal sites (Pz)	May shift anteriorly (Fz, Cz)
Clinical Correlation	Stable	Correlates with cognitive decline

Alzheimer's

- Greater P300 latency prolongation and amplitude reduction often correlate with:
  - Lower Mini-Mental State Exam (MMSE) scores.
  - Poorer memory and executive function test performance.
- Some longitudinal studies suggest P300 latency worsens over time as dementia progresses.
- An anterior shift is also sometimes seen (P3A?)
- Mild Cognitive Impairment (MCI) Shows Intermediate Patterns – but sensitivity and specificity not sufficient for clinical prediction

Polich et al. 2005, *Journal of Clinical Neurophysiology*

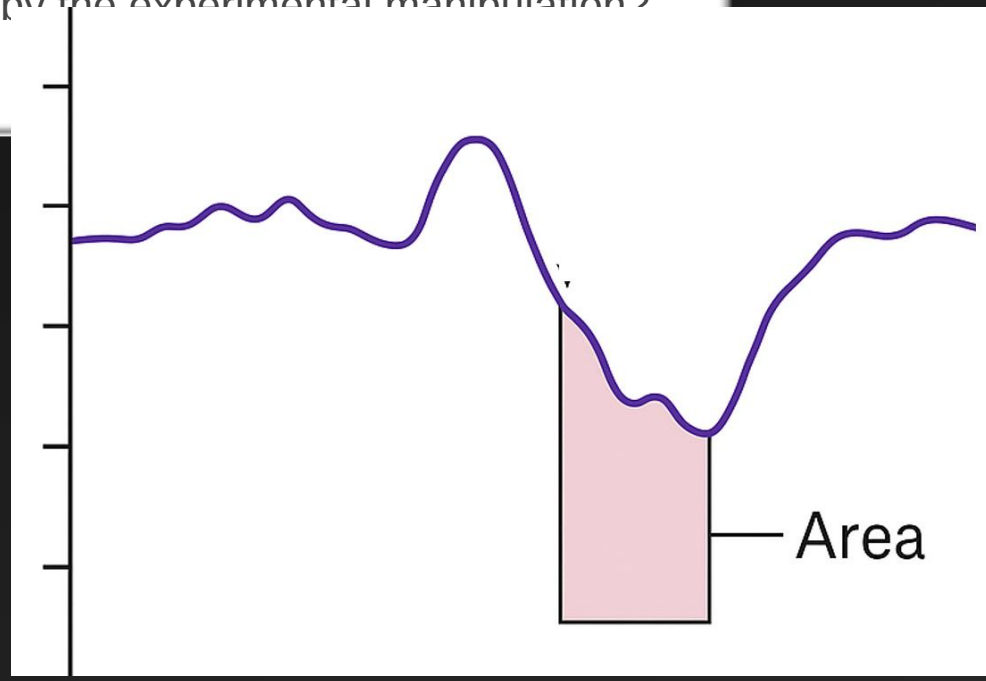
ADHD

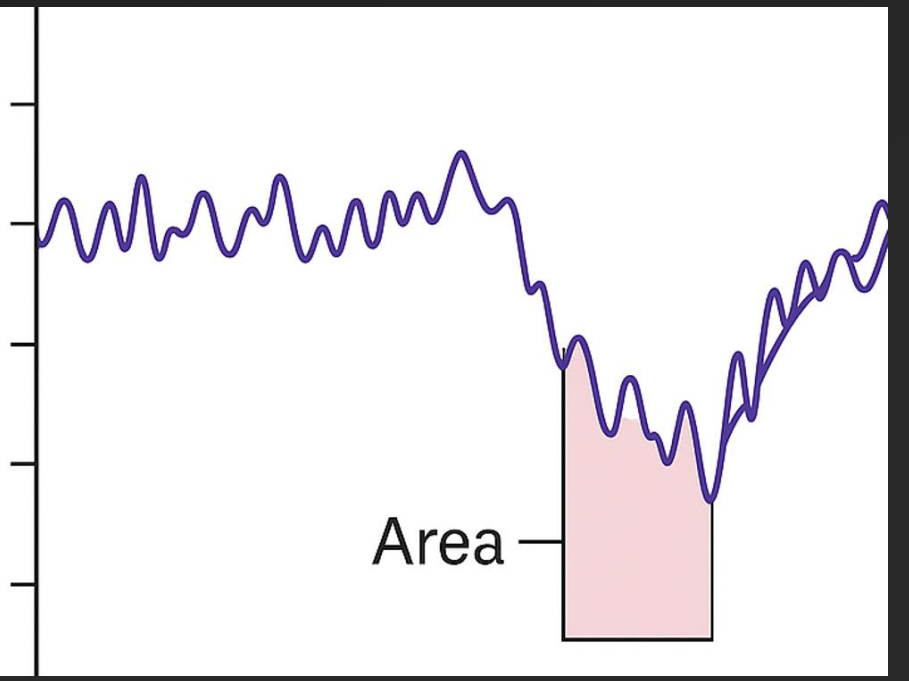
- Similar findings of reduced amplitude and increased latency
- Effects seen most consistently in tasks with higher demand for attentional control (Go/NoGo, Flanker)
- Some evidence of "normalizing" with stimulant medications

Johnstone et al. 2013, *Clinical Neurophysiology*

Feedback and Questions

You mentioned ERP components are quantified by things like amplitude, latency, area etc. Are there acceptable ranges for all of the above characteristics for each component? Or is there one characteristic that is favored when identifying a component? Likewise, are all three used when comparing components in the context of inferential stats, or does the measure used differ by the experimental manipulation?





Feedback and Questions

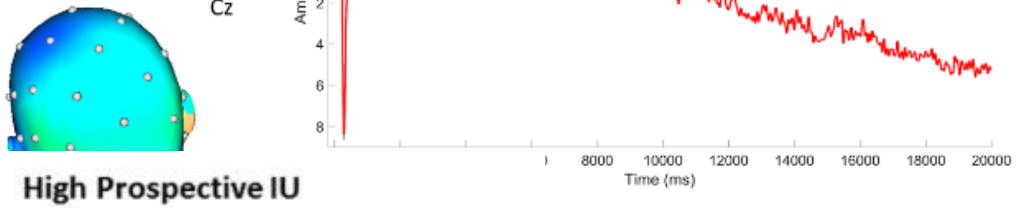
Most ERP studies we covered in class used time windows of less than 1,000 ms from stimulus onse
However, I came across a study (MacNamara, 201
that used a time window of 20,000 ms (not 2,000!)
stimulus onset and 10,000 ms from stimulus offset
you think this approach is reliable?

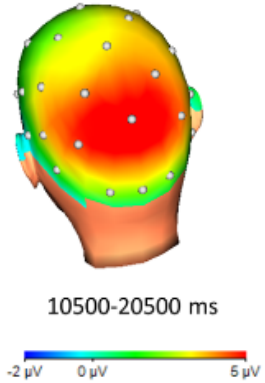
MacNamara, A. (2018). In the mind's eye: The la
positive potential to negative and neutral mental
imagery and intolerance of uncertainty.
Psychophysiology, 55(5), e13024.

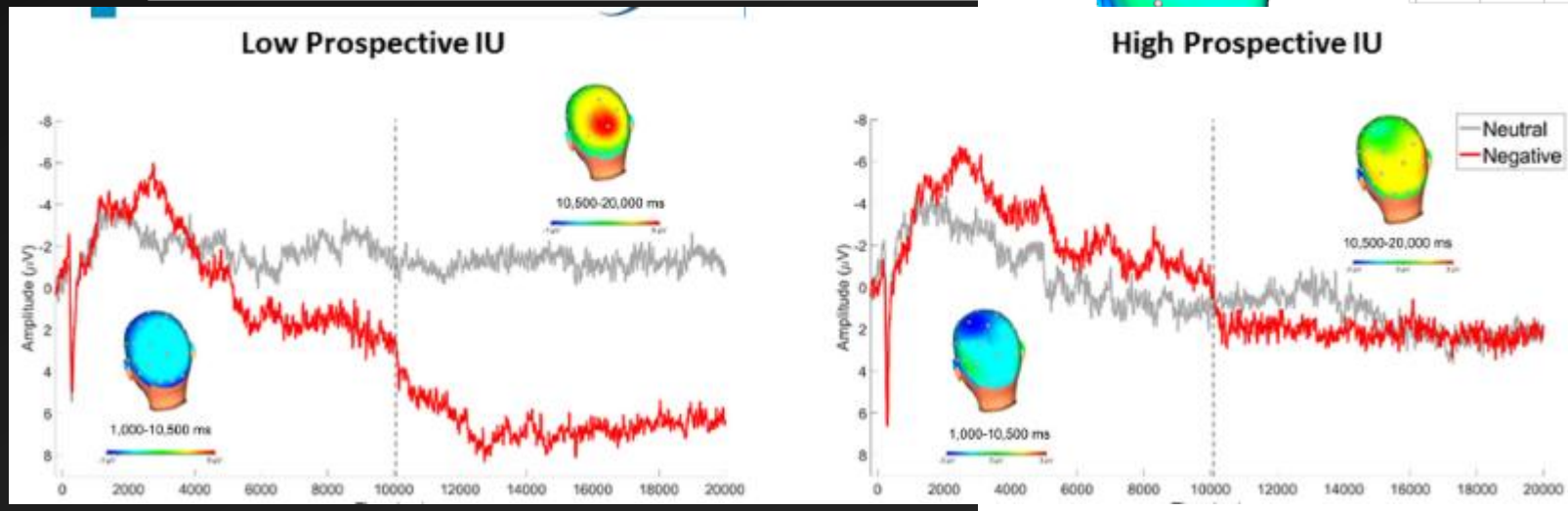
"You head to the kitchen to prepare breakfast. As you wait for the toaster to finish, you sit at the kitchen table, reading the paper, and listening to the traffic outside."

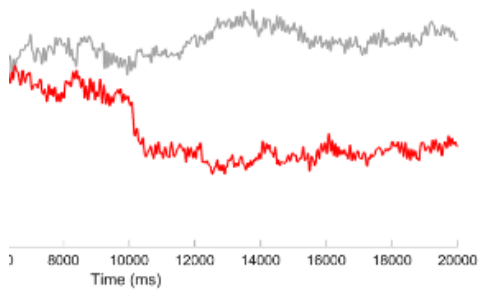
OR

"His face contorted, your best friend falls to the floor, unable to breathe. You run to him, but he doesn't see or hear you. Hands shaking, you search desperately for the phone."









Feedback and Questions

I am currently in my psychology 408 class and we are currently watching a video on the study you did with psychedelic drugs, I thought it was really interesting and I think it is super awesome how you helped someone out with their OCD and contributed to this area of research!

Feedback and Questions

In the DID study that was mentioned during the lecture, were the demographics the participants were parts of (ages 39-51, at least a college level education, etc) purposely selected for, and if so why? If not, why was it like that? My concern regarding it is that having the study only contain participants of those criteria could potentially have skewed the results.

Feedback and Questions

While the question I had was somewhat answered in class with respect to the connection between depression and reward behaviors, I specifically wanted to ask about the connection between depression and AVOIDANCE behaviors against negative stimuli. I believe the question in class asked about a relationship between clinical depression and reward, but do we see a similar lack of negative stimulus avoidance as in psychopaths?

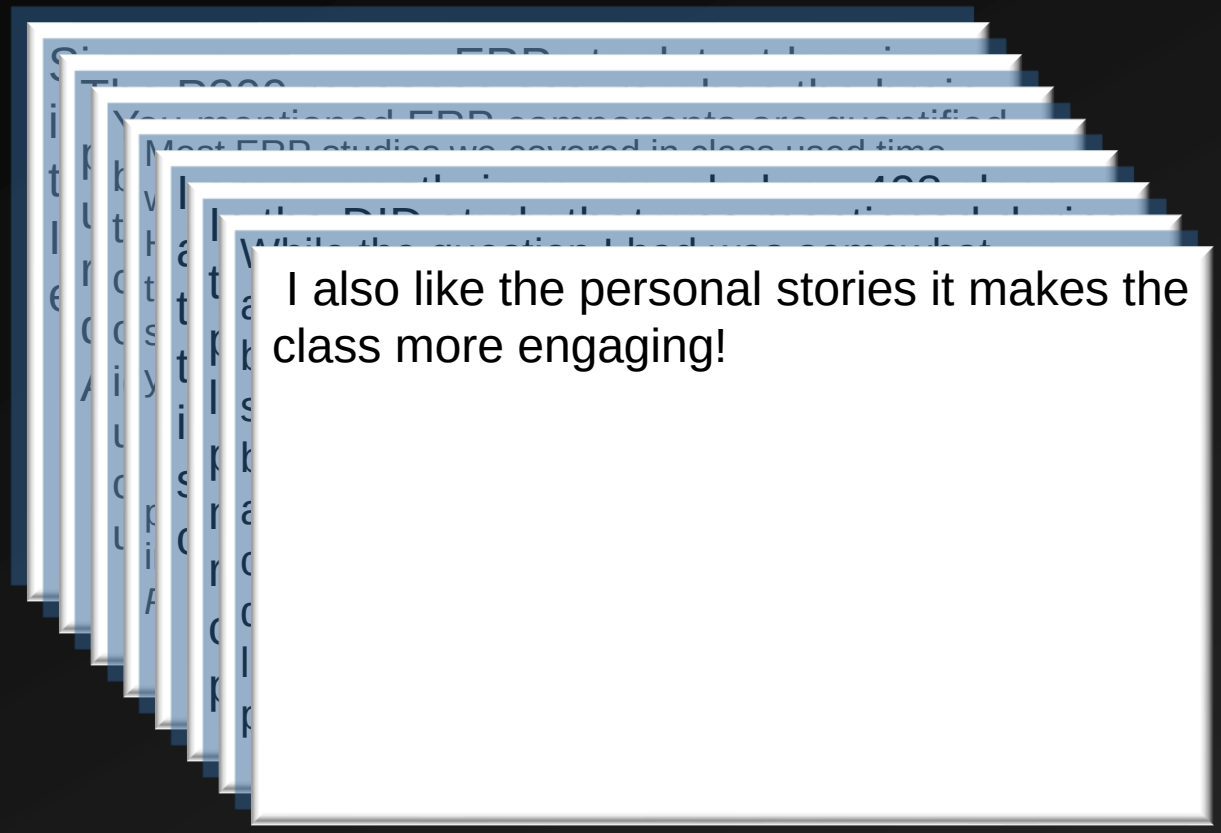
Short answer: Avoidance, yes (but psychopaths don't avoid…)

Examples

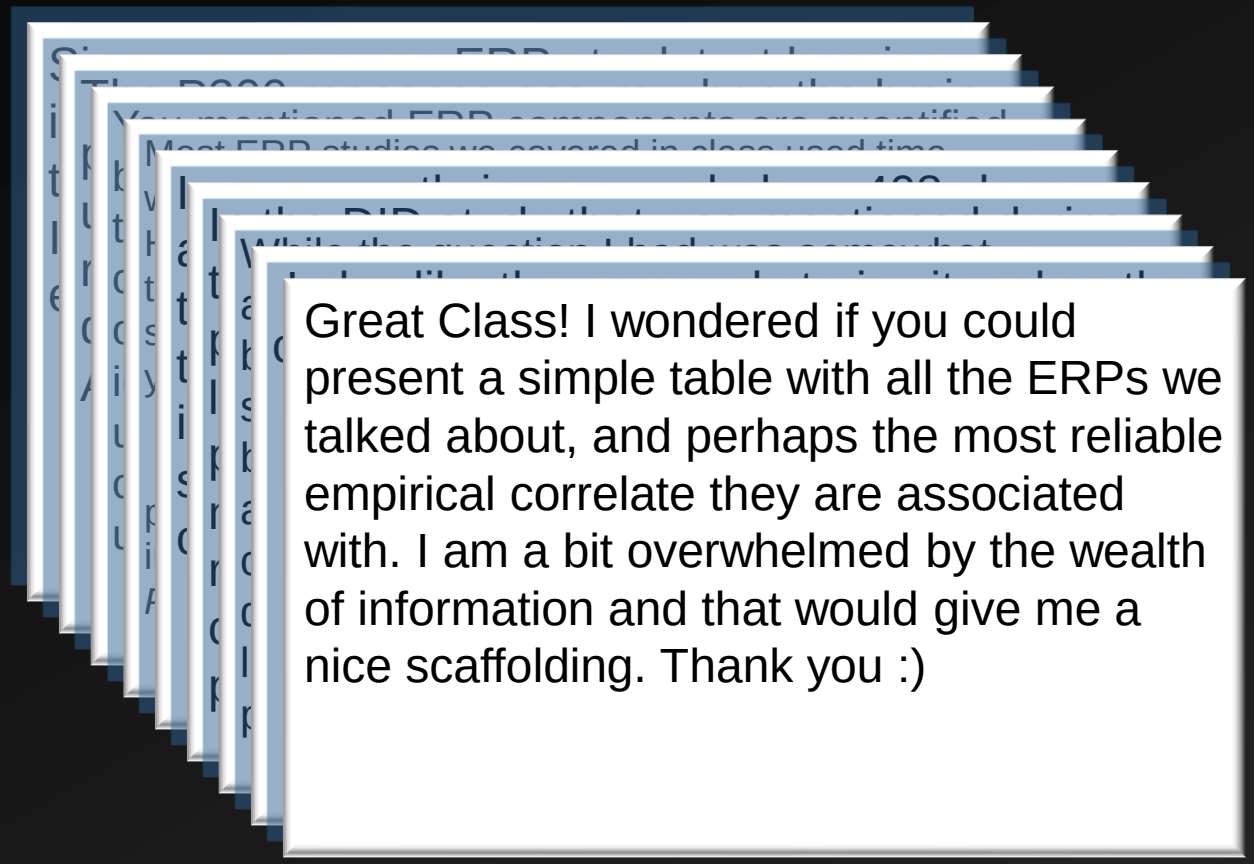
- fMRI studies showing greater activations in MDD to negative emotional stimuli and negative feedback
- ERP N170 shows enhancement in MDD to negatively-valenced faces
- Larger LPP in MDD to negative stimuli
- But in very severe anhedonic MDD, responses may be blunted

Avoidance
Negativity Bias ➔ Heightened Fear of Failure/Negative Feedback ➔ Behavioral Avoidance ➔ Reduced Positive Reinforcement ➔ Worsening Depression

Feedback and Questions



Feedback and Questions



Great Class! I wondered if you could present a simple table with all the ERPs we talked about, and perhaps the most reliable empirical correlate they are associated with. I am a bit overwhelmed by the wealth of information and that would give me a nice scaffolding. Thank you :)

Feedback and Questions

Component Name	First Publication	Scalp Site Maximum	What It Reflects
MMN (Mismatch Negativity)	Näätänen et al., 1978	Frontocentral (e.g., Fz, Cz)	Automatic detection of auditory deviance; pre-attentive sensory memory processes.
P1 (in attention)	Hillyard & Anllo-Vento, 1998 (review; early findings in 1970s)	Occipital (e.g., Oz, POz)	Early sensory enhancement of attended stimuli; modulation of visual input by selective attention.
P300 / P3b	Sutton et al., 1965; further differentiated by Donchin, 1981	Parietal (e.g., Pz)	Context updating; stimulus evaluation and memory updating when a task-relevant event occurs.
P3a	Squires et al., 1975	Fronto-central (e.g., Fz, FCz)	Orienting to novelty; involuntary attention shift to unexpected, novel stimuli.
N400	Kutas & Hillyard, 1980	Centroparietal (e.g., Cz, Pz)	Semantic processing difficulty; detection of semantic incongruity in language and other meaningful stimuli.
ERN (Error-Related Negativity)	Falkenstein et al., 1991; Gehring et al., 1993	Frontocentral (e.g., FCz)	Rapid internal monitoring of errors during action execution.
FRN (Feedback-Related Negativity)	Miltner et al., 1997	Frontocentral (e.g., FCz)	Detection of unfavorable or unexpected outcomes (especially following feedback).
RewP (Reward Positivity)	Holroyd et al., 2008 (reinterpretation of FRN)	Frontocentral (e.g., FCz)	Positive reward processing; reflects a reward-related positivity that overlaps with reduced FRN.

Advanced Signal Processing I

Digital Filters

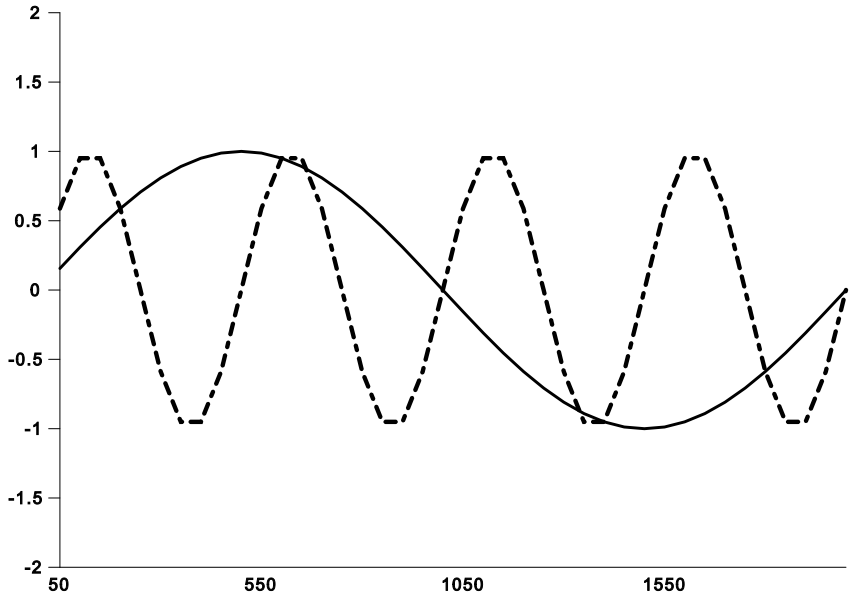
Time Frequency Approaches

Ocular Artifacts

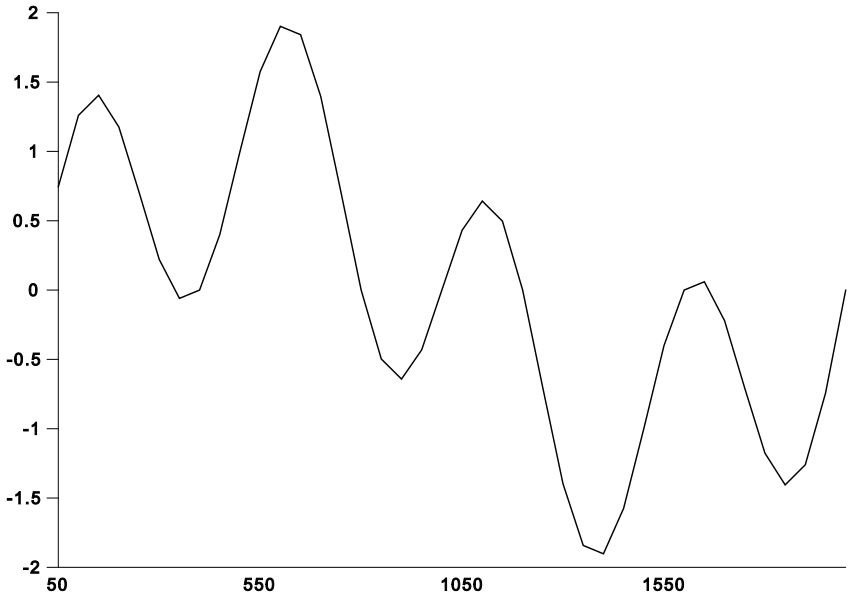
Digital Vs. Analog Filtering

- 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
- Analog filters are irreversible – once applied, there’s no turning back
- 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

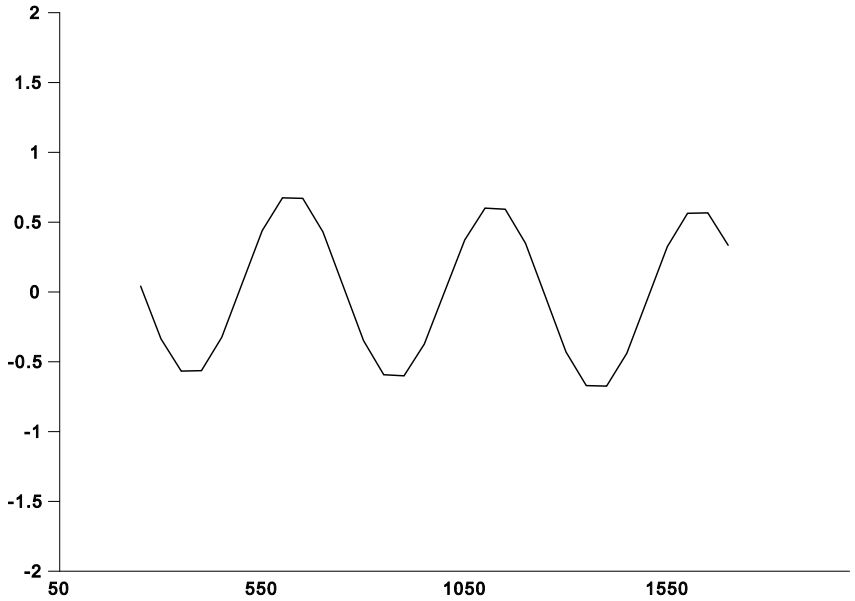
Constituent Waveforms



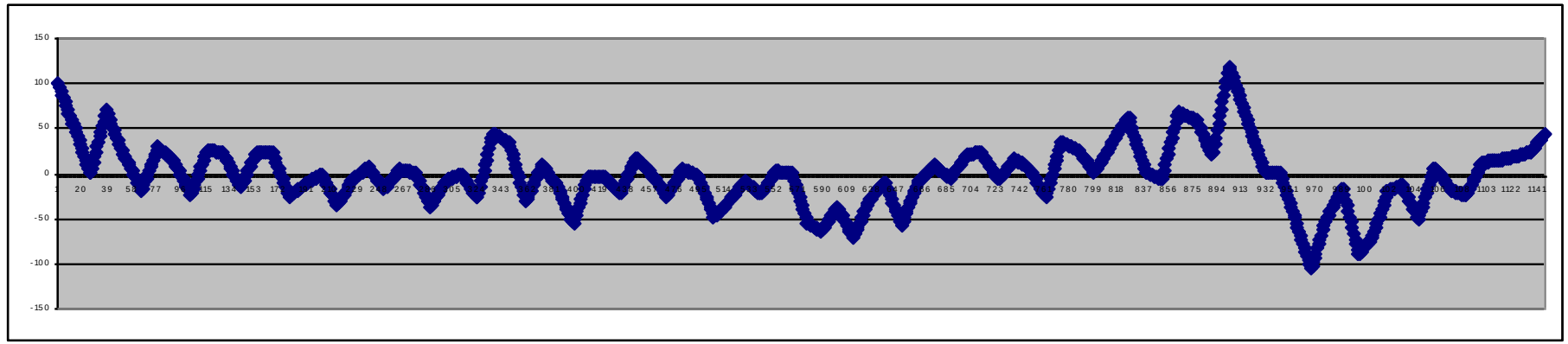
Resultant Waveform



High Pass Filtered



Low Pass Filtered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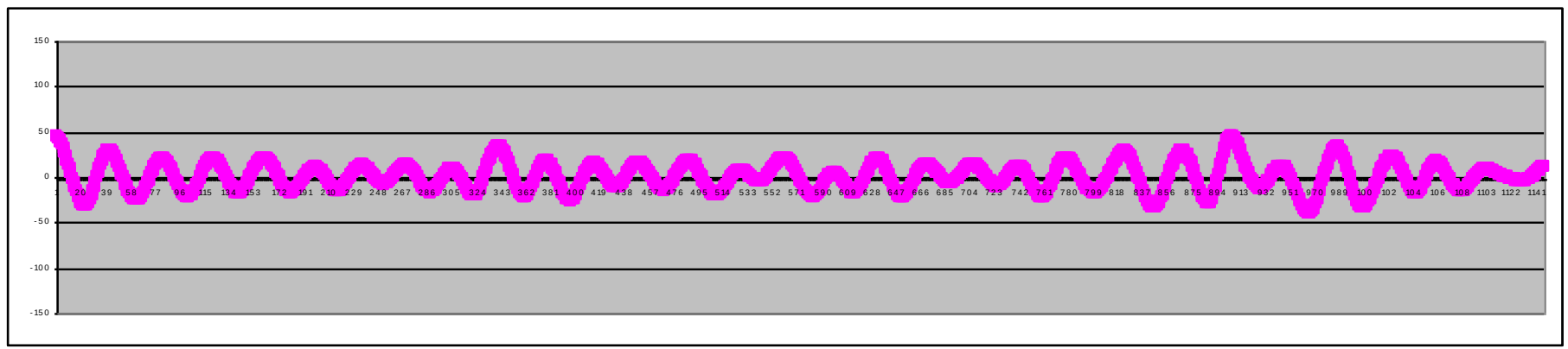
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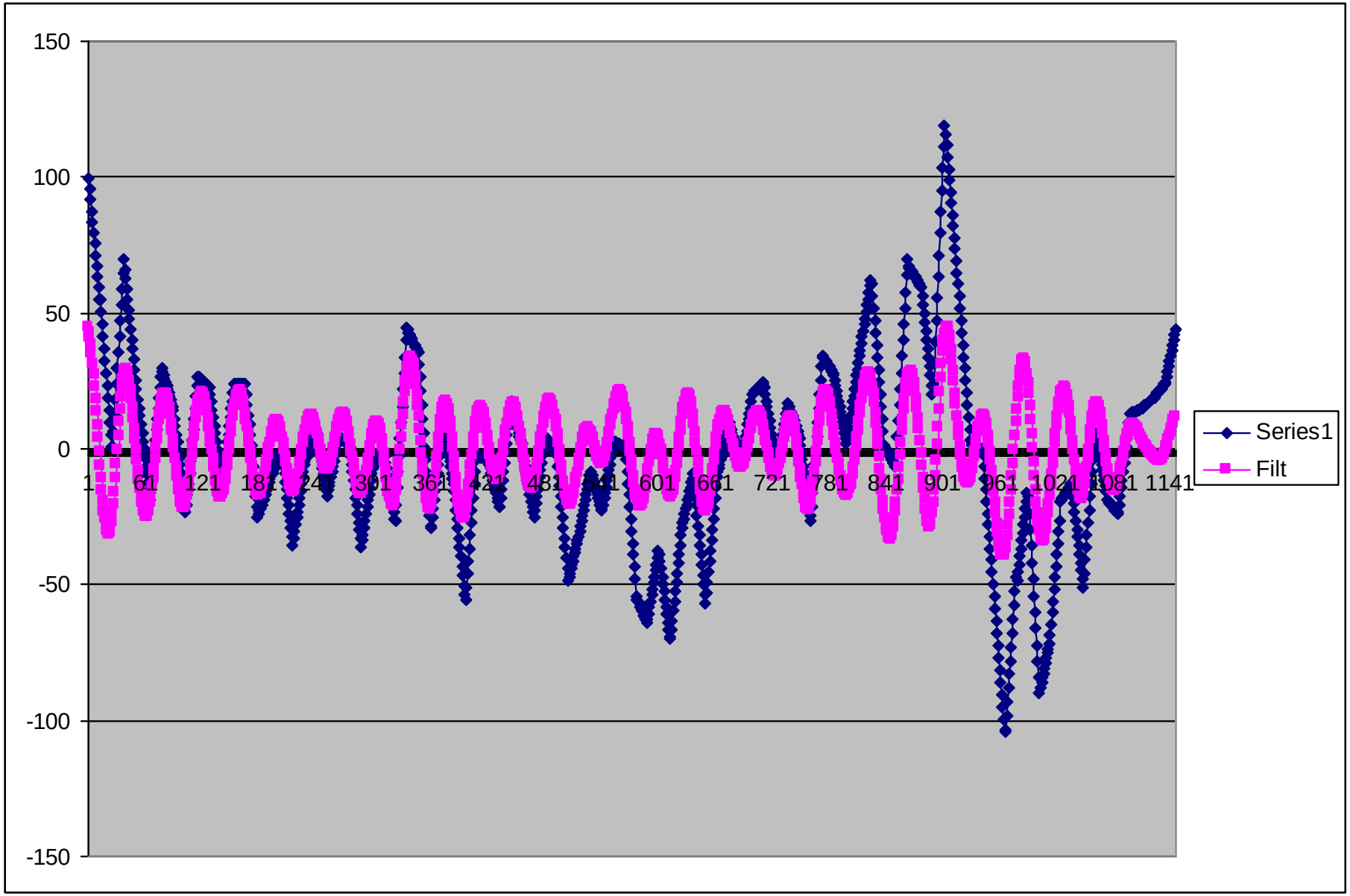
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961
1021
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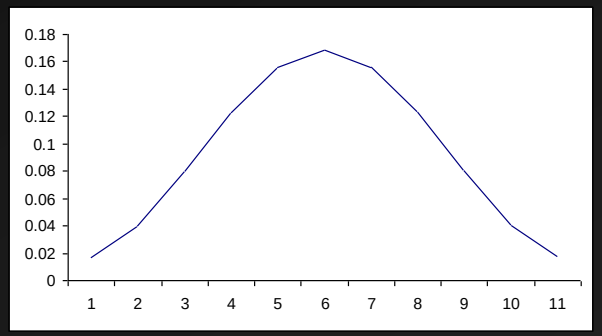
1141
Series1
Filt

The Details!

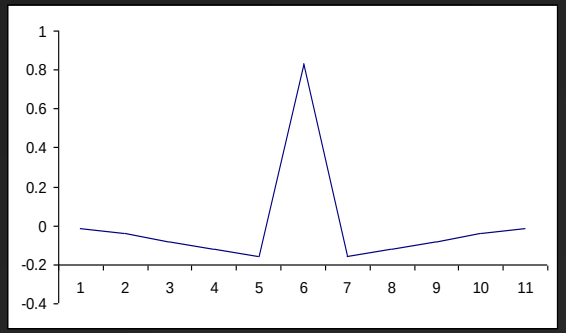
- Handout on Digital Filtering

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	3
0.1231	2	-0.1231	2
0.1561	1	-0.1561	1
0.1684	0	0.8316	0
0.1561	-1	-0.1561	-1
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

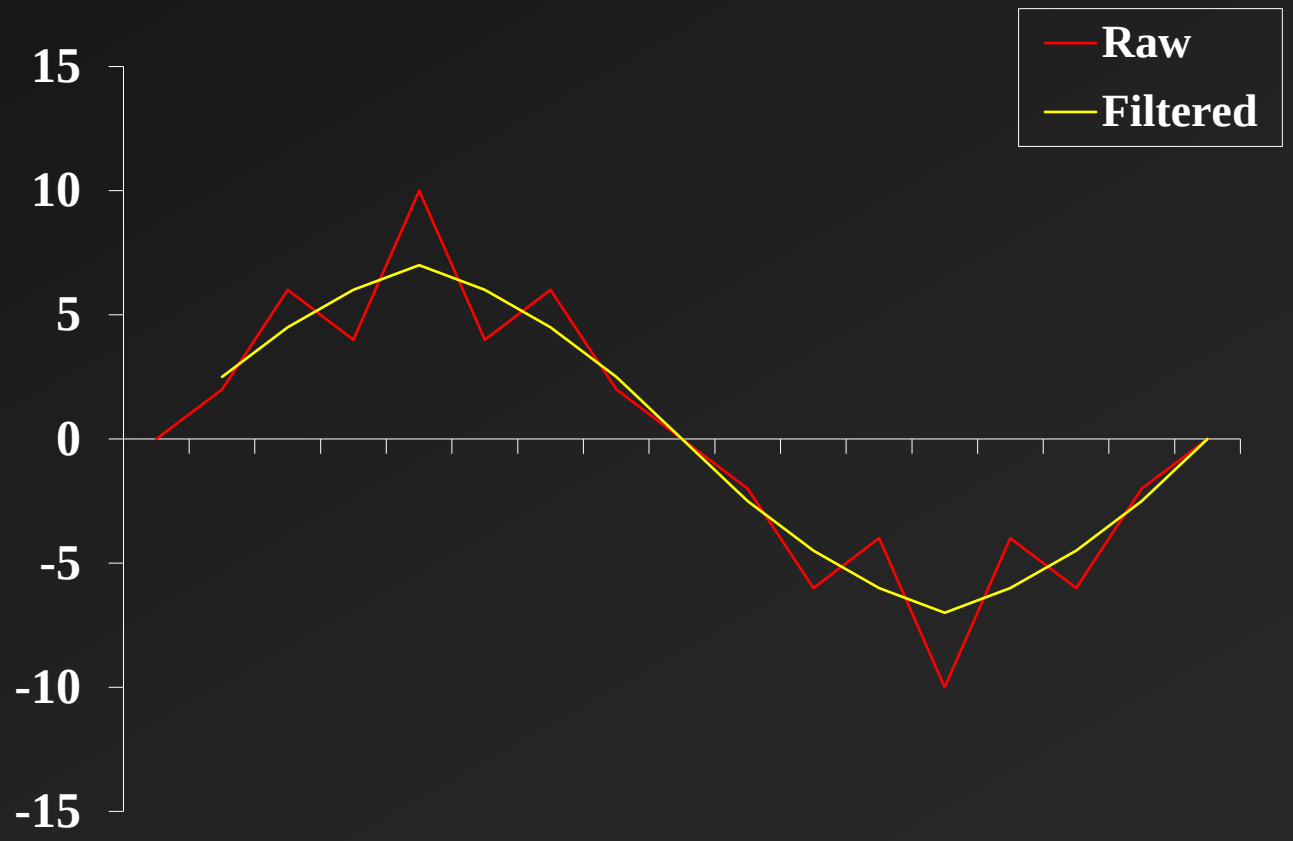
  17.5/200 = x/20 ; x = 1.75 @ 20 Hz Sampling rate

Very 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

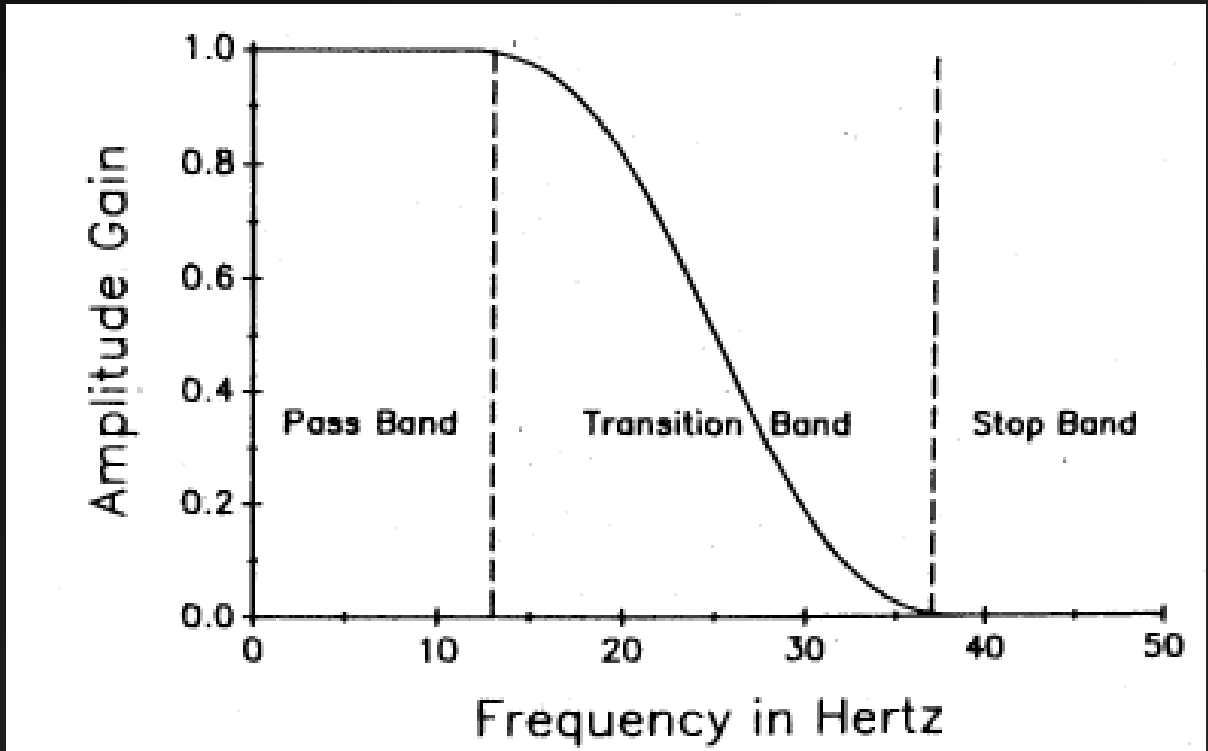
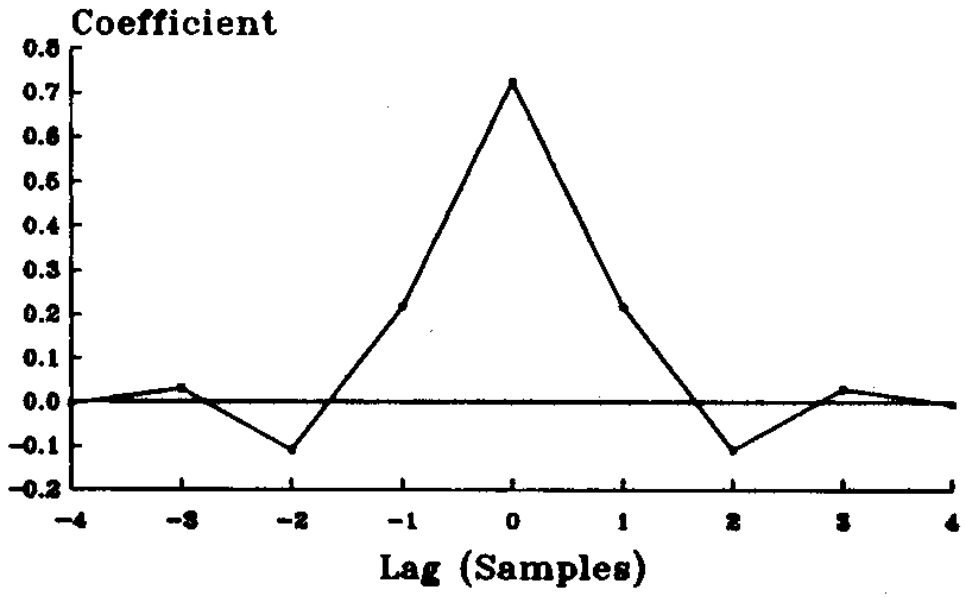


Figure 1. The gain function of a filter is divided into the pass band, transition band, and stop band. The gain function shown is for a low-pass filter.

Cook & Miller, 1992

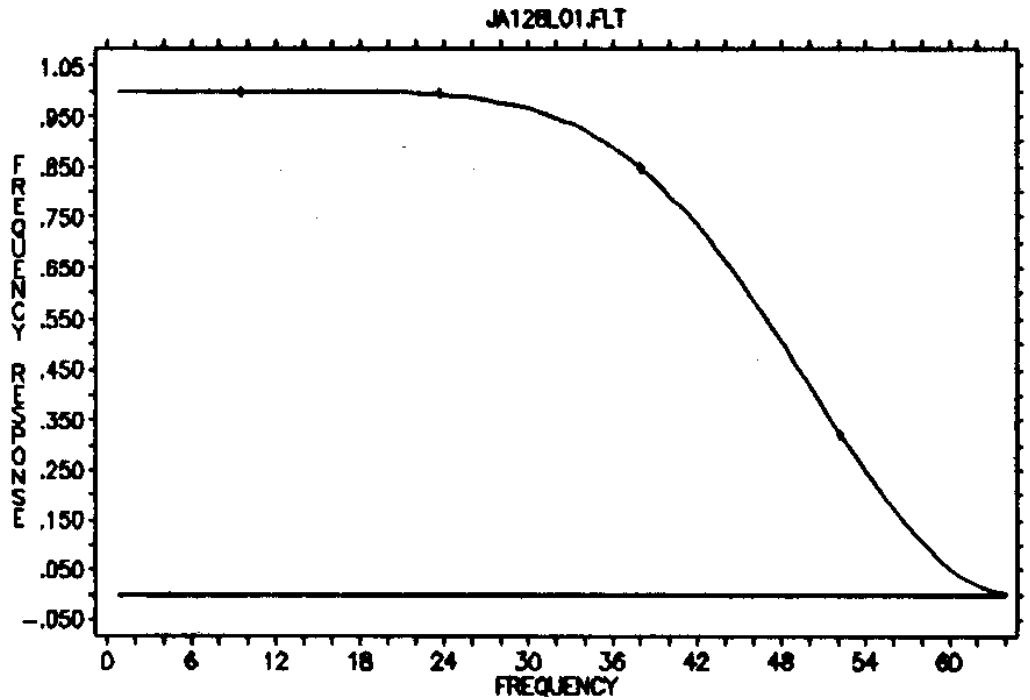


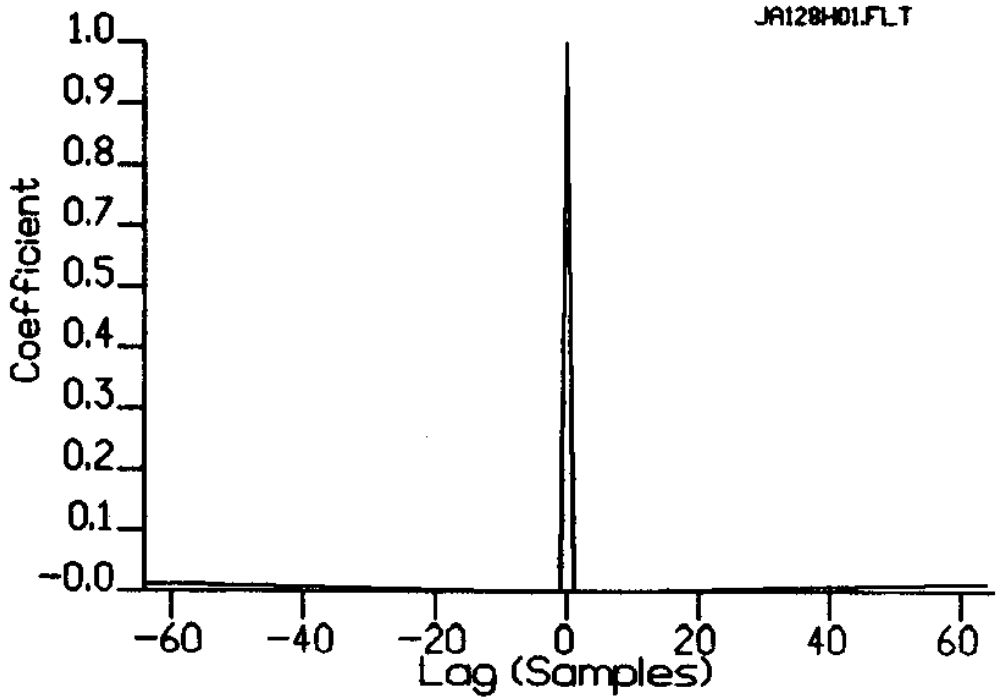
Impulse Response

Note:

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

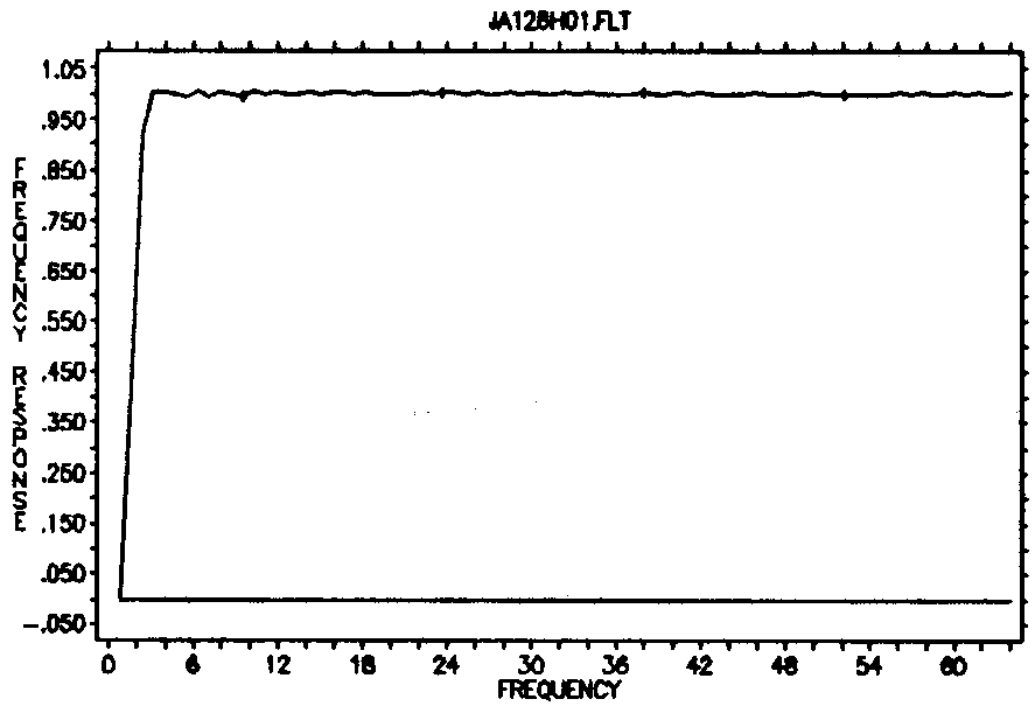
Transfer Function

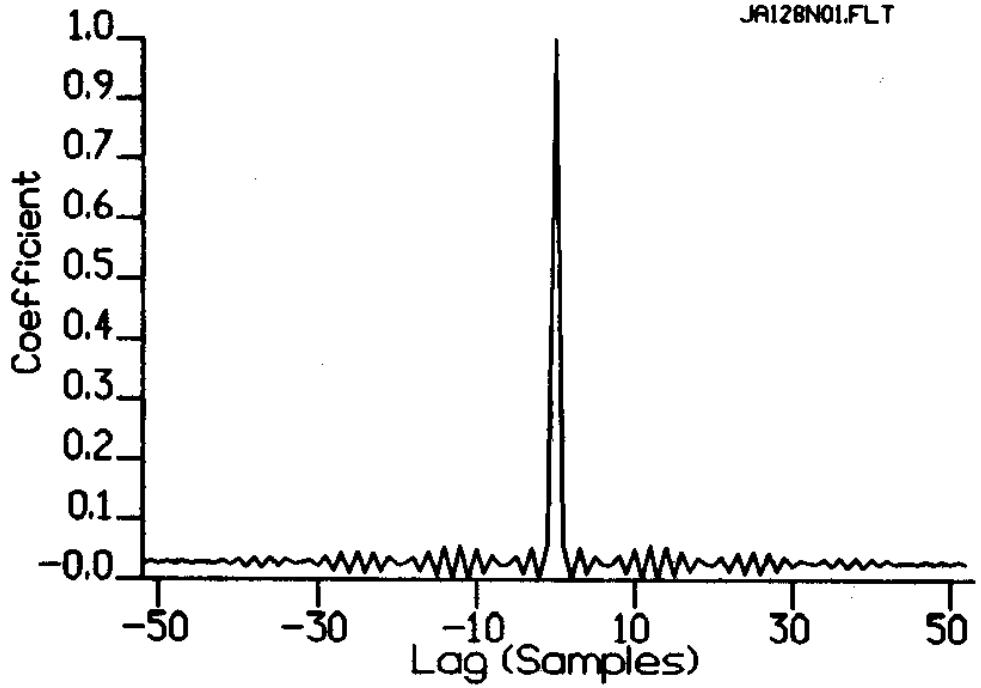




Impulse Response

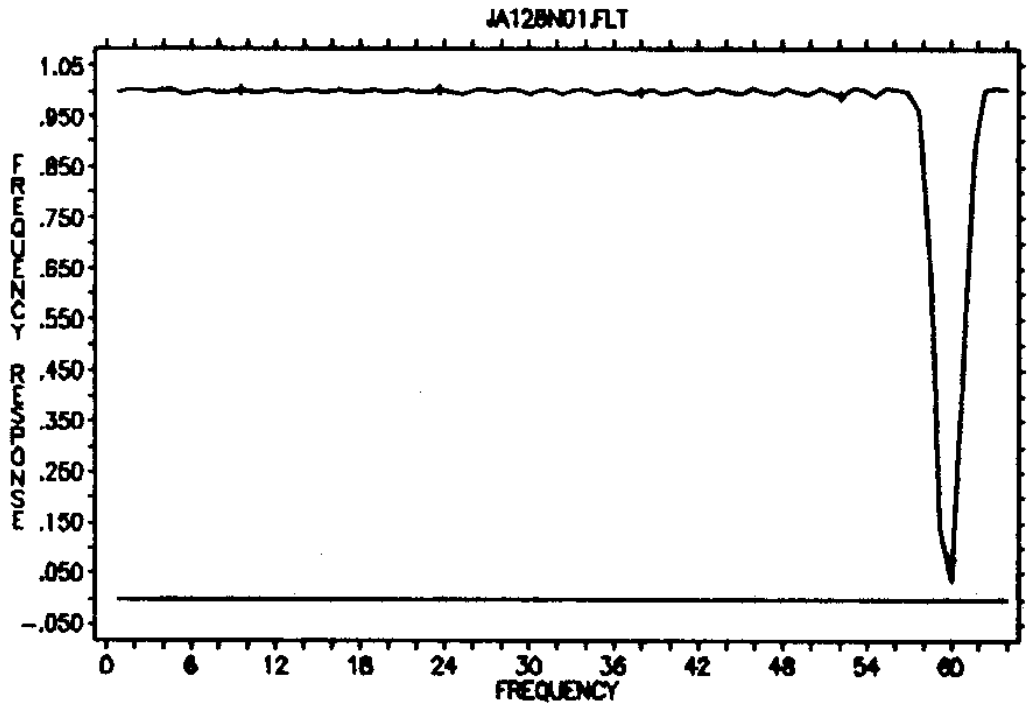
Transfer Function

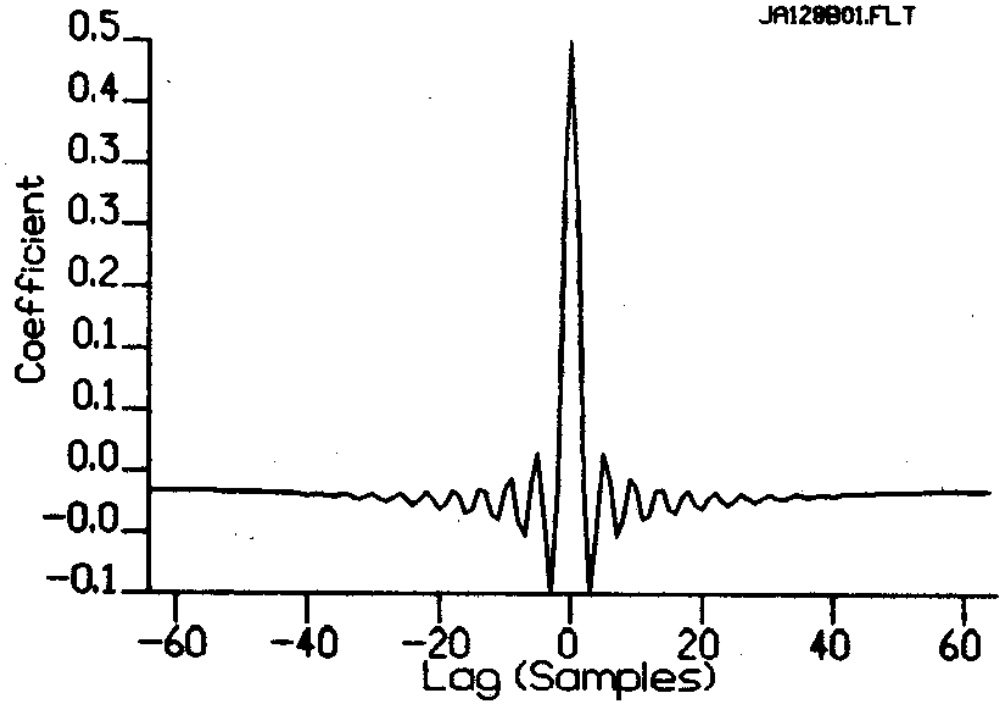




Impulse Response

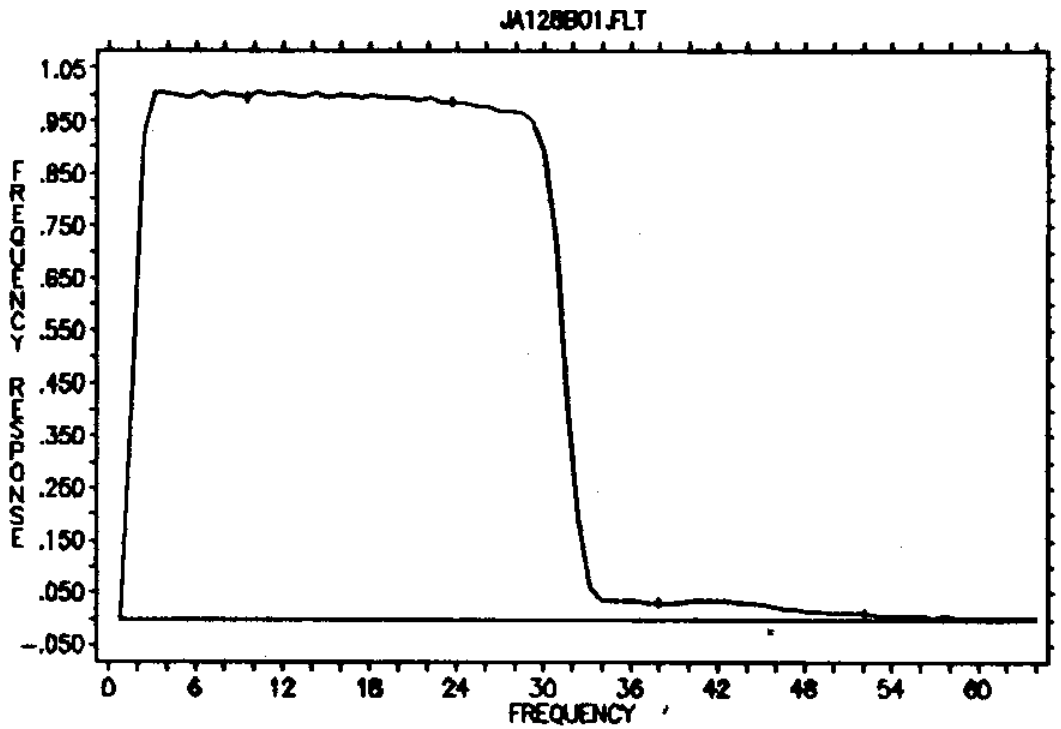
Transfer Function





Impulse Response

Transfer Function

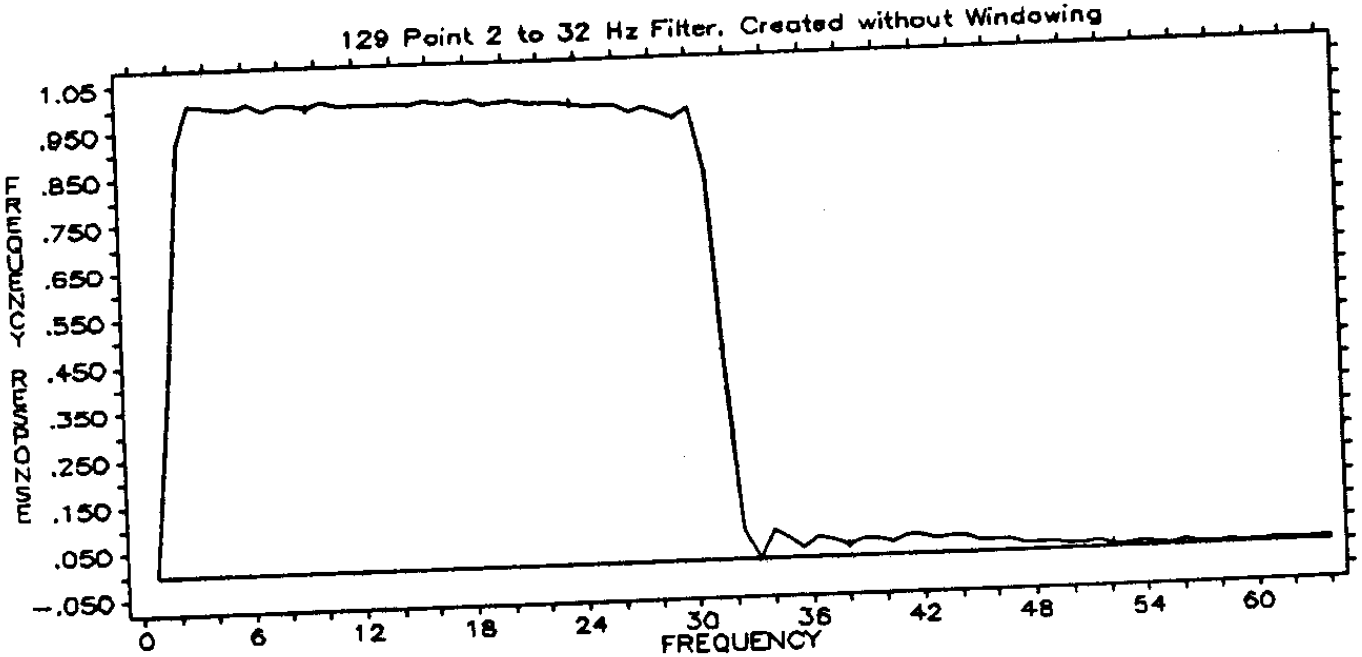


Pragmatic concerns

- 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

Ripple and Windowing

- Filters will have ripple near the transition band
- Can be mitigated with windowing



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

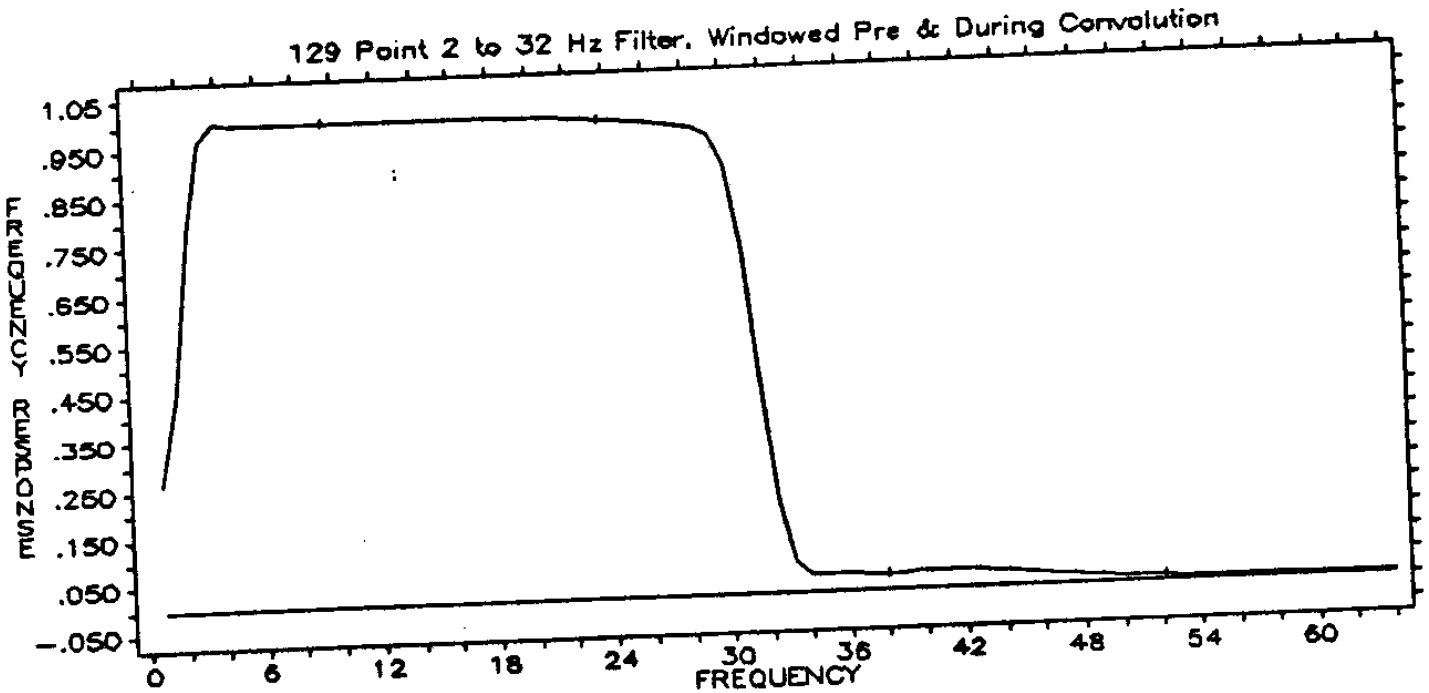
Hamming Taper, for *i* coefficients -*j* to +*j*,

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

where:

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

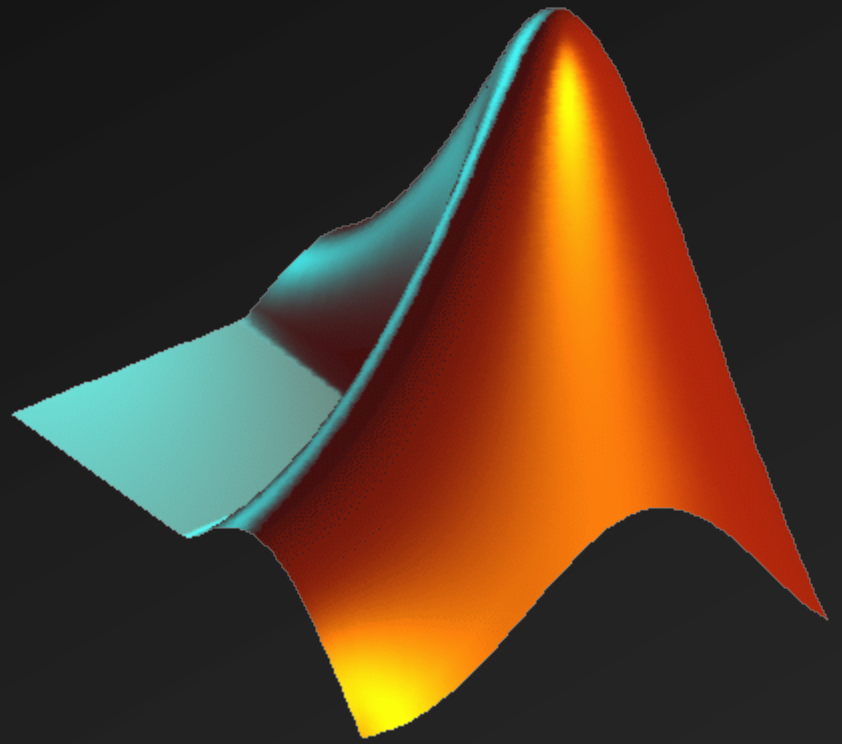
$p_i = i/(j+1)$



Use in Single Trial Analysis

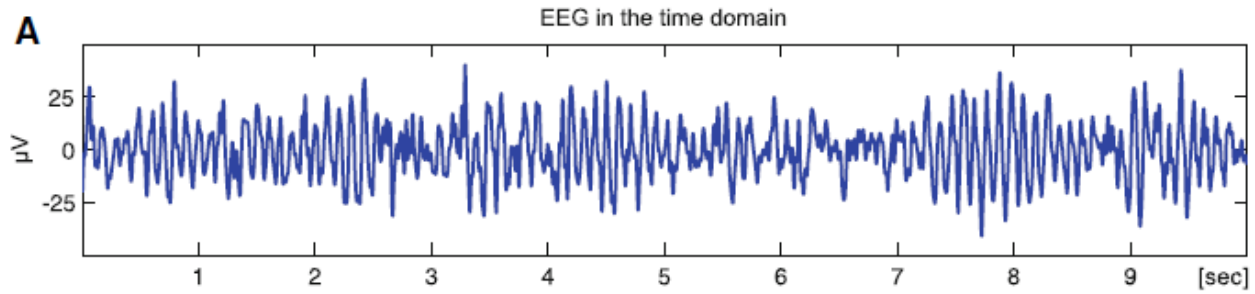
- With stringent digital filtering, you may be able to discern peaks on an individual trial basis

Digital Filtering and More!



Time-Frequency Approaches

Brain Topogr (2014) 27:438–450

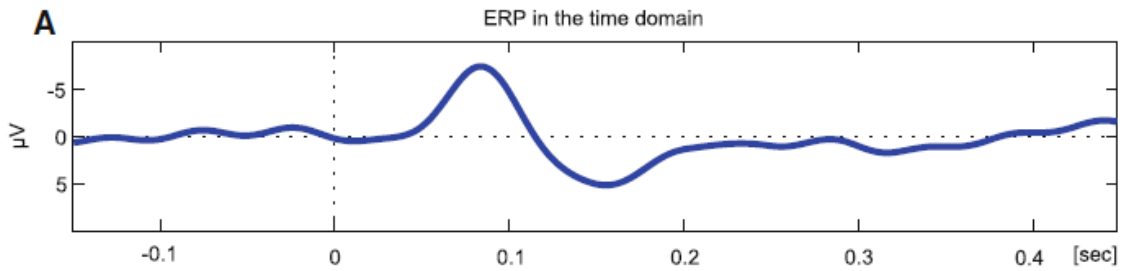


Let’s make sure we understand Time-Frequency Space!

MUSICLAB.CHROMEEXPERIMENTS.COM/SPECTROGRAM

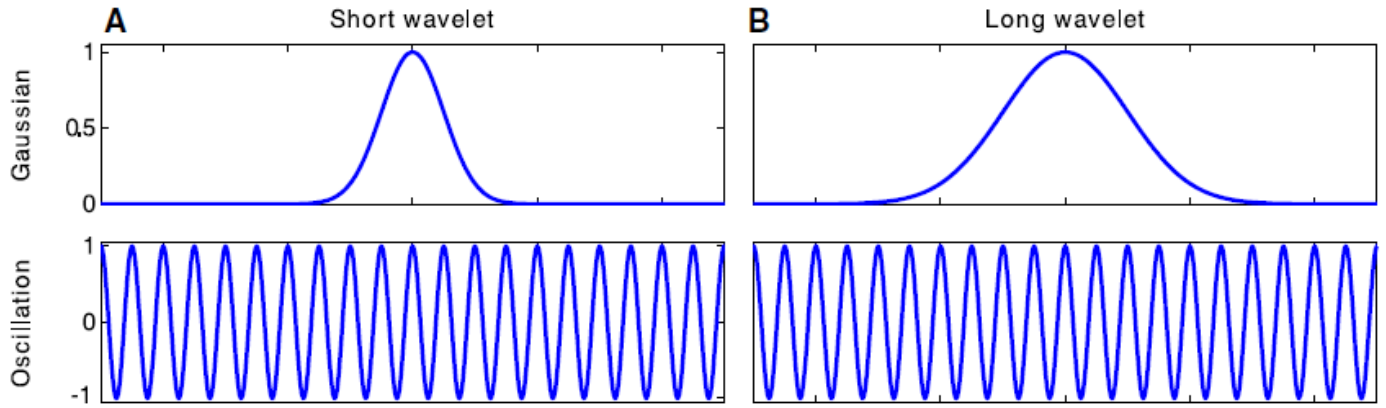
Time-Frequency Approaches

Brain Topogr (2014) 27:438–450



Time-Frequency Approaches

Brain Topogr (2014) 27:438–450



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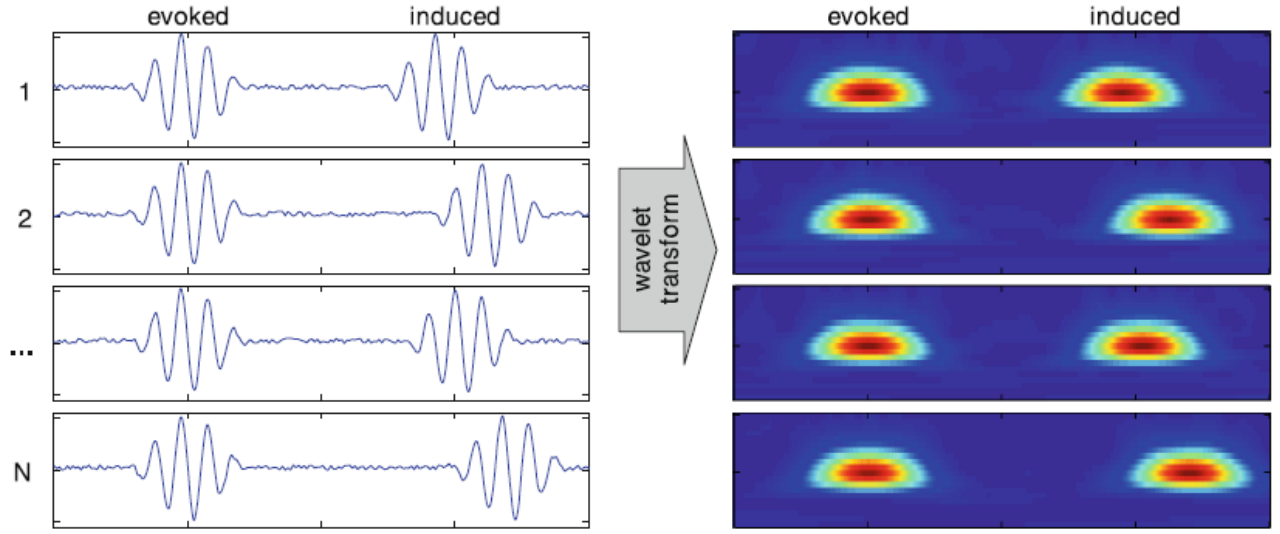
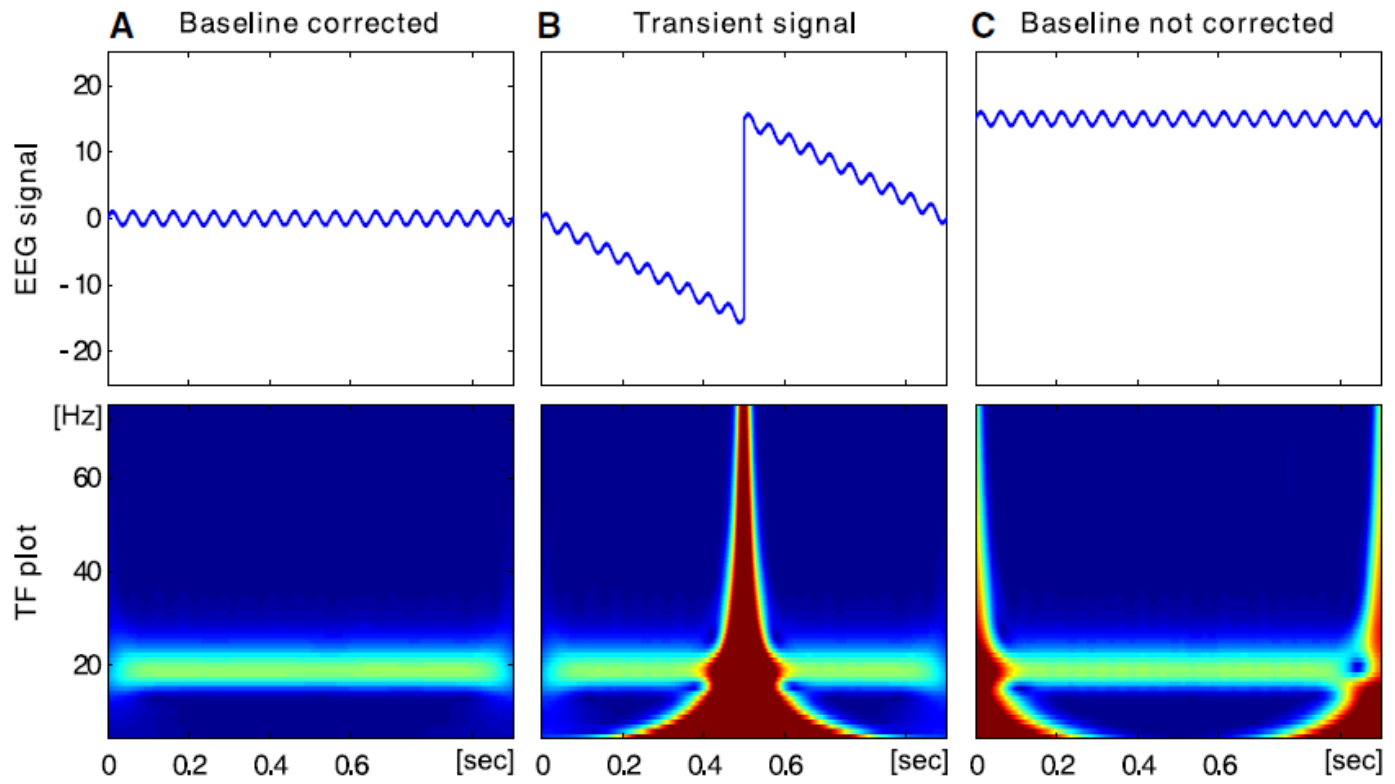


Time-Frequency Approaches

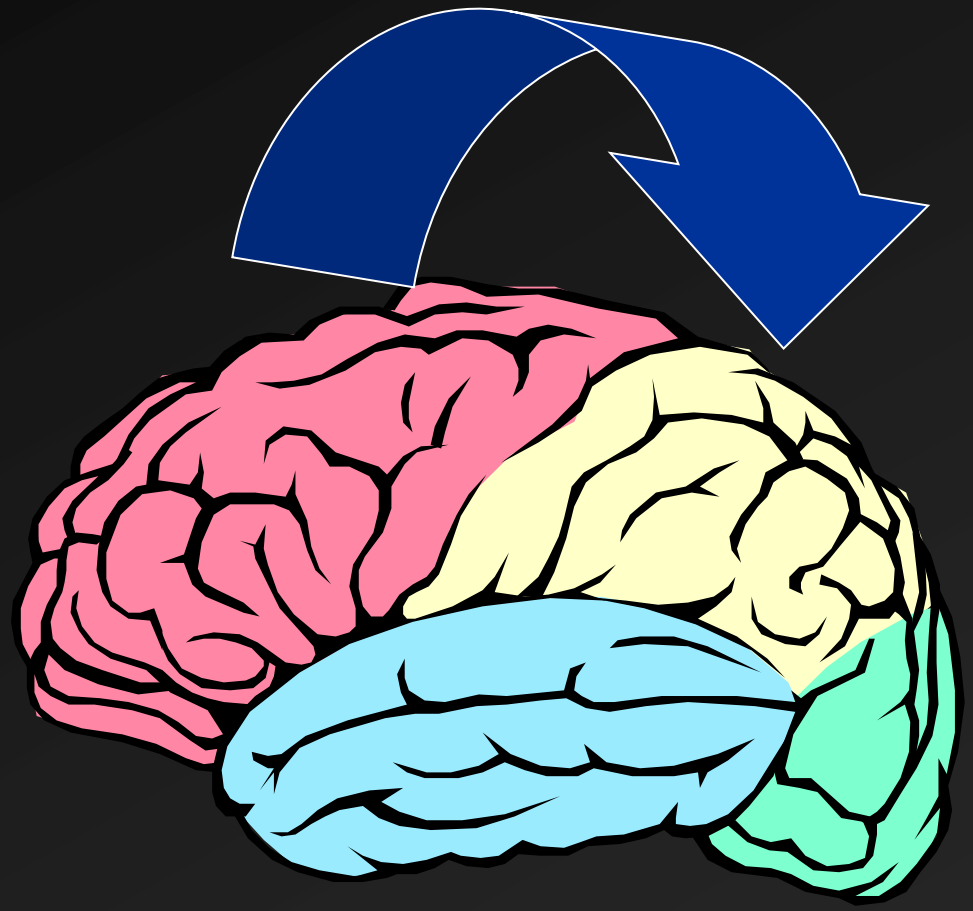
Brain Topogr (2014) 27:438–450



A bit more on phase and such

COURTESY OF MIKE COHEN

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

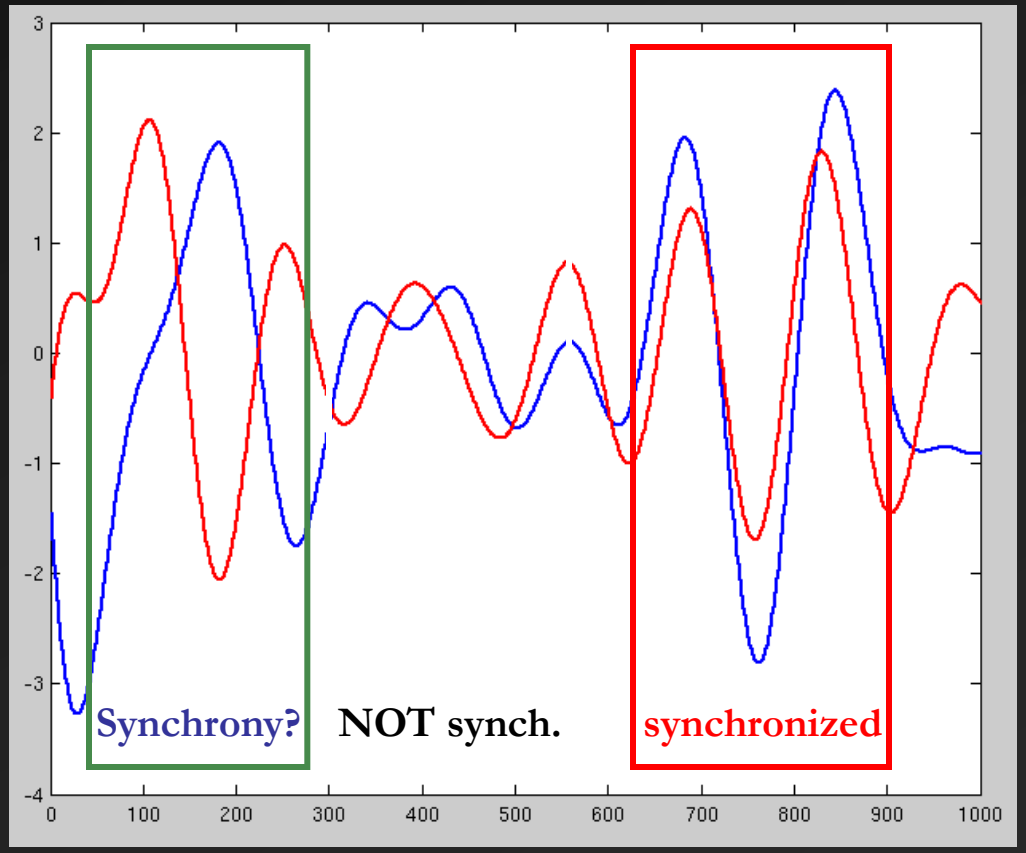


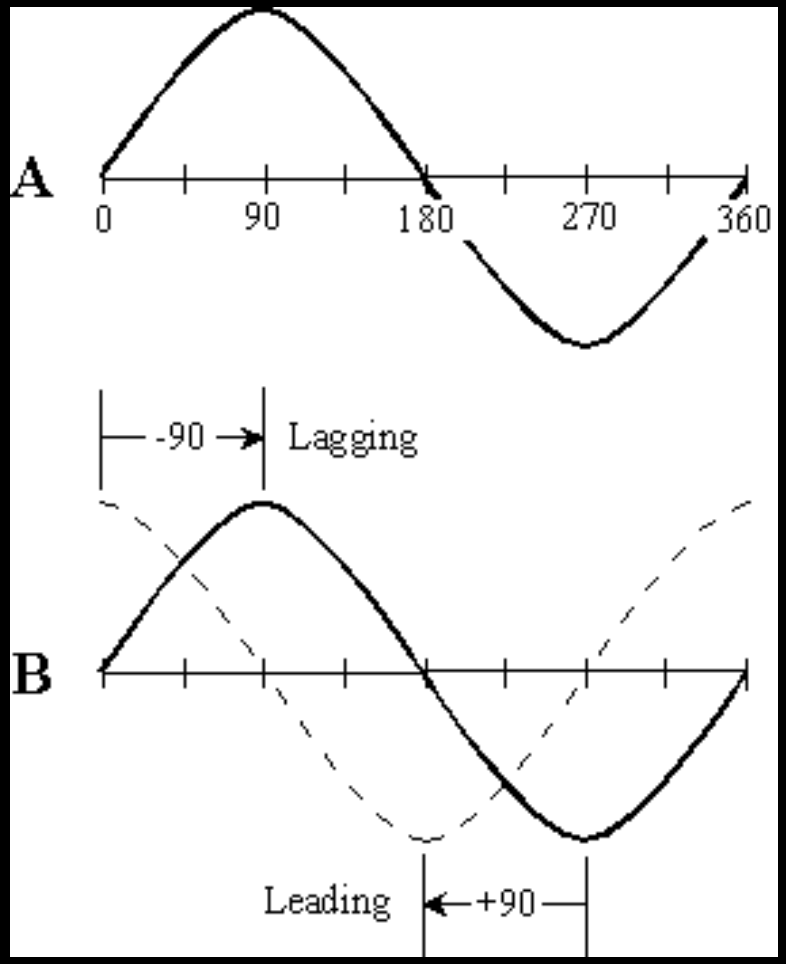
Perhaps through synchronized oscillations!

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?



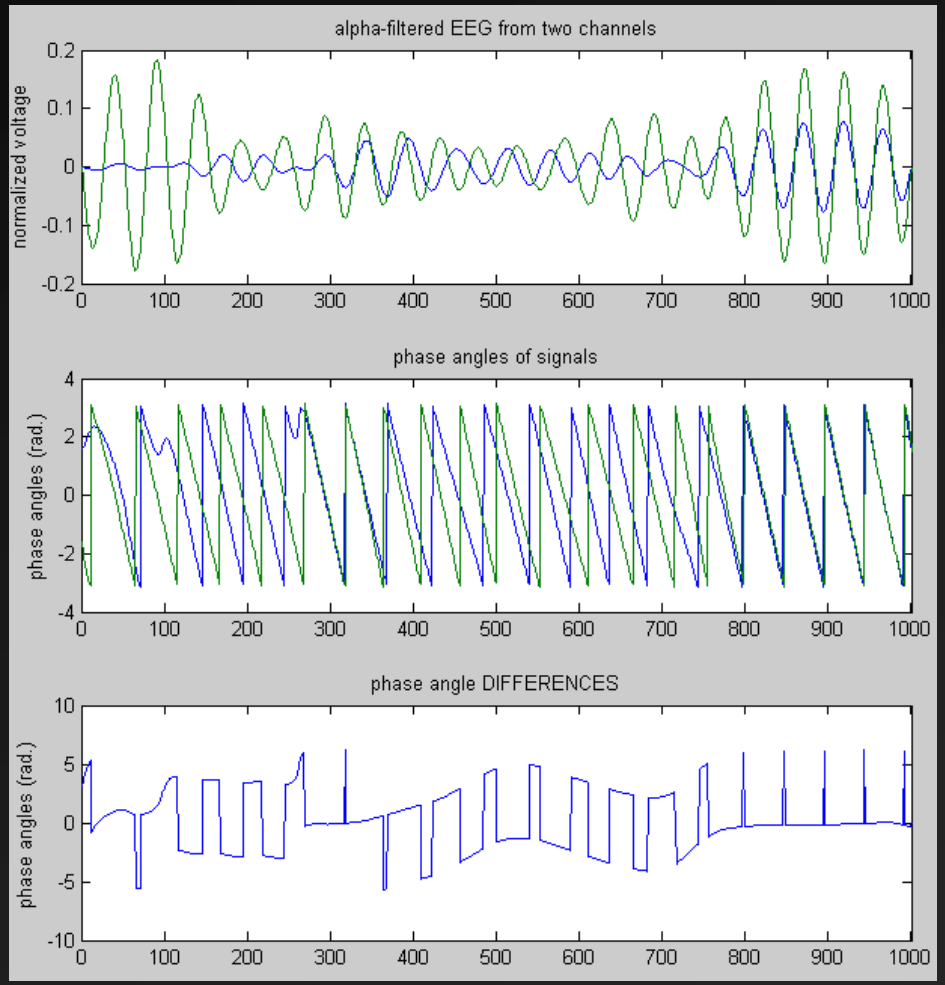


- The time interval for one degree of phase is inversely proportional to the frequency.
- You know…. the frequency of a signal f is expressed in Hz)
- The time *t* (in seconds) corresponding to:
  - one degree of phase is:
    $t_{deg} = 1 / (360\ f)$
  - one radian of phase is approximately:
    $t_{rad} = 1 / (6.28\ f)$

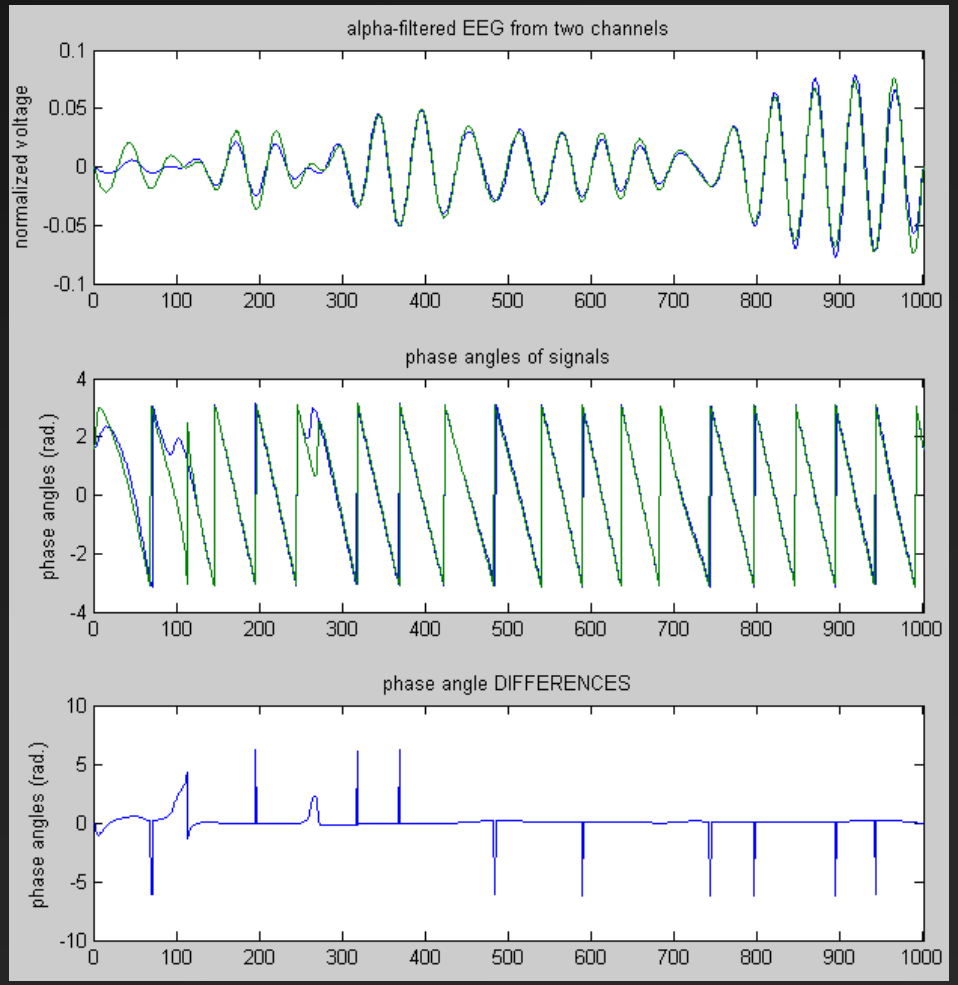
Adapted from http://whatis.techtarget.com/

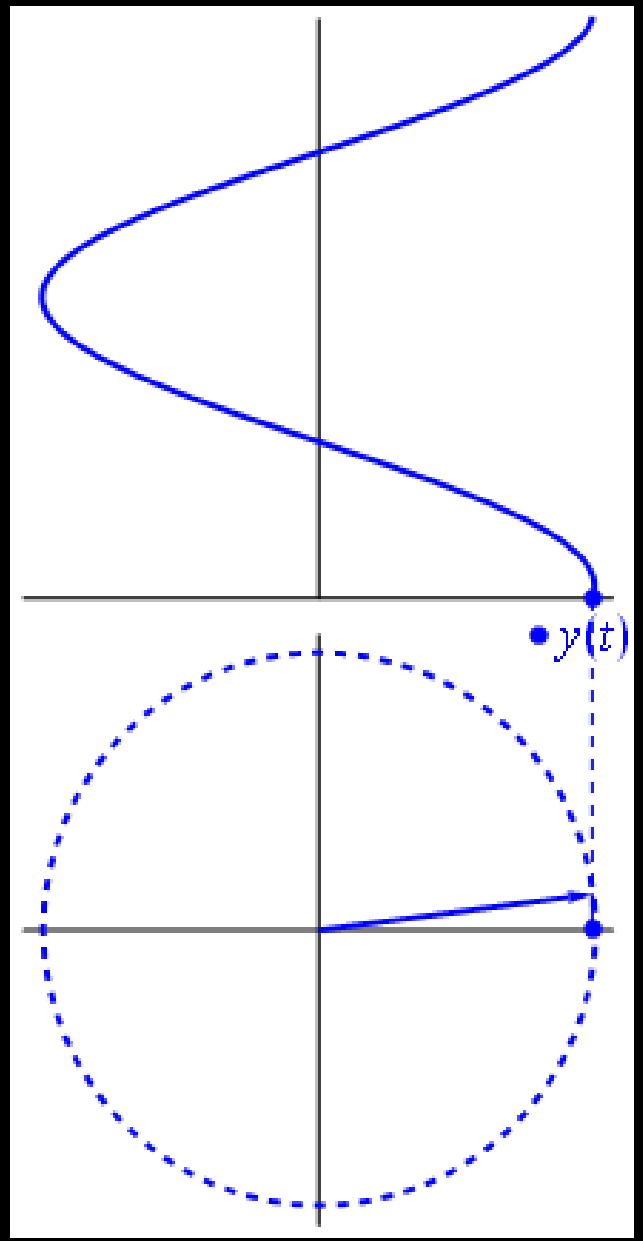
2. Inter-site phase coherence.

Electrodes: Fp1 & C4



Electrodes: Fp1 & Fp2

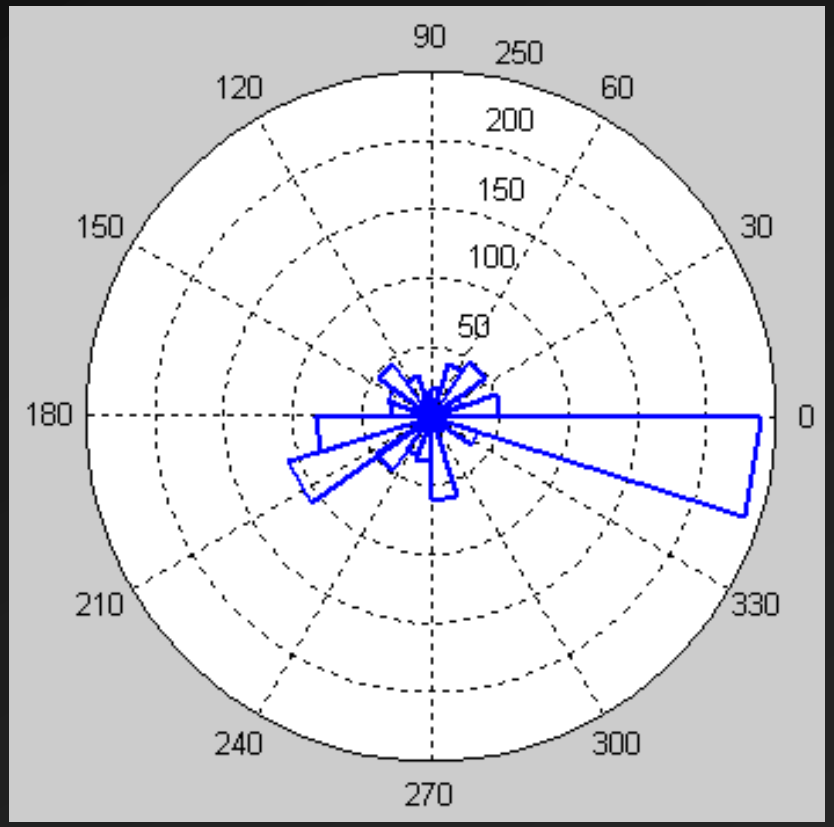



$y(t)$

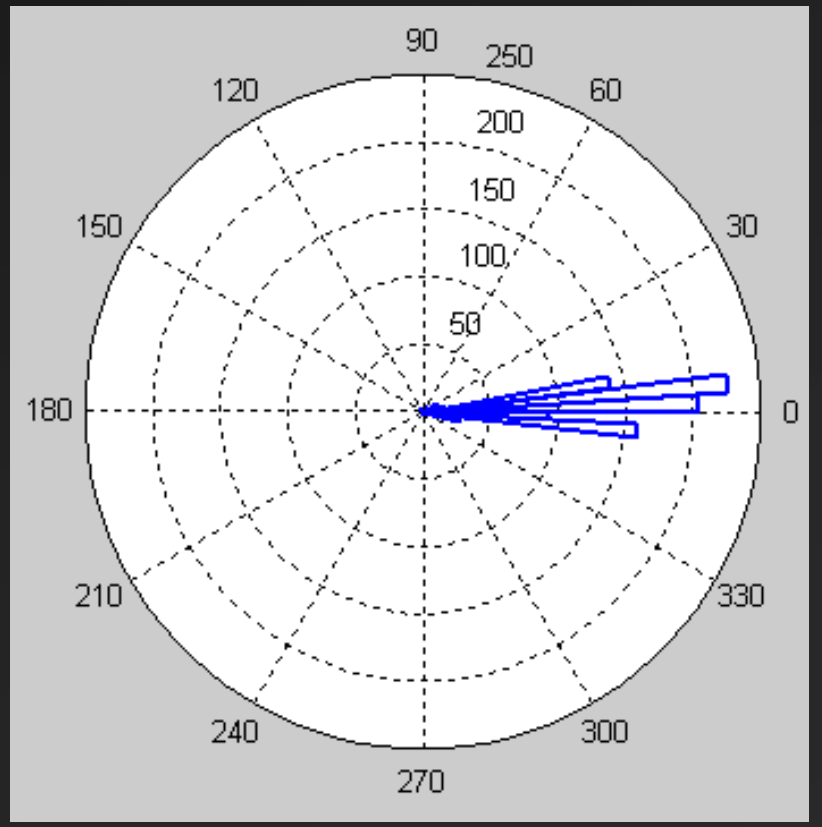
2. Inter-site phase coherence?

“Polar plot” of phase angle differences.

Electrodes: Fp1 & C4



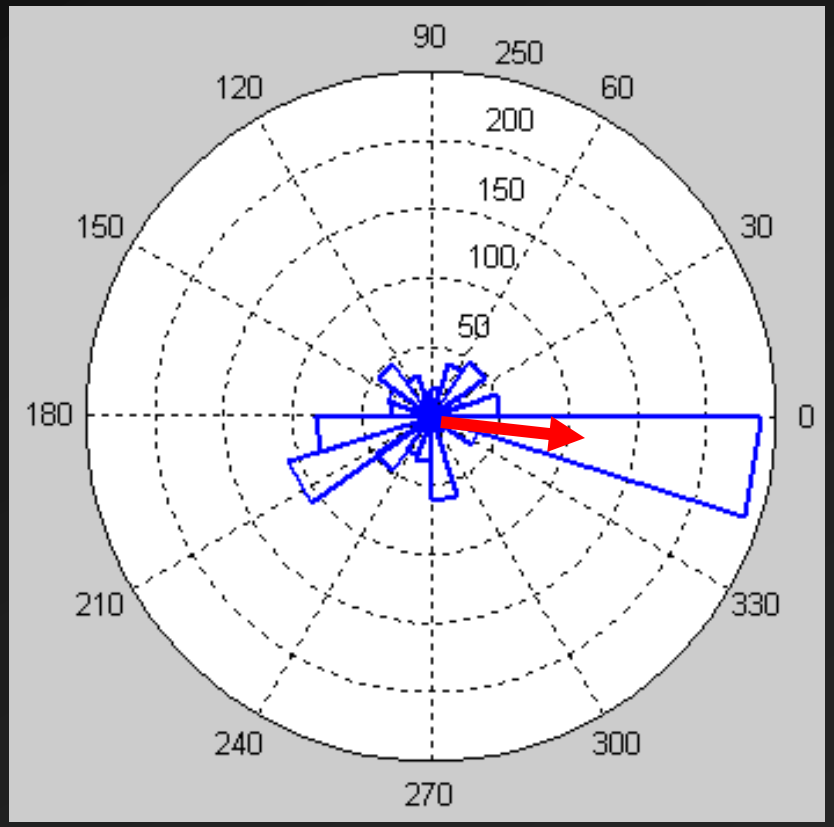
Electrodes: Fp1 & Fp2



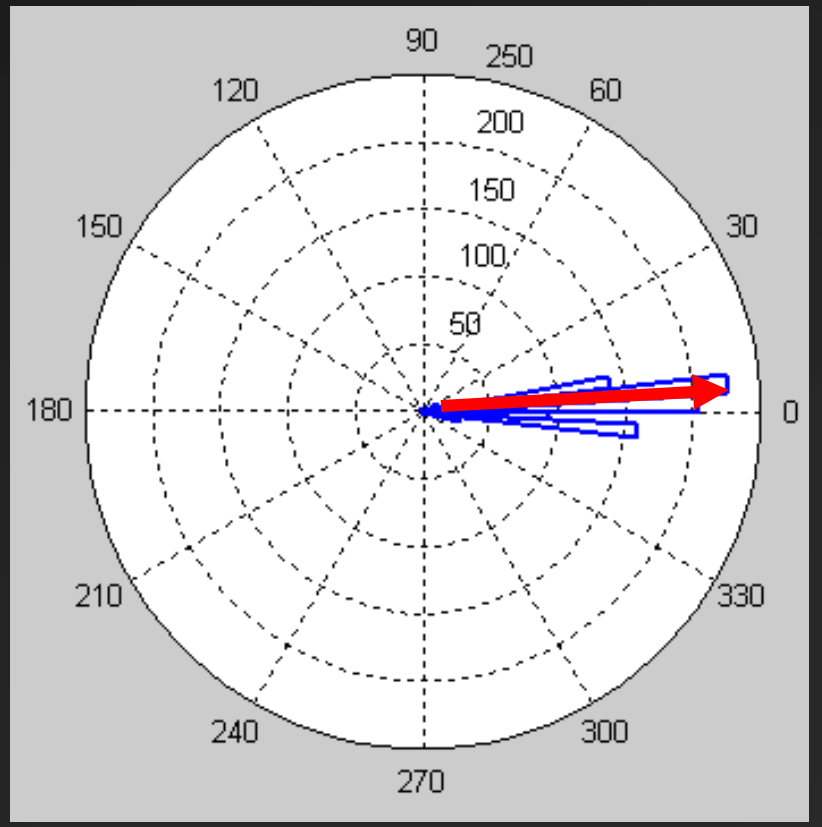
2. Circular variance.

Draw a line through the “average” of vectors.

Electrodes: Fp1 & C4



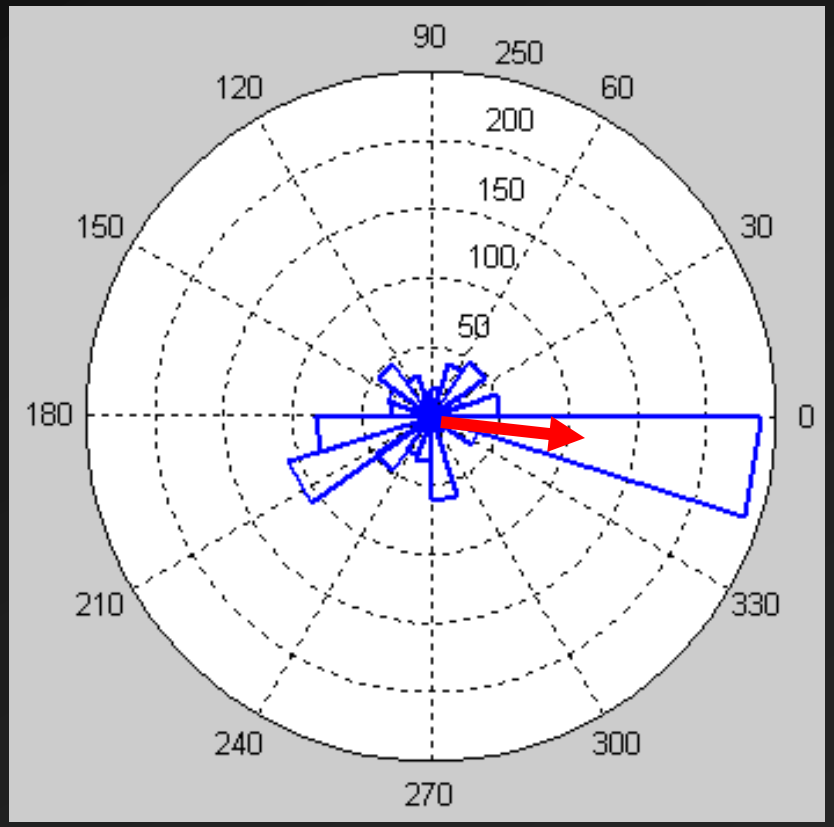
Electrodes: Fp1 & Fp2



2. Circular variance.

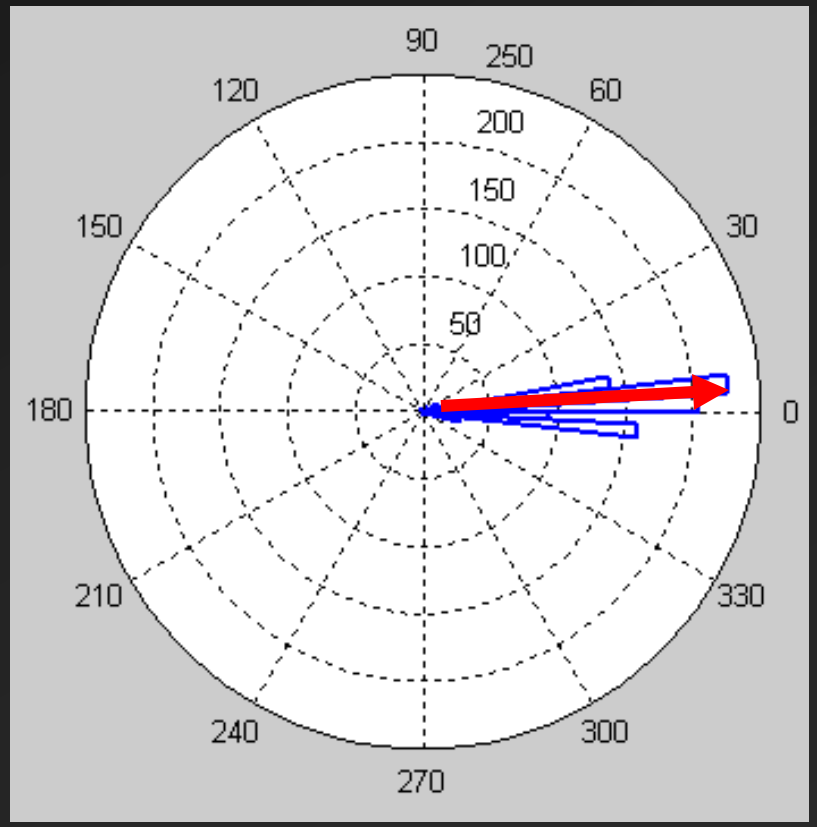
The length (magnitude) of that vector varies from 0 to 1, and is the <u>phase coherence</u>.

Electrodes: Fp1 & C4



Phase coherence: 0.11

Electrodes: Fp1 & Fp2



Phase coherence: 0.94

2. Circular variance.

The equation for phase coherence is simple:

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

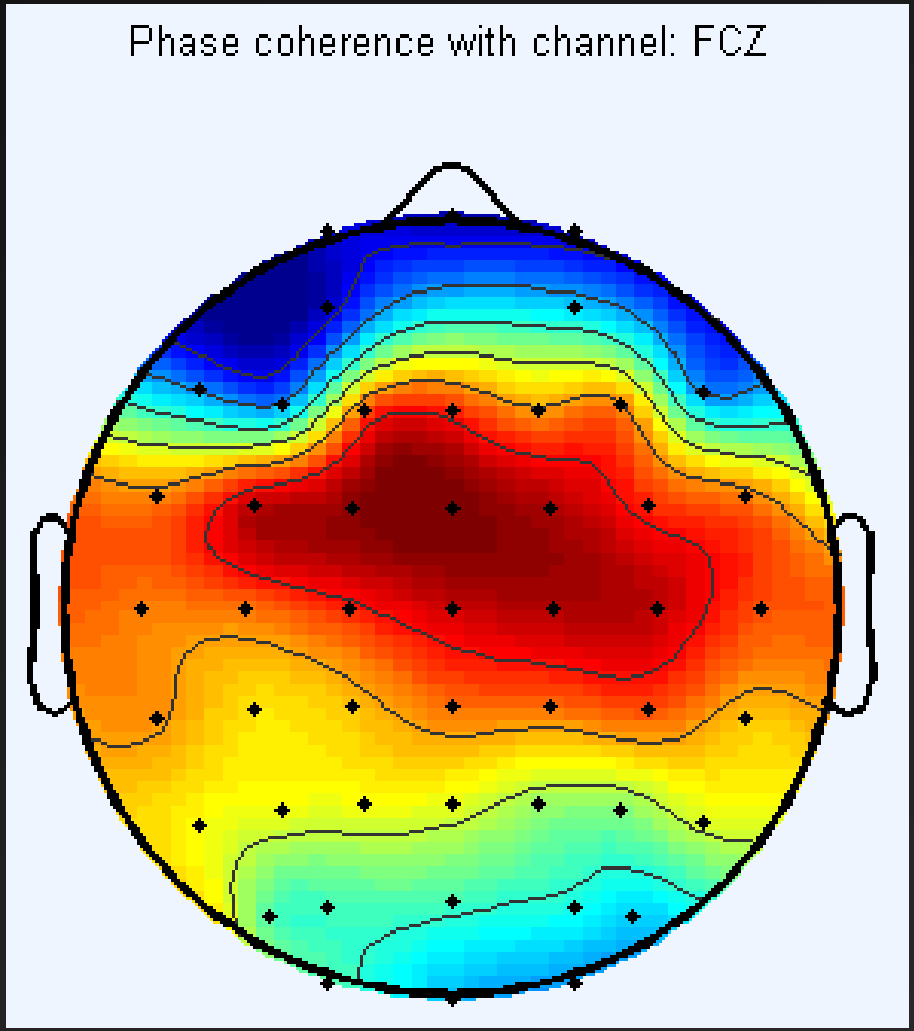
Magnitude of vector

Average across values

Transform to complex plane

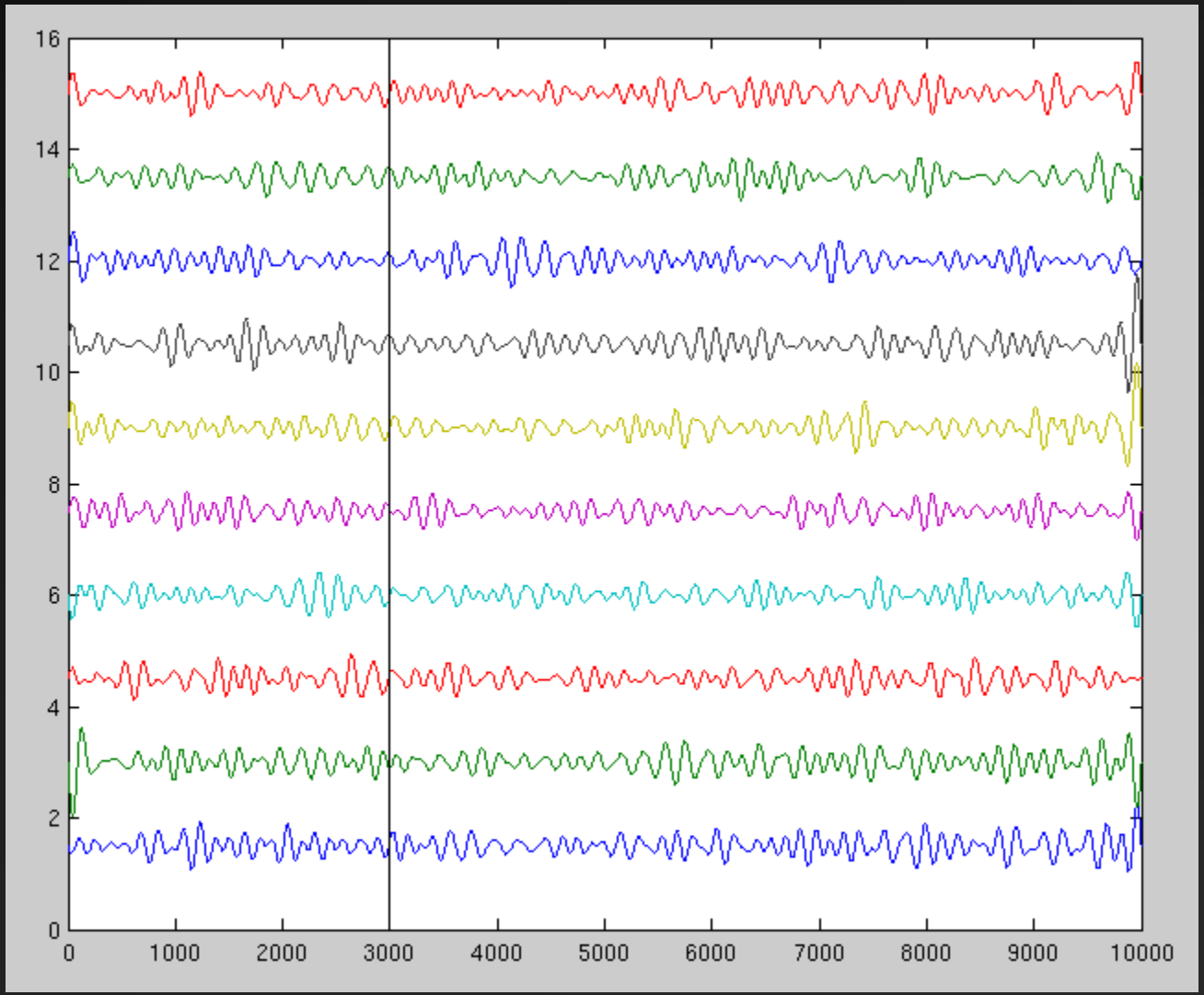
Phase angle differences between channels

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

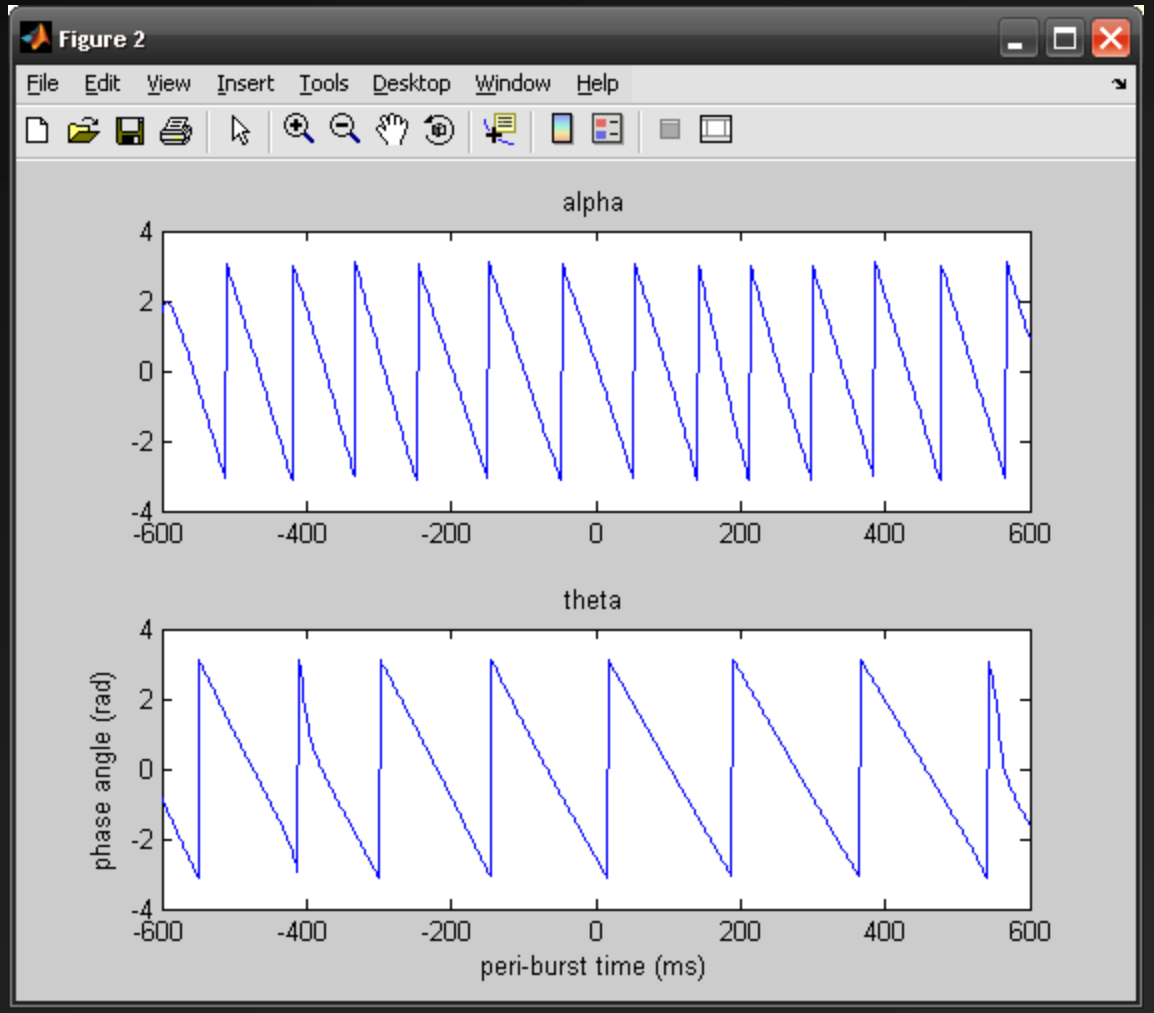


2. Inter-trial phase synchrony within one electrode.

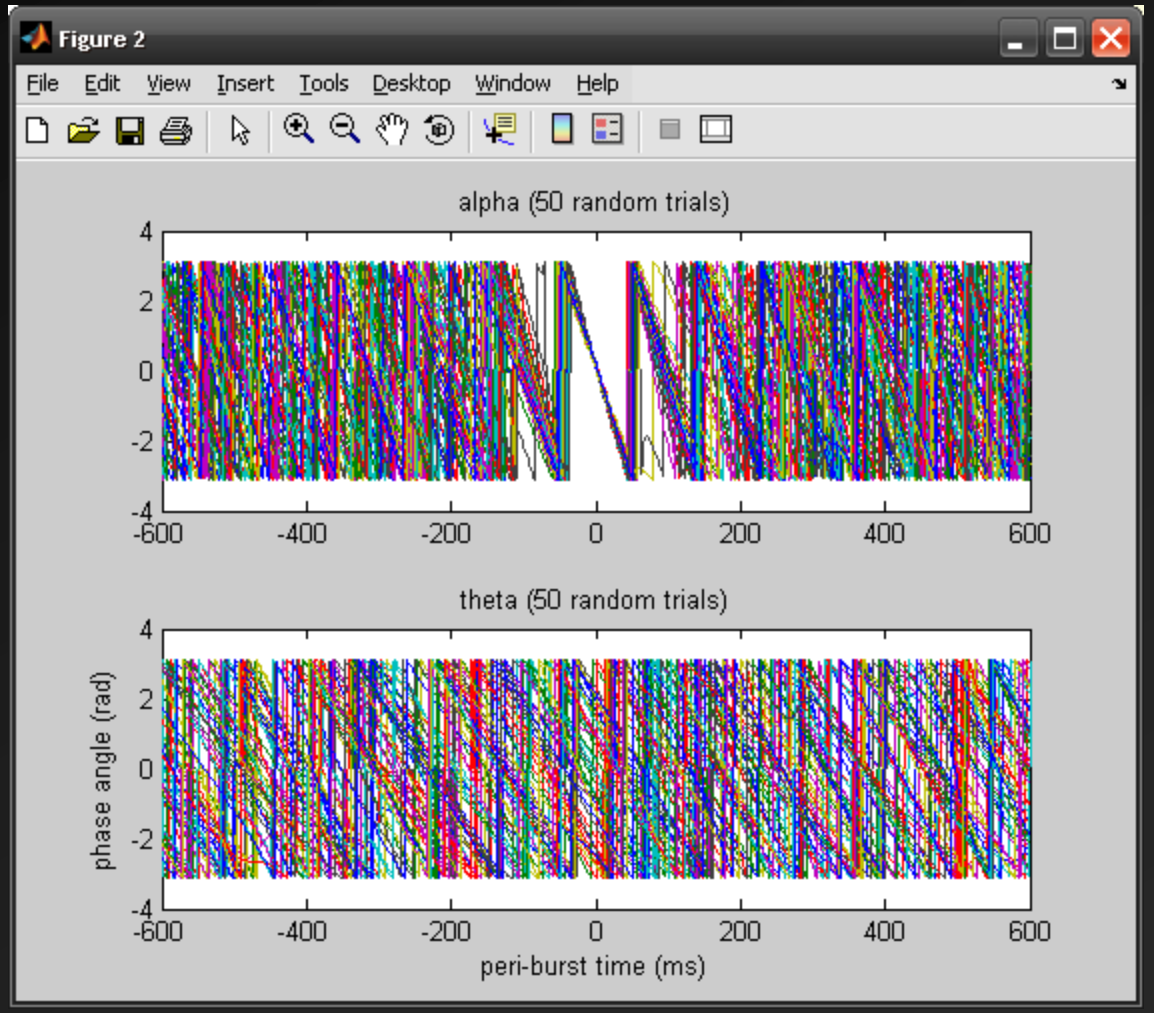
Many trials from the same electrode:



2. Inter-trial phase coherence

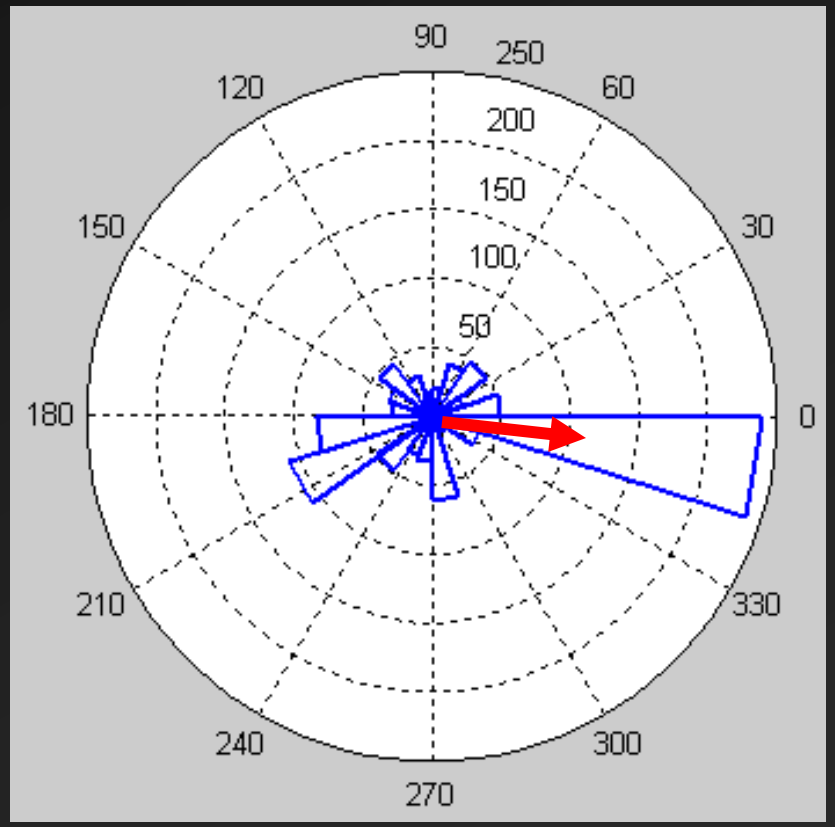


2. Inter-trial phase coherence

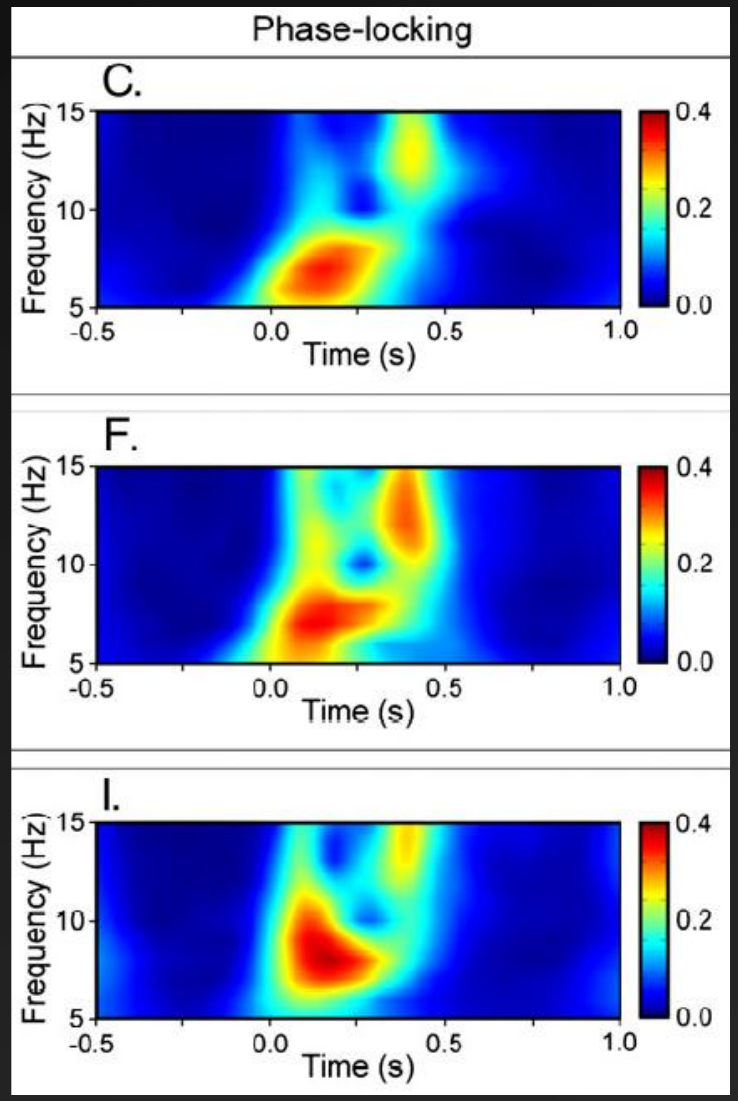


Calculate phase coherence across trials at each time point

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

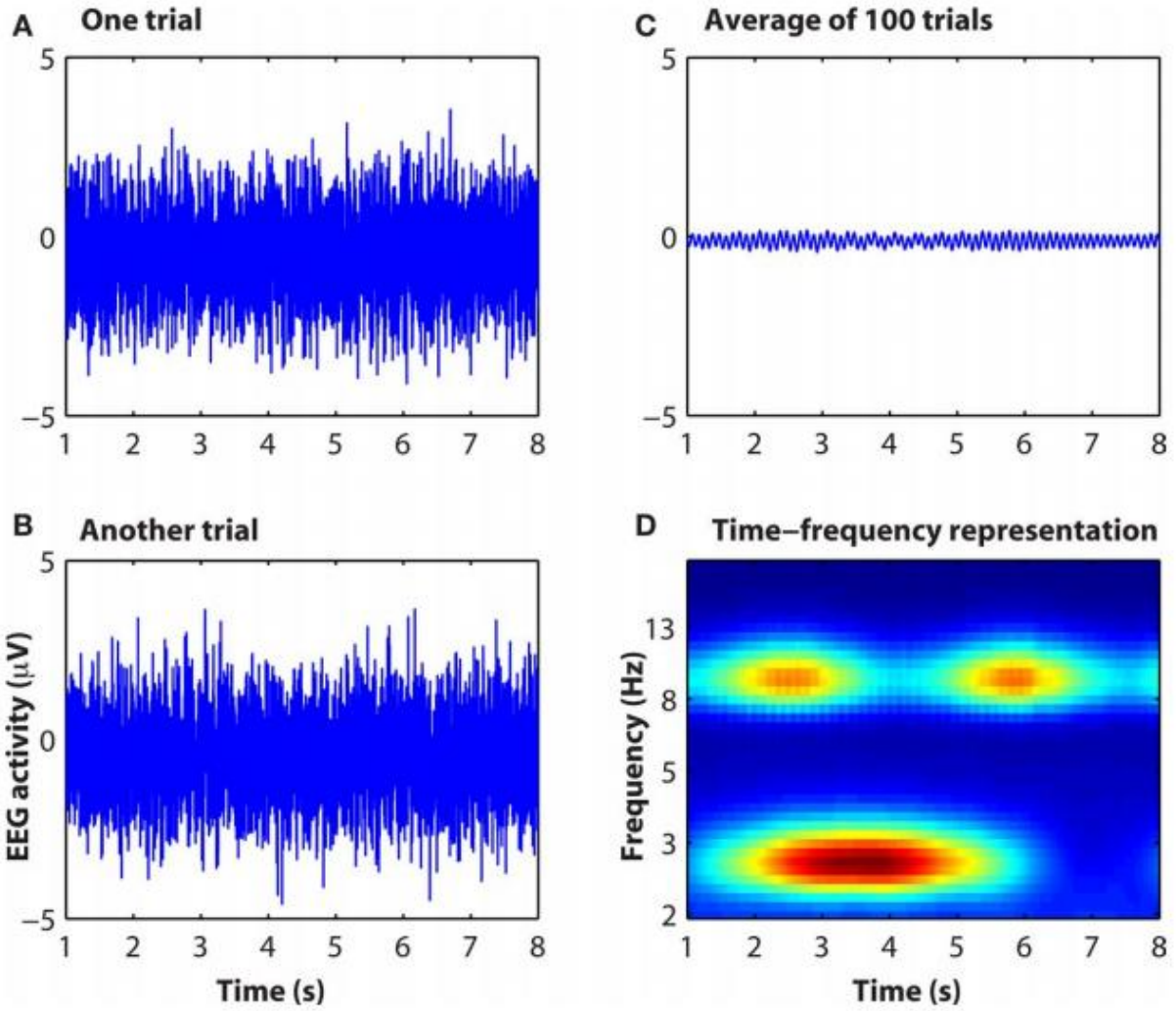
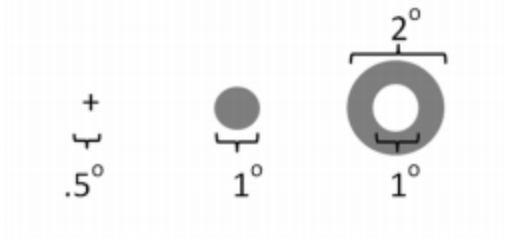
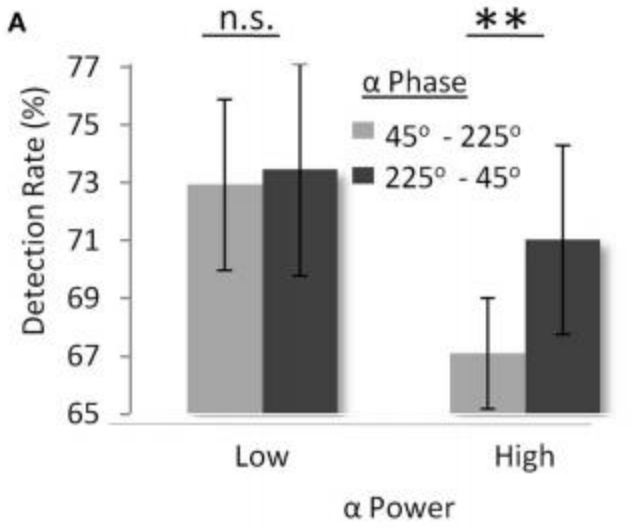


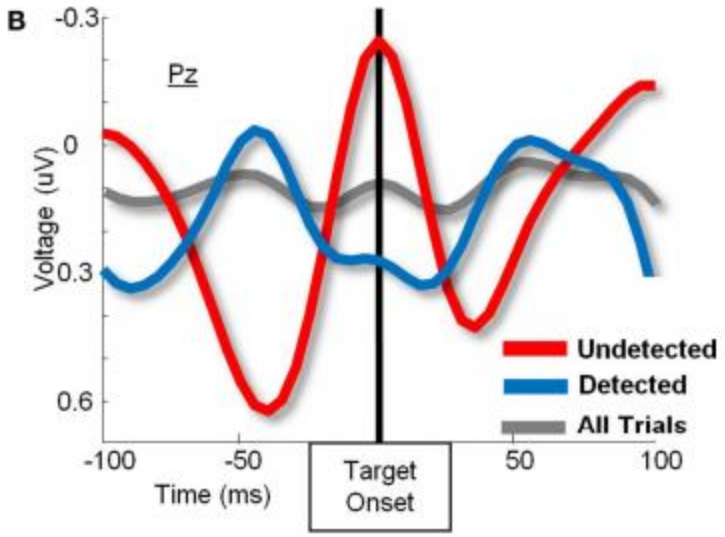
FIGURE 3 | Simulated data showing how information contained in raw EEG data [(A,B): single "trials"] is not apparent in the event-related potential **(C)** but is readily observable in the time–frequency representation **(D)**. Matlab code to run this simulation is available from the author.

Cohen, 2011, *Frontiers in Human Neuroscience*

The Importance of Phase!







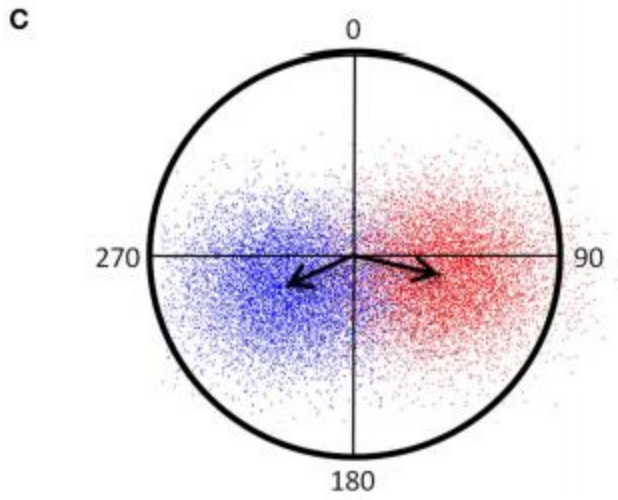


FIGURE 3 | (A) Detection rate as a function of alpha power and phase before stimulus onset. When alpha power is low (left bar graph), there is no difference in masked-target detection as a function of pre-target alpha-phase. When alpha power is high (right bar graph), however, not only is detection lower 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).

The alpha cycle reflects **periodic fluctuations** in cortical excitability.

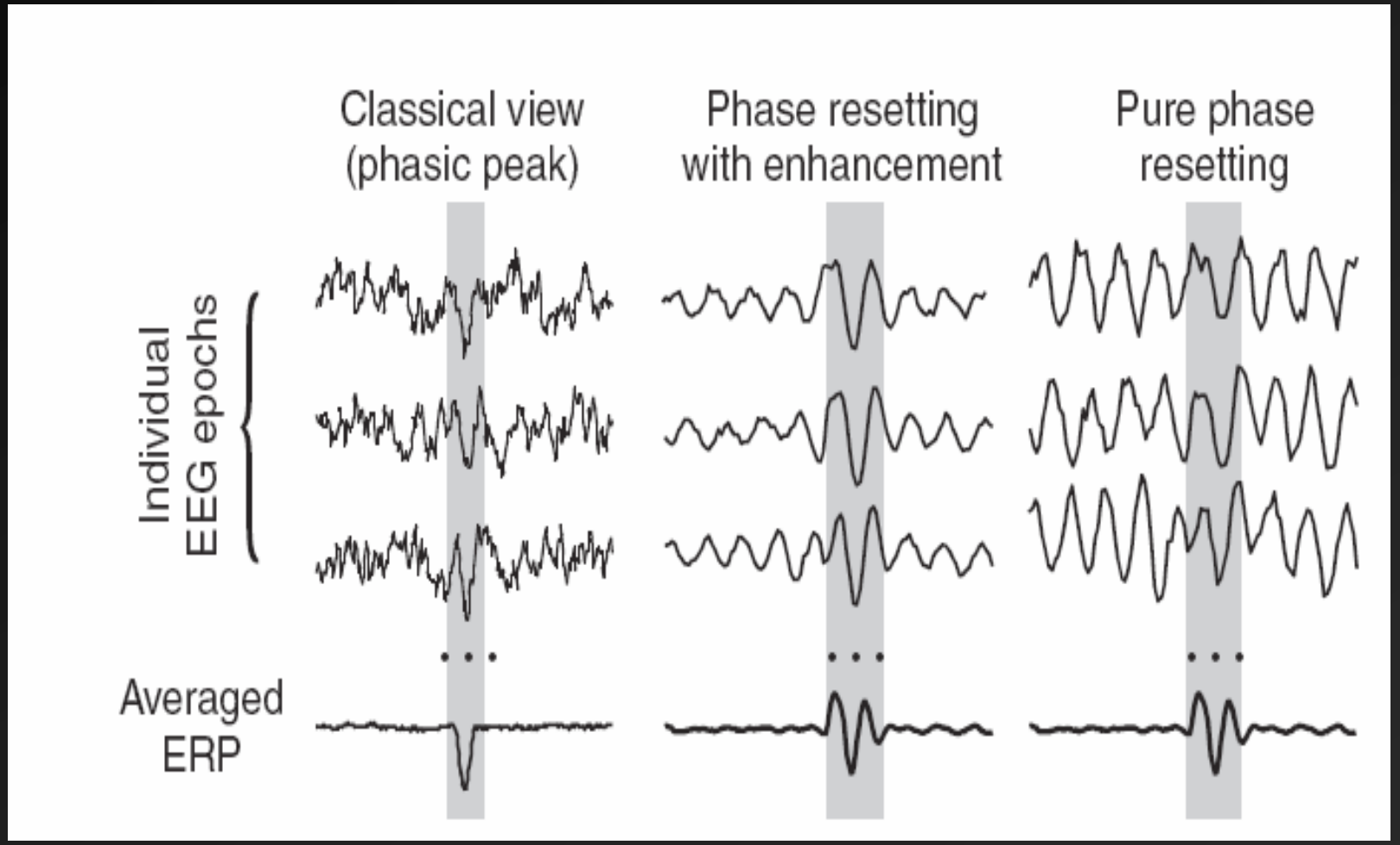
•At certain phases (e.g., the trough of the alpha wave), cortical neurons are **more excitable**, making stimulus detection more likely.

•At other phases (e.g., the peak), the cortex is **less excitable**, reducing the chance of conscious perception.

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

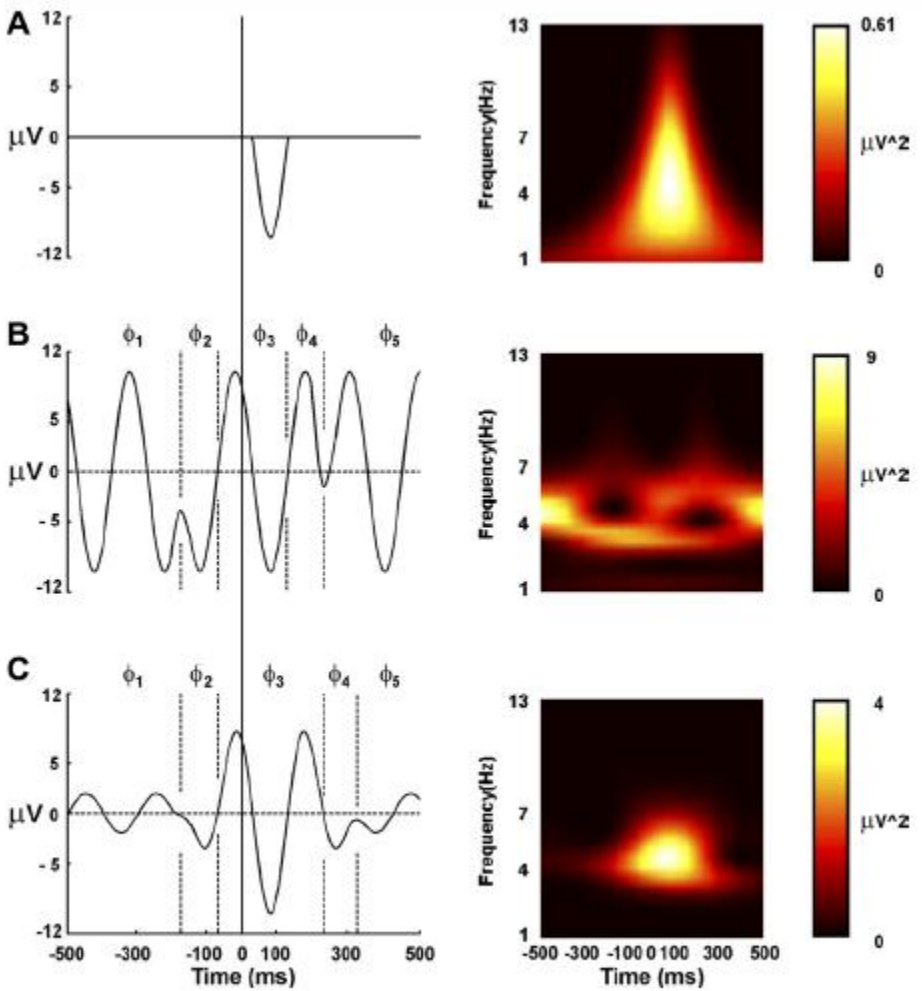
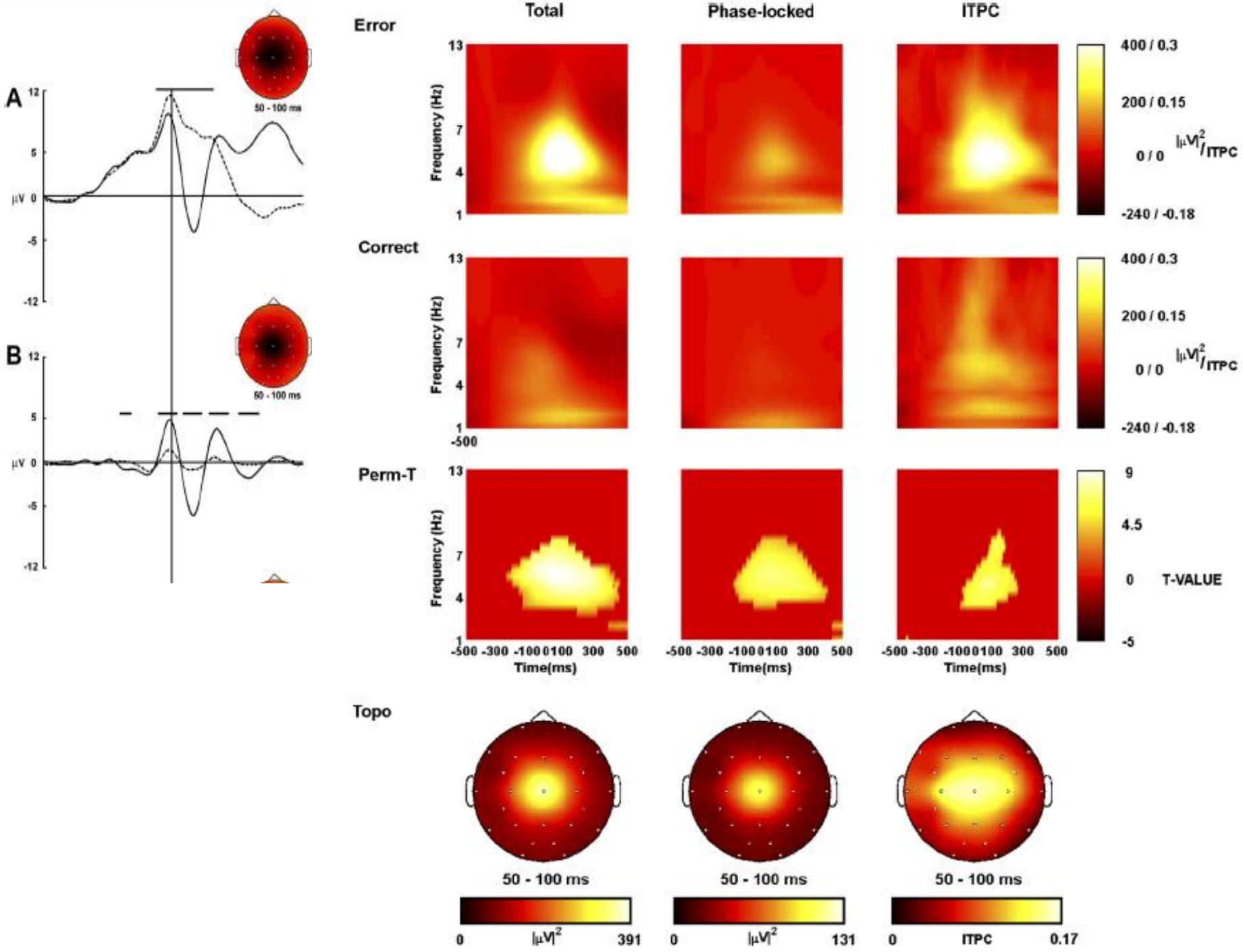
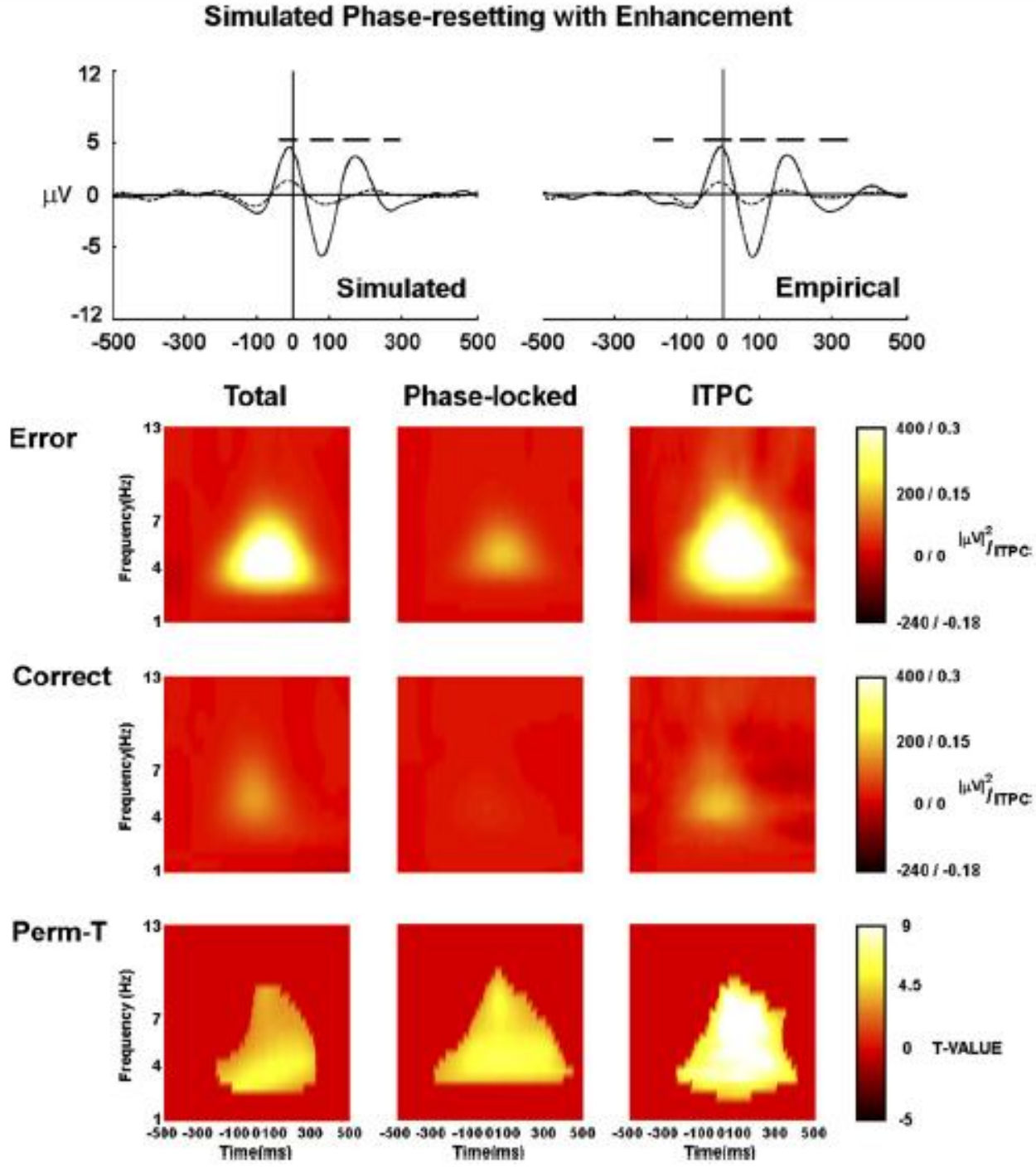
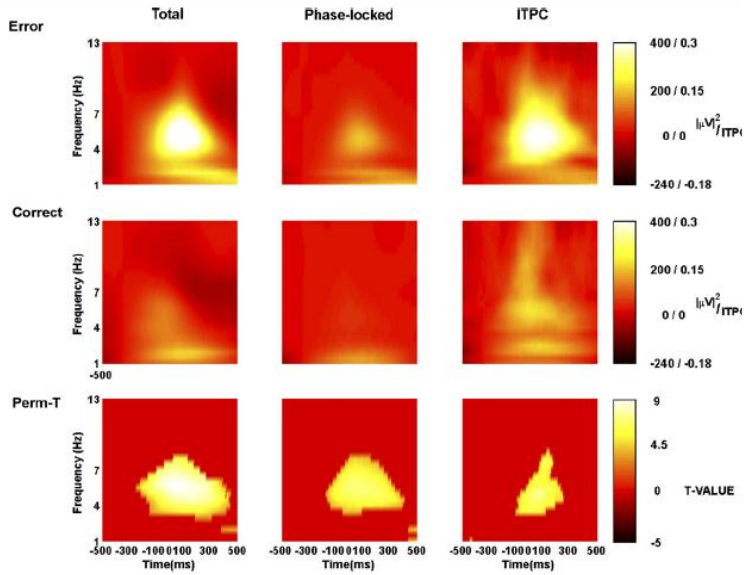


Fig. 1. Left column: Basic oscillatory waveforms used to simulate ERN responses according to the (A) *classic*, (B) *pure phase-resetting*, and (C) *phase-resetting with enhancement* hypotheses of ERN generation. Right column: Corresponding non-baseline-corrected wavelet-based time–frequency representations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

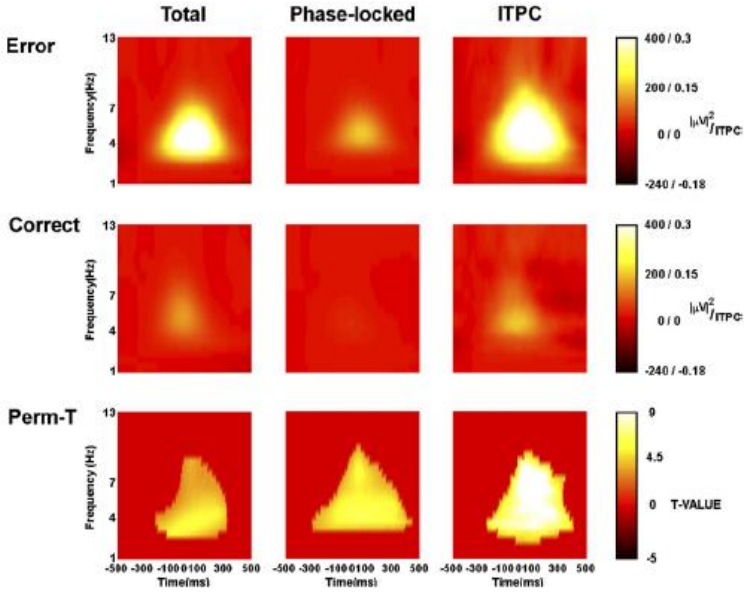

A
B
50 - 100 ms
60 - 100 ms
12
5
μV 0
-5
-12
Error
Correct
Perm-T
Total
Phase-locked
ITPC
Frequency (Hz)
13
7
4
1
-500
Time(ms)
-500 -300 -100 0100 300 500
400 / 0.3
200 / 0.15
0 / 0
-240 / -0.18
|μV|²/ITPC
9
4.5
0
-5
T-VALUE
Topo
50 - 100 ms
0
|μV|²
391
131
ITPC
0.17


Simulated Phase-resetting with Enhancement
12
5
μV 0
-5
-12
Simulated
Empirical
-500 -300 -100 0 100 300 500
Total
Phase-locked
ITPC
Error
Correct
Perm-T
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)

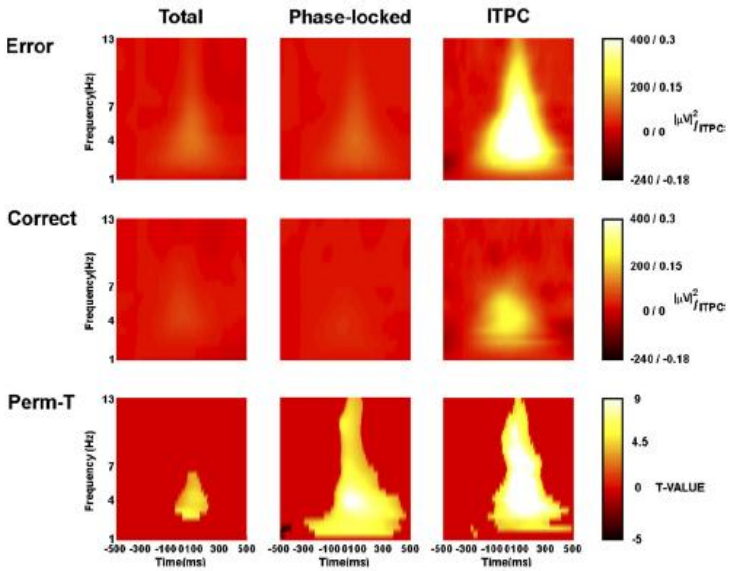
Empirical



Simulated Phase + Amp Enhance



Simulated Classic



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

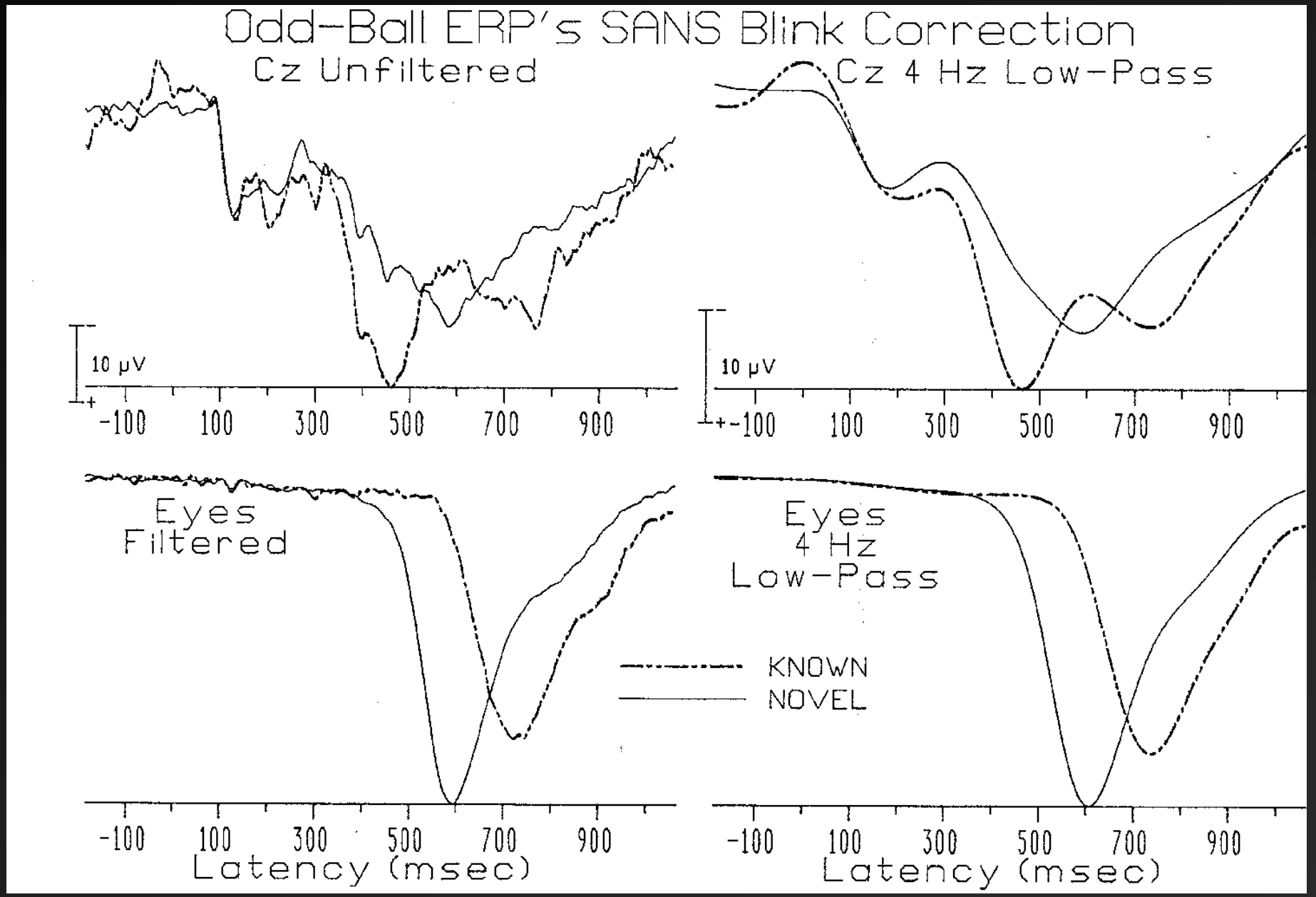
- Signal averaging will not remove this "noise" (noise wrt signal of interest)
- Average waveform a(t) is mixture of timelocked signal s(t) and randomly distributed error (noise)

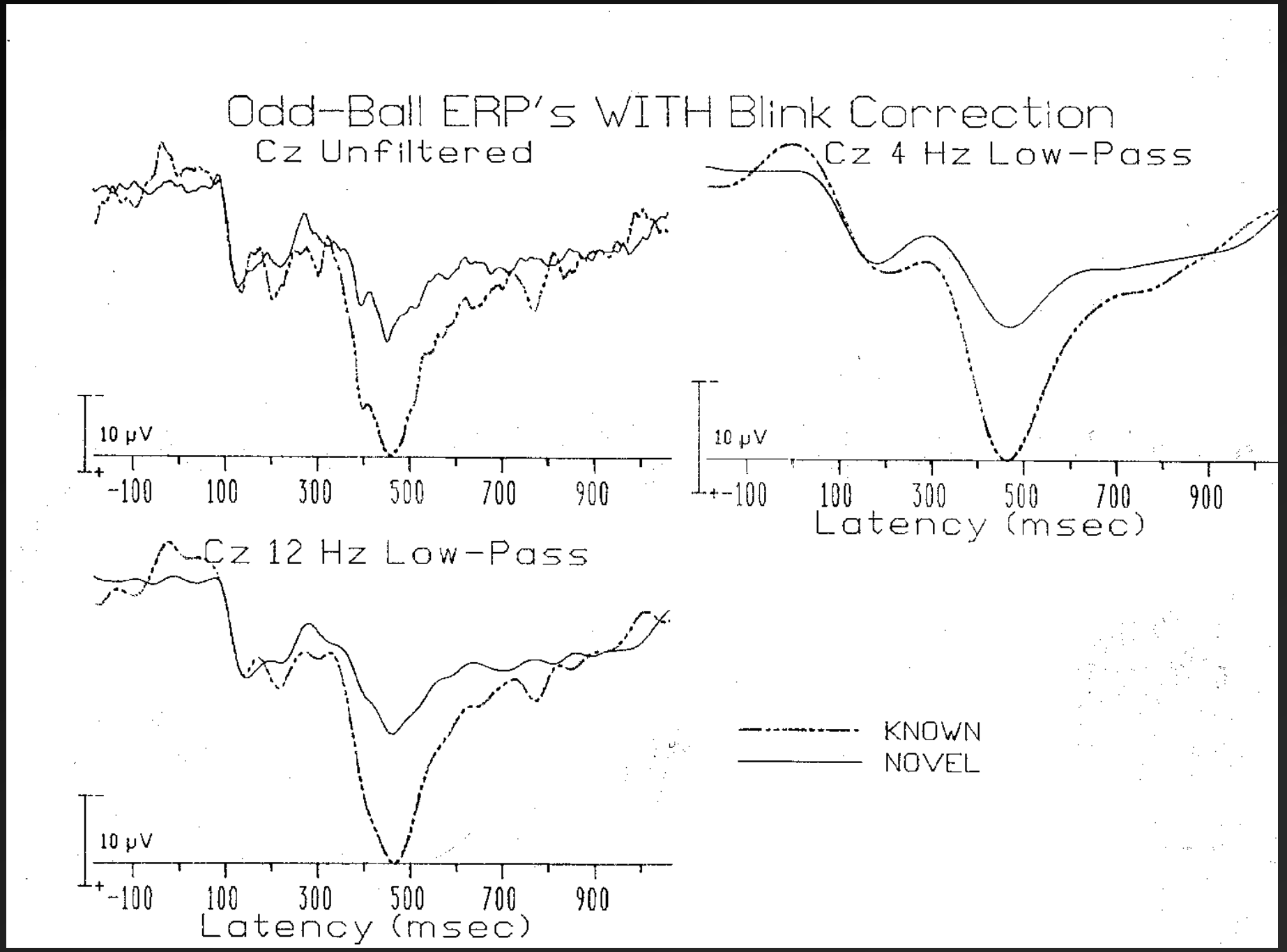
$$a(t) = s(t) + \frac{\sum_{1}^{n} e(t)}{n}$$

- 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

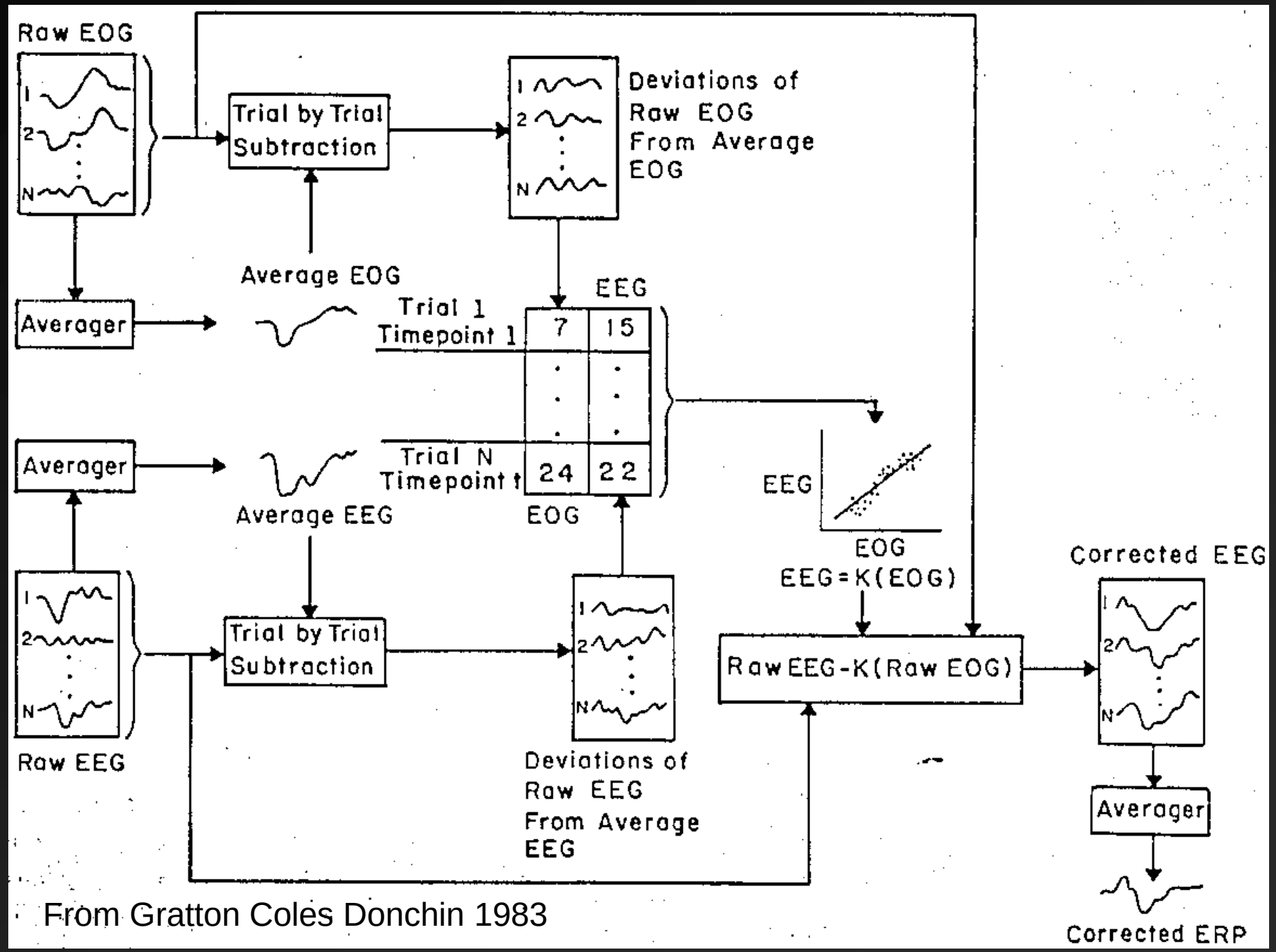
- Eye-blinks tend to occur at the cessation of processing.
  - Recall that the P300 is also a good index of cessation of processing.
- As a result, eye-blink artifact tends to appear as a late P300ish component


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

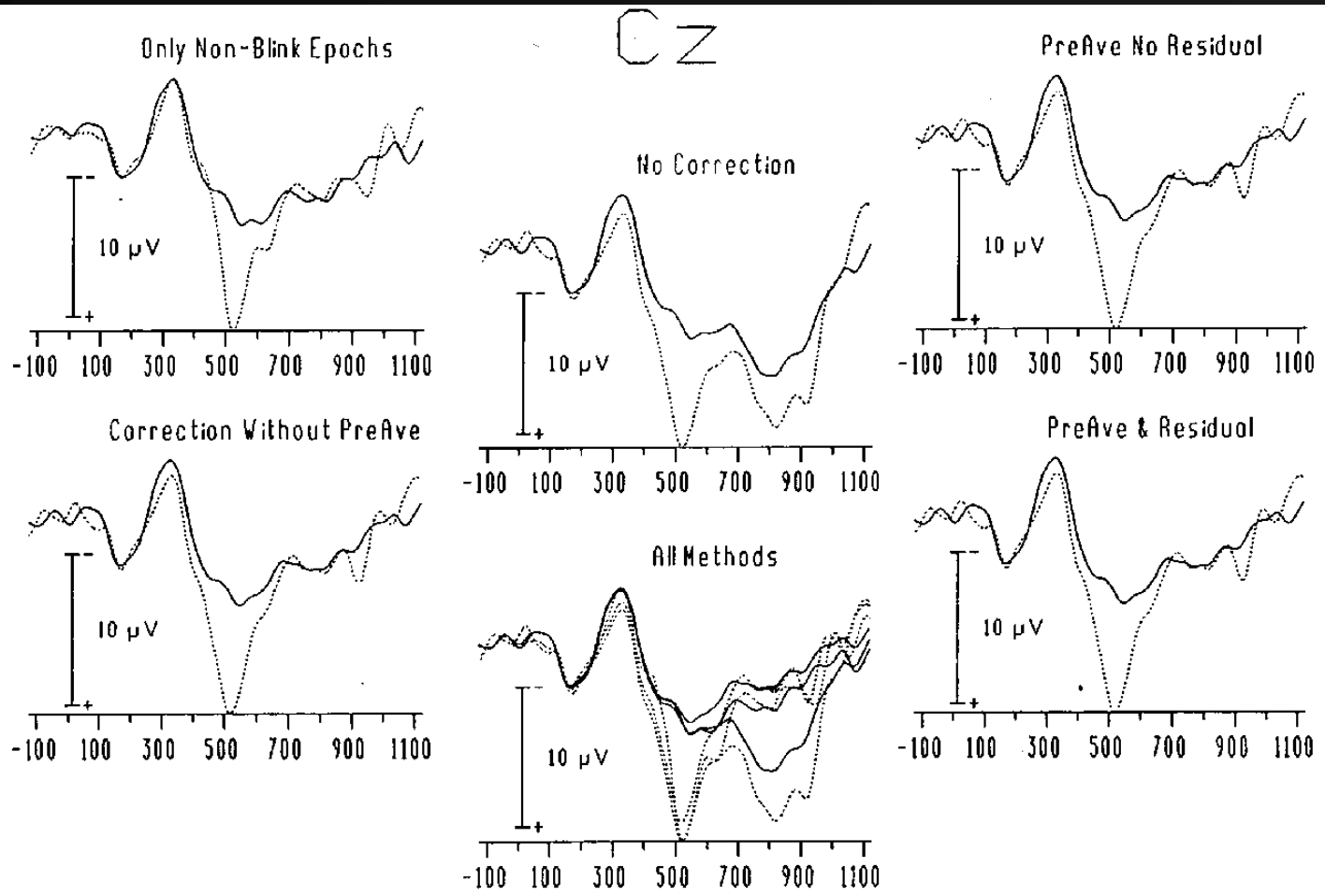
- Must determine extent to which EOG signal propagates to various scalp loci
  - Propagation factors computed only after any event-related activity is removed from both EOG & EEG channels
  - Event related activity in both channels may spuriously inflate estimate of propagation
  - Based upon correlation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

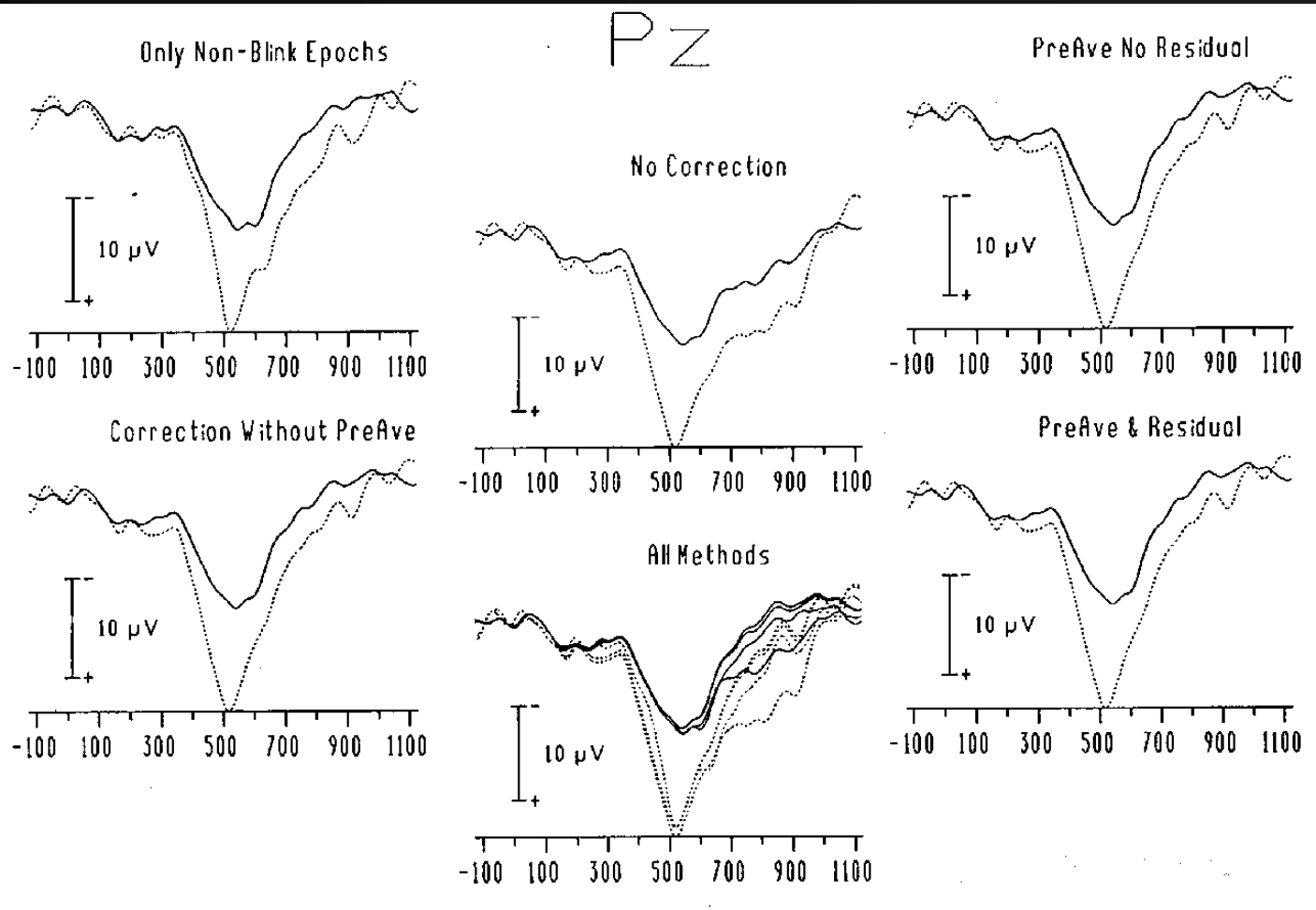
Validity of Ocular Correction

- 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).



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.

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"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).

Other Methods (in brief)

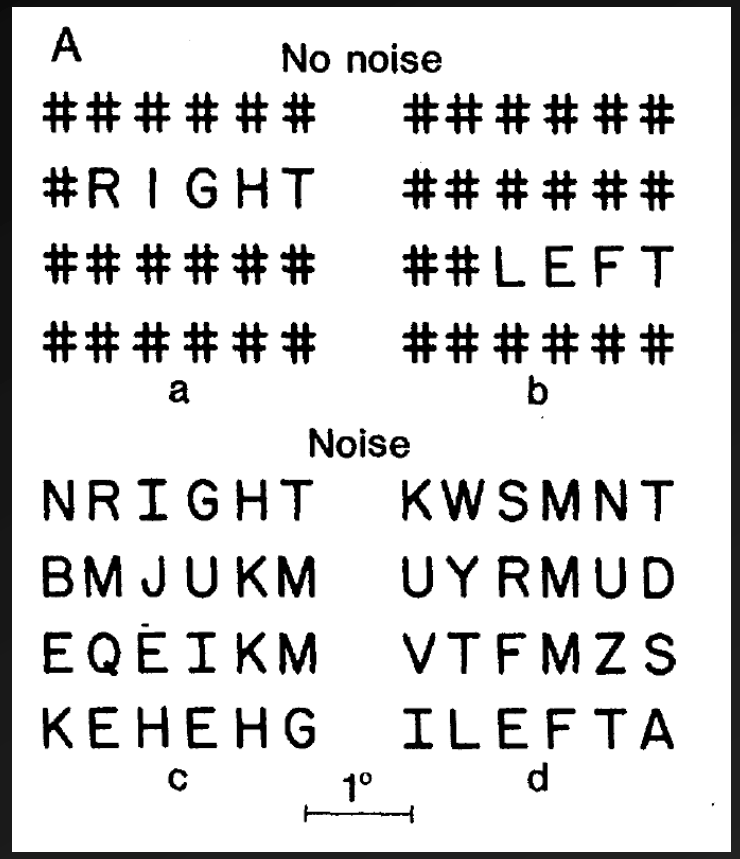
- Most other methods also depend upon subtraction of a proportion of the EOG signal or some transformation of the EOG signal
  - Frequency-domain methods recognize that not all frequencies in the EOG channel propagate equally to scalp sites
  - Source localization methods attempt to derive a source that 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

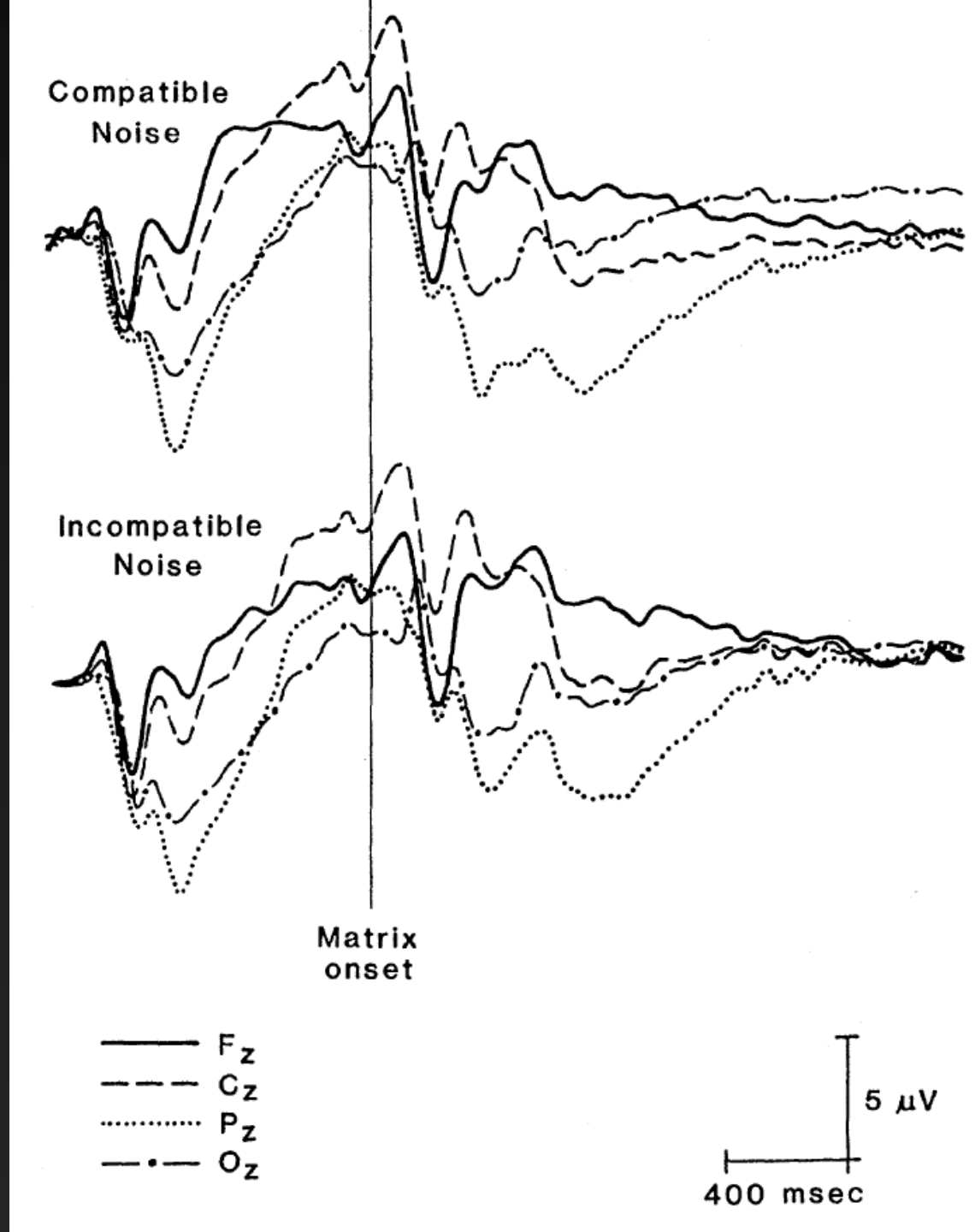
Demonstration of Ocular Correction

One more advanced topic…

The Problem of Latency Jitter

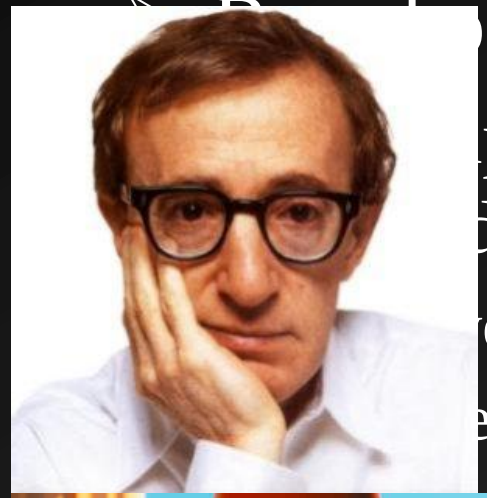
- The averaging assumption of invariance in signal is not always warranted
  - Especially for the later endogenous components
  - To the extent that the signal varies from trial to trial, the average will produce potentially misleading results
- Two common possibilities:
  - Smearing of components;
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


A
No noise
######
#RIGHT
######
######
######
######
a
######
##LEFT
######
######
b
Noise
NRIGHT
BMJUKM
EQEIKM
KEHEHG
c
KWSMNT
UYRMUD
VTFMZS
ILEFTA
d
1°


Compatible
Noise
Incompatible
Noise
Matrix
onset
Fz
Cz
Pz
Oz
5 μV
400 msec

The Solution

- The Woody Adaptive Filter (Woody, 1967)
- n Cross-co
  - ptions less r aver
    ds
  - eform (morph onsta
    ency need not



Details

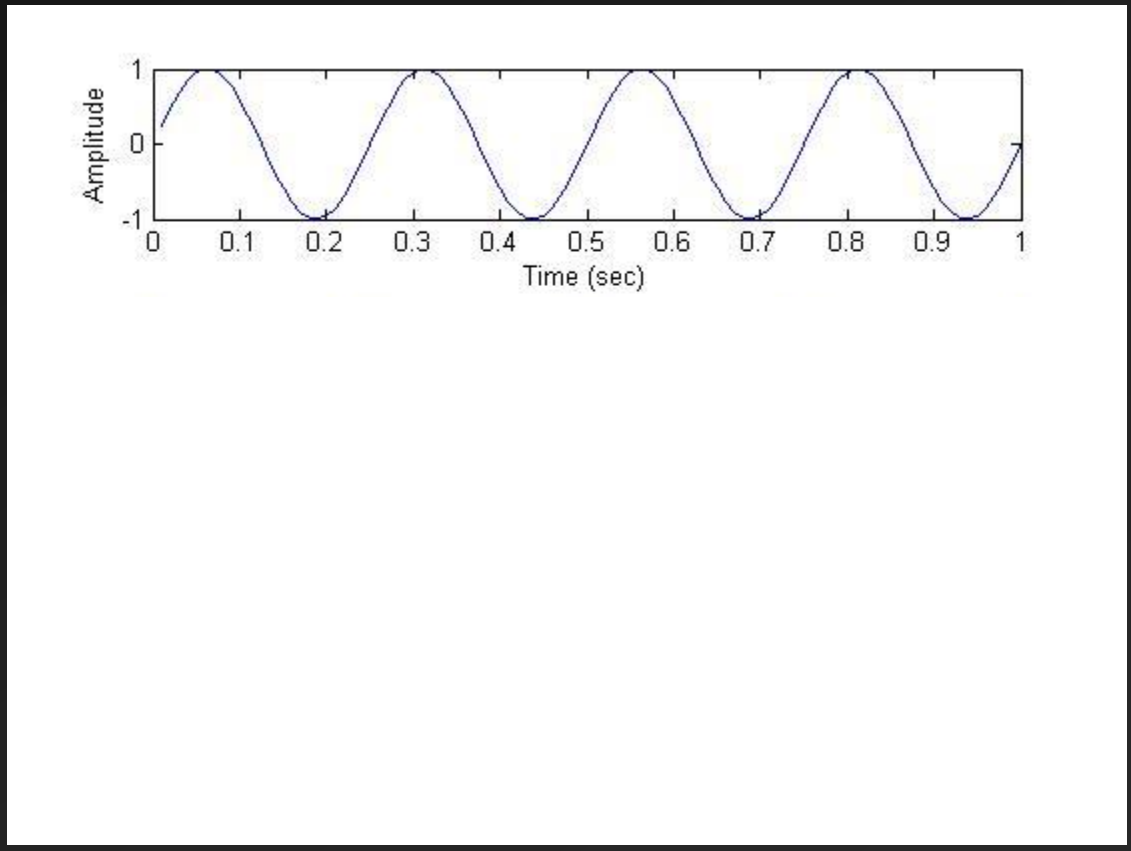
- Cross-correlational series
  - For two waveforms the correlation between each of them is computed
    - first with no lag in time
      a1, a2, ..., an
      b1, b2, ... bn
    - then with one lagged with respect to the other
      a1, a2, ..., an-1
      b2, b3, ... bn
  - A series of correlation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

The Basic Idea

Sine

Cosine

Cross-Correlation



See … CrossCorr_Sin_Cos.m

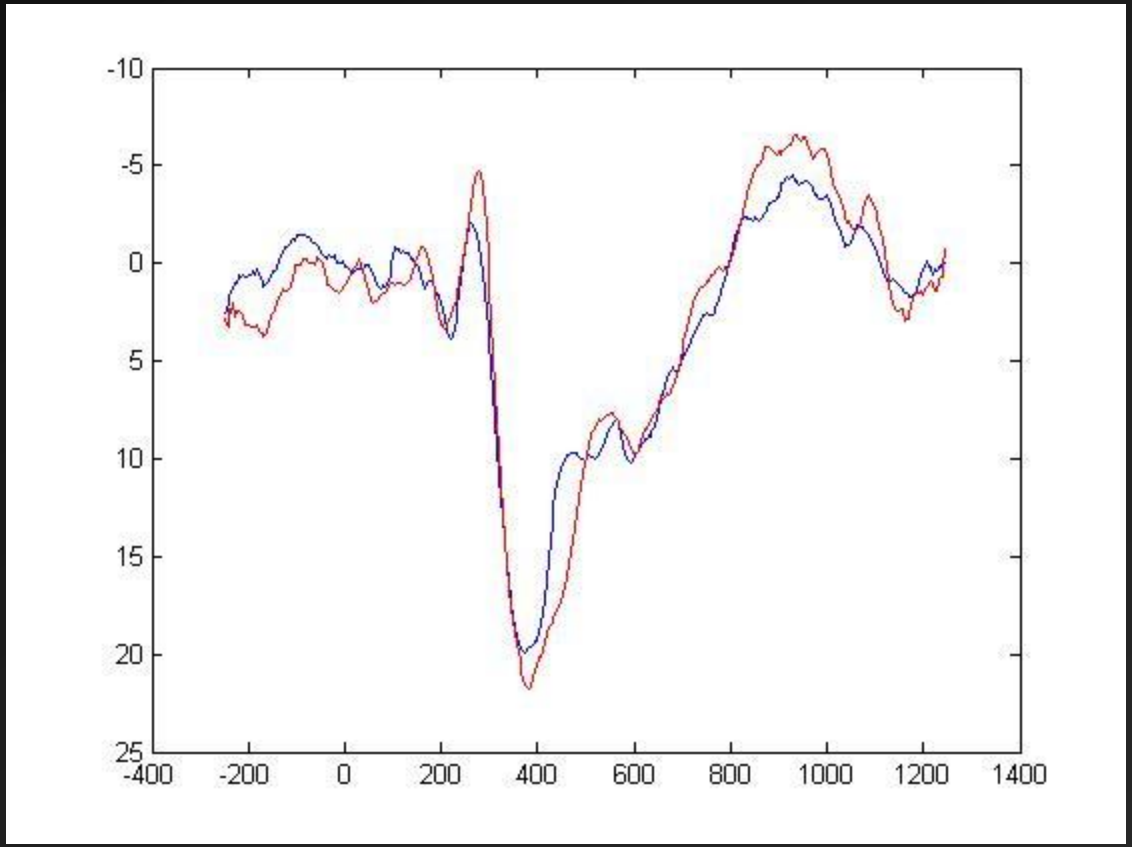
More Details

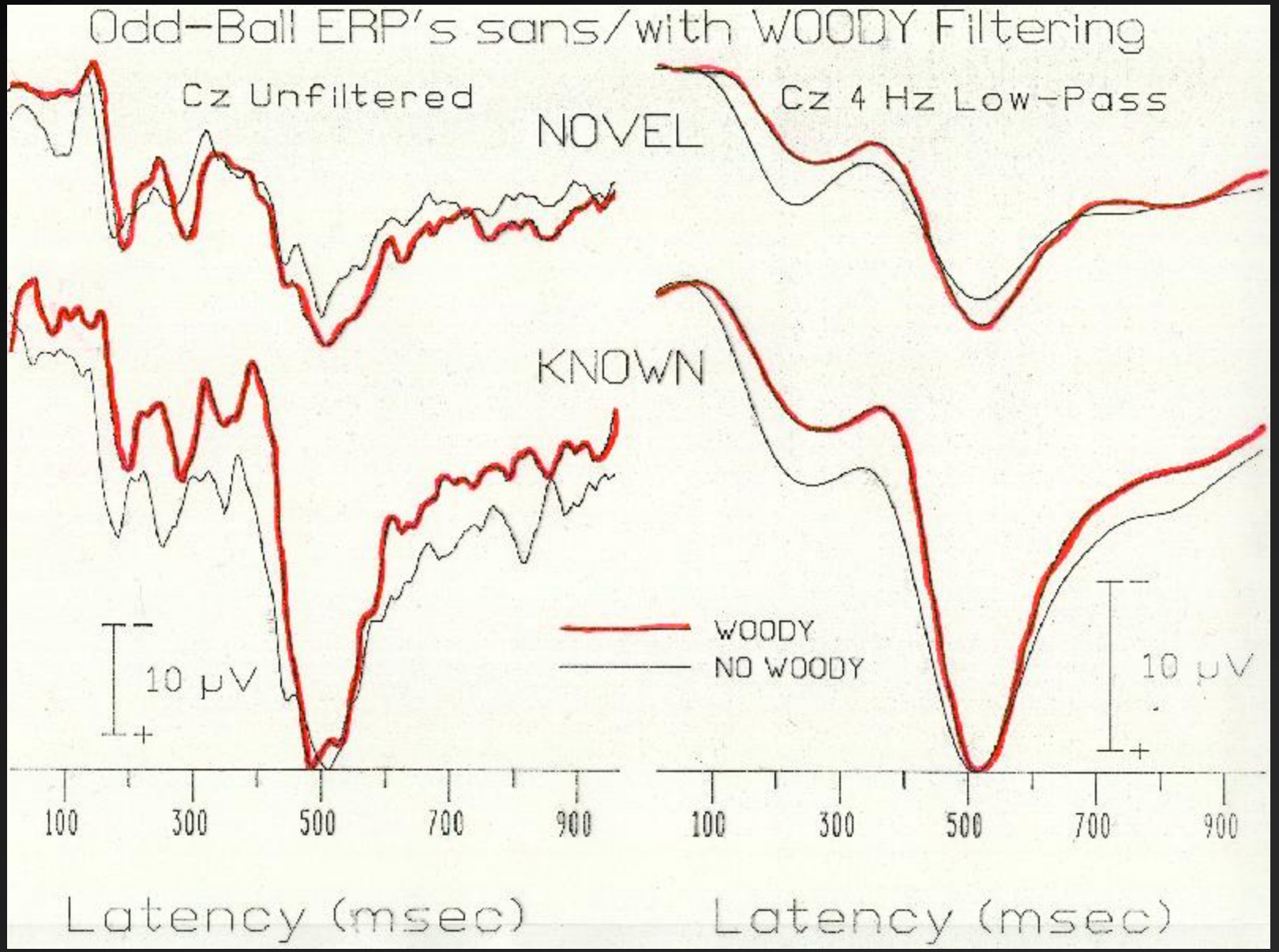
- Can be used as a "template matching" procedure
- Compare running average with raw EEG epochs
- This is a method of single-trial signal detection:
  - First create a template: either predetermined (e.g., sine wave) or empirically determined (e.g., average)
  - Then calculate cross-correlational series 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 typically over a limited range of samples (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 $\underline{r}$ 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

Woody Filtering Demo!




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