More ERPs and…

Advanced Signal Processing I

Digital Filters

Time Frequency Approaches

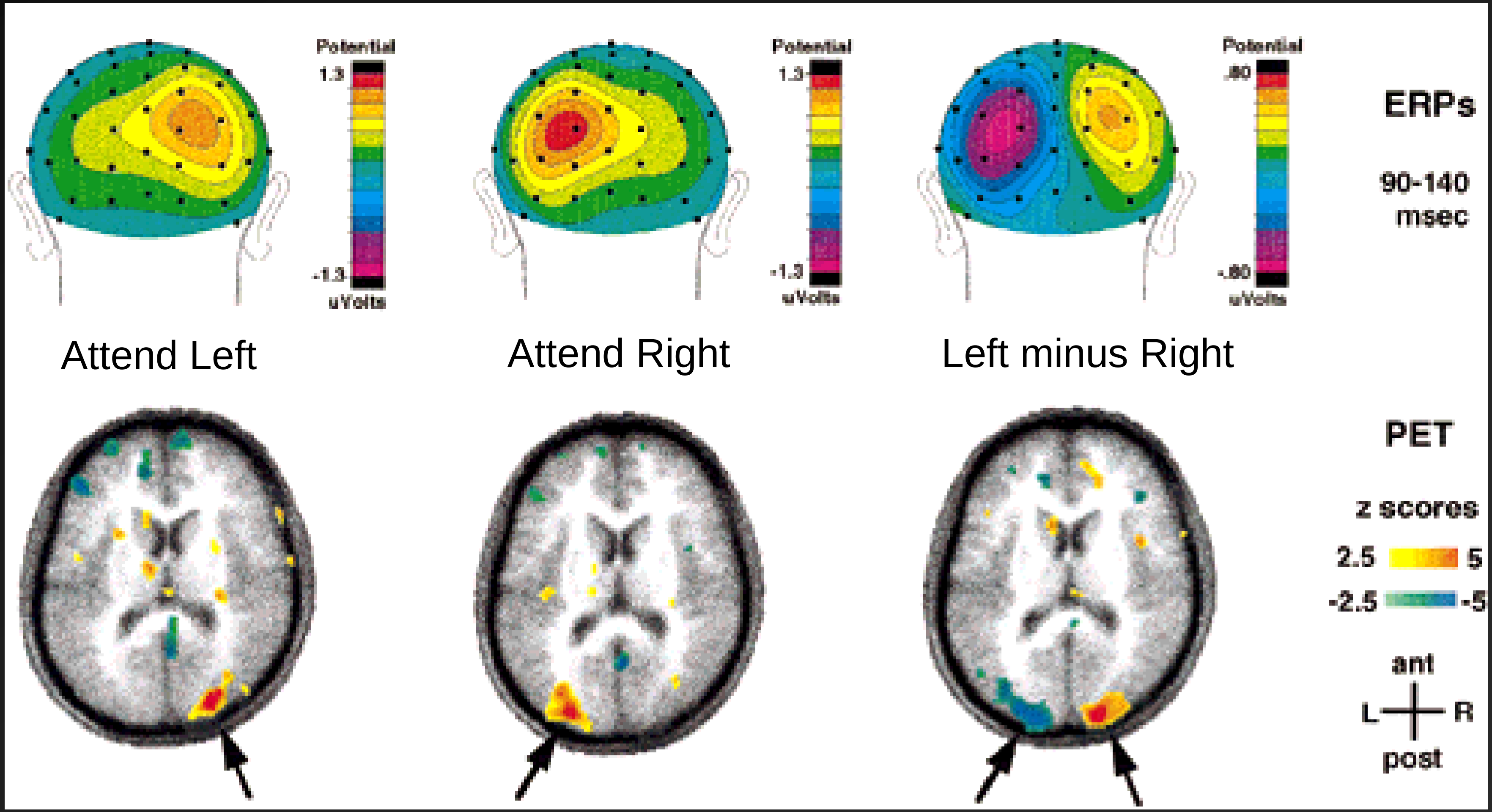
Ocular Artifacts

Announcements 4/19/21

- Paper/Proposal Guidelines available on course webpage (link in D2L too)
  - Two paragraph prospectus due (on D2L "Research Prospectus") no later than TODAY
  - Rubric for grading now available for preview on D2L
- Topics for final sessions:

  19 Apr: Advanced Signal Processing I
  26 Apr: Neurostimulation and Neuromodulation
  3 May: Advanced Signal Processing II
- Course Evals now available
- Class Feedback and Q&A

"These combined PET/ERP data therefore provide strong evidence that sustained visual spatial attention results in a preset, top-down biasing of the early sensory input channels in a retinotopically organized way"



Woldorff et al., *Human Brain Mapping*, 1997

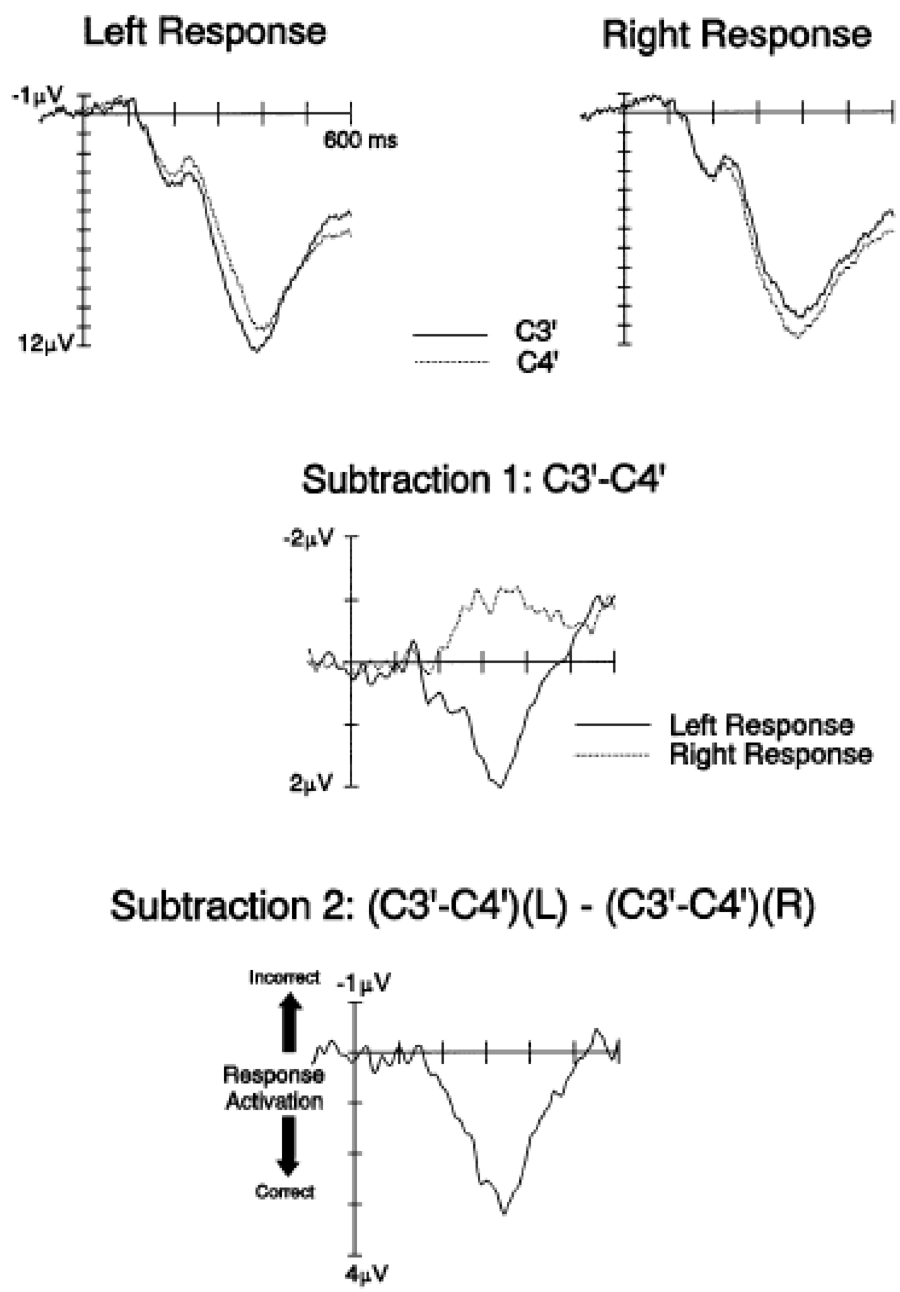
ERP continued…

Response-locked and feedback potentials

Response-locked potentials

- Lateralized Readiness Potential (LRP), a special case of movement-related potentials
- Error-related Negativity (ERN, aka N_E)

Eimer 1998, *Beh Res Methods*



Lateralized Readiness Potential

- LRP can be stimulus-locked or response-locked
- For stim-locked, latency is time between stimulus onset and LRP onset
- For rsps-locked latency is time between an LRP deflection and the overt response.

Figure 1. Computation of the lateralized readiness potential (LRP) with the double subtraction method on the basis of event-related brain potential (ERP) waveforms elicited at electrodes C3′ (left hemisphere) and C4′ (right hemisphere). Top panels: Grand-averaged ERP waveforms from 10 subjects elicited at C3′ (solid lines) and C4′ (dashed lines) in response to stimuli requiring a left-hand response (left side) and to stimuli requiring a right-hand response (right side). Middle panel: Difference waveforms resulting from subtracting the ERPs obtained at C4′ from the ERPs obtained at C3′ separately for left-hand responses (solid line) and right-hand responses (dashed line). Bottom panel: LRP waveform resulting from subtracting the C3′ − C4′ difference waveform for right-hand responses from the C3′ − C4′ difference waveform for left-hand responses. A downward-going (positive) deflection indicates an activation of the correct response; an upward-going (negative) deflection indicates an activation

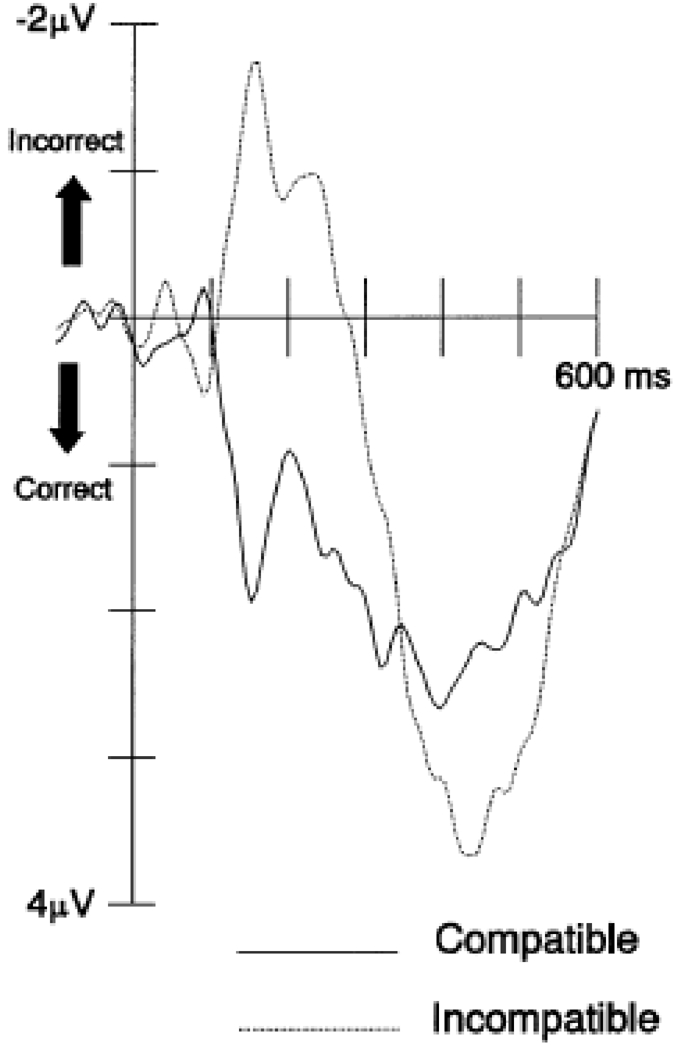
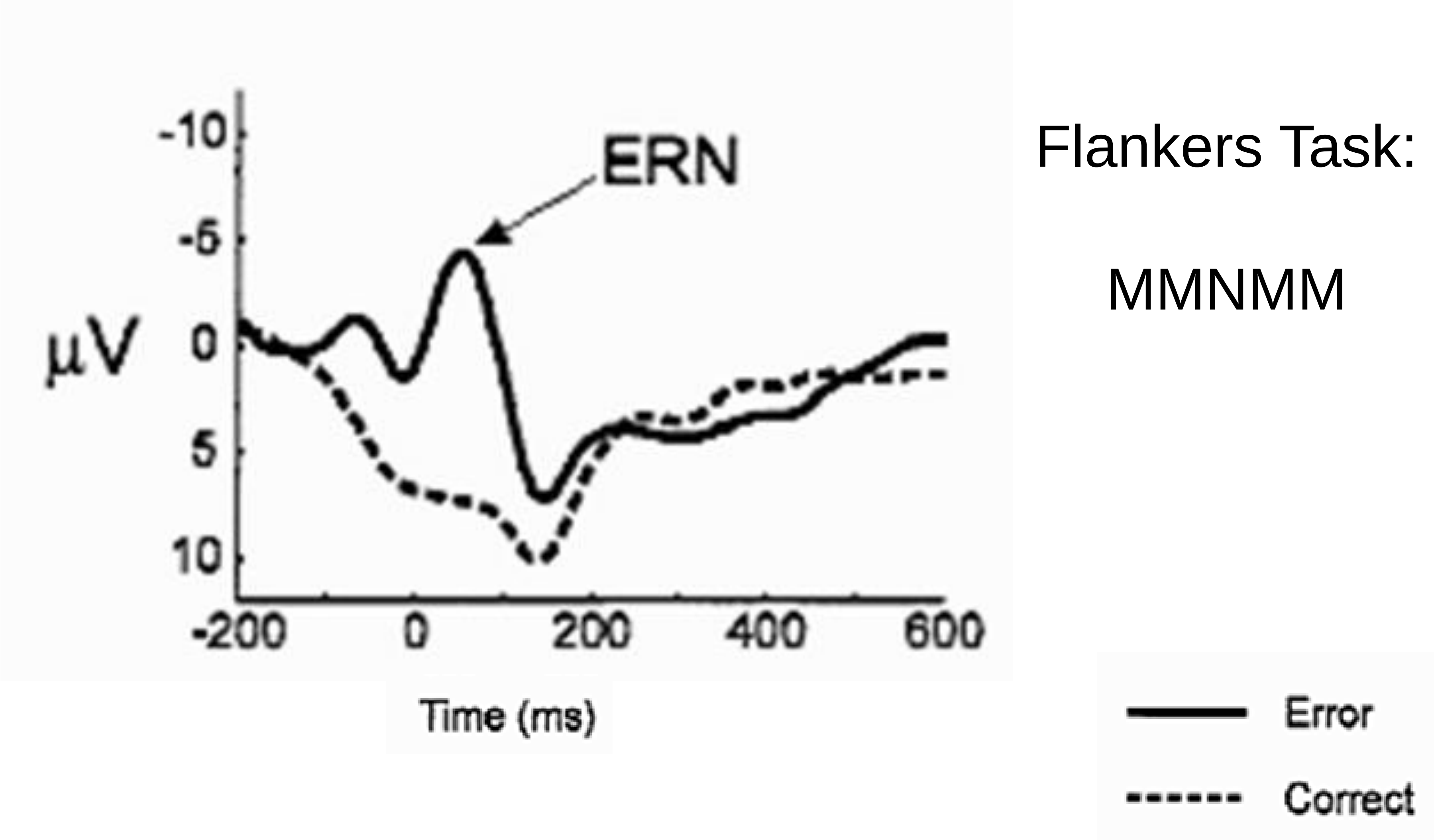


Figure 2. Top: Examples of stimulus displays in an experiment on spatial stimulus–response compatibility (Eimer, 1993, Experiment 1a) in which stimulus and response sides could either be compatible (left side) or incompatible (right side). Bottom: Grand-averaged LRP waveforms from 10 subjects, elicited in compatible trials (solid line) and in incompatible trials (dashed line).

Response conflict in the LRP

Eimer 1998, *Beh Res Methods*

The ERN

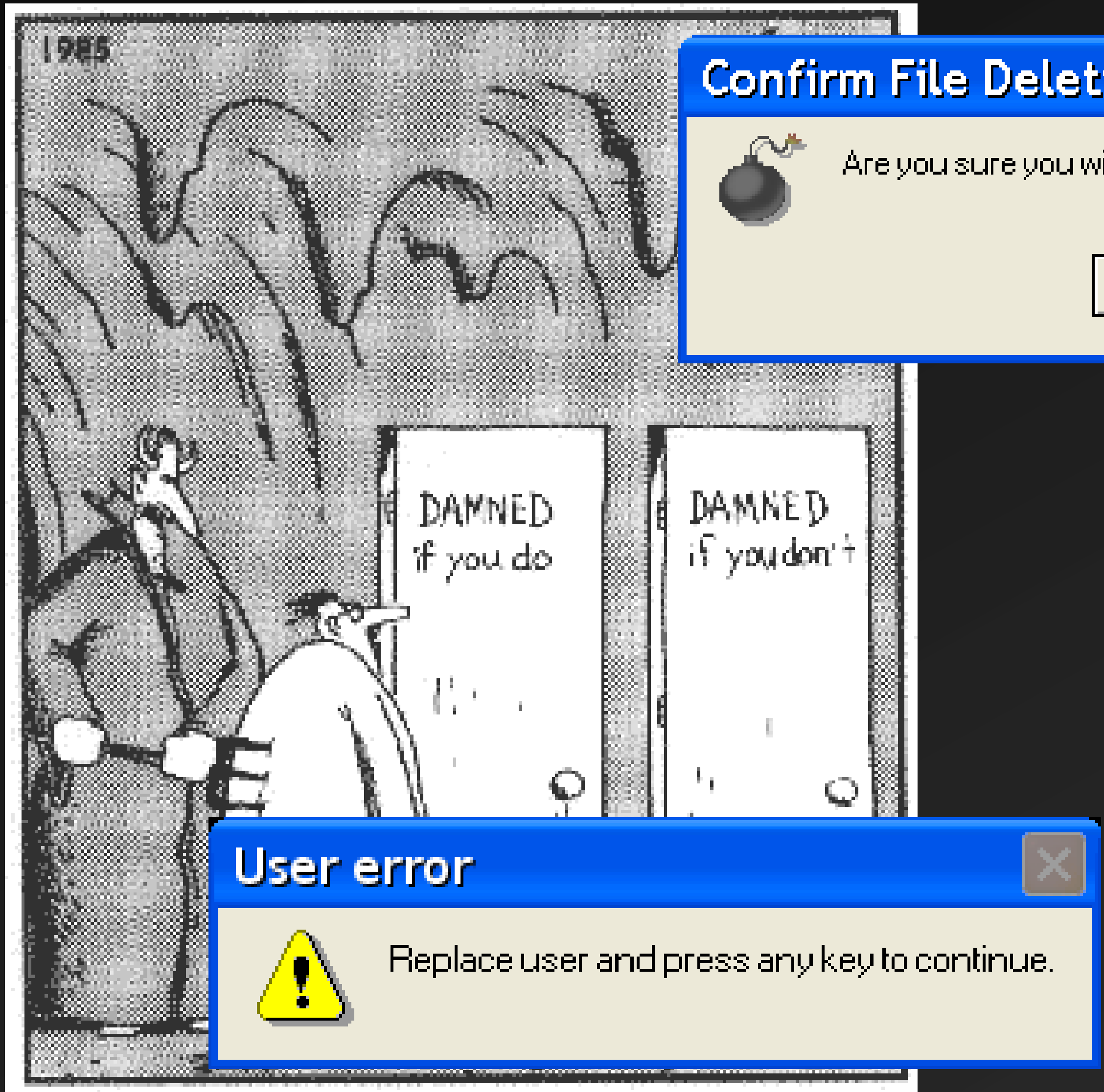


Flankers Task:

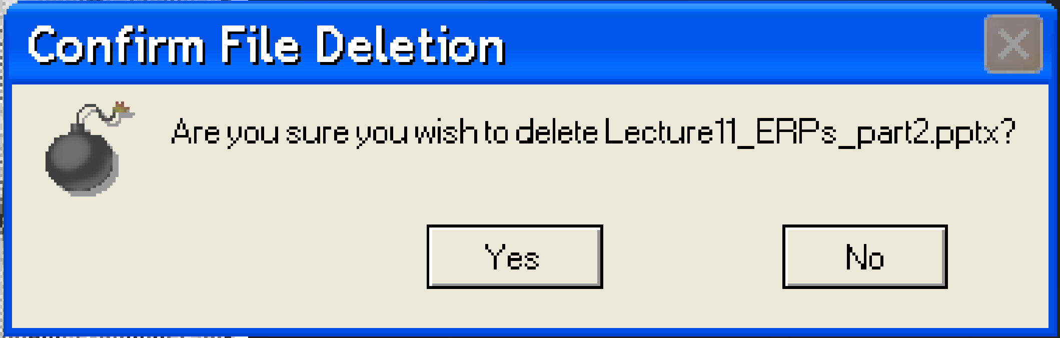
MMNMM

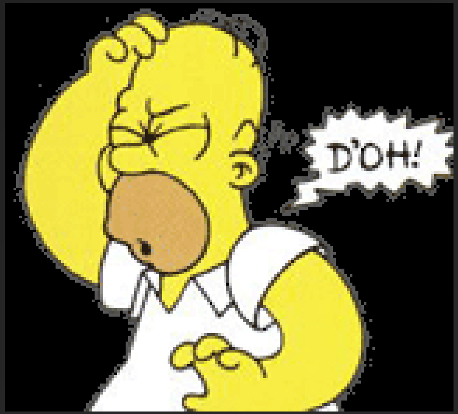
Also sometimes termed Ne

Life is full of choices … and consequences



"C'mon, c'mon—it's either one or the other."





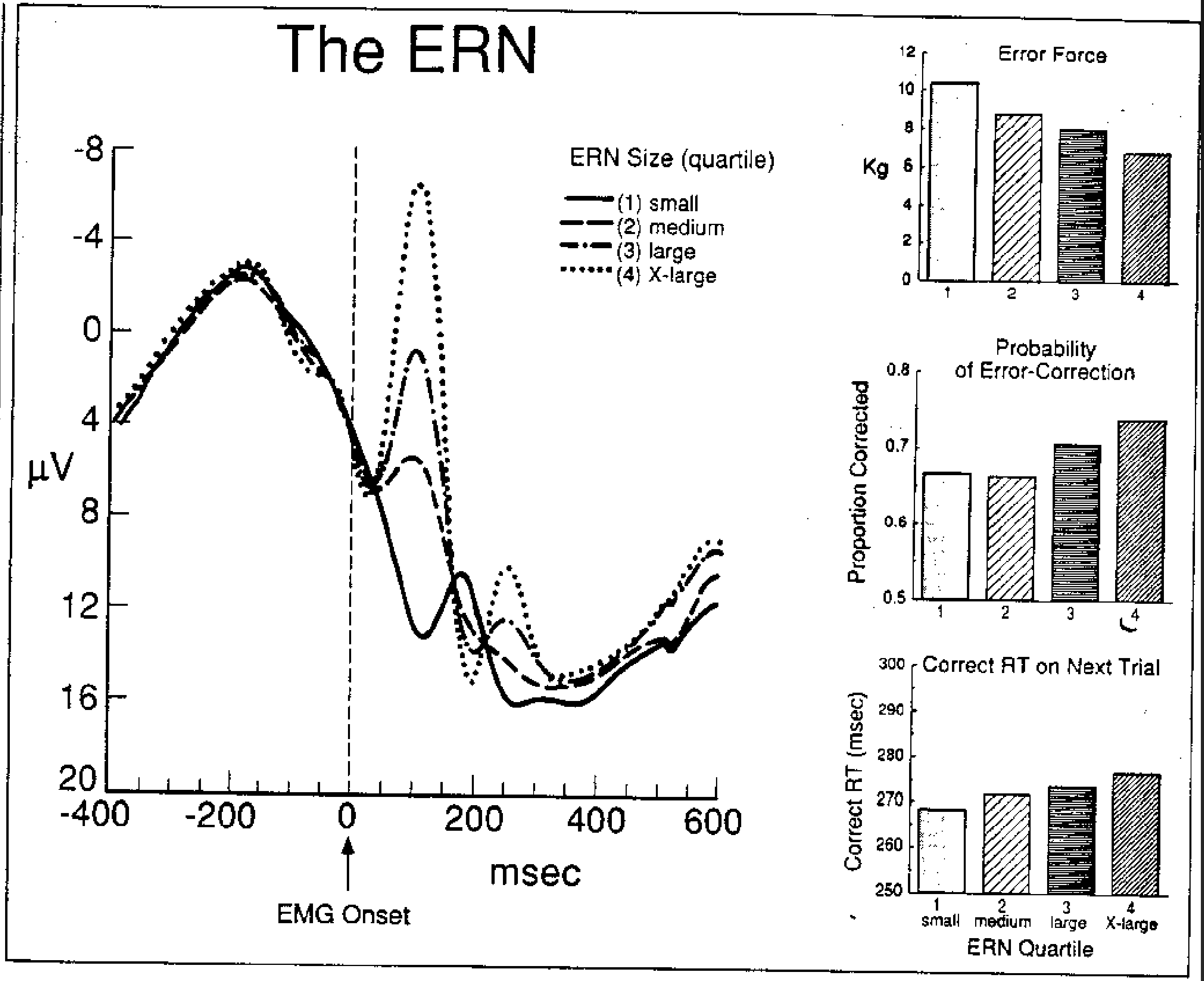


Fig. 3. Relationship between error-related negativity (ERN) amplitude and three measures of compensatory behavior. Left panel: Average event-related potentials at the C_z electrode as a function of the four levels of the posterior probability measure of ERN amplitude. Right panel, top: Error squeeze force in Kg as a function of the four ERN levels. Right panel, middle: Probability of error correction as a function of the four ERN levels. Right panel, bottom: Correct reaction time on the trial following an error as a function of the four ERN levels.

Gehring et al., 1993

Modality Specific?

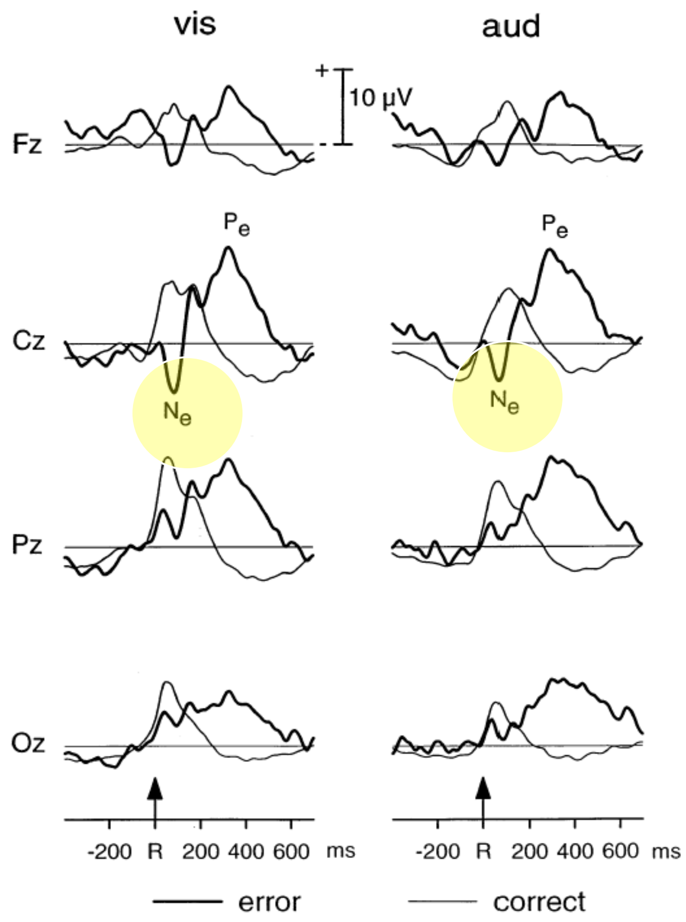
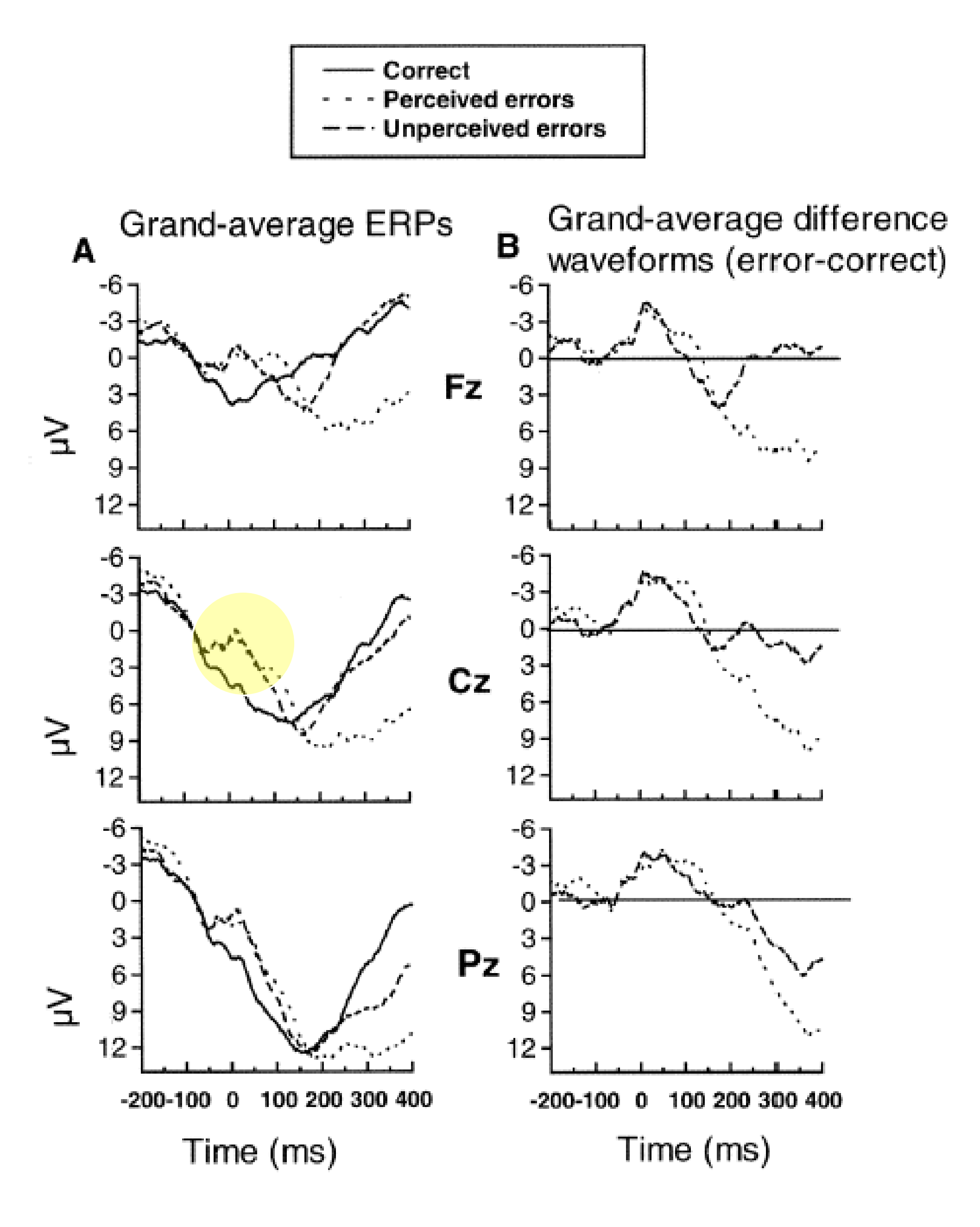


Fig. 1. Grand averages (Experiment 4; $n = 12$) of the RTA for errors (heavy lines) and correct trials (light lines) after visual (vis) and auditory letter stimuli (aud) in a 2-CR task. The error negativity ('Ne') is seen as a sharp negative deflection with central maximum peaking at about 80 ms after the incorrect key press (R). The error positivity ('Pe') is seen as a late parietal positivity with Cz maximum peaking at about 300 ms after the incorrect key press. On correct trials a positive complex with Pz maximum is seen.

- Does not matter what modality stimulus was presented



- Does not matter what modality response was made
- Eye

Nieuwenhuis et al., 2001:
Saccade Task

C.B. Holroyd et al. / Neuroscience Letters 242 (1998) 65–68

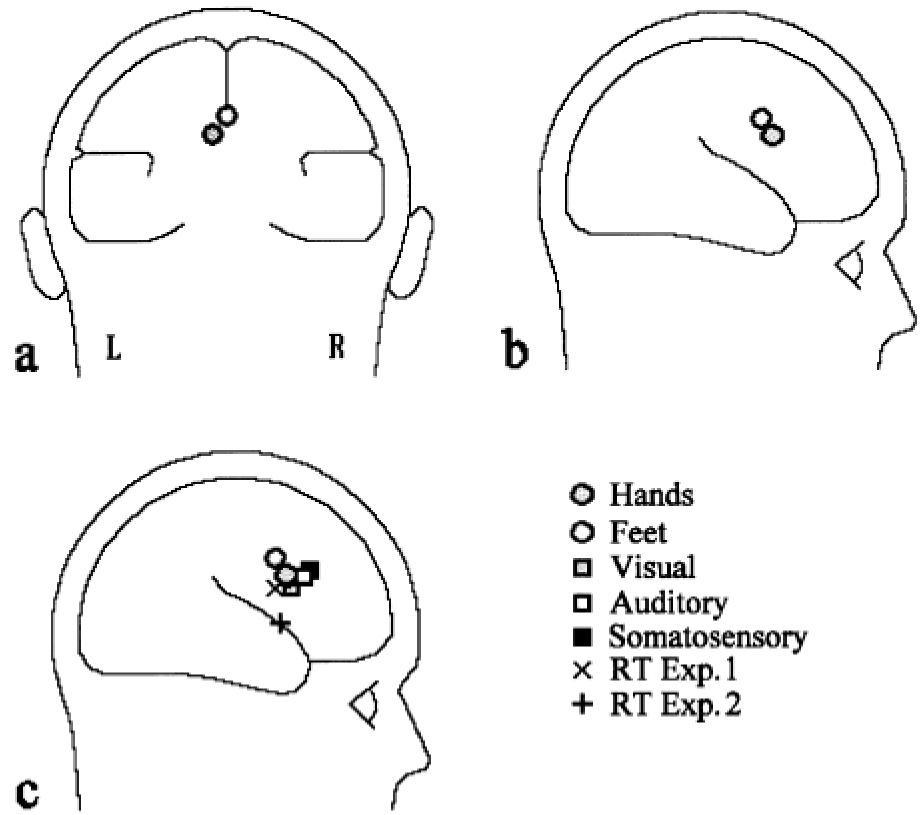


Fig. 2. Source localization of the error-related negativity. Circles represent locations of sources determined for hand and foot responses: (a) coronal view; (b) sagittal view; (c) for comparison, source locations of the ERN determined in previous studies are depicted along with the locations of the ERN obtained in the present study. Squares represent locations of sources found for ERNs elicited by visual, auditory, and somatosensory feedback [10]. Crossed symbols represent locations of sources found for ERNs elicited by errors in two reaction time experiments [2].

- ➢Does not matter what modality response was made
  - ➢ Eye
  - ➢ Hand
  - ➢ Foot

Error Detection Vs. Error Compensation

- If Error Compensation, ERN/Ne should not be present in tasks where compensation impossible
- Ergo…
  - the Go-Nogo!
  - Play along… press only for X following X

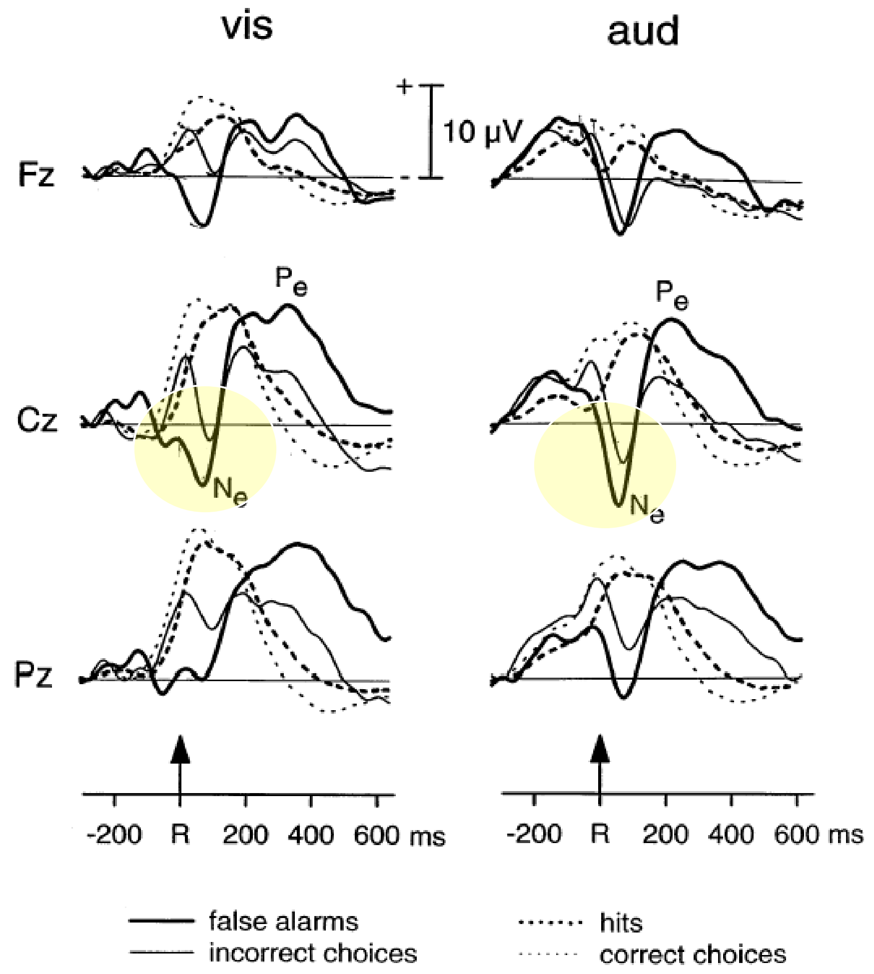


Fig. 5. Grand averages (Experiment 2; $n = 10$) of the RTA for false alarms and hits in Go/Nogo tasks (heavy lines), and choice errors and correct choice trials in two-way choice tasks (thin lines). Errors continuous lines, correct responses broken lines. The Ne is delayed relative to the incorrect key press, and the Pe is smaller, for choice errors compared to false alarms. In correct trials a positive complex with Pz maximum is seen, which is larger after visual than after auditory stimuli. However, this complex is not larger for hits than for correct choice trials.

Falkenstein Hoormann Christ & Hohnsbein, *Biological Psychology,* 2000, Summary of Falkenstein et al 1996

Error Detection Vs. Outcome Impact

- Might the “cost” or “importance” or “salience” of an error be relevant to this process?
- Studies relevant to error salience
  - Speed-accuracy trade off
  - Individual differences

Speed Vs. Accuracy

M. Falkenstein et al. / Biological Psychology 51 (2000) 87–107

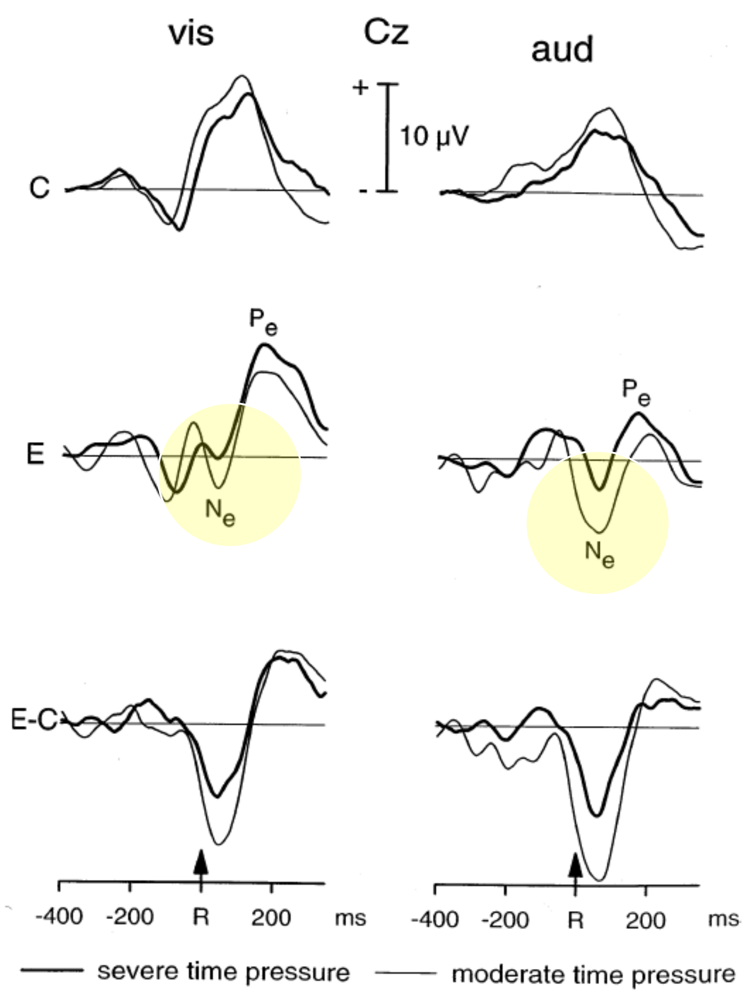


Fig. 4. Grand averages (Experiment 1; $n = 9$) of the RTA for correct responses (C), errors (E), and difference waveshapes (error minus correct; E – C) in a 2-CR task under moderate (light lines) and severe time pressure (heavy lines). The error rates were 15% (moderate) and 30% (severe); the number of error trials used was equalised for the two conditions. The Ne is smaller for severe time pressure/high error rate.

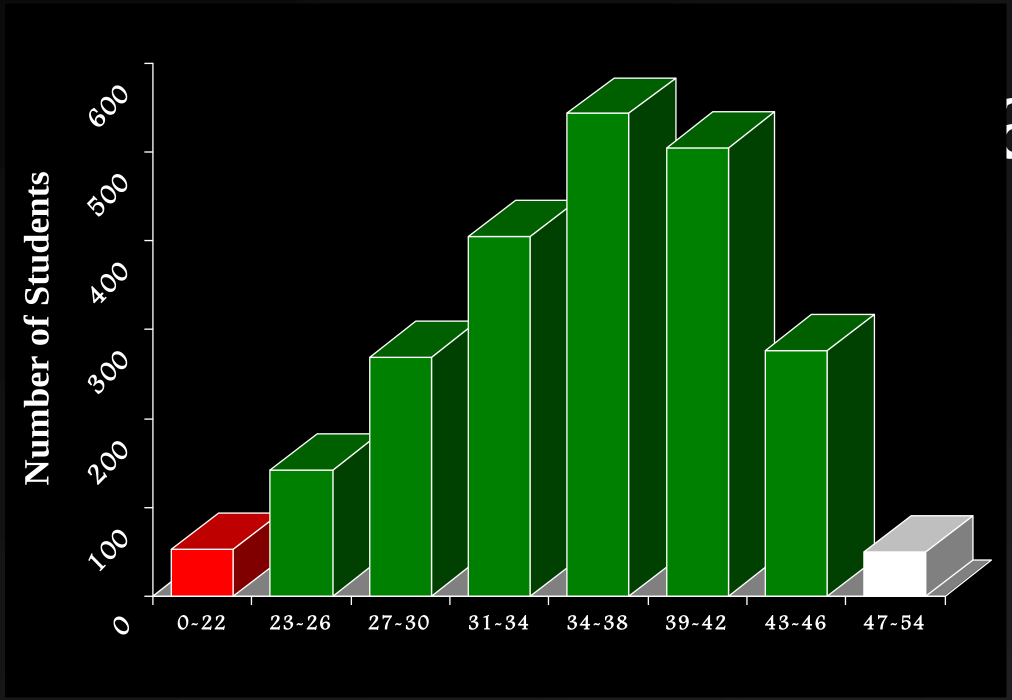
Individual Differences

- Psychopathy (or analog)
- OCD

Deficits in Error Monitoring in Psychopathy

- Psychopaths appear unable to learn from the consequences of their errors
  - Avoidance learning deficits
  - In the context of rewards *and* punishments
  - Deficient anticipatory anxiety

ants



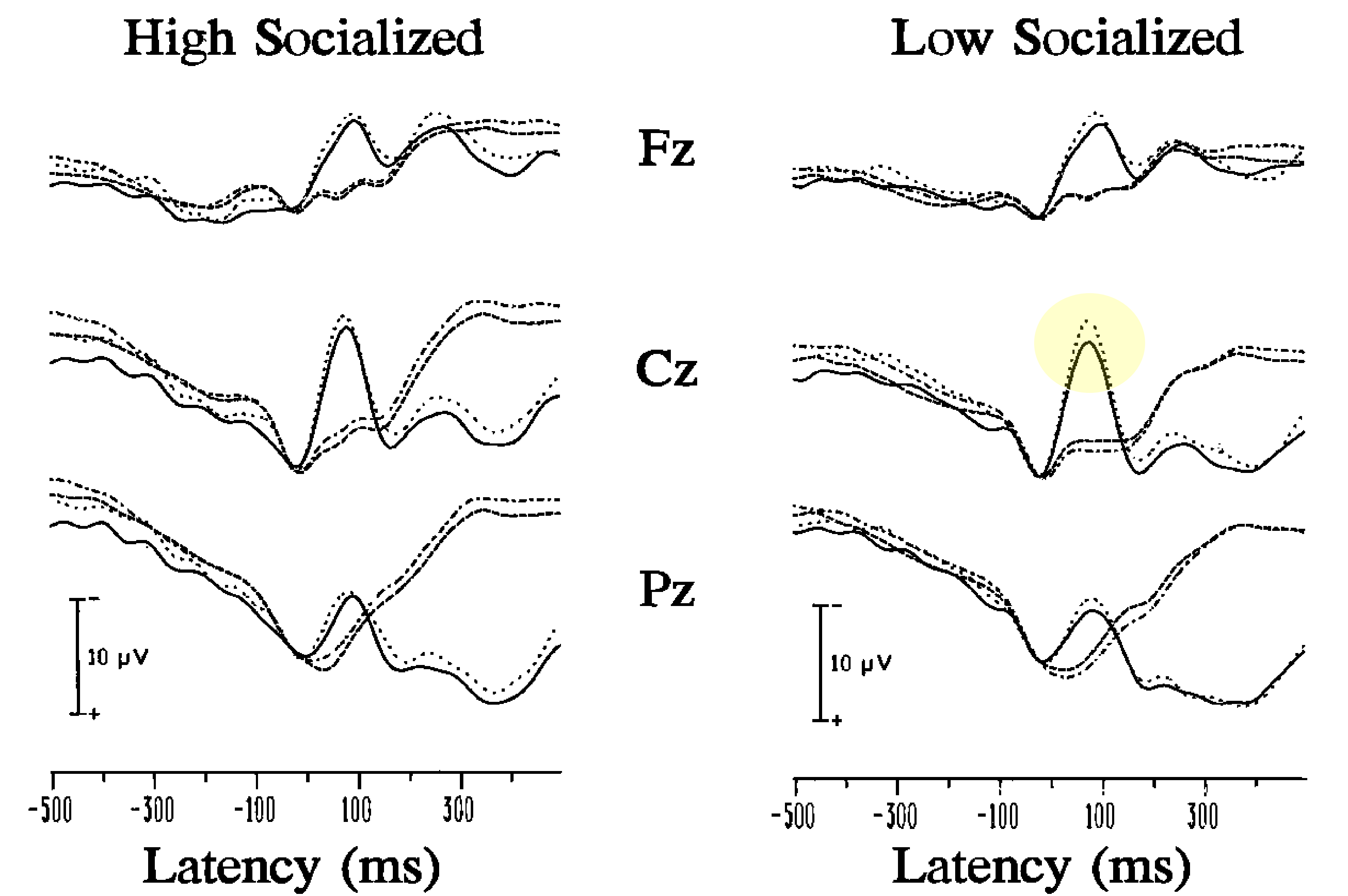
Thirty participants selected: **15 high SO**

15 low SO

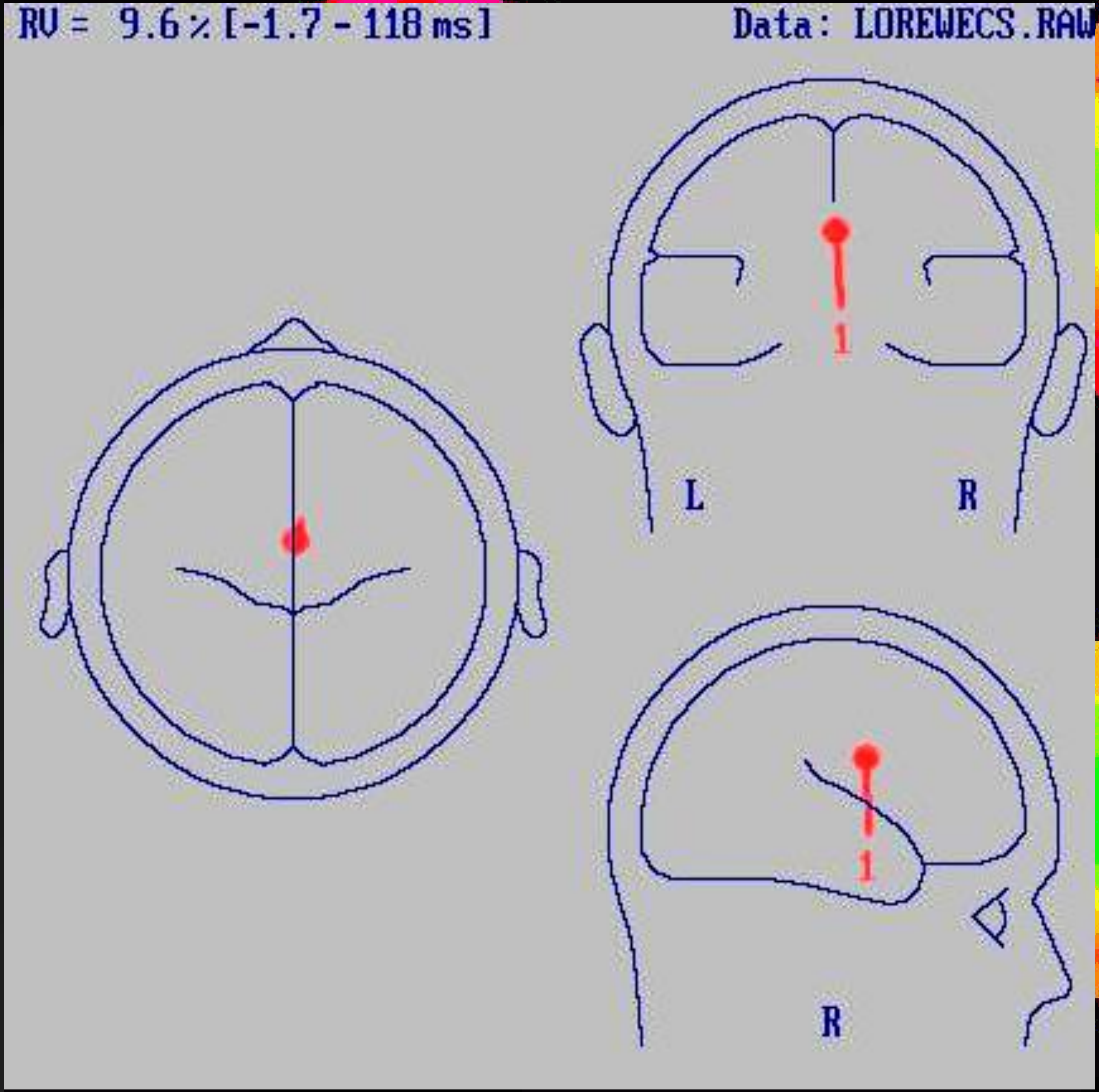
Dikman & Allen, 2000, *Psychophysiology*

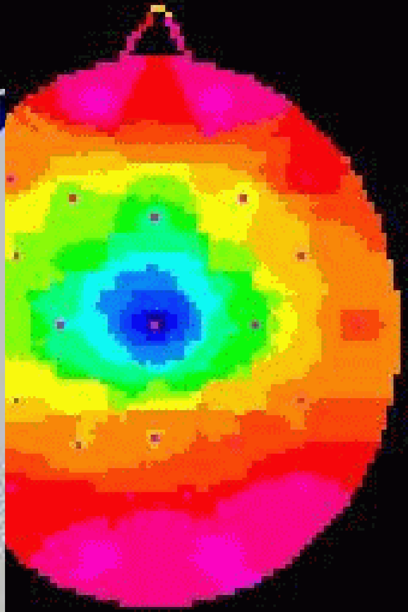
Procedure

- Eriksen flanker task: SSHSS
- Two conditions for each subject
  - Reward (REW), errors “No $”
  - Punishment (PUN), errors 95 dB tone
- Consequences of errors could be avoided by self-correcting response within 1700 msec window
- Response mapping switched at start of each of 10 blocks, total trials 600
- Only corrected error trials examined

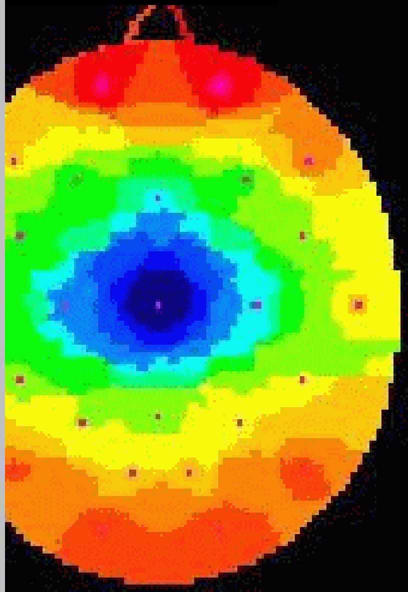


Dikman & Allen, 2000, *Psychophysiology*





Rew



Results re matched trials

ERN in OCD

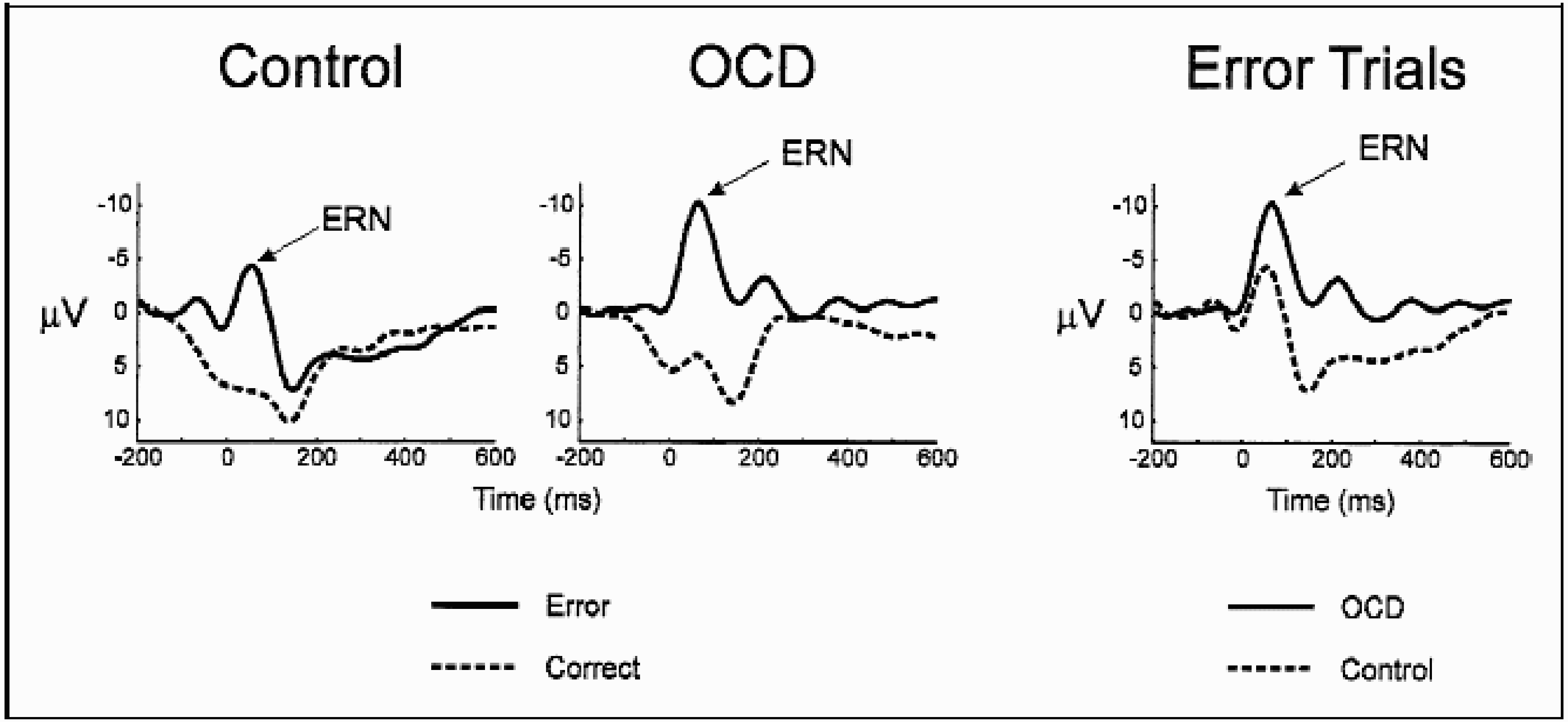


Fig. 1. Response-locked event-related potential waveforms at the Cz electrode location. The left panel compares correct-trial and error-trial waveforms for control participants and for individuals with obsessive-compulsive disorder (OCD). The right panel compares error-trial waveforms for the two groups. Times are plotted relative to the latency of the button-press response. ERN = error-related negativity.

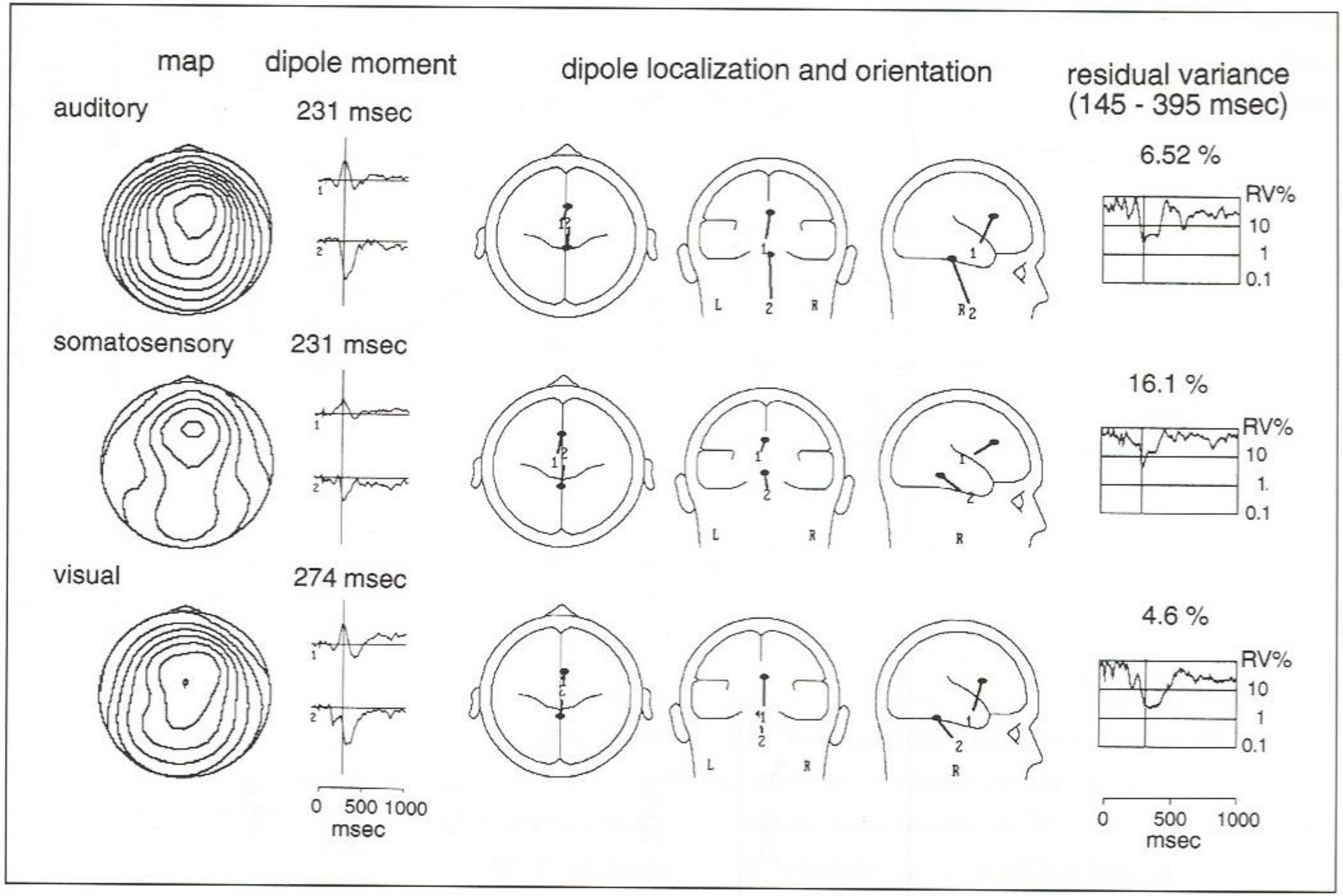
And amplitude of ERN correlates with Symptom severity (correlation magnitude ~.50); Gehring et al. (2000)

Errors and Feedback

- Endogenous Error Detection
- Exogenous Error Feedback
- Common Mechanism?

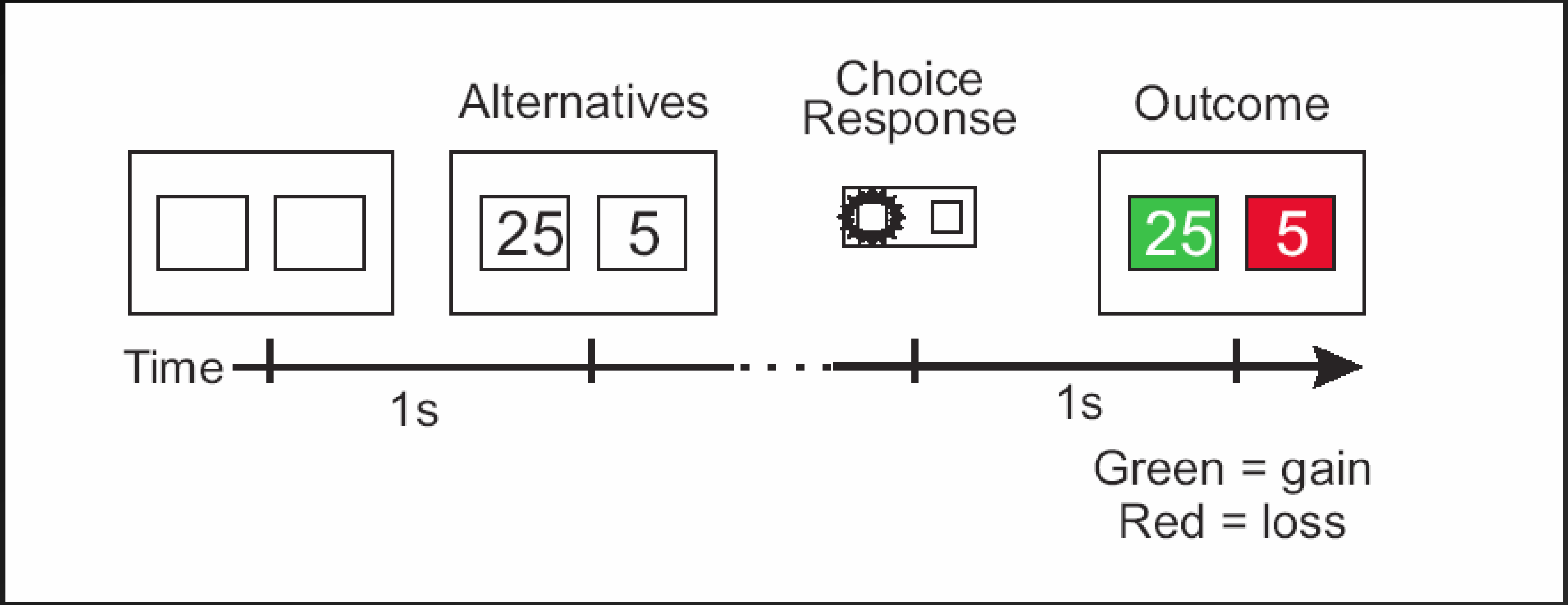
Choices and Feedback

The Feedback Medial Frontal Negativity



Miltner, Braun, & Coles, (1997) *Journal of Cognititive Neuroscience*

The Gambling Task



Gehring and Willoughby, 2002 *Science*

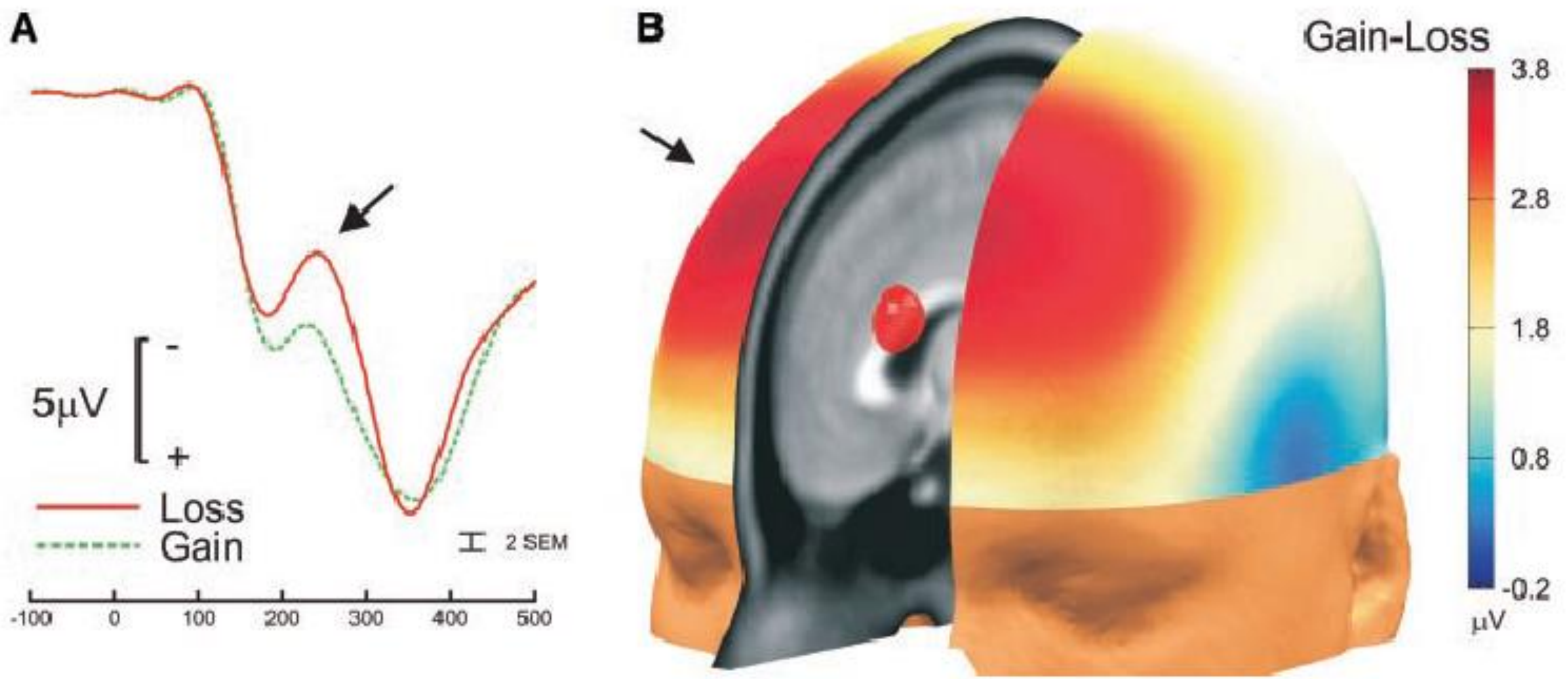
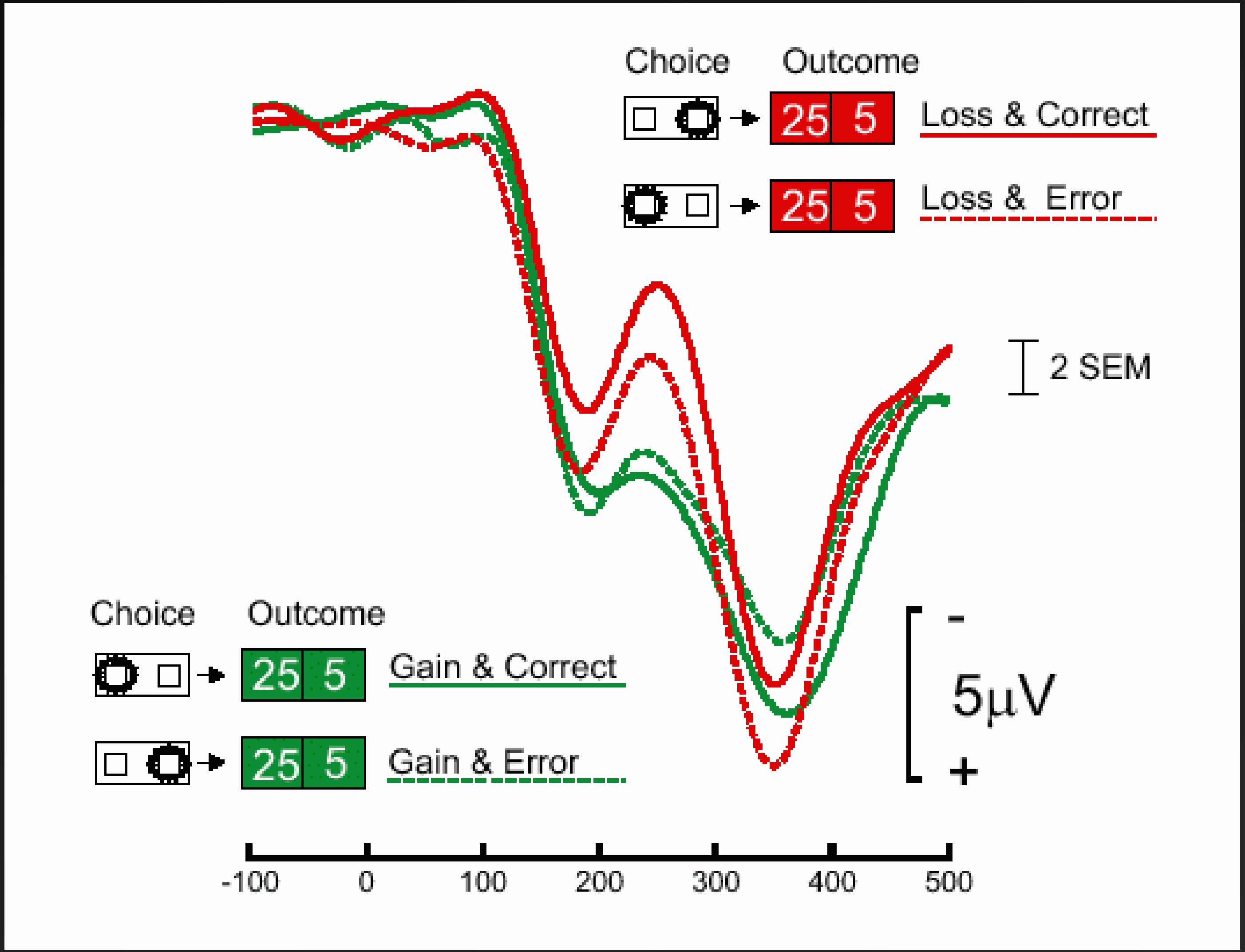


Fig. 2. ERP waveforms, scalp topography, and likely neural generator of the MFN. (**A**) The waveforms are shown at the Fz (frontal) electrode site. The solid red line corresponds to the average ERP waveform for all trials in which the participant lost money. The dashed green line corresponds to those trials in which the participant gained money. The MFN is indicated by the arrow. The error bar represents two standard errors of the mean, based on the mean squared error from the ANOVA (*9*). (**B**) The map of scalp activity shows the voltages, derived by subtracting the loss-trial waveform from the gain-trial waveform, computed at 265 ms after the onset of the outcome stimulus. Larger positive values correspond to a greater MFN effect. The MFN is indicated by the focus of activity at the Fz electrode (designated by the arrow). The best-fitting dipole model of the generator of the MFN is shown as a red sphere centered in the ACC on a canonical magnetic resonance imaging template of the human head (*9*).

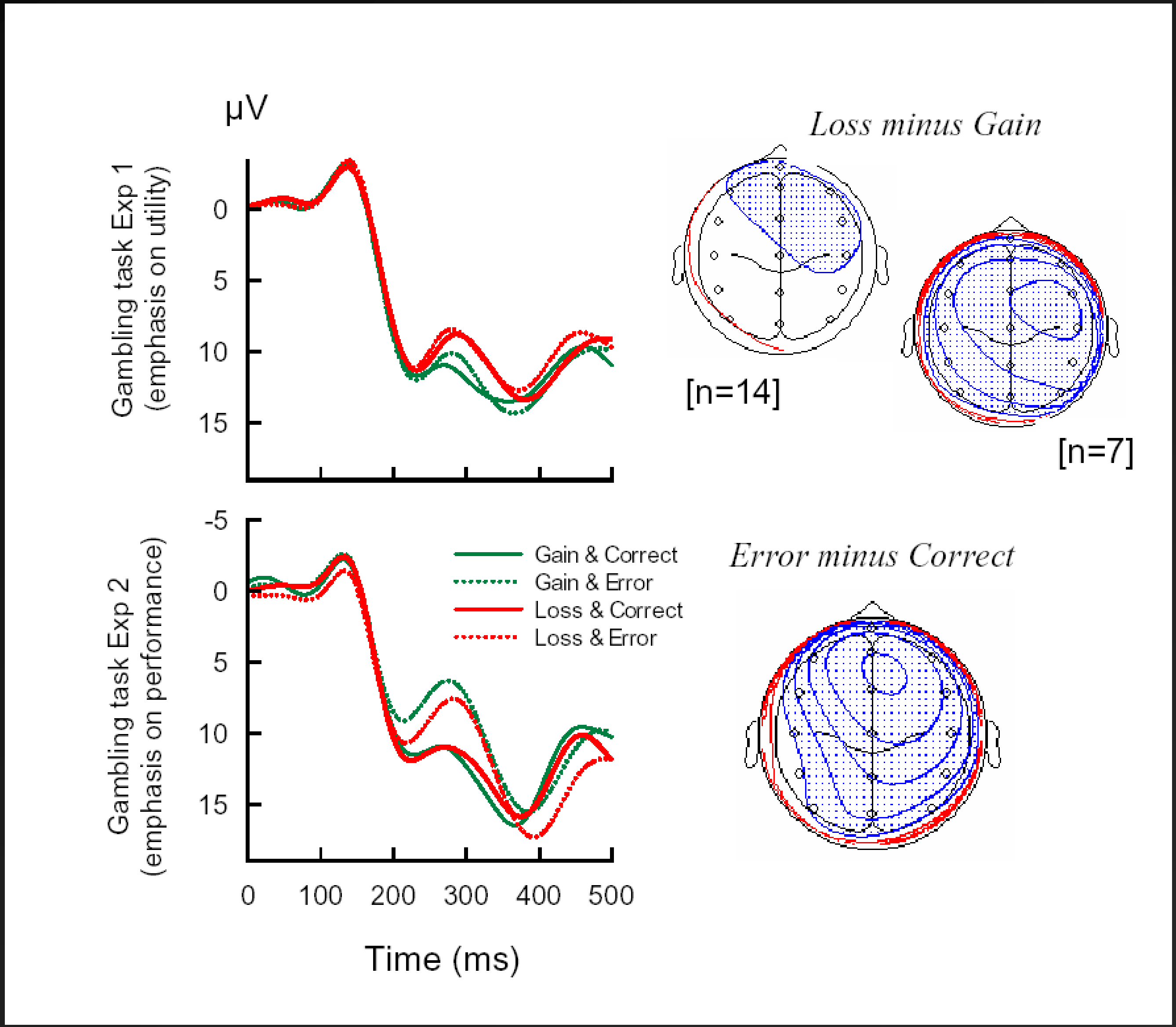
Gehring and Willoughby, 2002 *Science*

Error, or motivation?



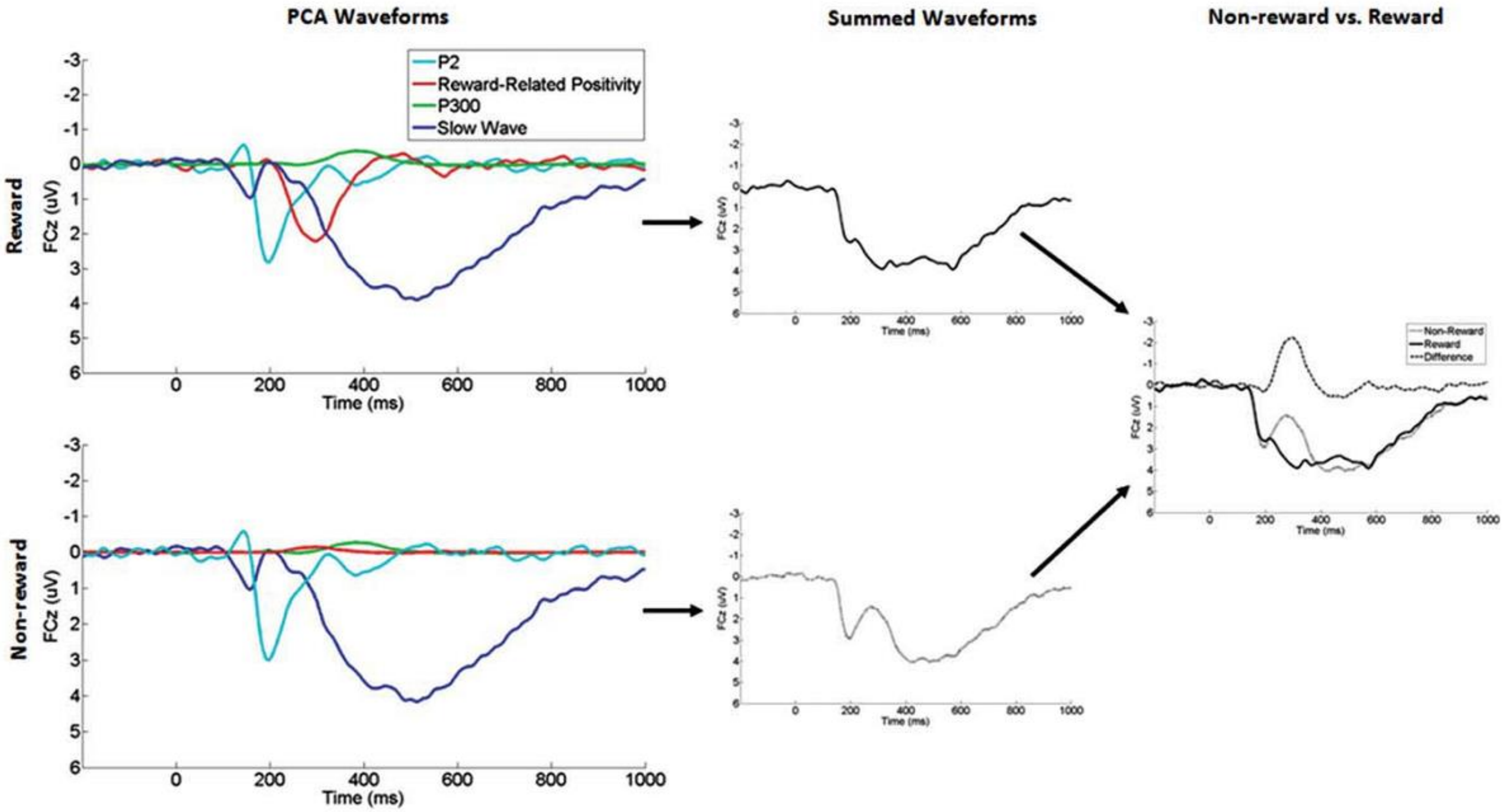
Gehring and Willoughby, 2002 *Science*

Effect may depend on *relevant* dimension of feedback



Nieuwenhuis, Yeung, Holroyd, Schurger, & Cohen (2004), Cerebral Cortex

FRN may be absence of Reward Positivity



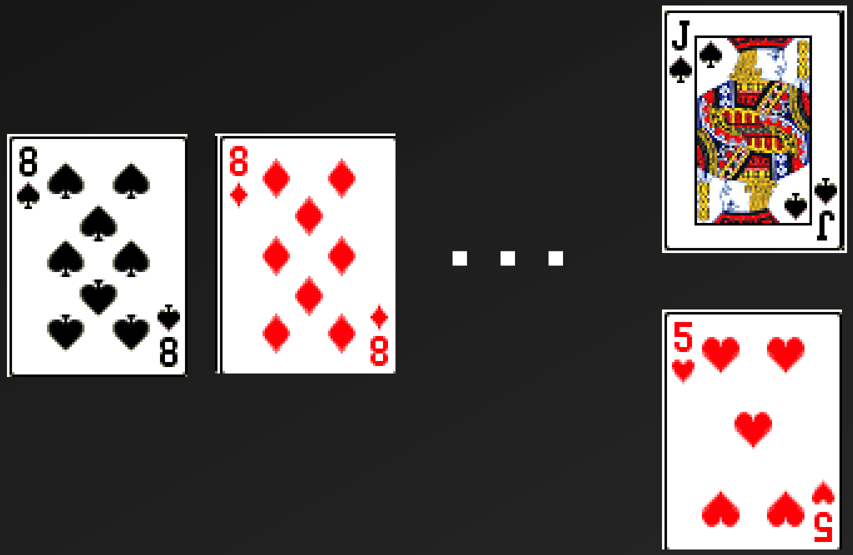
Foti et al. (2011). *HBM*

FRN and Problem Gambling

Why do Gamblers Gamble?

Black Jack Study

- 20 Problem Gamblers, 20 Controls
- Black Jack

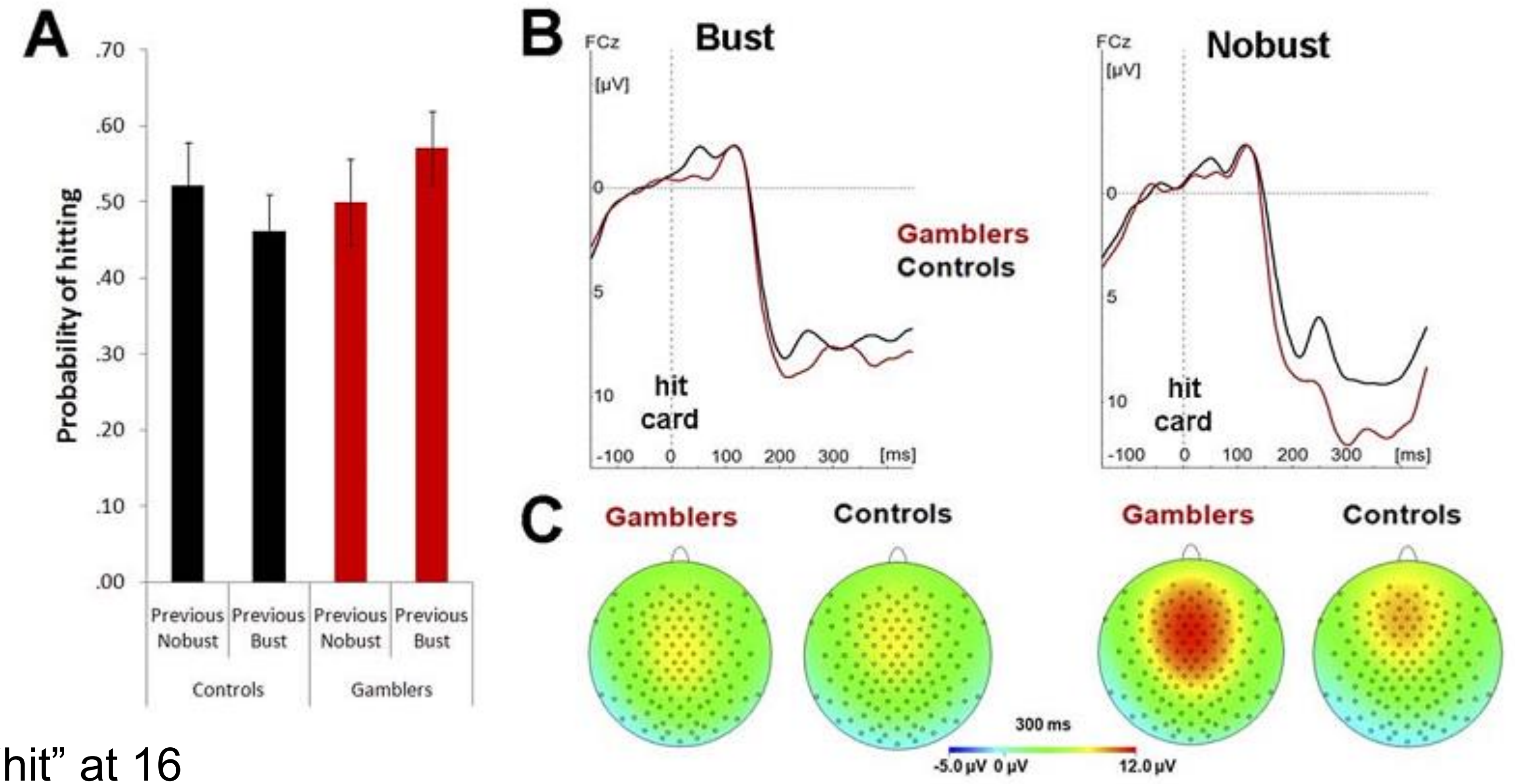


BUST!

21!

Hewig et al. (2010). *Biological Psychiatry*

Black Jack Study



Prob "hit" at 16

Hewig et al. (2010). *Biological Psychiatry*

Advanced Signal Processing I

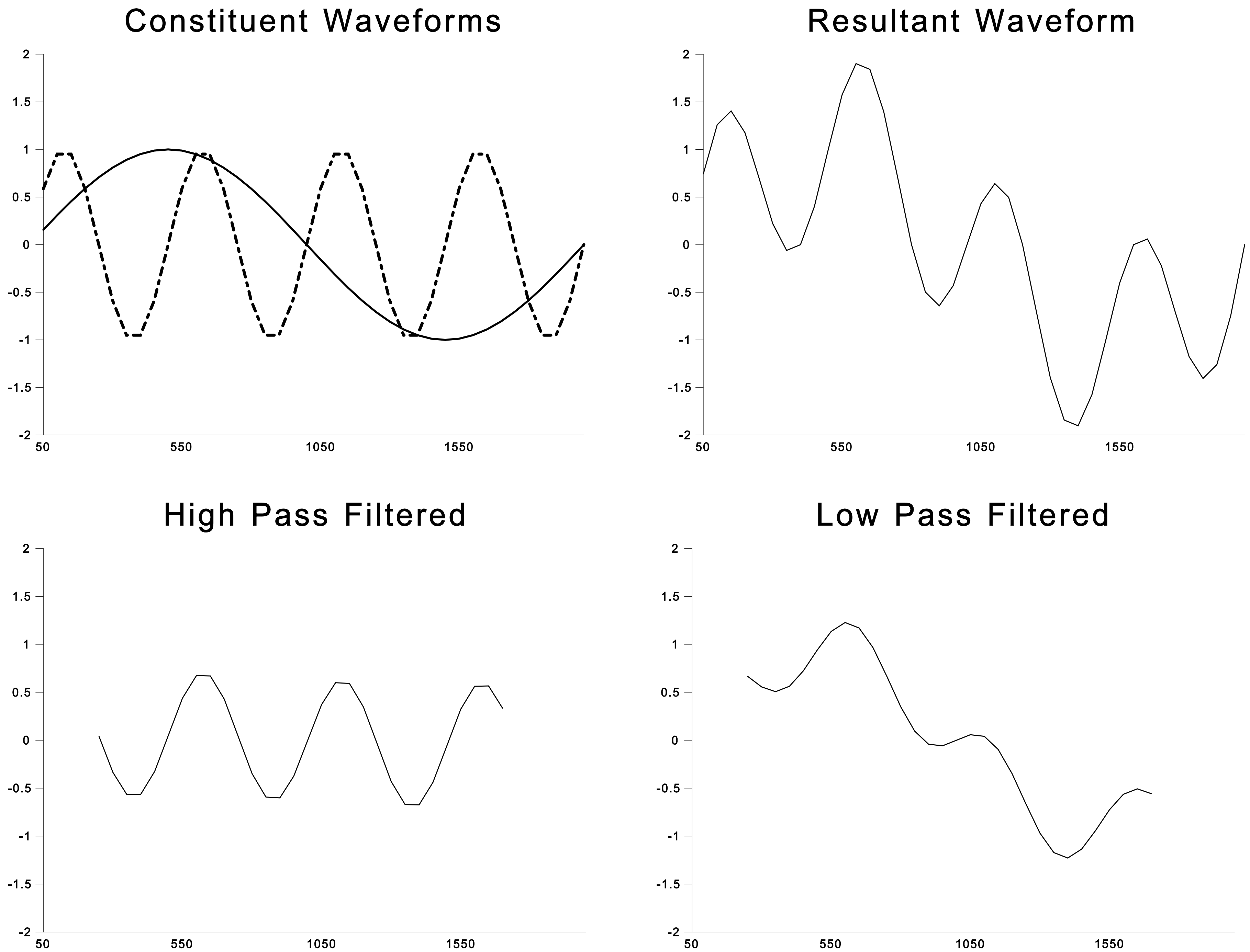
Digital Filters

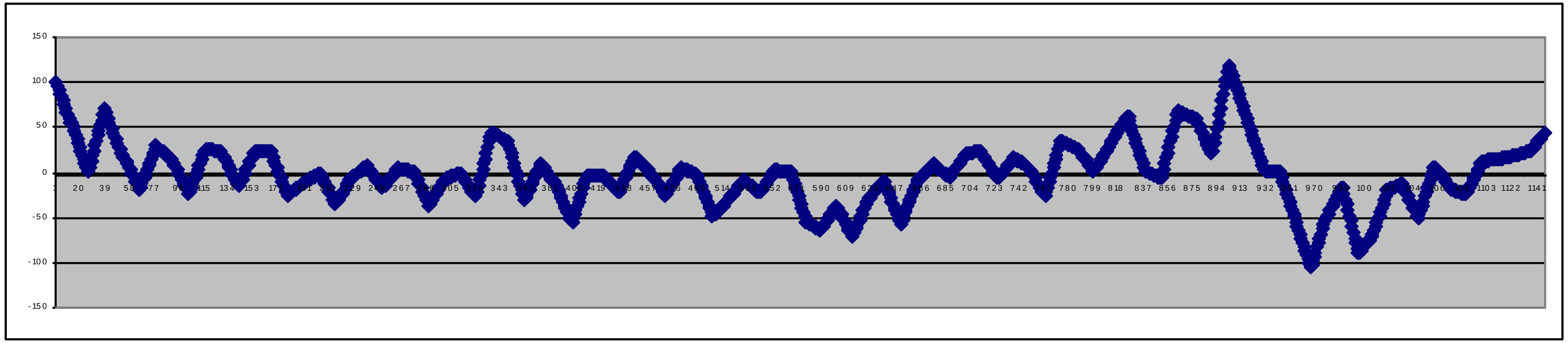
Time Frequency Approaches

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
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
50
550
1050
1550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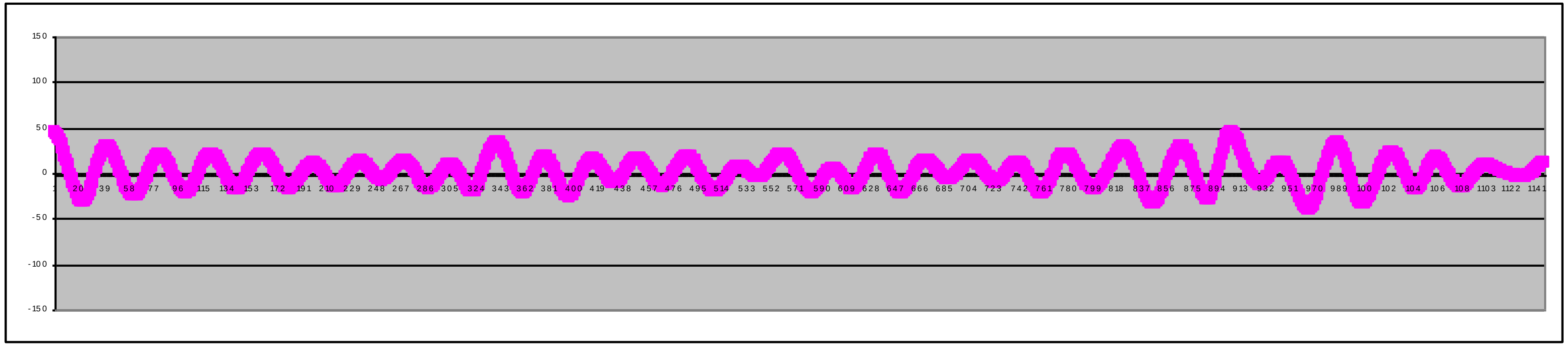
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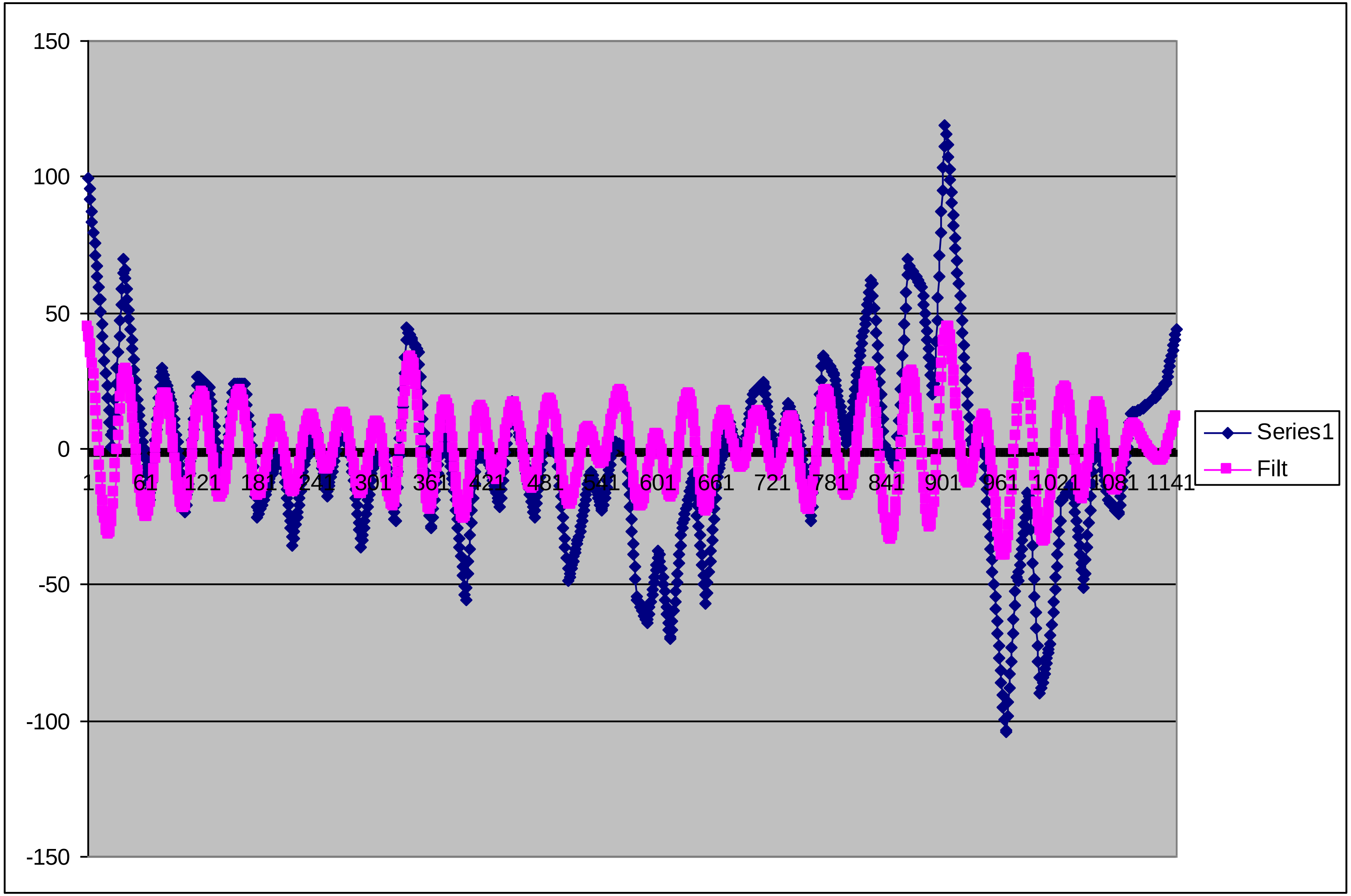
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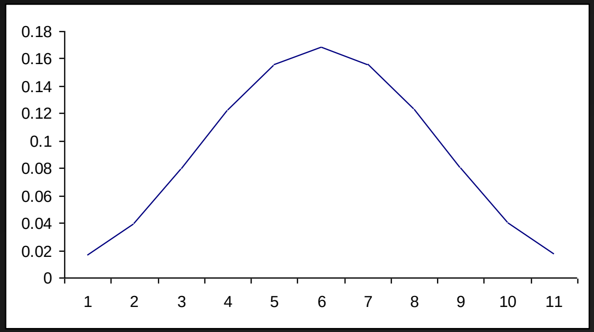
781
841
901
961
1021
1081
1141
Series1
Filt

The Details!

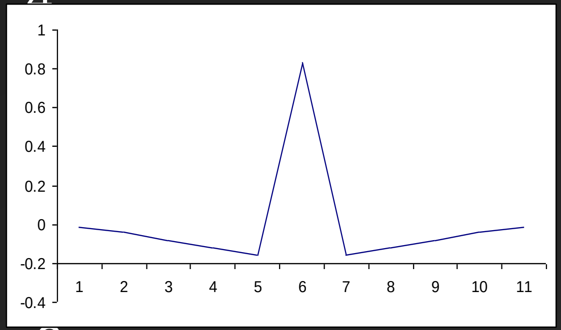
- Handout on Digital Filtering

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 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 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

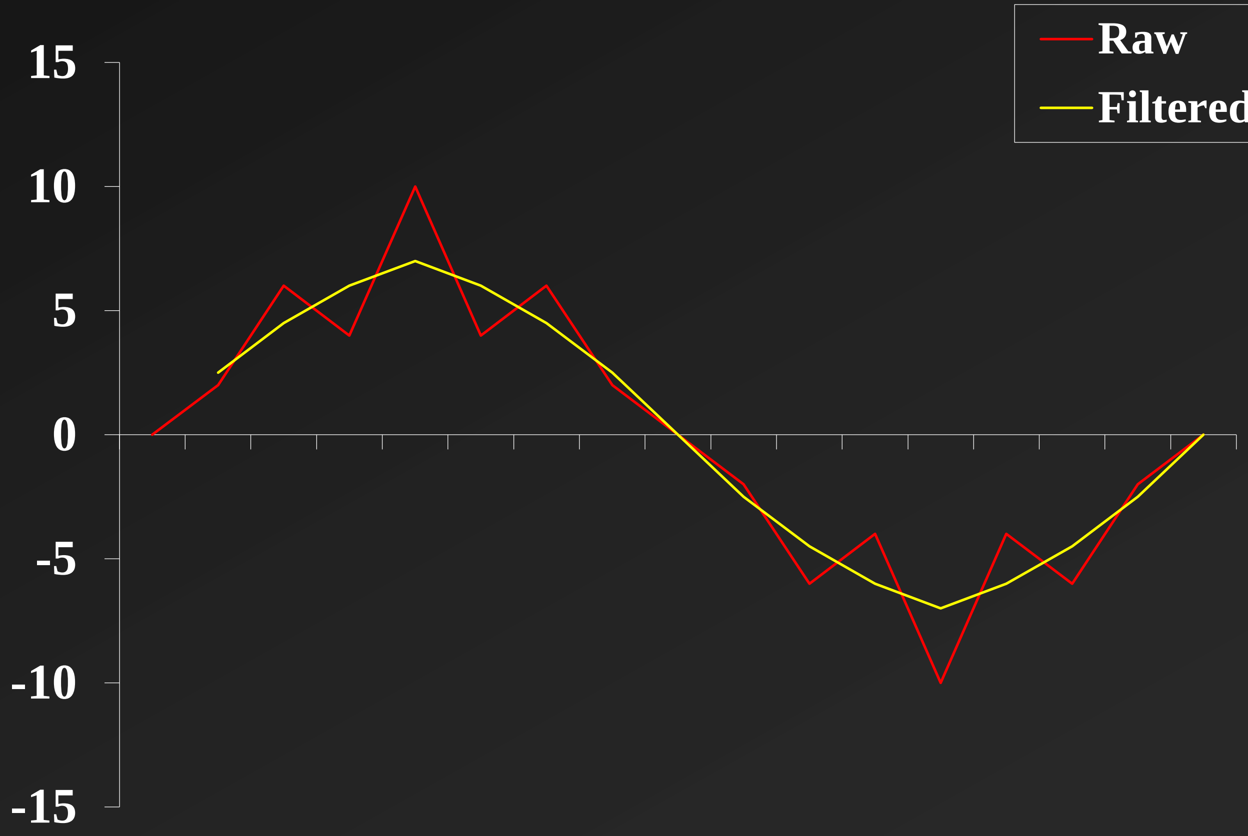
  17.5/200 = x/20 ; x = 1.75 @ 20 Hz Sampling rate

Muy Simple Filter

[.25 .5 .25]

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

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



Some filters and their Transfer Functions

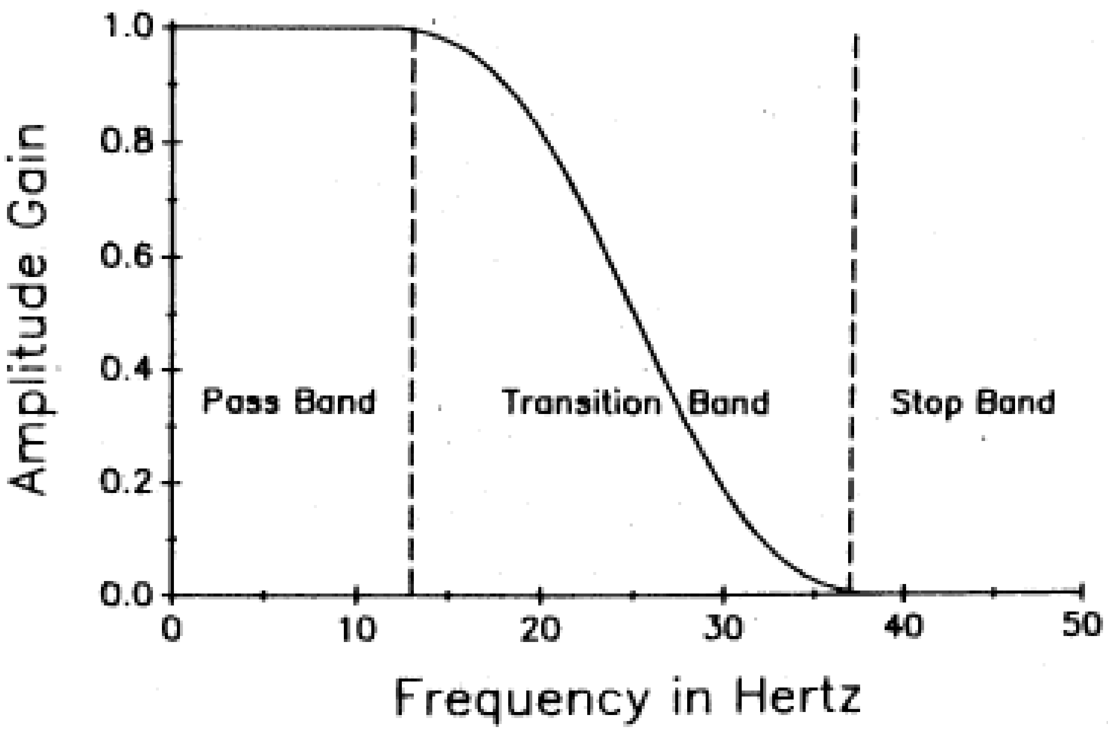
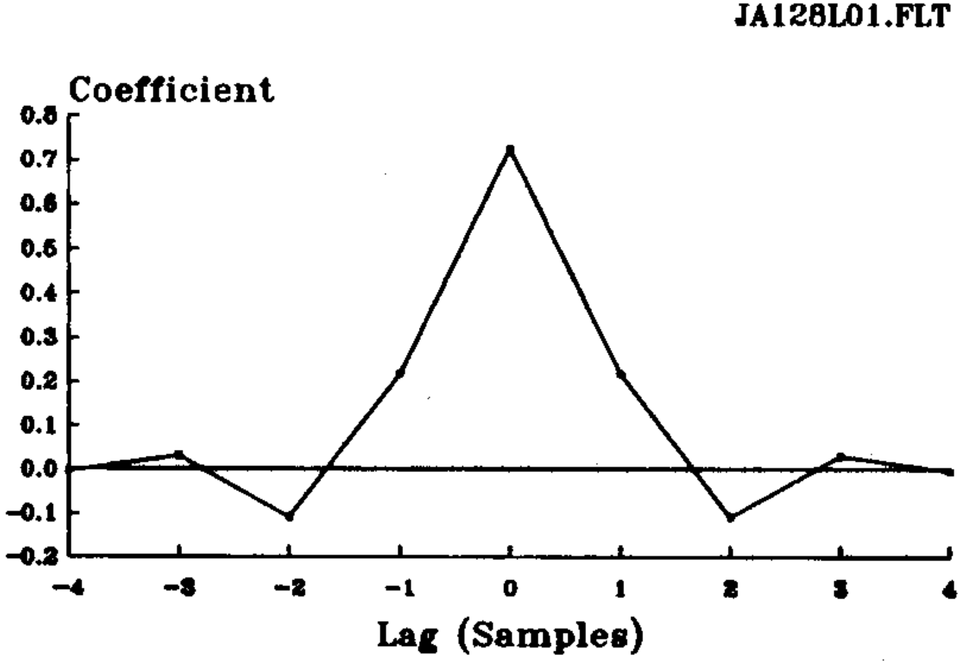


Figure 1. The gain function of a filter is divided into the pass band, transition band, and stop band. The gain function shown is for a low-pass filter.

Cook & Miller, 1992

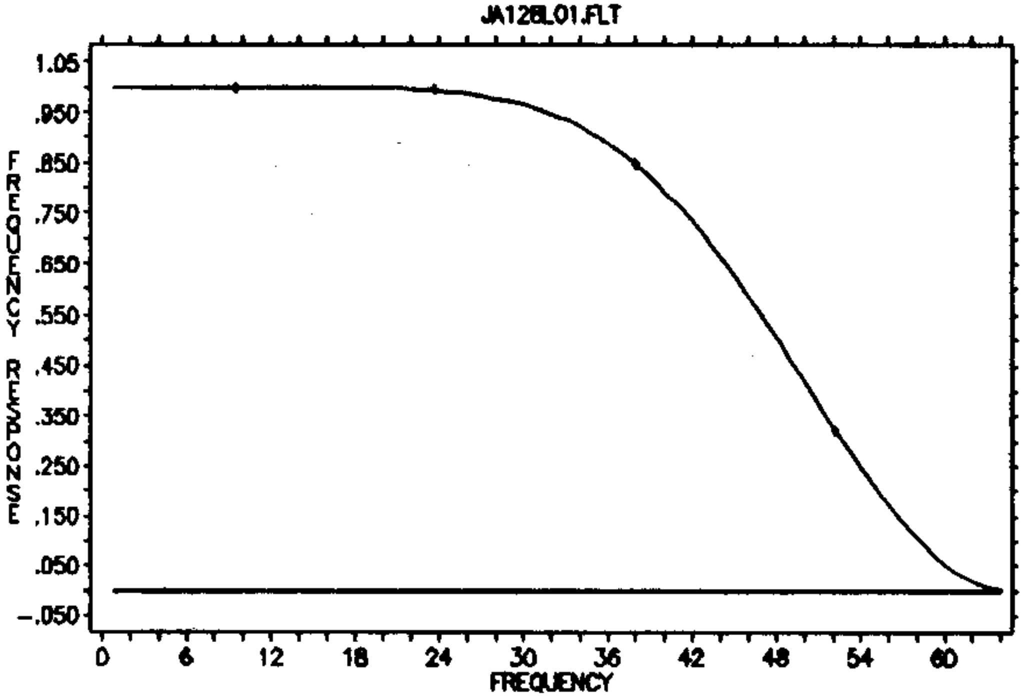


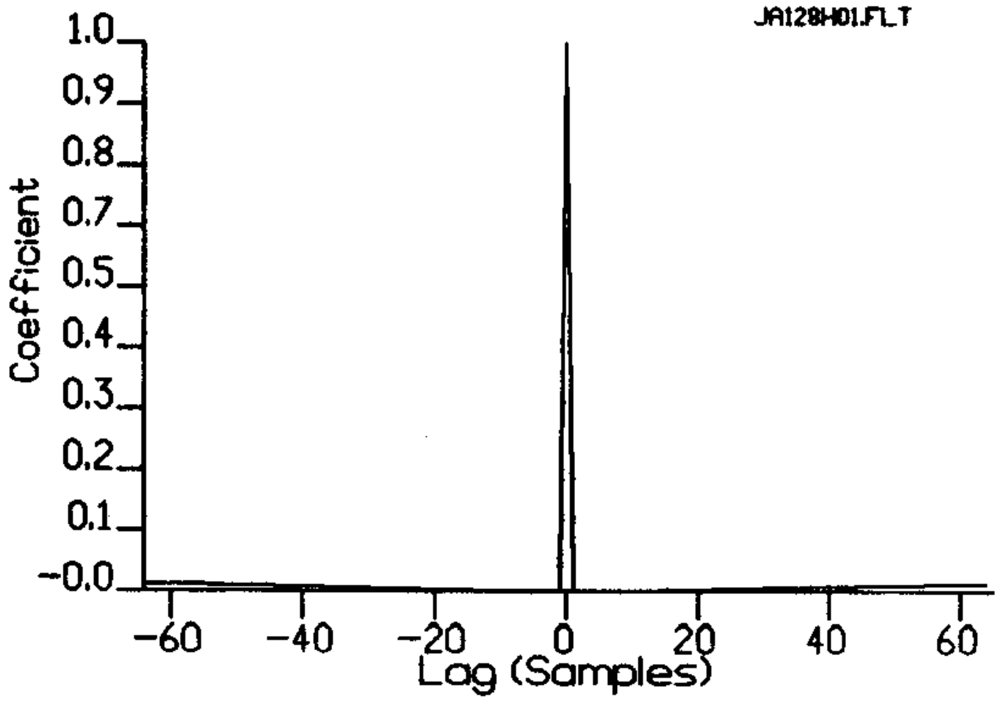
Impulse Response

Note:

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

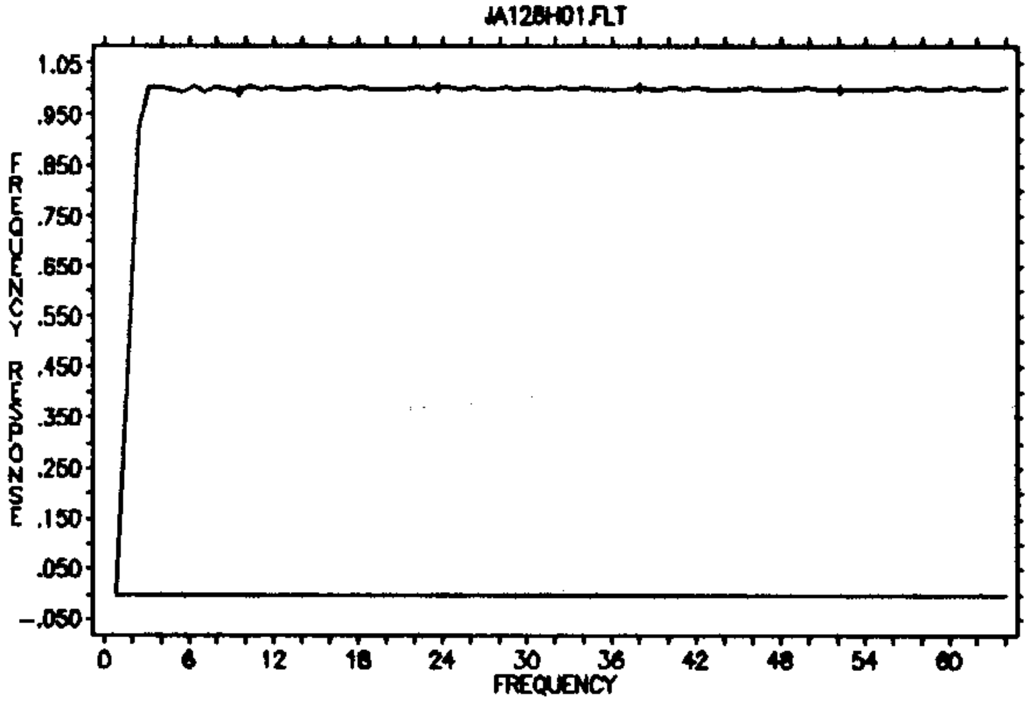
Transfer Function

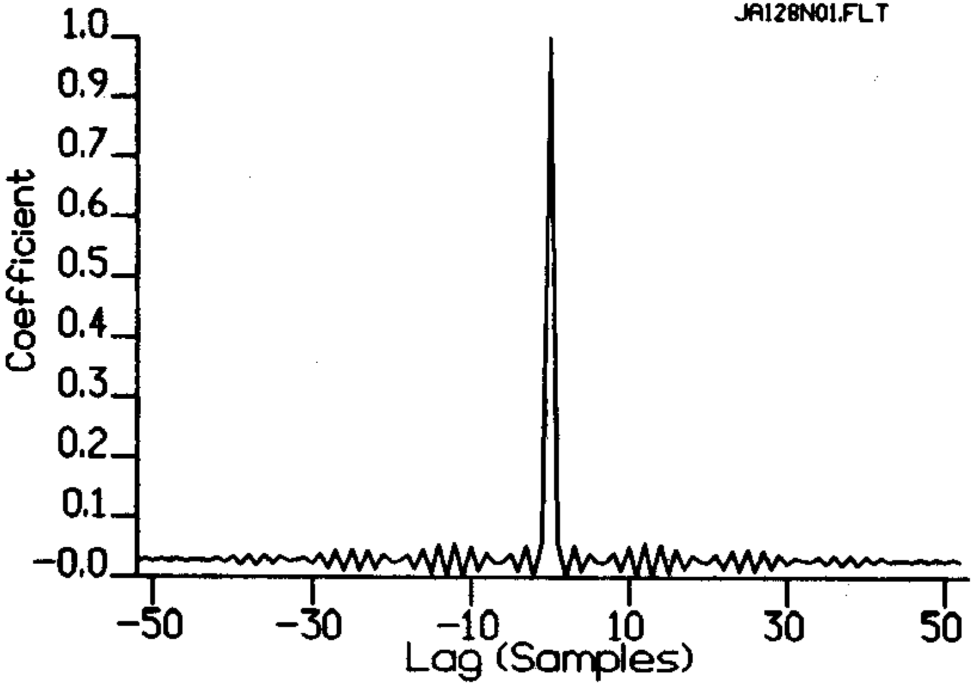




Impulse Response

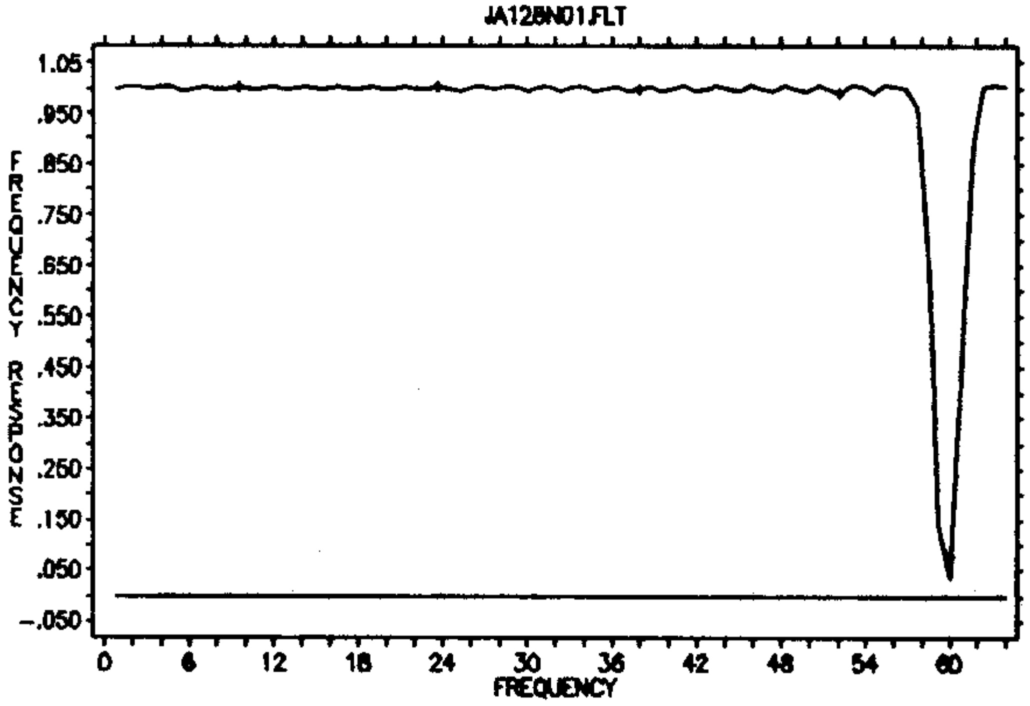
Transfer Function

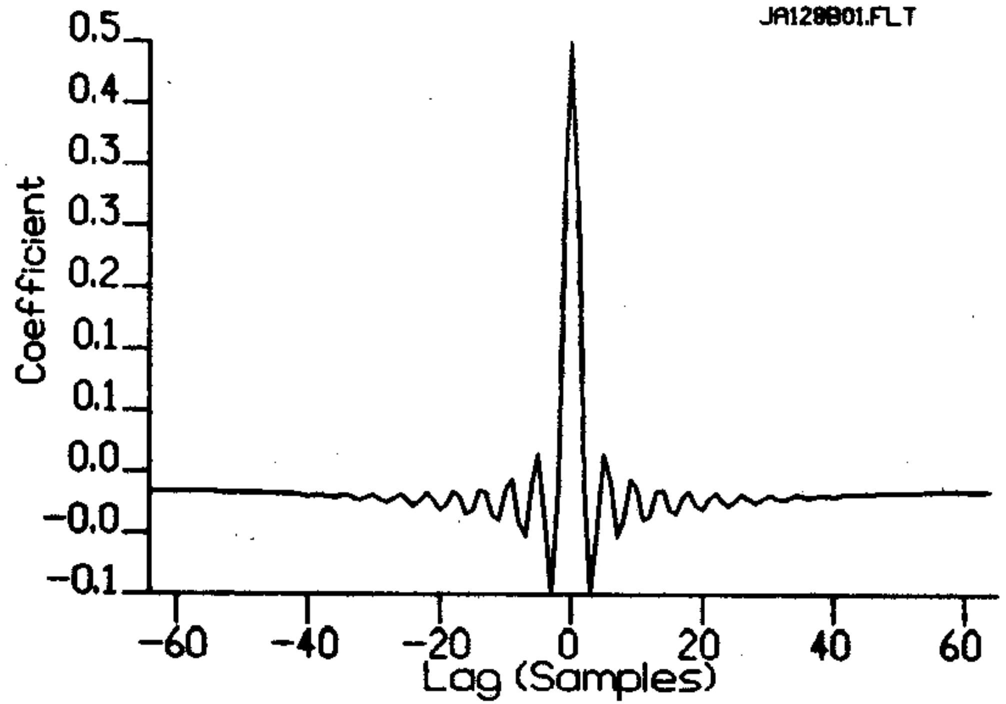




Impulse Response

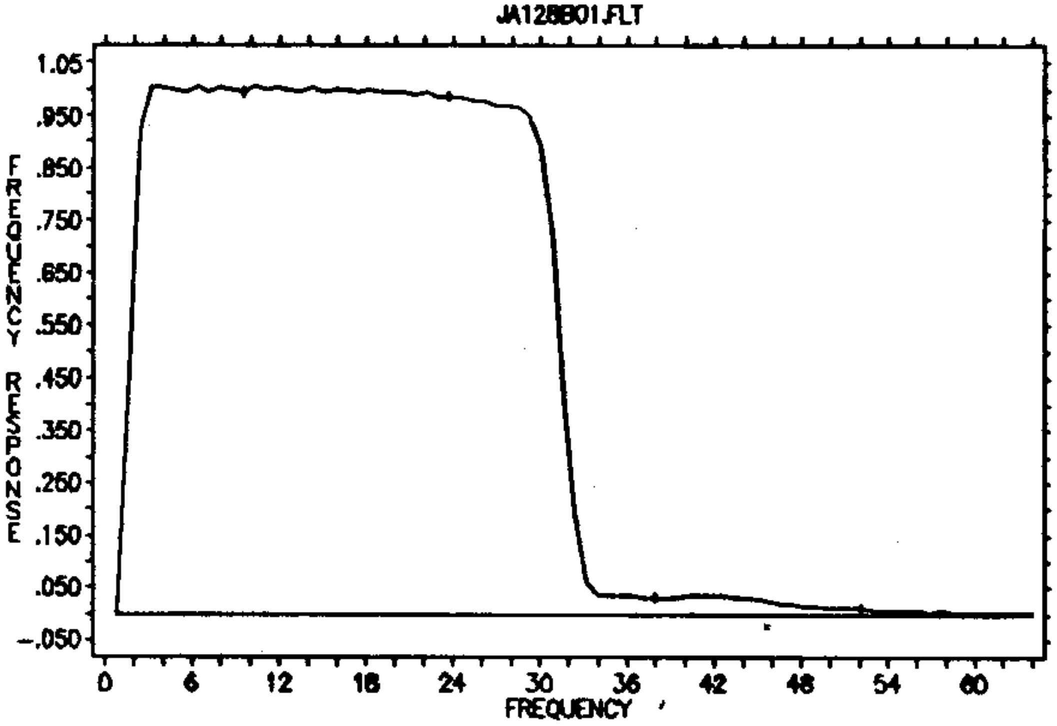
Transfer Function





Impulse Response

Transfer Function

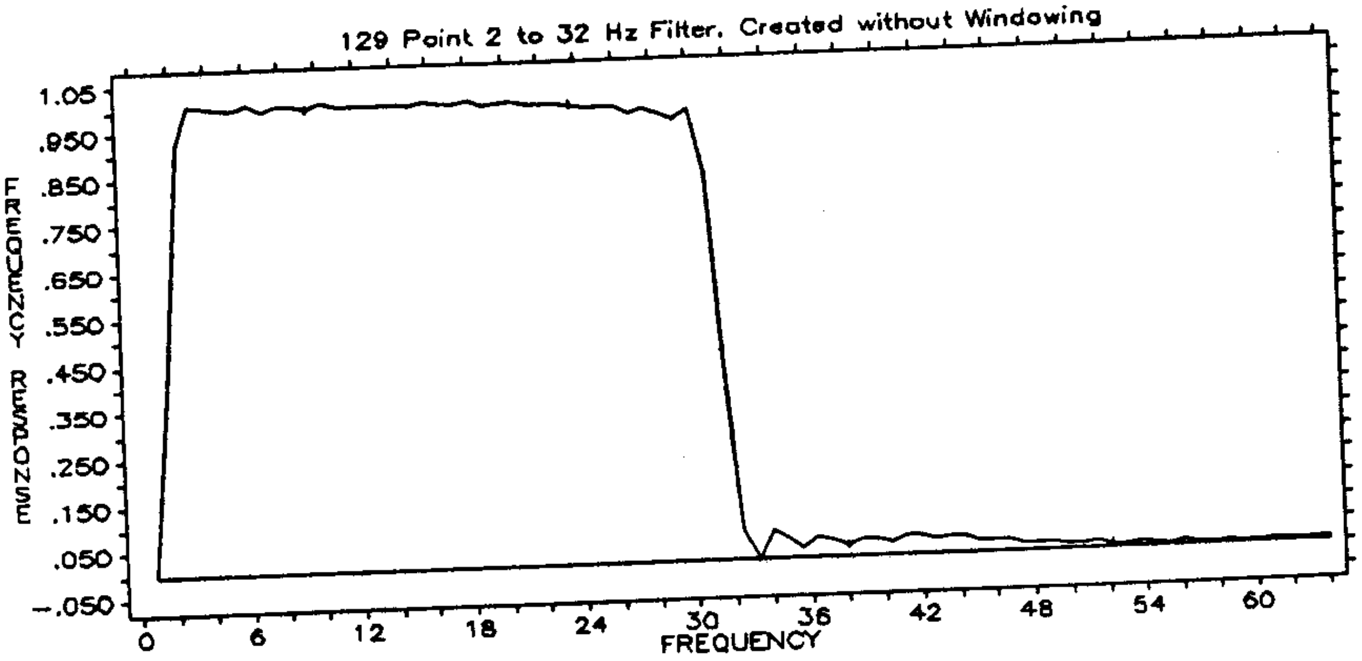


Pragmatic concerns

- 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

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

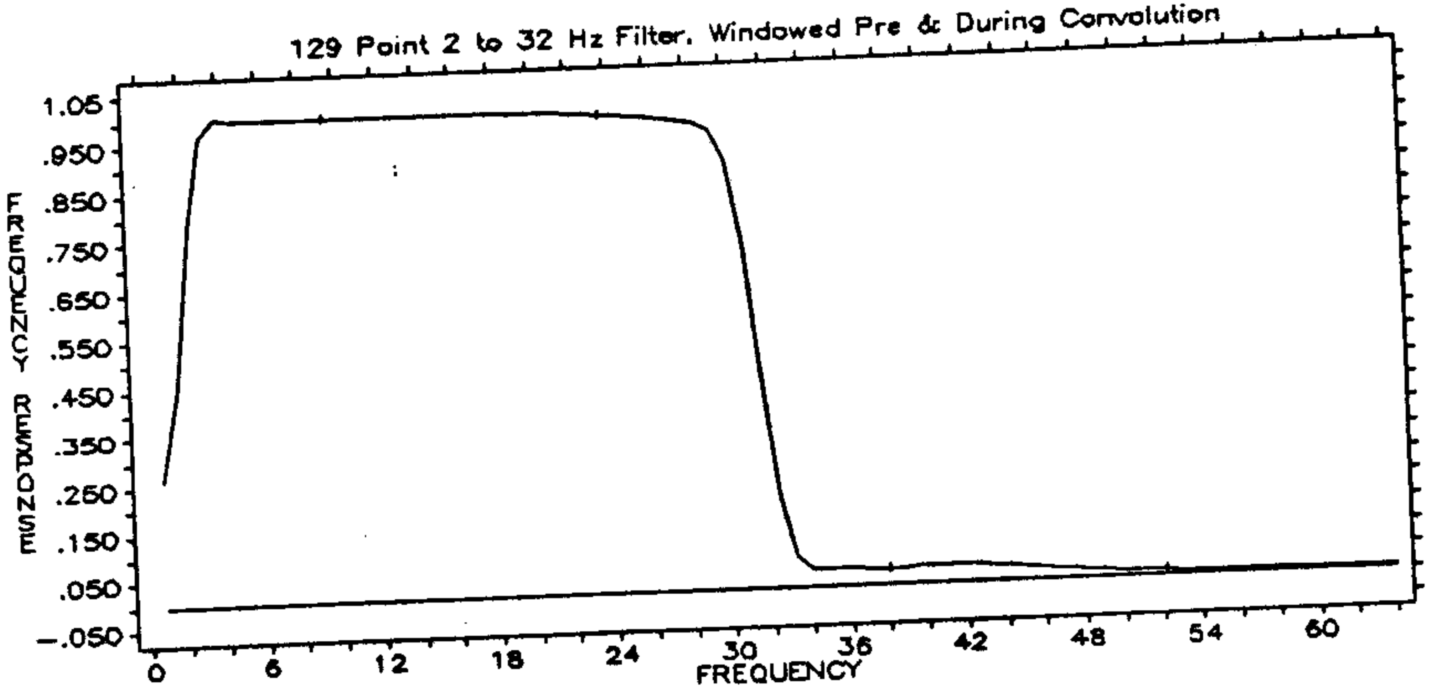
Hamming Taper, for *i* coefficients -*j* to +*j*,

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

where:

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

$p_i = i/(j+1)$



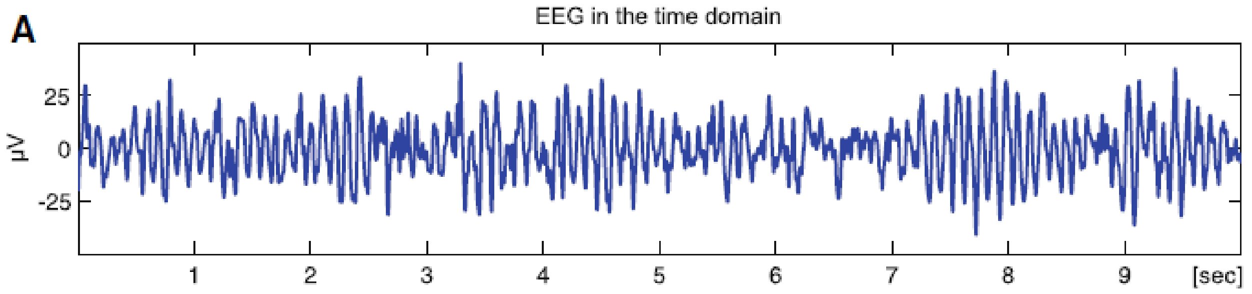
Use in Single Trial Analysis

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

Digital Filtering and More!

Time-Frequency Approaches

Brain Topogr (2014) 27:438–450

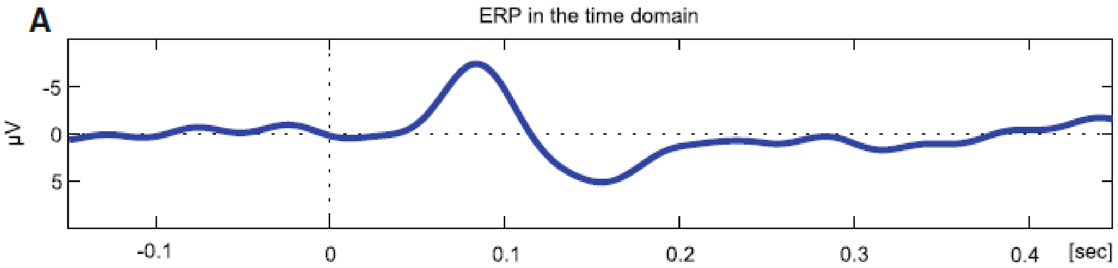


Let’s make sure we understand Time-Frequency Space!

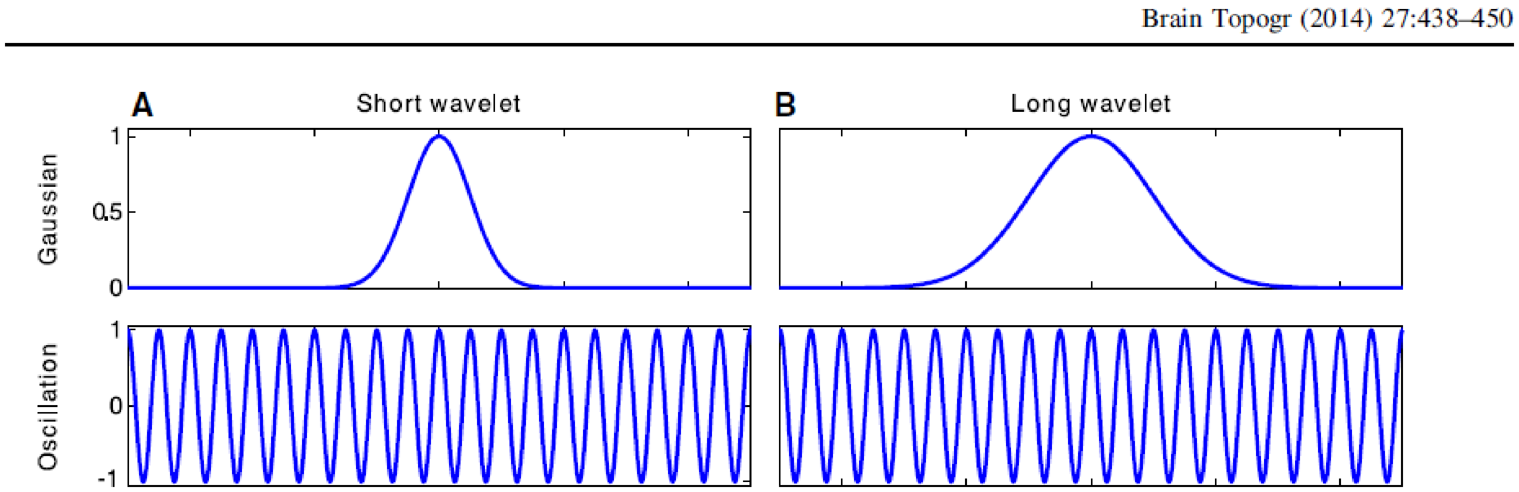
[MUSICLAB.CHROMEEXPERIMENTS.COM/SPECTROGRAM](https://musiclab.chromeexperiments.com/spectrogram)

Time-Frequency Approaches

Brain Topogr (2014) 27:438–450

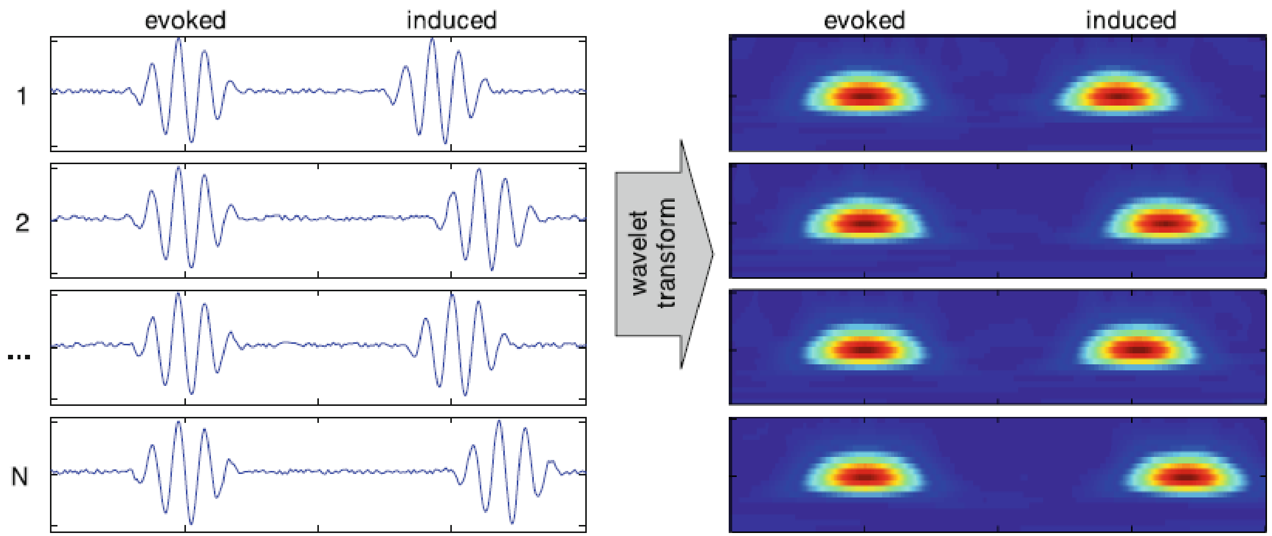


Time-Frequency Approaches



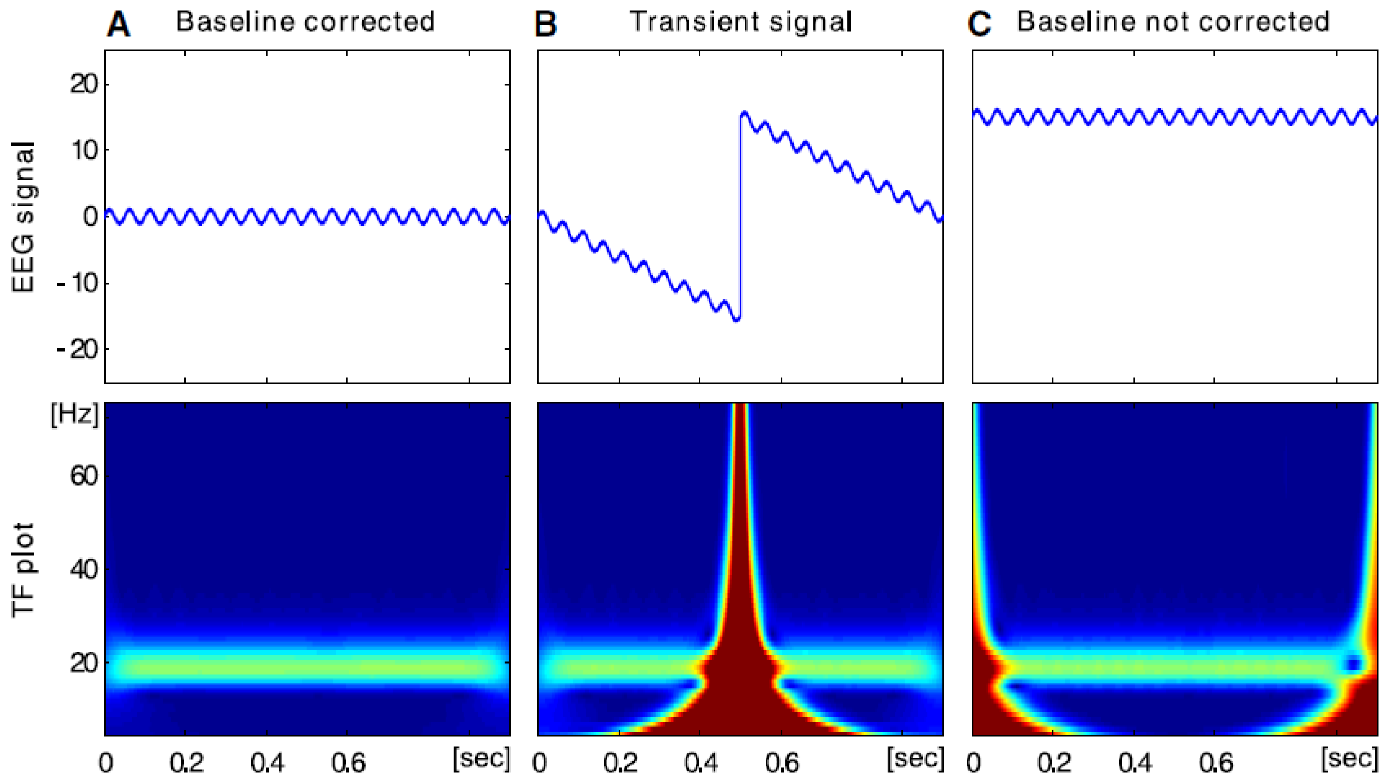
Time-Frequency Approaches

Brain Topogr (2014) 27:438–450



Time-Frequency Approaches

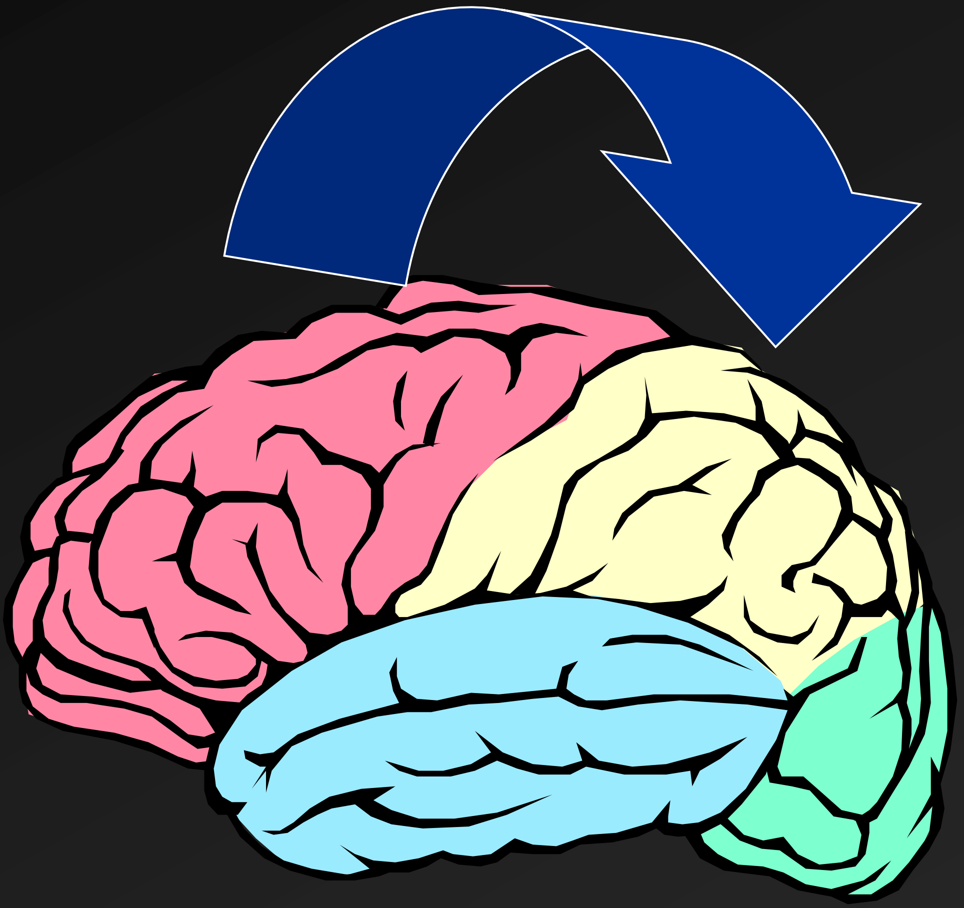
Brain Topogr (2014) 27:438–450



A bit more on phase and such

COURTESY OF MIKE COHEN

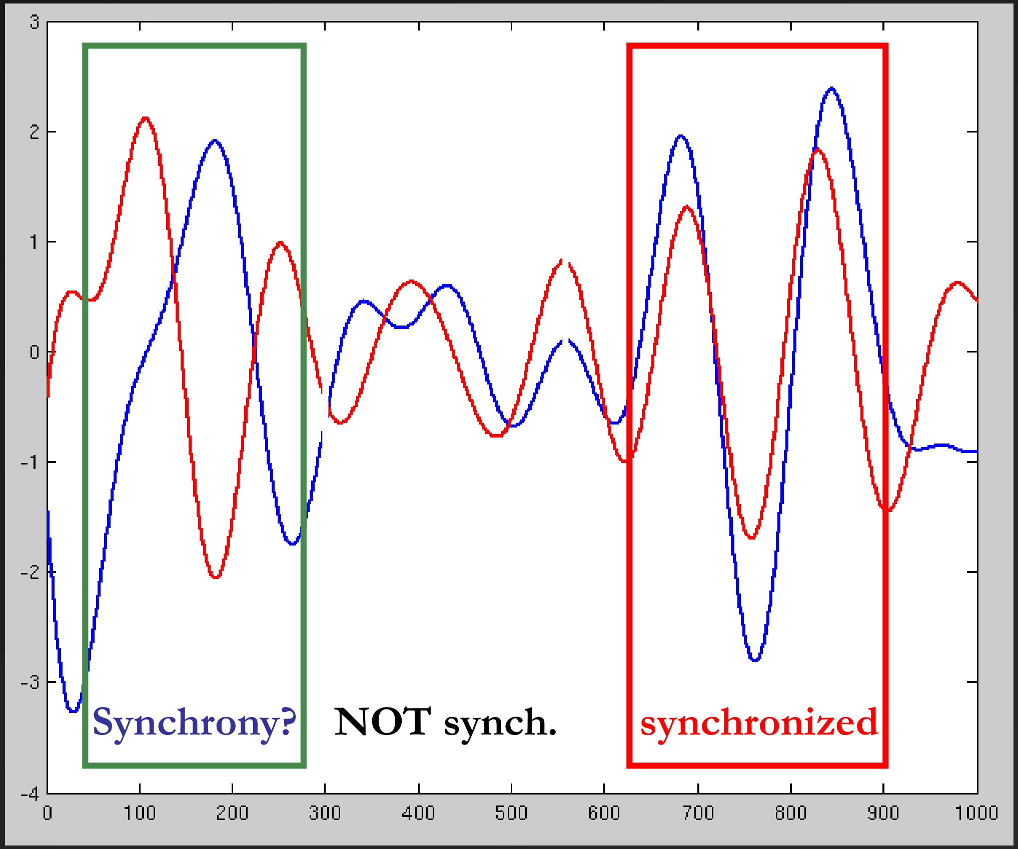
2. How do brain regions "talk" to each other?

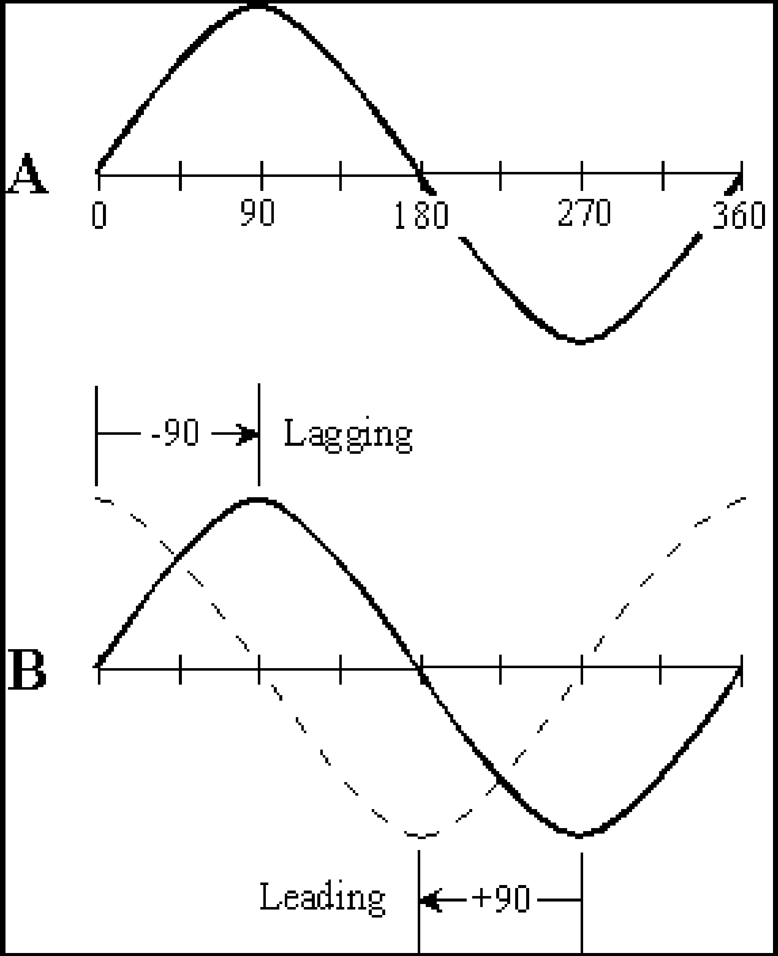


Perhaps through synchronized oscillations!

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

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



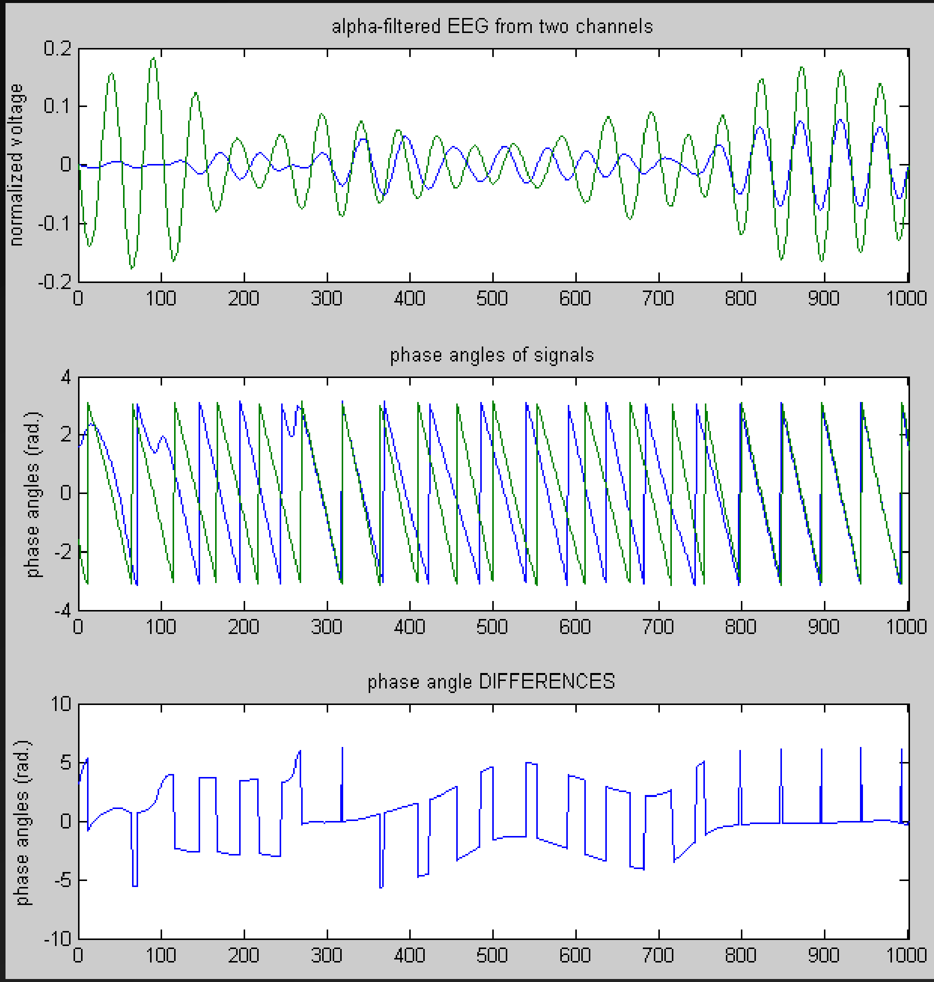


- The time interval for one degree of phase is inversely proportional to the frequency.
- You know…. the frequency of a signal f is expressed in Hz)
- The time *t* (in seconds) corresponding to:
  - one degree of phase is: $t_{deg} = 1 / (360 f)$
  - one radian of phase is approximately: $t_{rad} = 1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

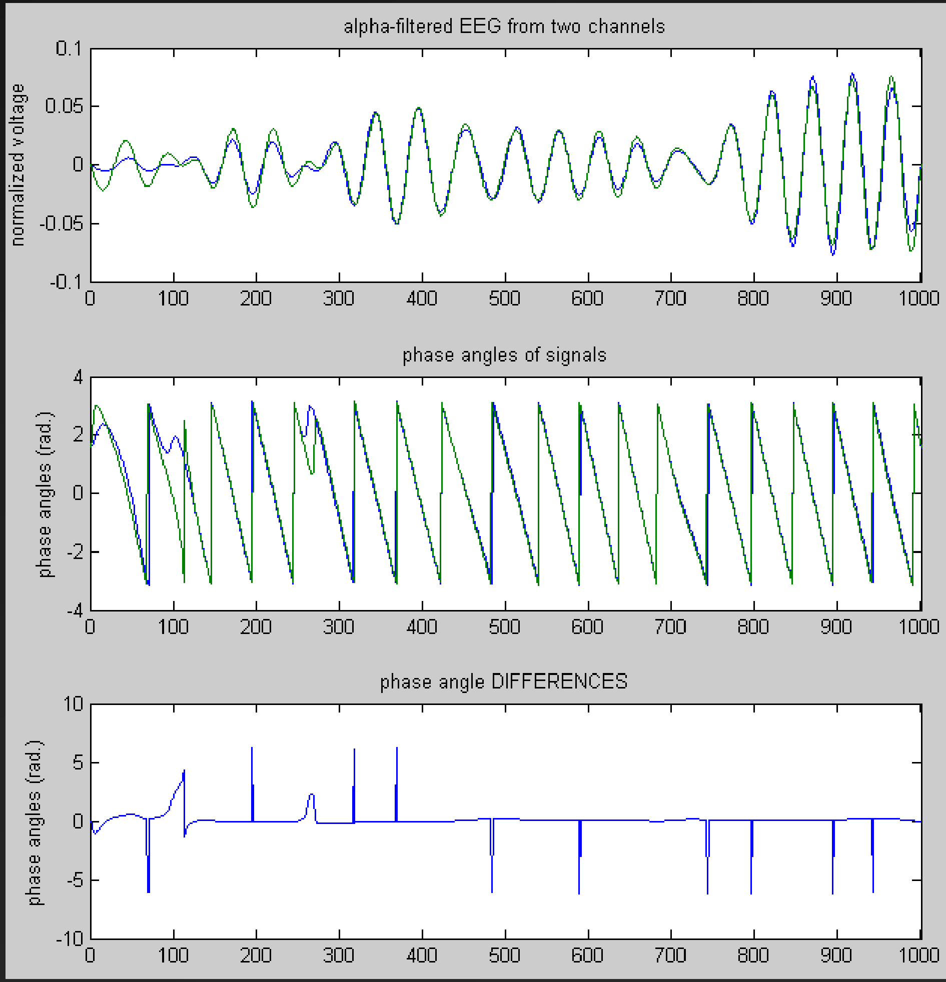
Adapted from http://whatis.techtarget.com/

2. Inter-site phase coherence.

Electrodes: Fp1 & C4

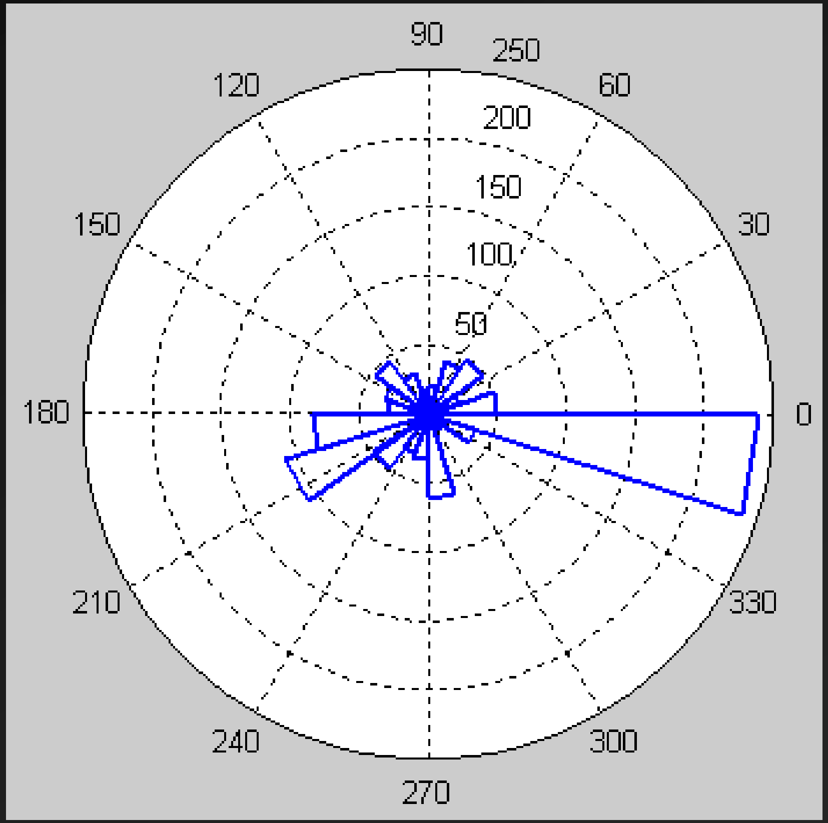


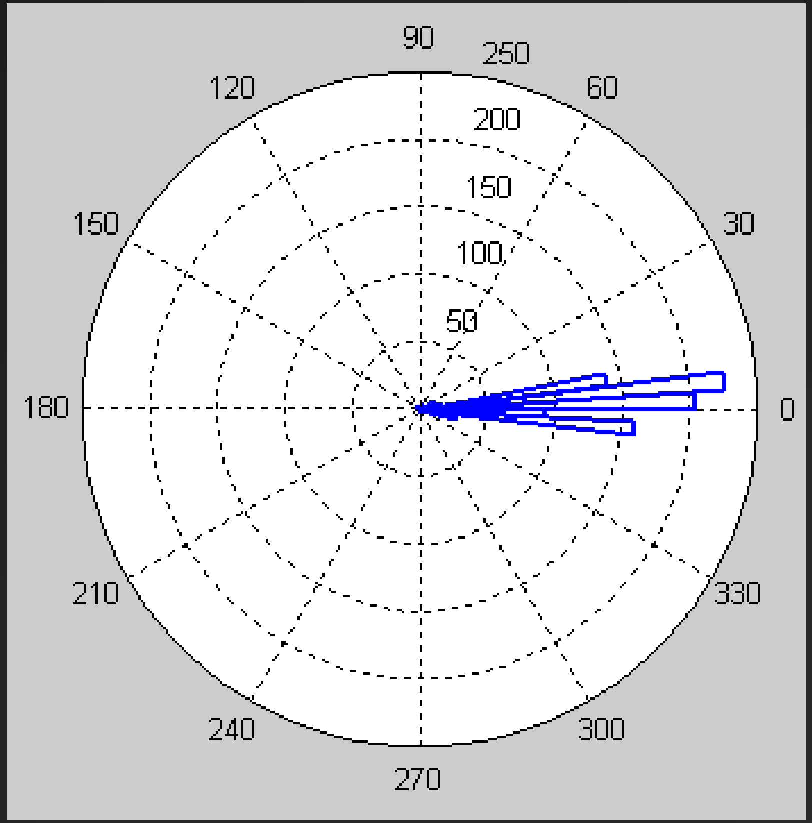
Electrodes: Fp1 & Fp2



2. Inter-site phase coherence?

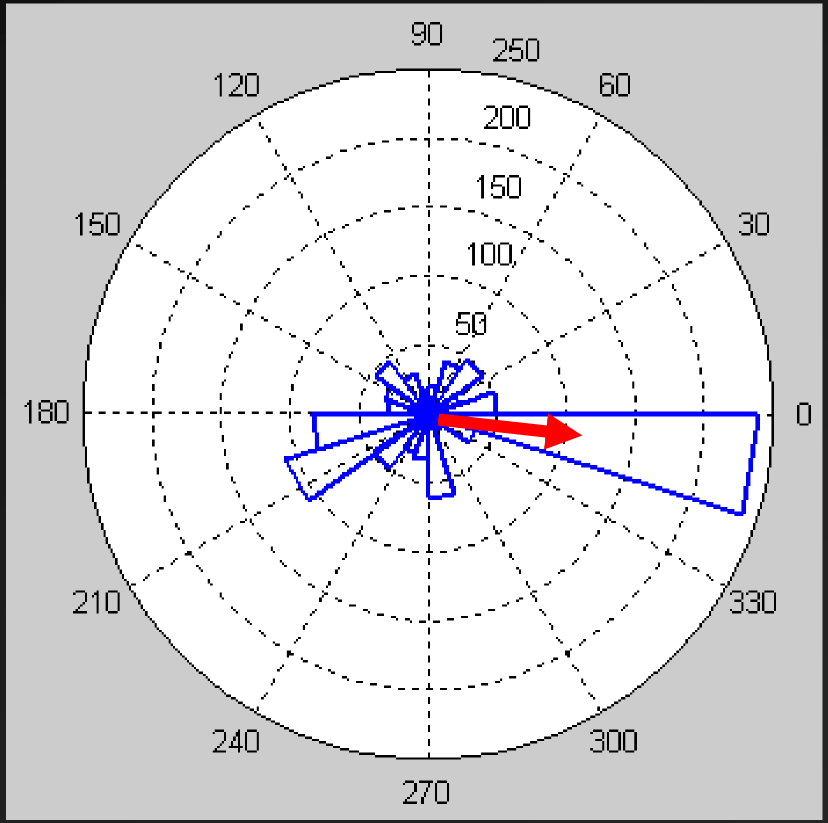
“Polar plot” of phase angle differences.

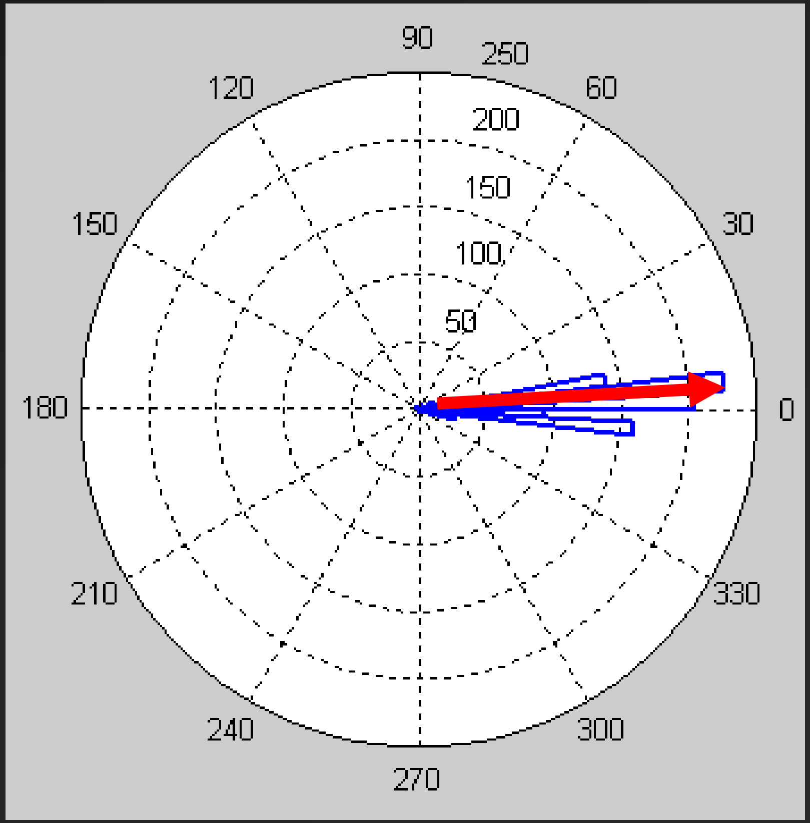




2. Circular variance.

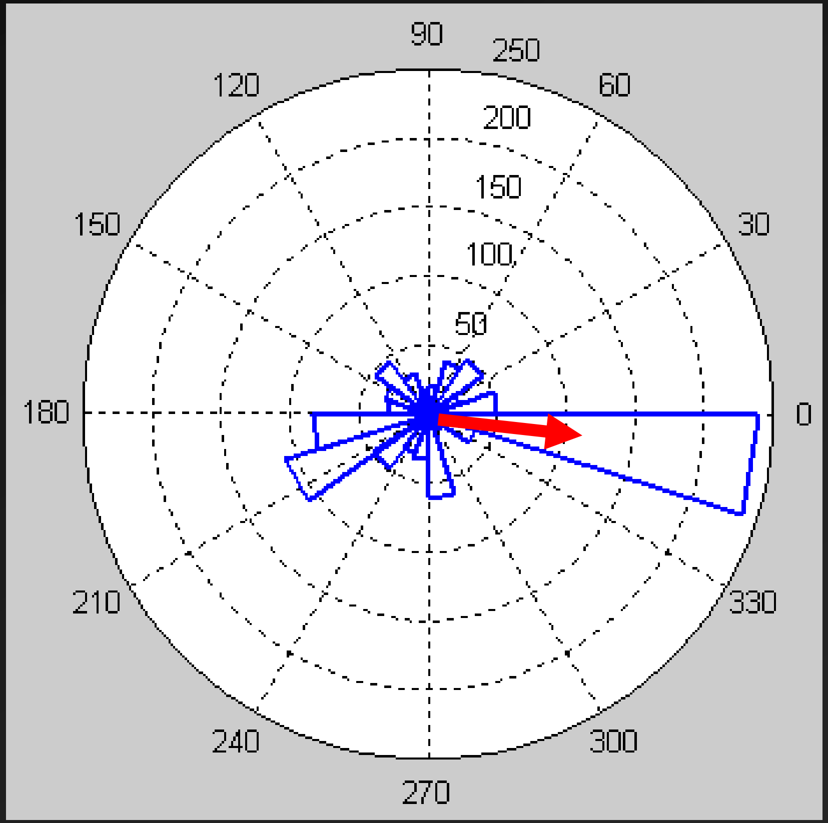
Draw a line through the "average" of vectors.



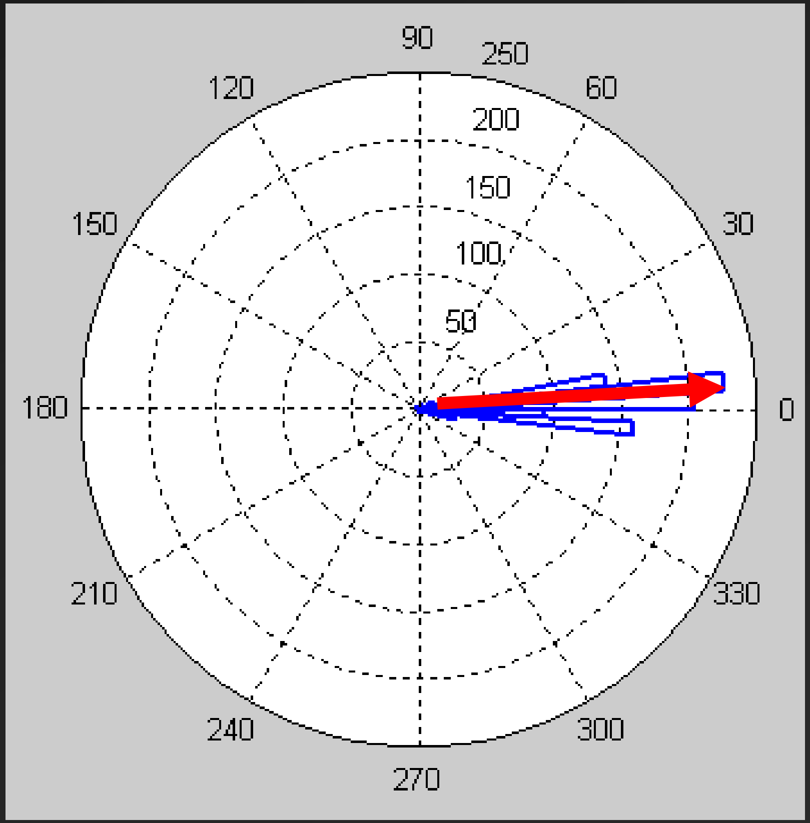


The length (magnitude) of that vector varies from 0 to 1, and is the phase coherence.

Phase coherence: 0.11



Phase coherence: 0.94



The equation for phase coherence is simple:

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

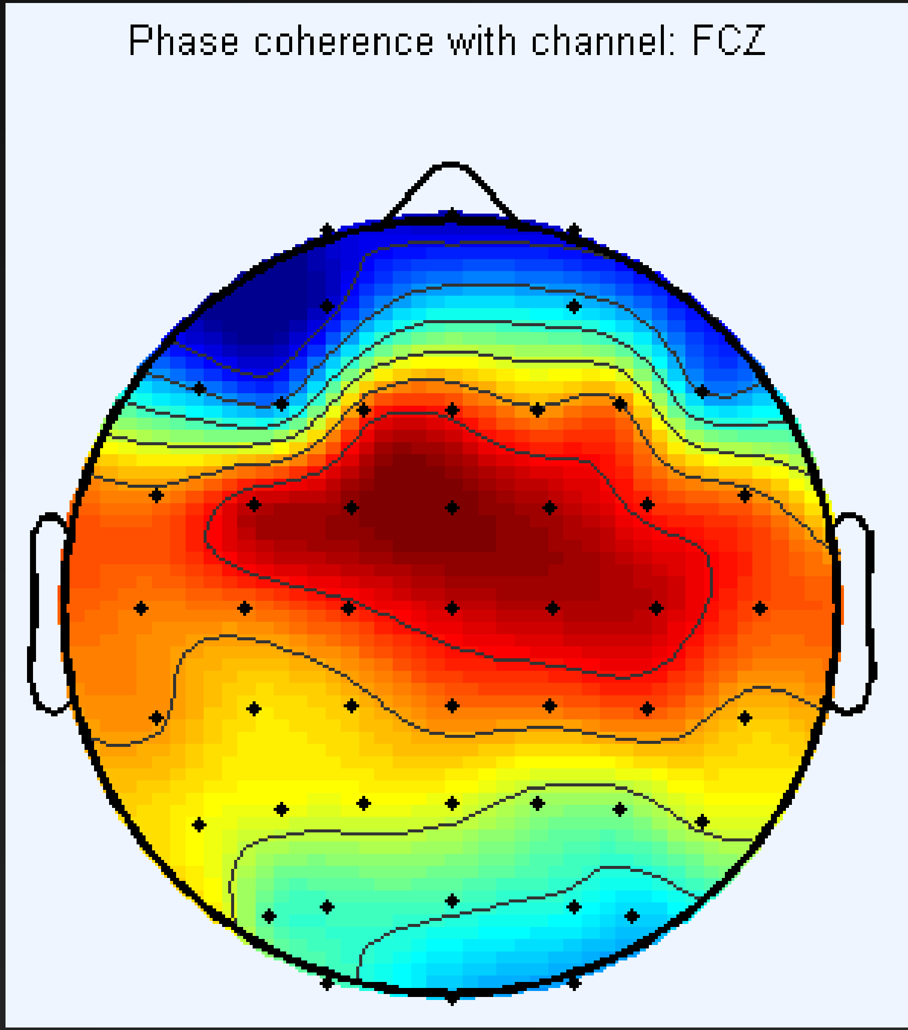
Magnitude of vector → `abs`

Average across values → `mean`

Transform to complex plane → `exp`, `i`

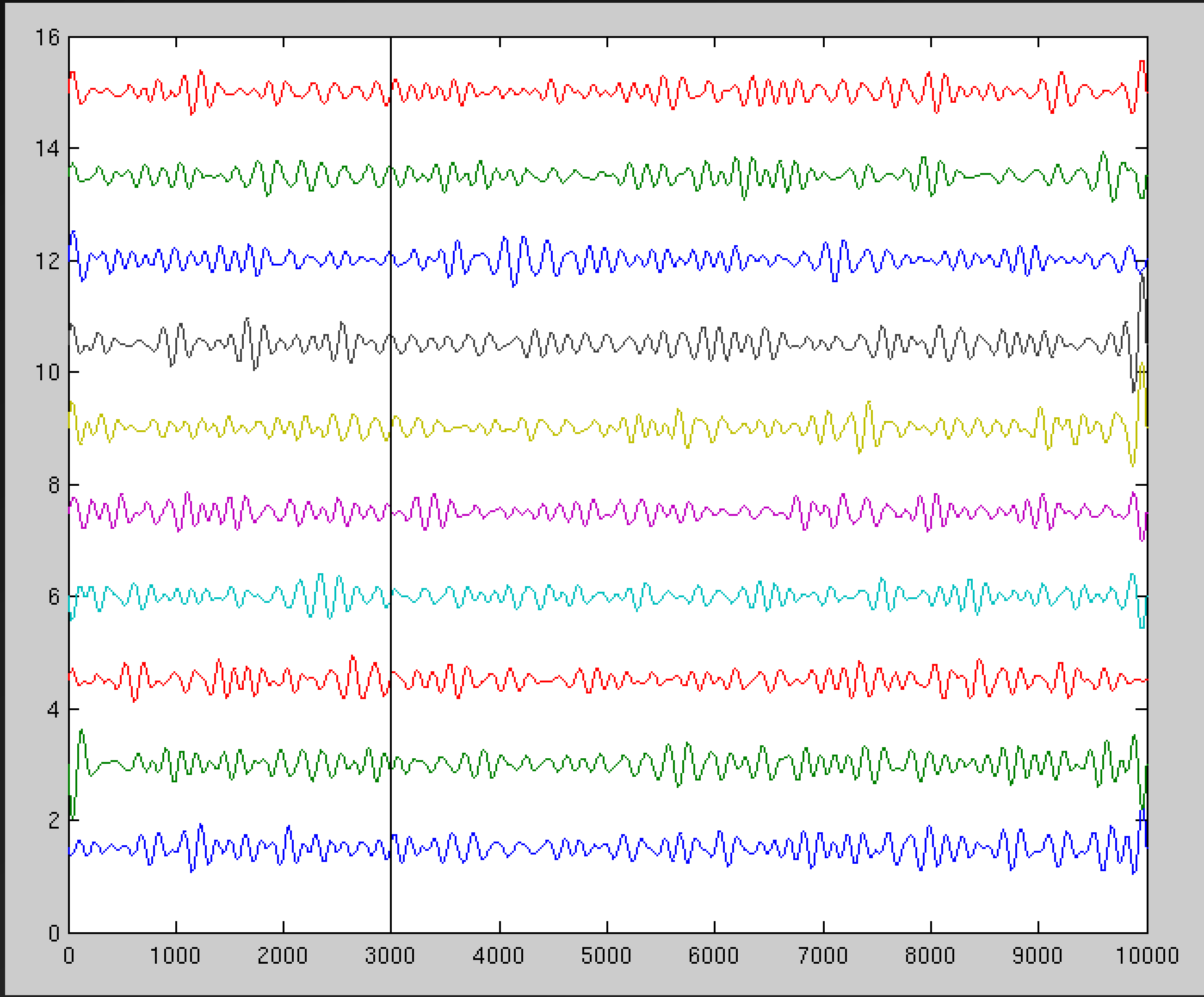
Phase angle differences between channels → `angle_differences`

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

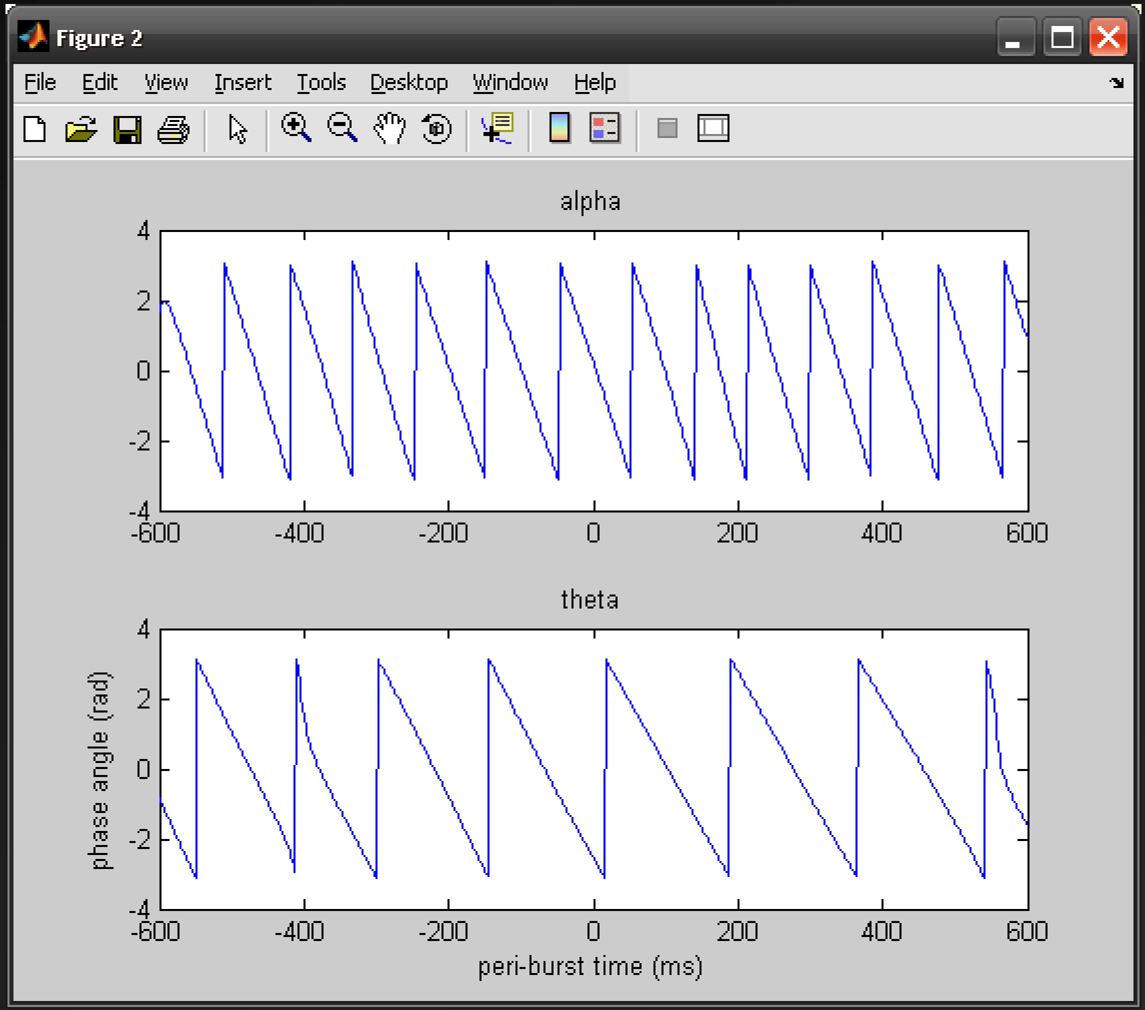


2. Inter-trial phase synchrony within one electrode.

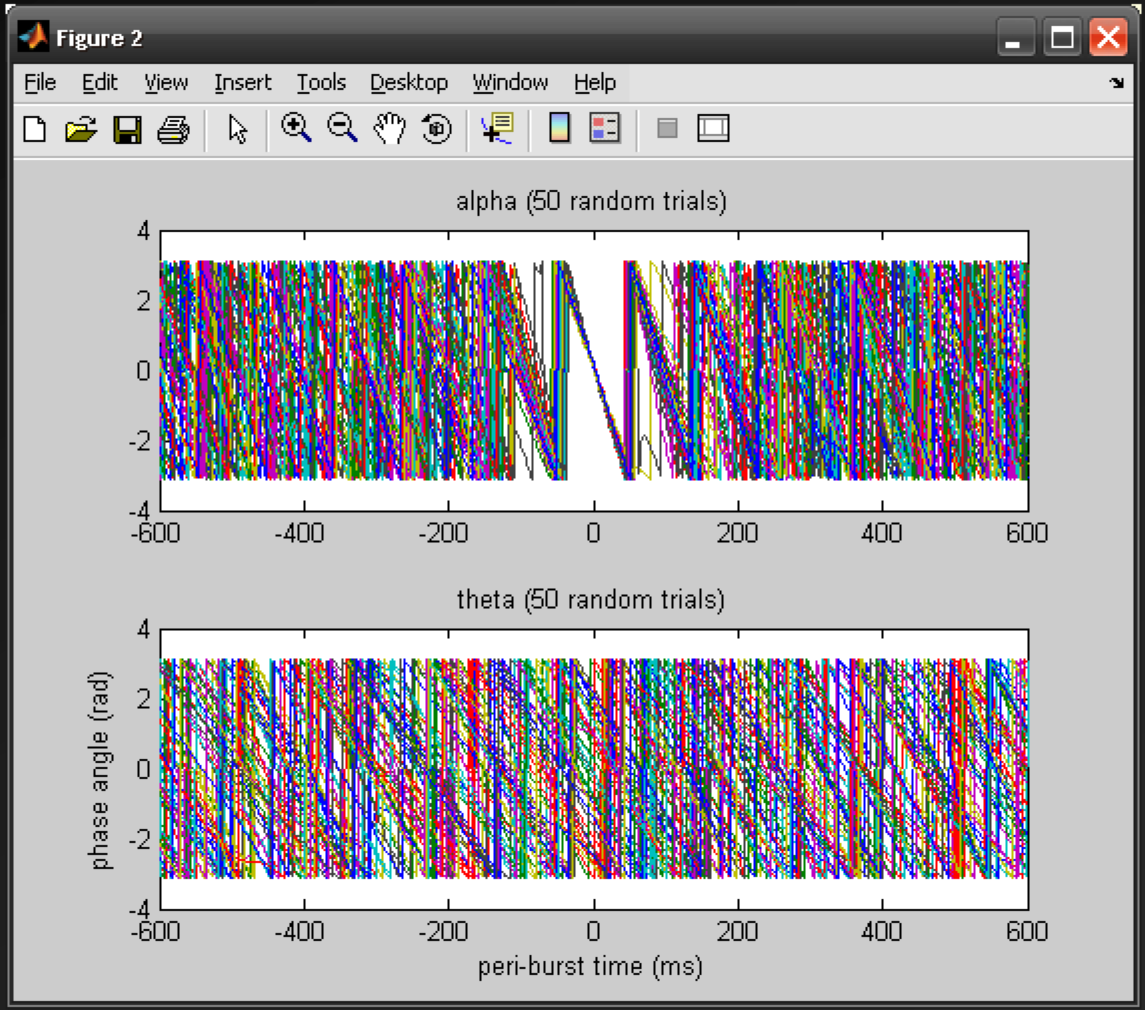
Many trials from the same electrode:



2. Inter-trial phase coherence

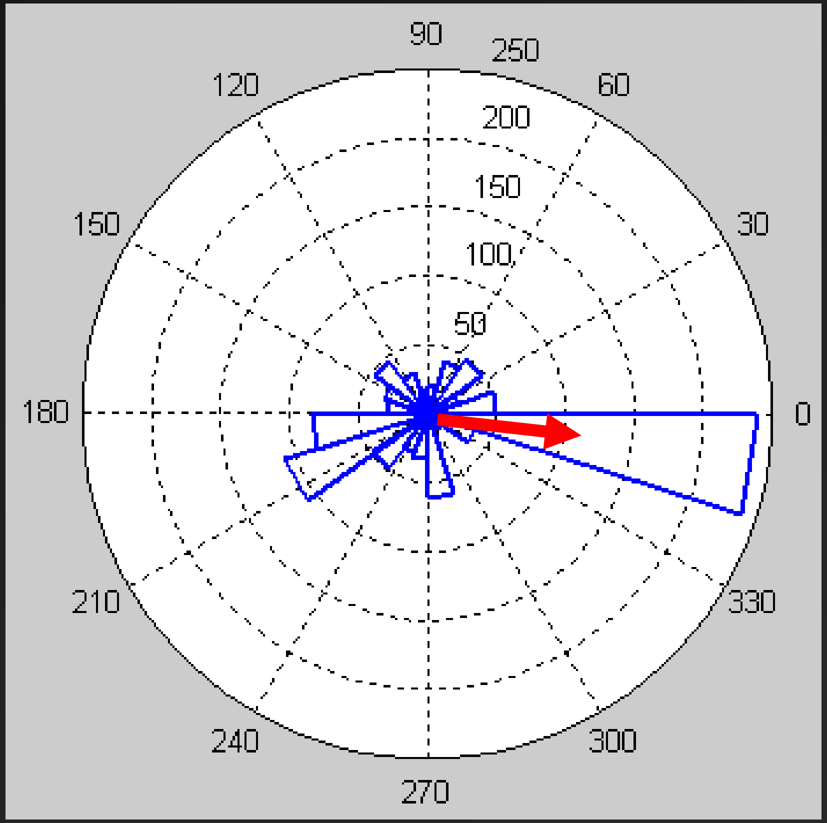


2. Inter-trial phase coherence

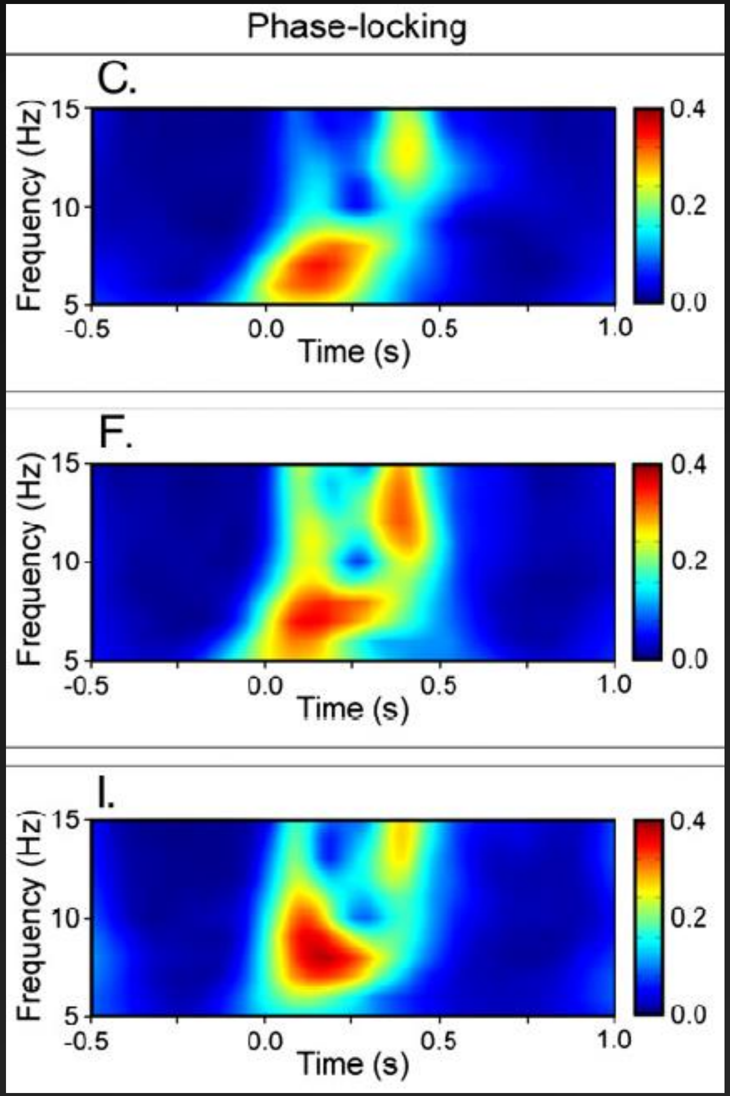


Calculate phase coherence across trials at each time point

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

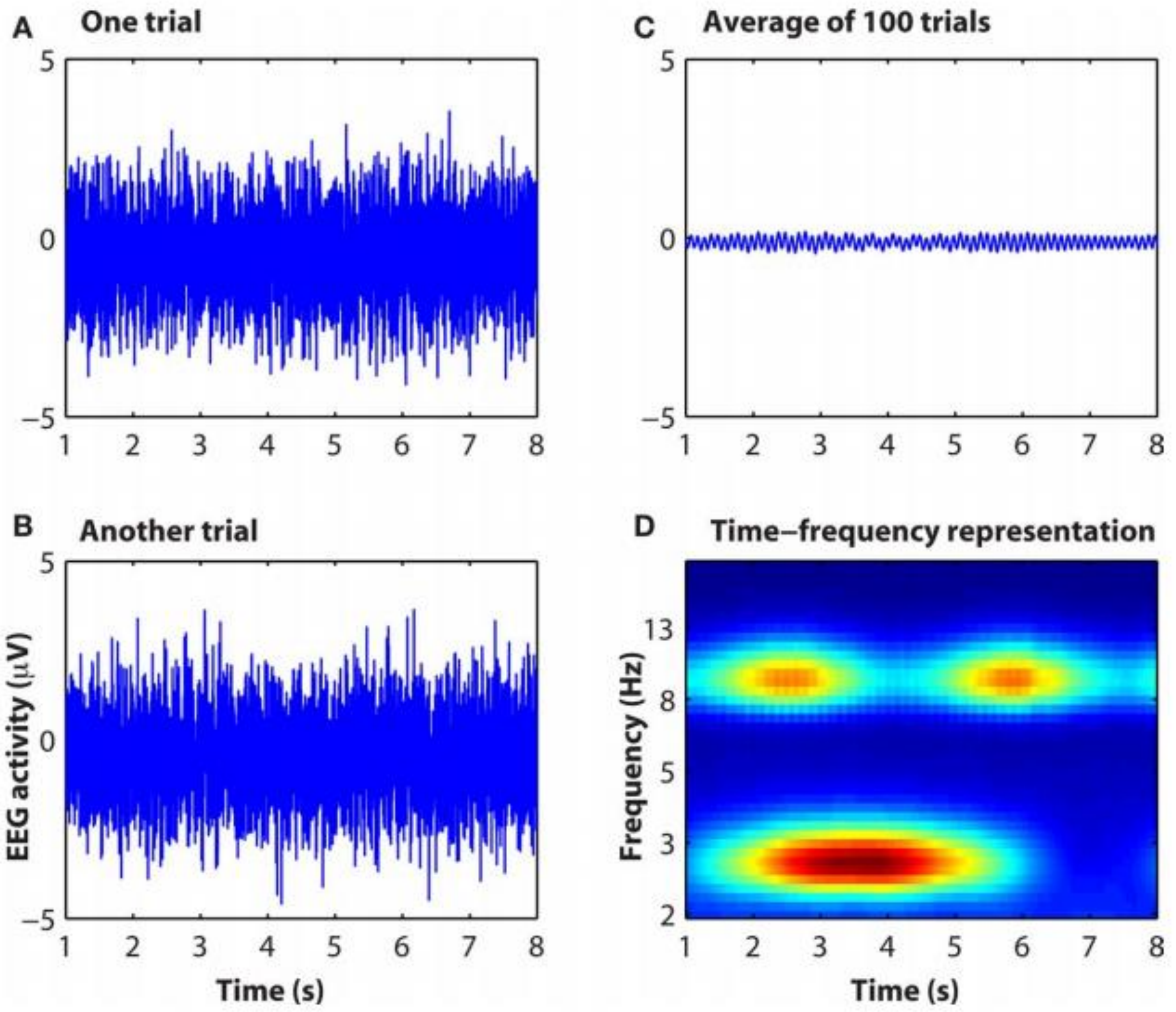
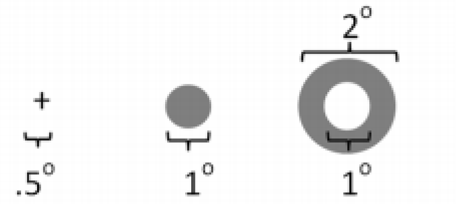
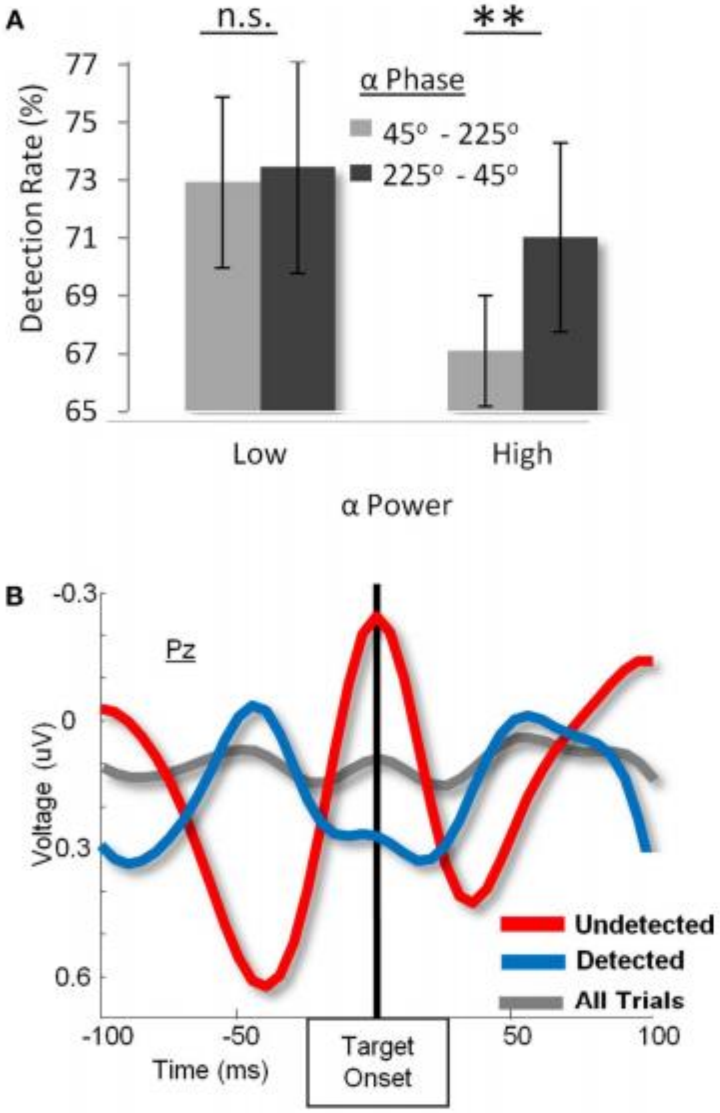


FIGURE 3 | Simulated data showing how information contained in raw EEG data [**(A,B)**: single "trials"] is not apparent in the event-related potential **(C)** but is readily observable in the time–frequency representation **(D)**. Matlab code to run this simulation is available from the author.

Cohen, 2011, *Frontiers in Human Neuroscience*

The Importance of Phase!





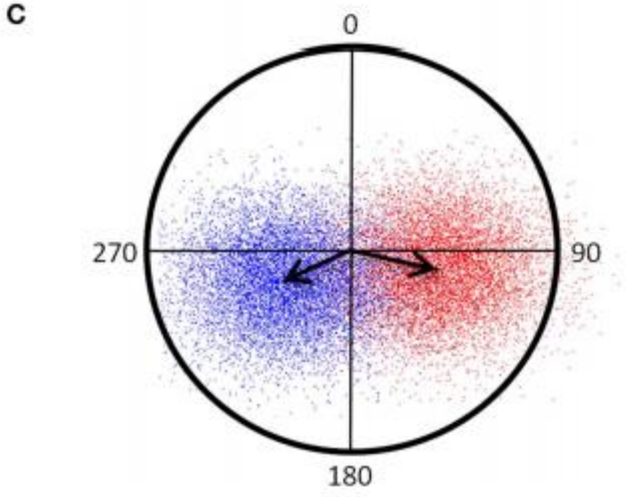
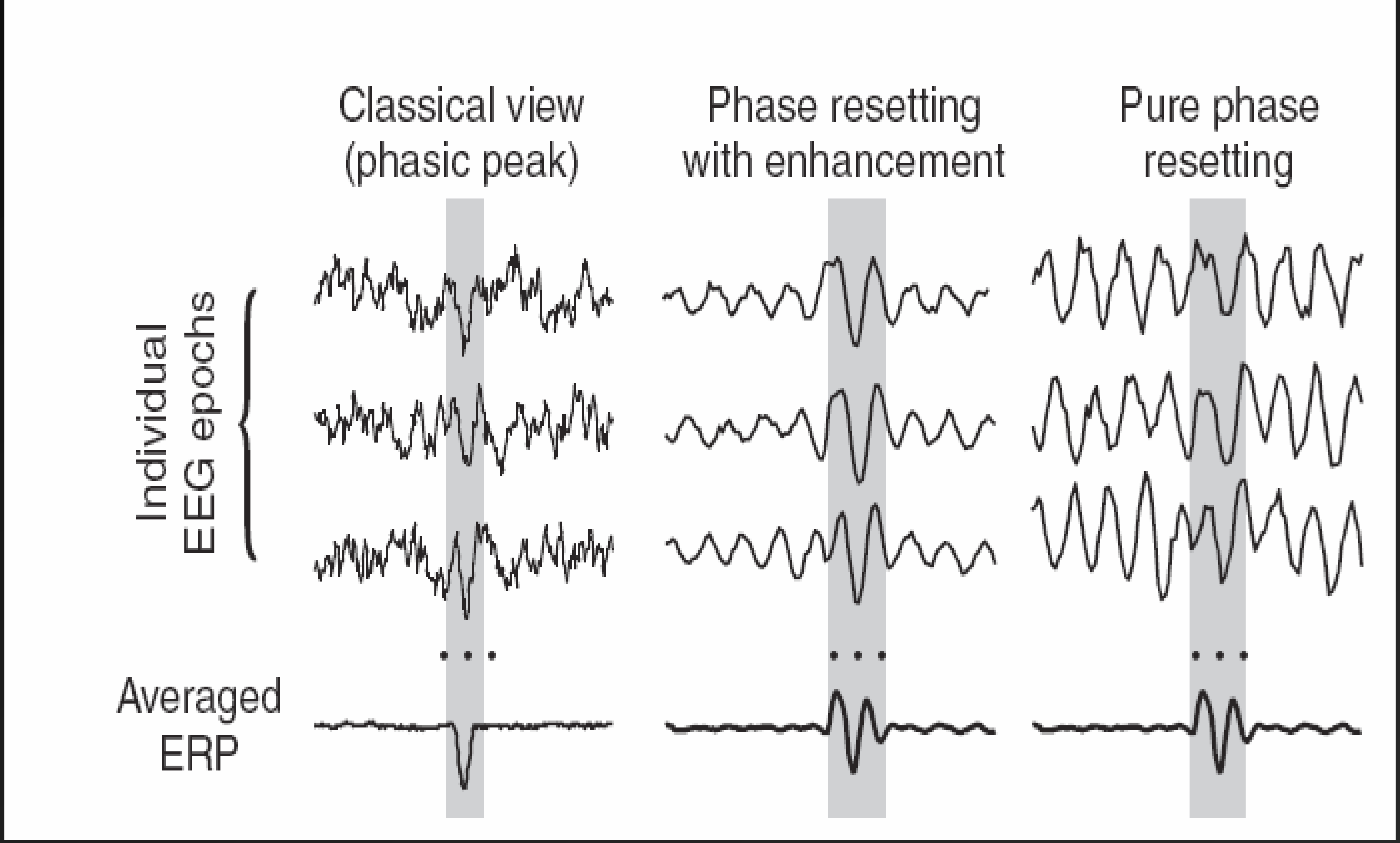


FIGURE 3 | (A) Detection rate as a function of alpha power and phase before stimulus onset. When alpha power is low (left bar graph), there is no difference in masked-target detection as a function of pre-target alpha-phase. When alpha power is high (right bar graph), however, not only is detection lower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

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

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

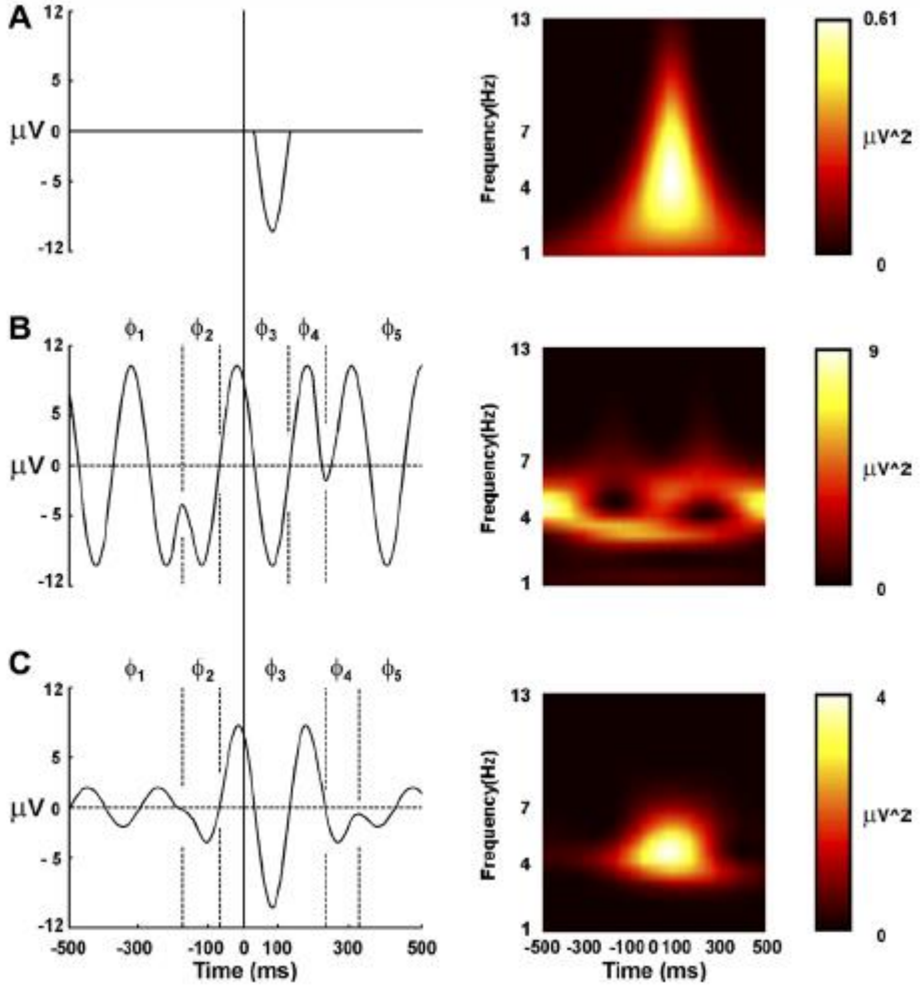
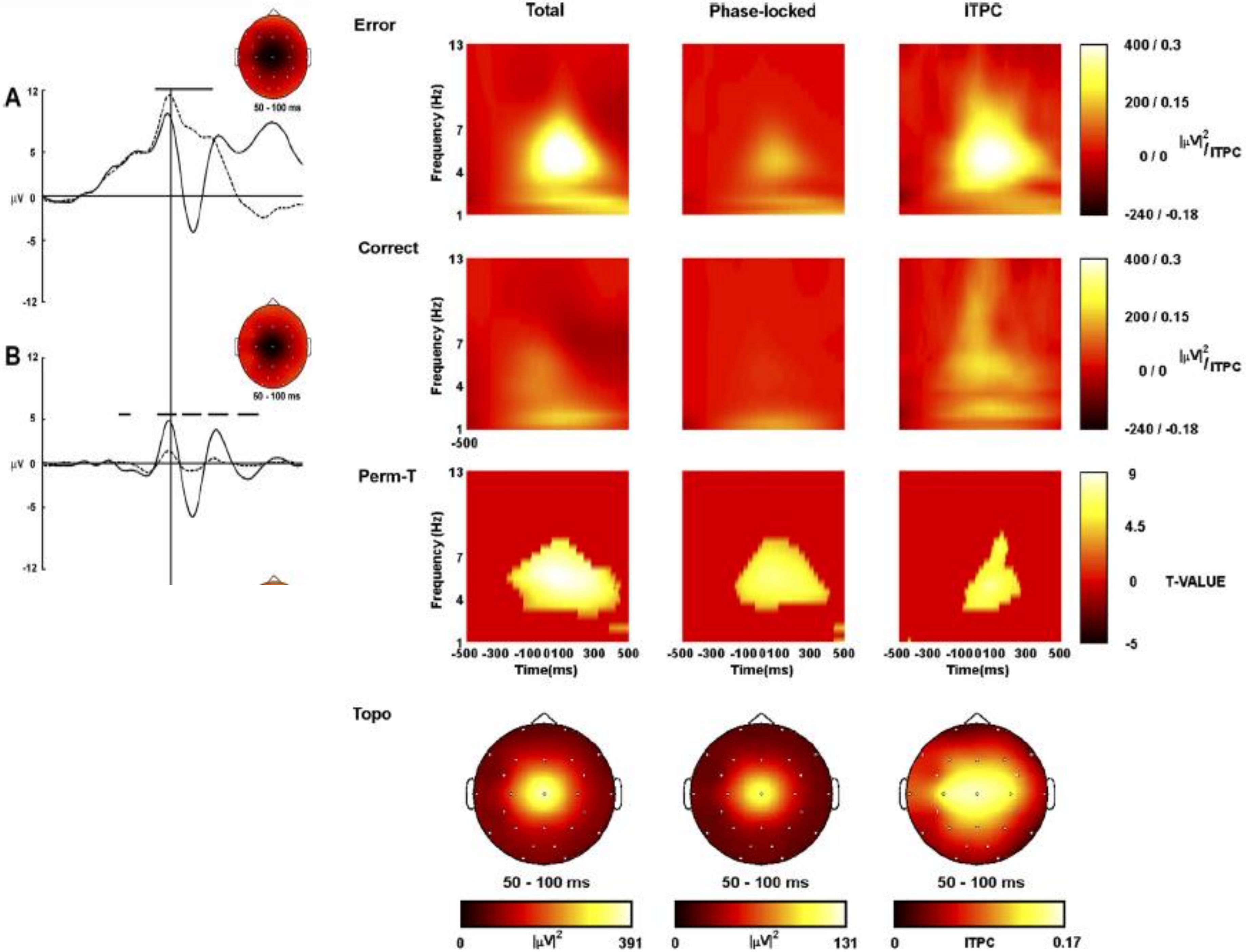
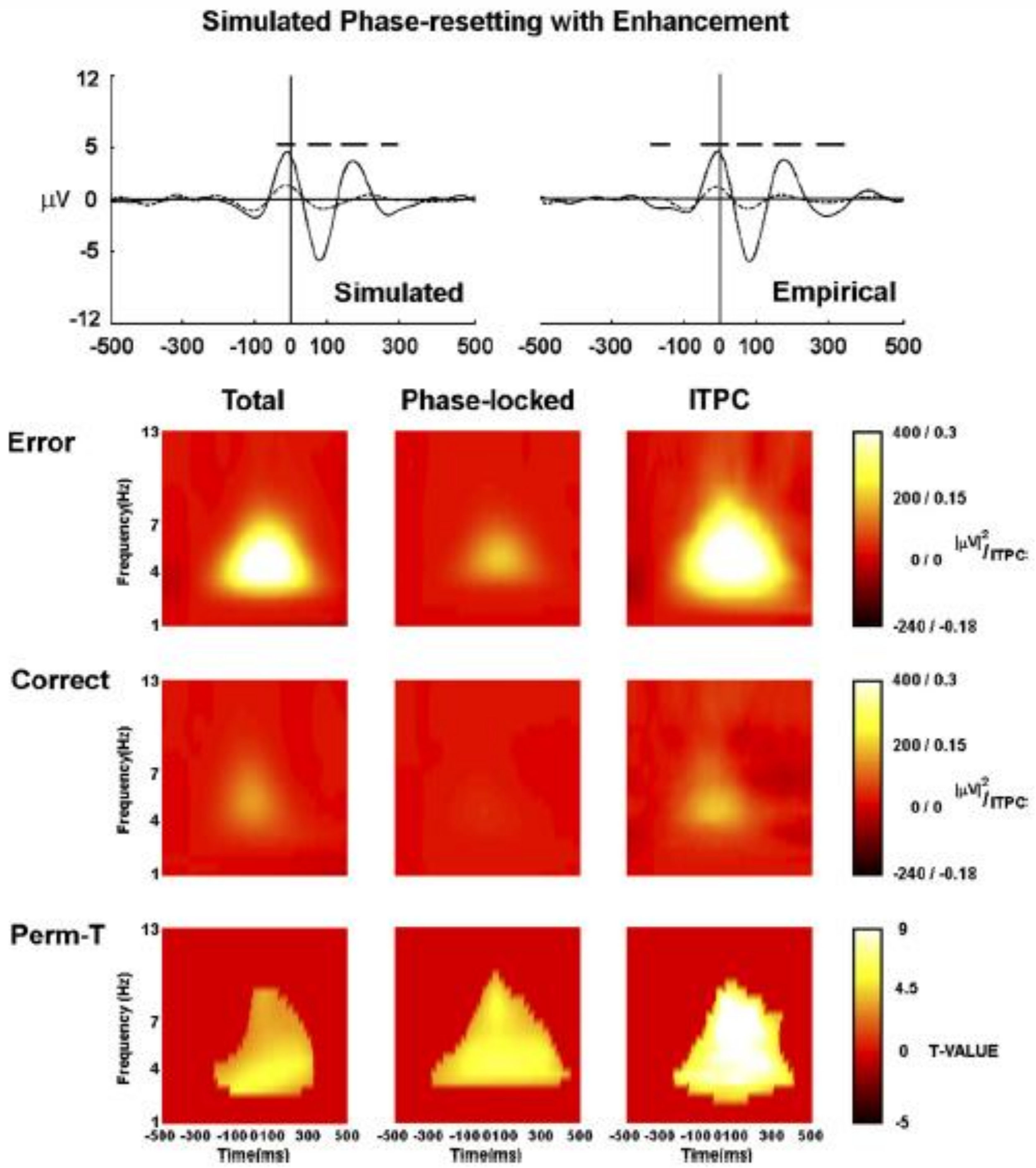


Fig. 1. Left column: Basic oscillatory waveforms used to simulate ERN responses according to the (A) *classic*, (B) *pure phase-resetting*, and (C) *phase-resetting with enhancement* hypotheses of ERN generation. Right column: Corresponding non-baseline-corrected wavelet-based time–frequency representations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

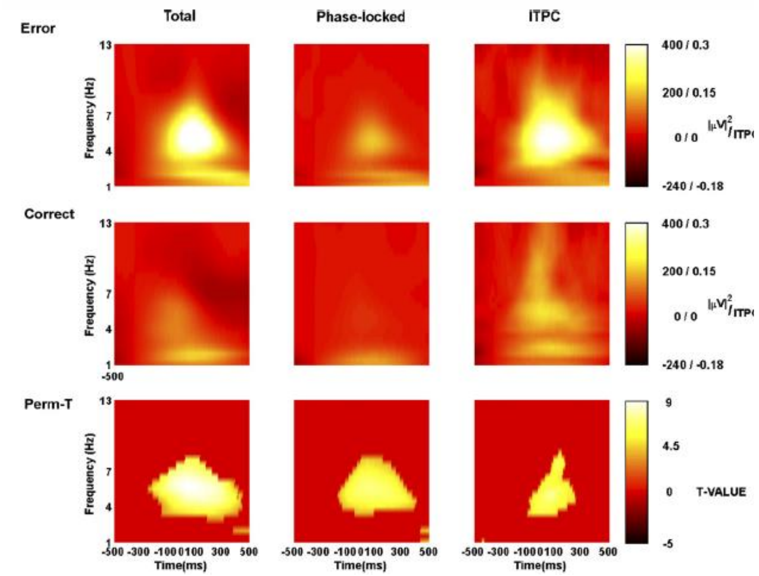


A
B
50 - 100 ms
Error
Correct
Perm-T
Topo
Total
Phase-locked
ITPC
Frequency (Hz)
Time(ms)
400 / 0.3
200 / 0.15
0 / 0
-240 / -0.18
|μV|²/ITPC
9
4.5
0
-5
T-VALUE
|μV|²
ITPC
391
131
0.17

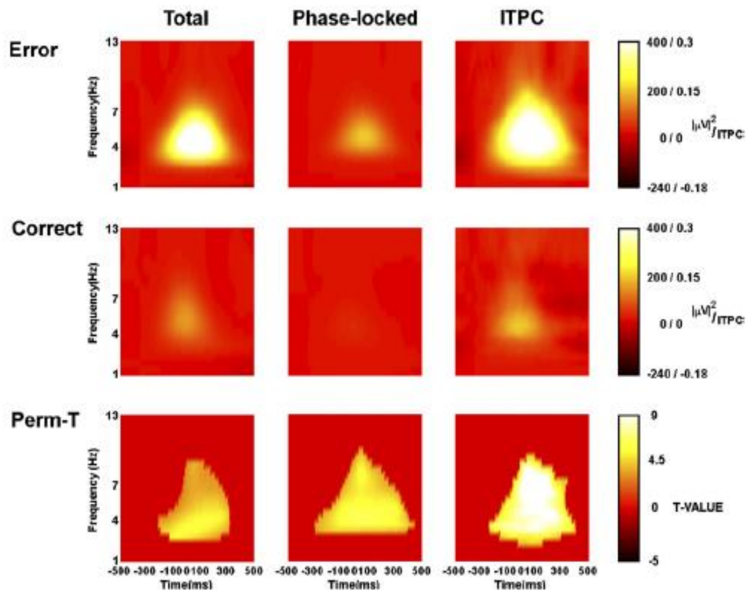


Simulated Phase-resetting with Enhancement
12
5
μV 0
-5
-12
Simulated
Empirical
-500 -300 -100 0 100 300 500
Total
Phase-locked
ITPC
Error
Correct
Perm-T
Frequency(Hz)
13
7
4
1
400 / 0.3
200 / 0.15
0 / 0
-240 / -0.18
|μV|²/ITPC
9
4.5
0
-5
T-VALUE
Time(ms)

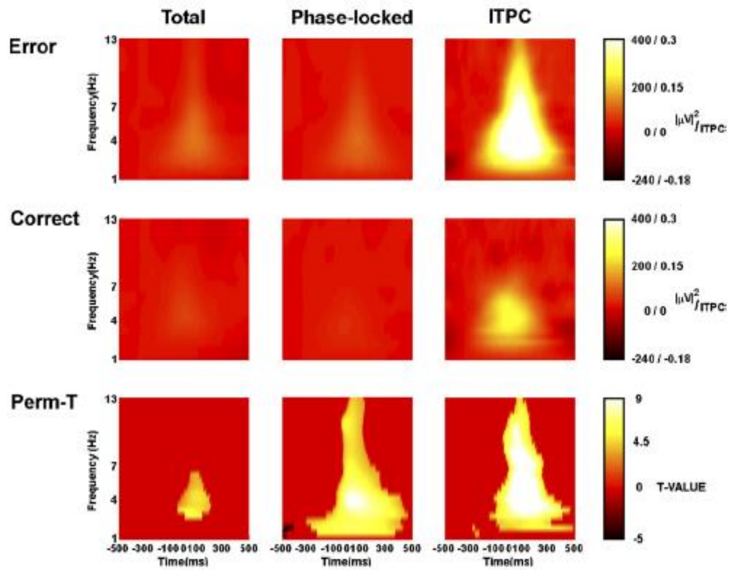
Empirical



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

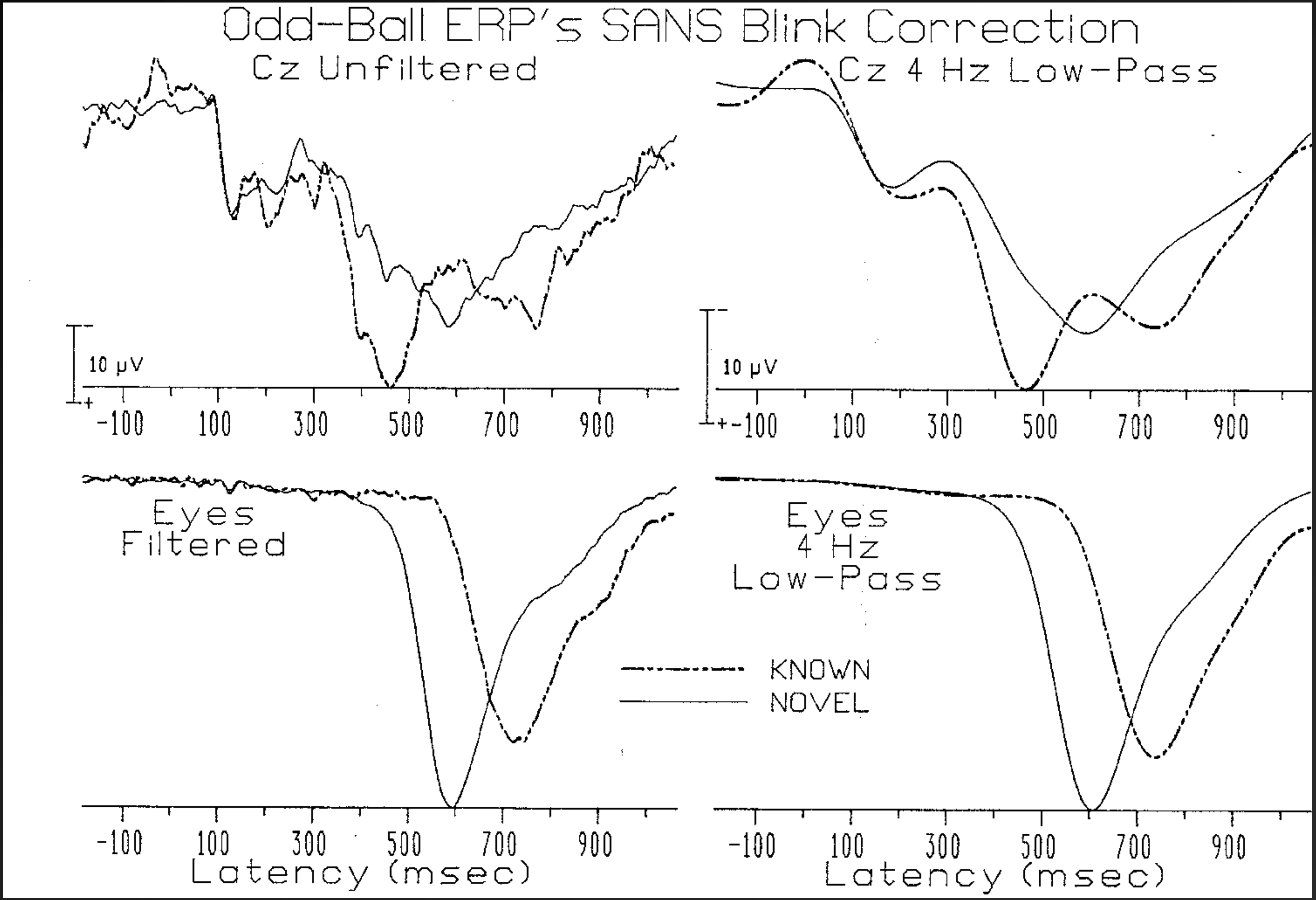
- Signal averaging will not remove this "noise" (noise wrt signal of interest)
- Average waveform a(t) is mixture of timelocked signal s(t) and randomly distributed error (noise)

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

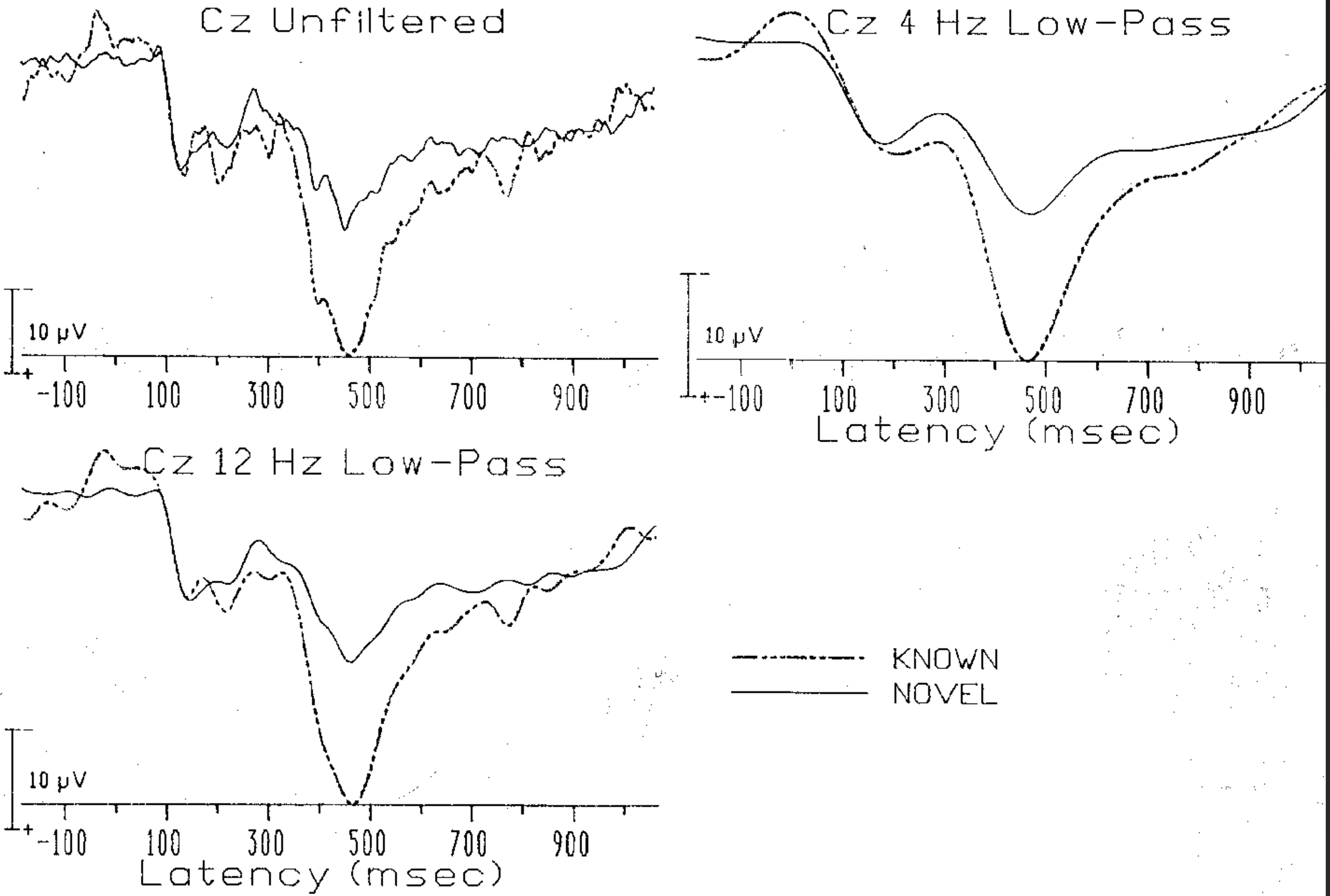
- If non-ERP signals are random with respect to stimulus onset, then the latter term will approach zero with sufficient trials (n)
- If not, the latter term will not sum to zero, but will include time-locked noise
- Noise will therefore average IN, not average OUT

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

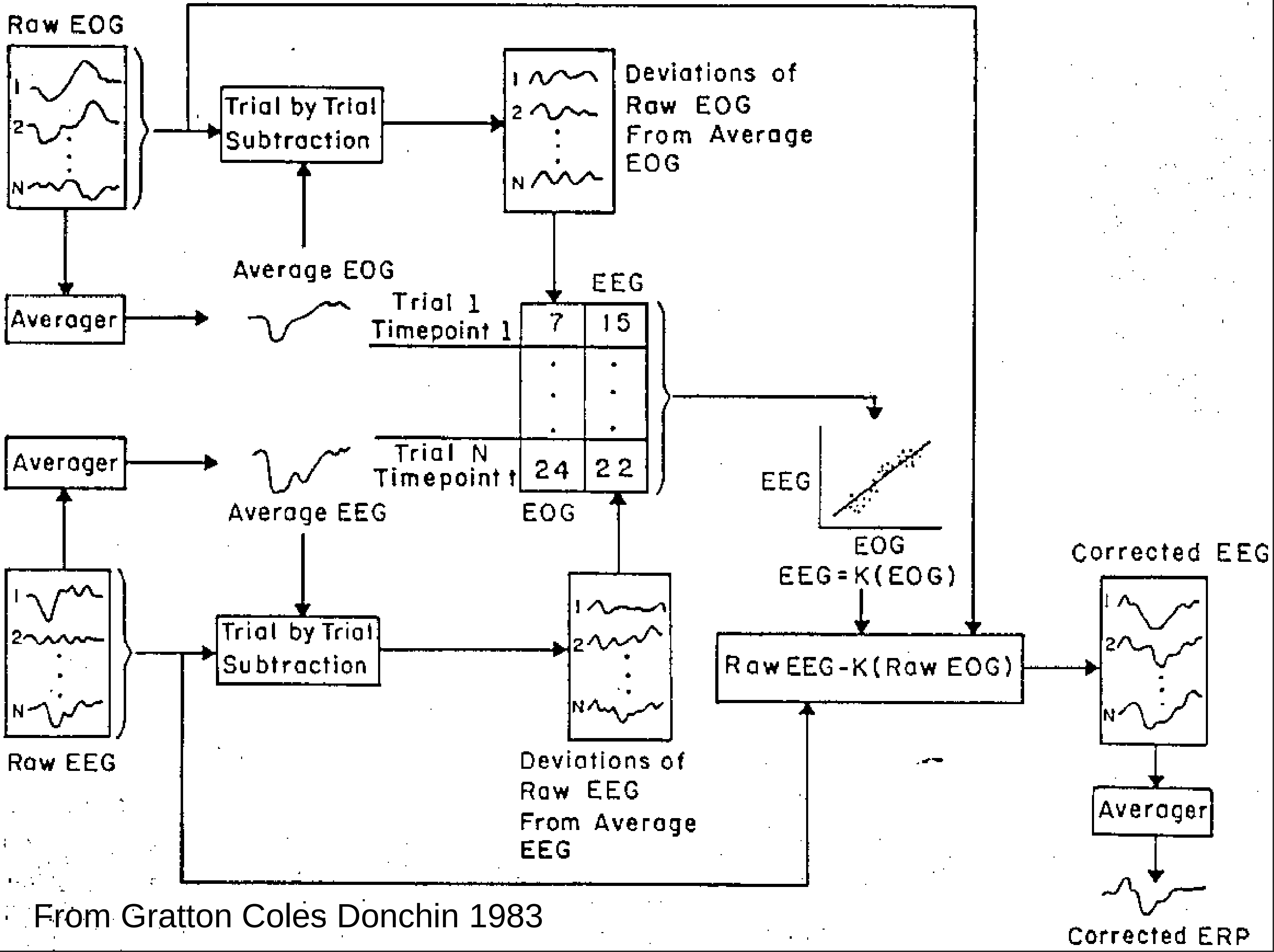

Odd-Ball ERP's SANS Blink Correction
Cz Unfiltered
Cz 4 Hz Low-Pass
10 μV
10 μV
-100
100
300
500
700
900
Eyes Filtered
Eyes 4 Hz Low-Pass
KNOWN
NOVEL
Latency (msec)
Latency (msec)

Odd-Ball ERP's WITH Blink Correction



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

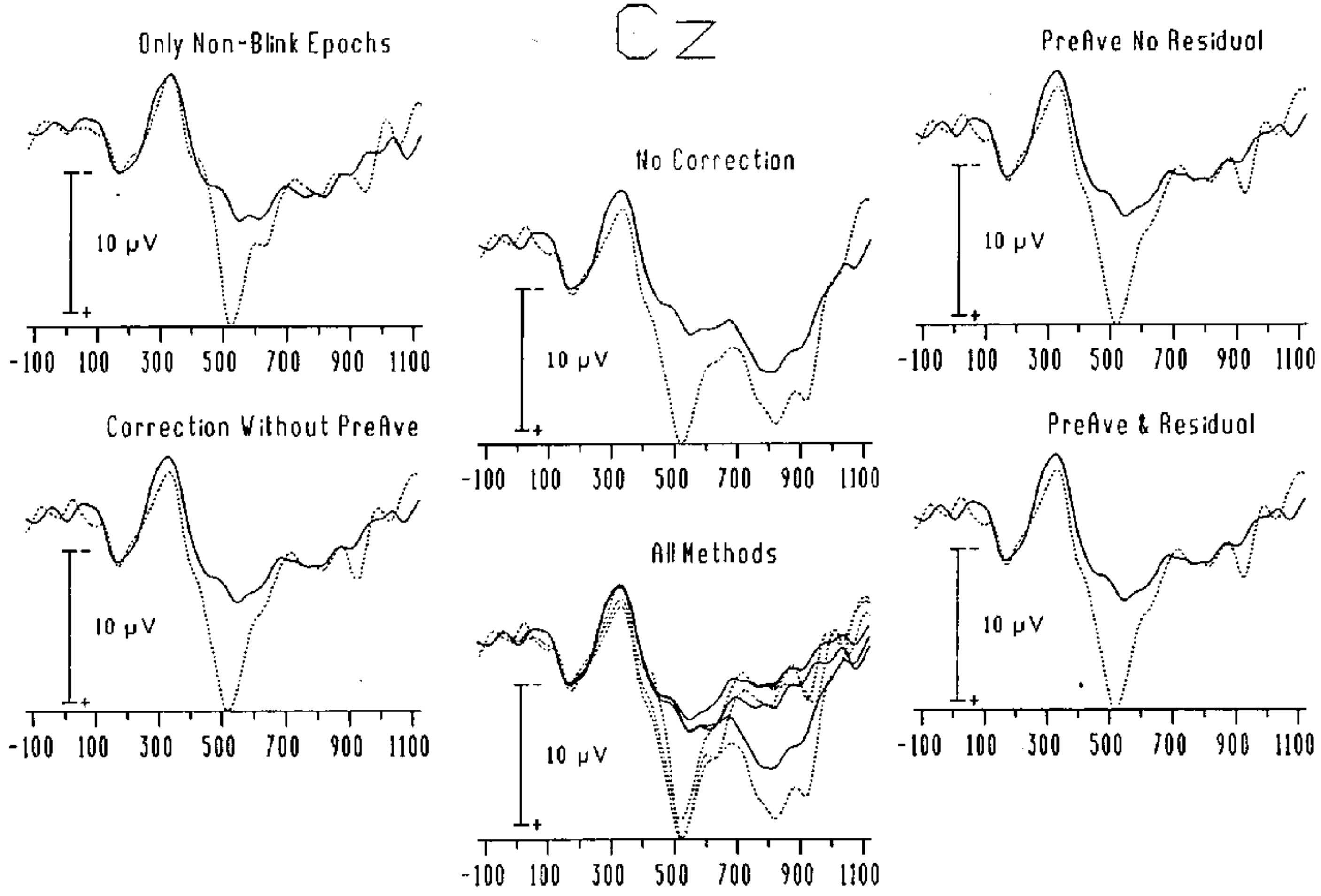
- Must determine extent to which EOG signal propagates to various scalp loci
  - Propagation factors computed only after any event-related activity is removed from both EOG & EEG channels
  - Event related activity in both channels may spuriously inflate estimate of propagation
  - Based upon correlation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

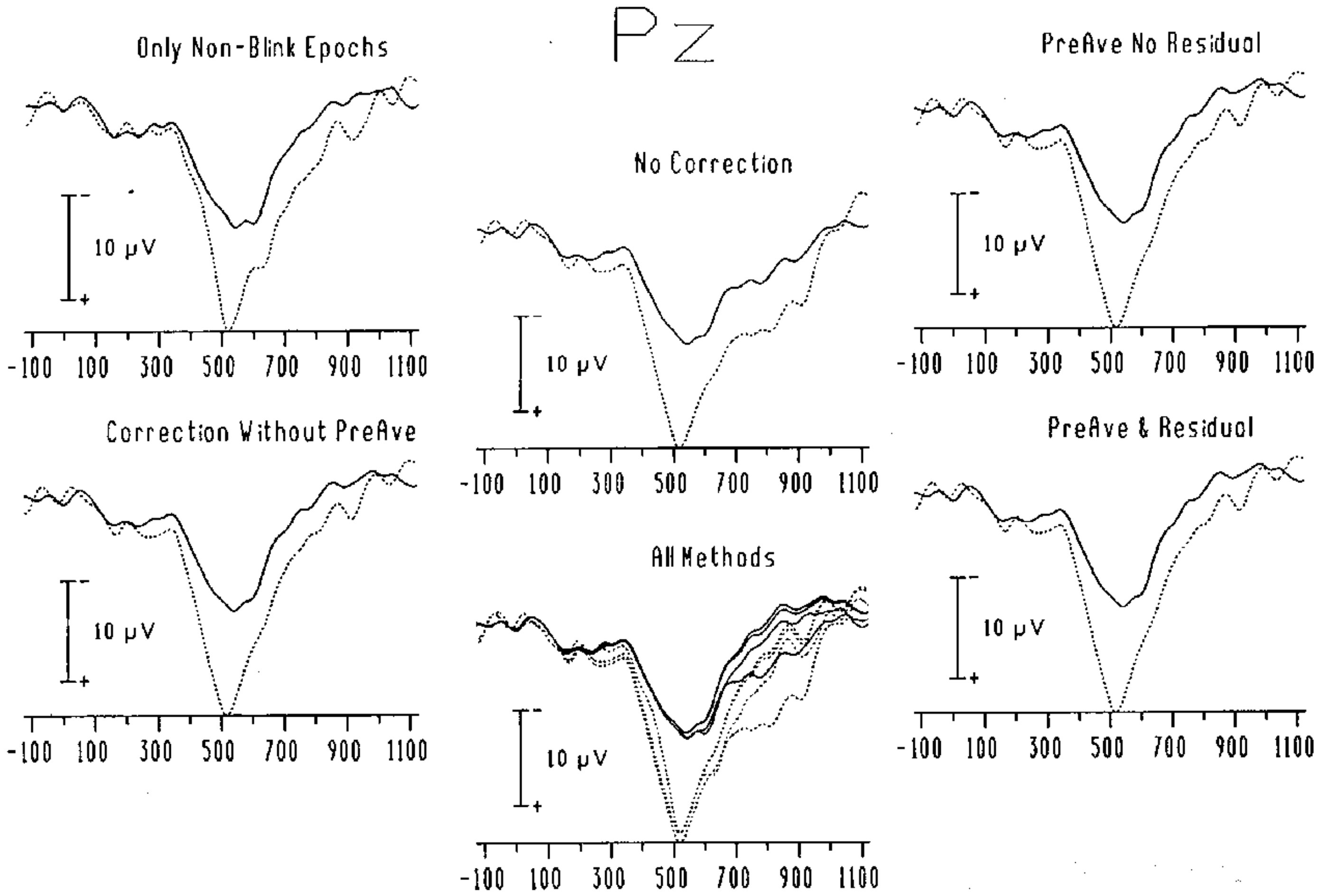
Validity of Ocular Correction

- 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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For comparison, non-corrected data and all methods are presented in the center column. Abscissa is latency (msec).

Other Methods (in brief)

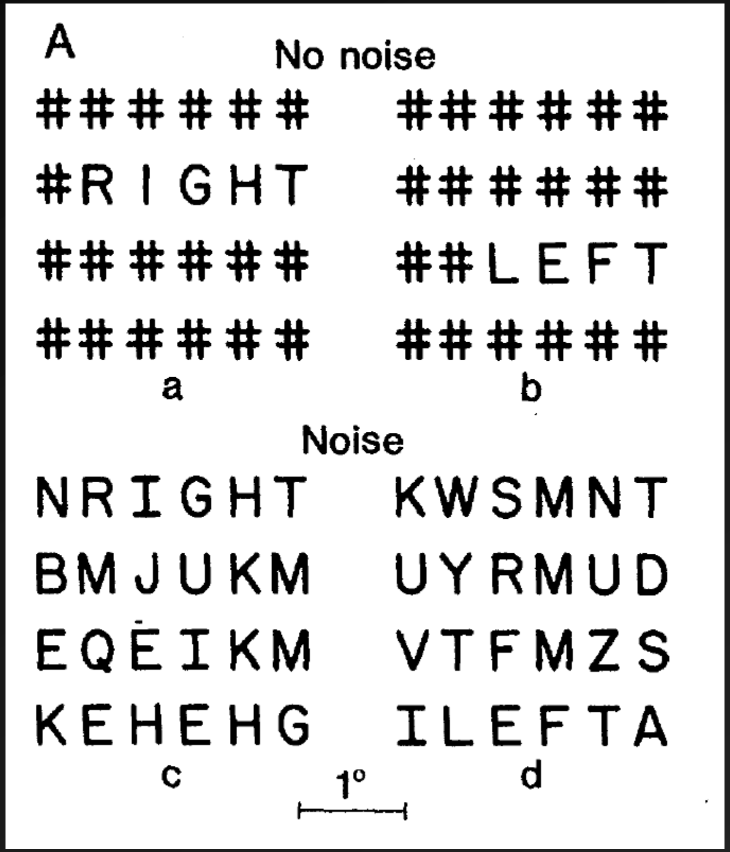
- Most other methods also depend upon subtraction of a proportion of the EOG signal or some transformation of the EOG signal
  - Frequency-domain methods recognize that not all frequencies in the EOG channel propagate equally to scalp sites
  - Source localization methods attempt to derive a source that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

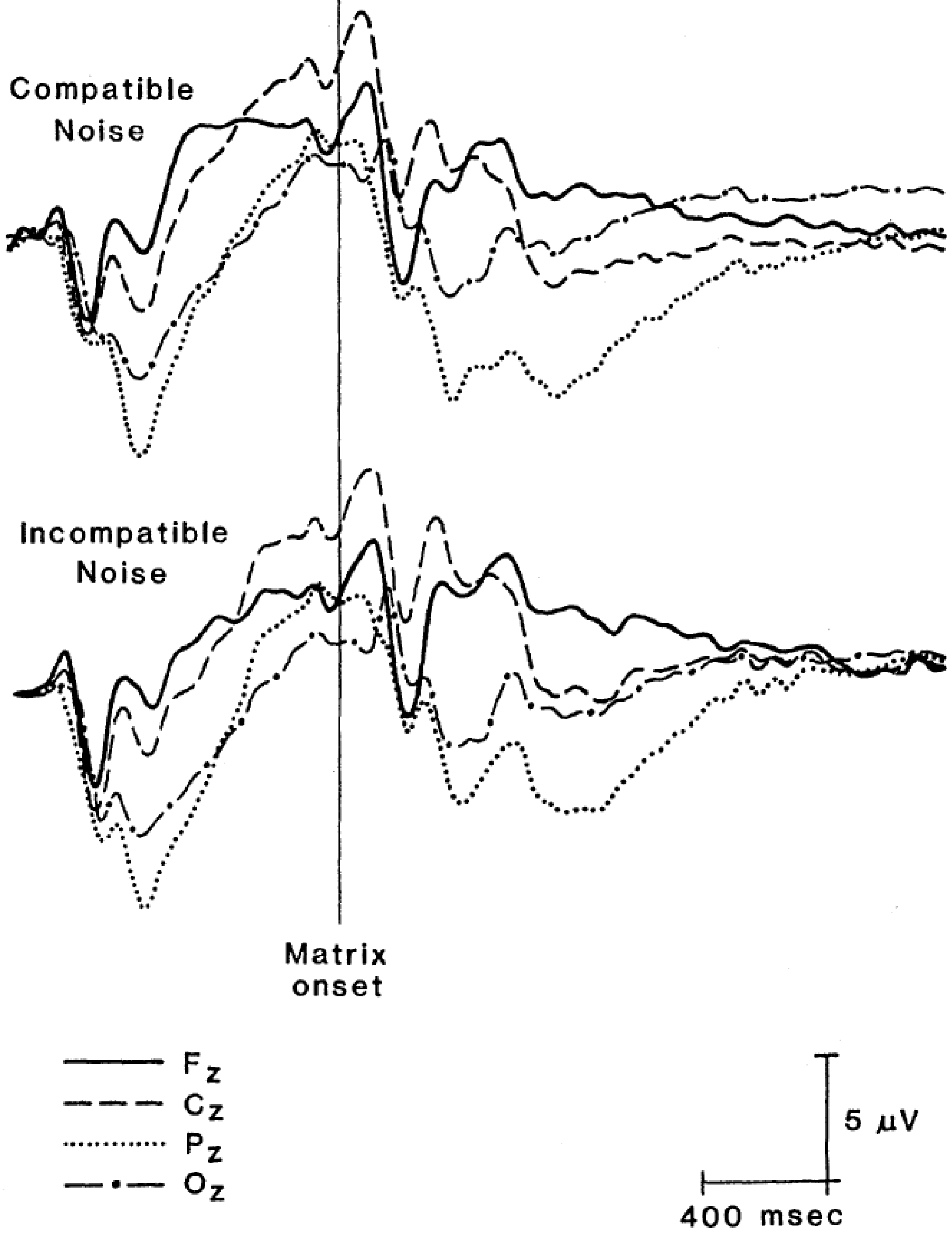
Demonstration of Ocular Correction

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   ######
##LEFT
######
a   b
Noise
NRIGHT   KWSMNT
BMJUKM   UYRMUD
EQEIKM   VTFMZS
KEHEHG   ILEFTA
c   d
1°


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

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

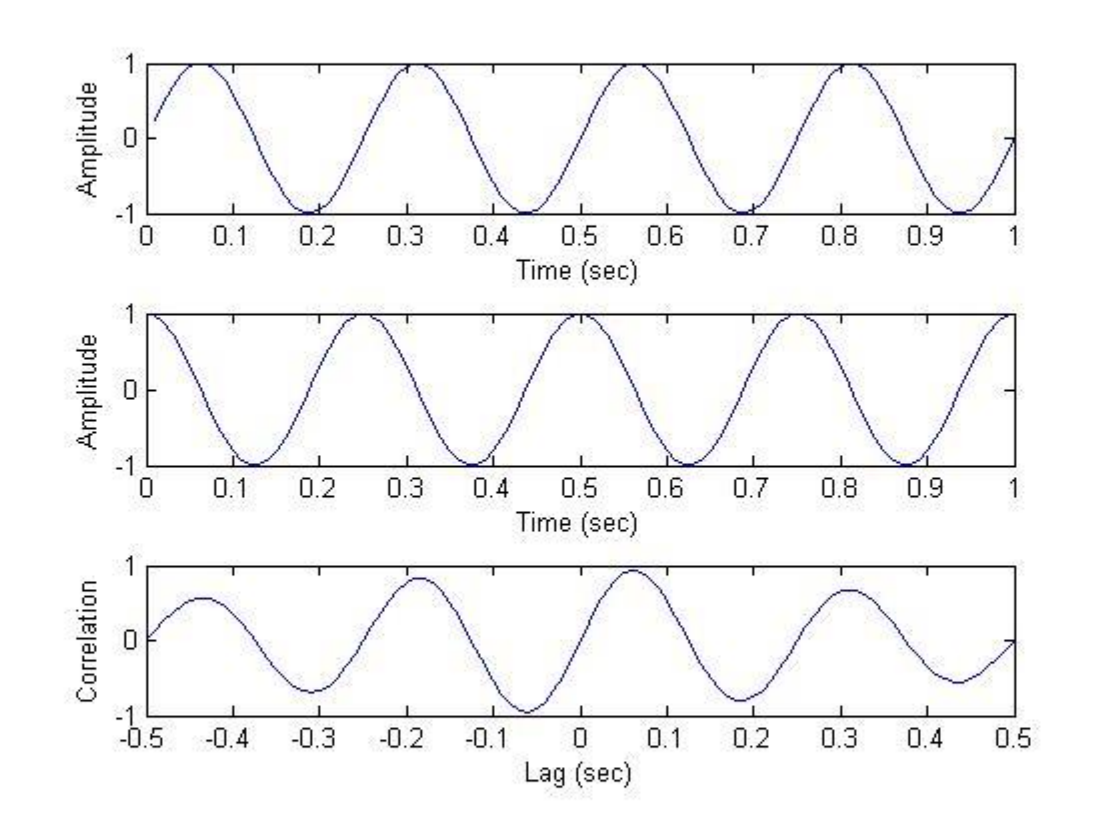
- Cross-correlational series
  - For two waveforms the correlation between each of them is computed
    - first with no lag in time
      a1, a2, ..., an
      b1, b2, ... bn
    - then with one lagged with respect to the other
      a1, a2, ..., an-1
      b2, b3, ... bn
  - A series of correlation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

The Basic Idea

Sine

Cosine

Cross-Correlation



See … CrossCorr_Sin_Cos.m

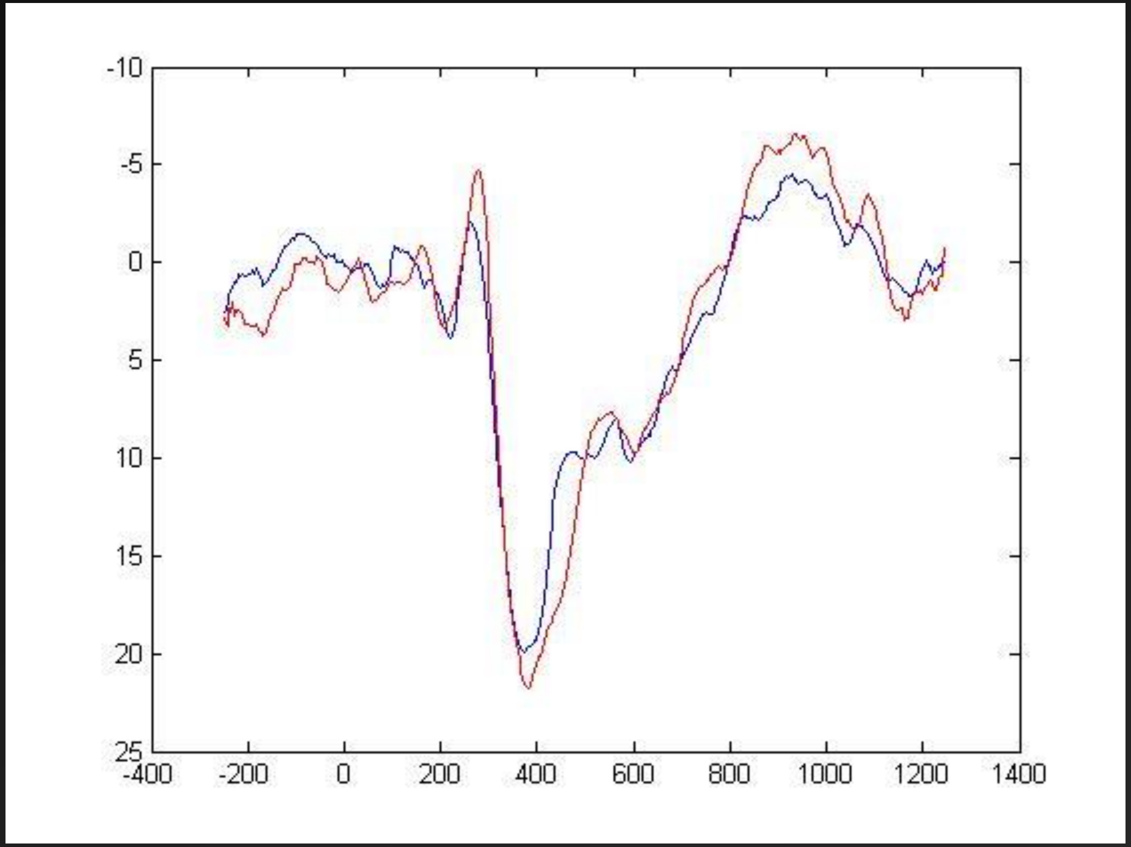
More Details

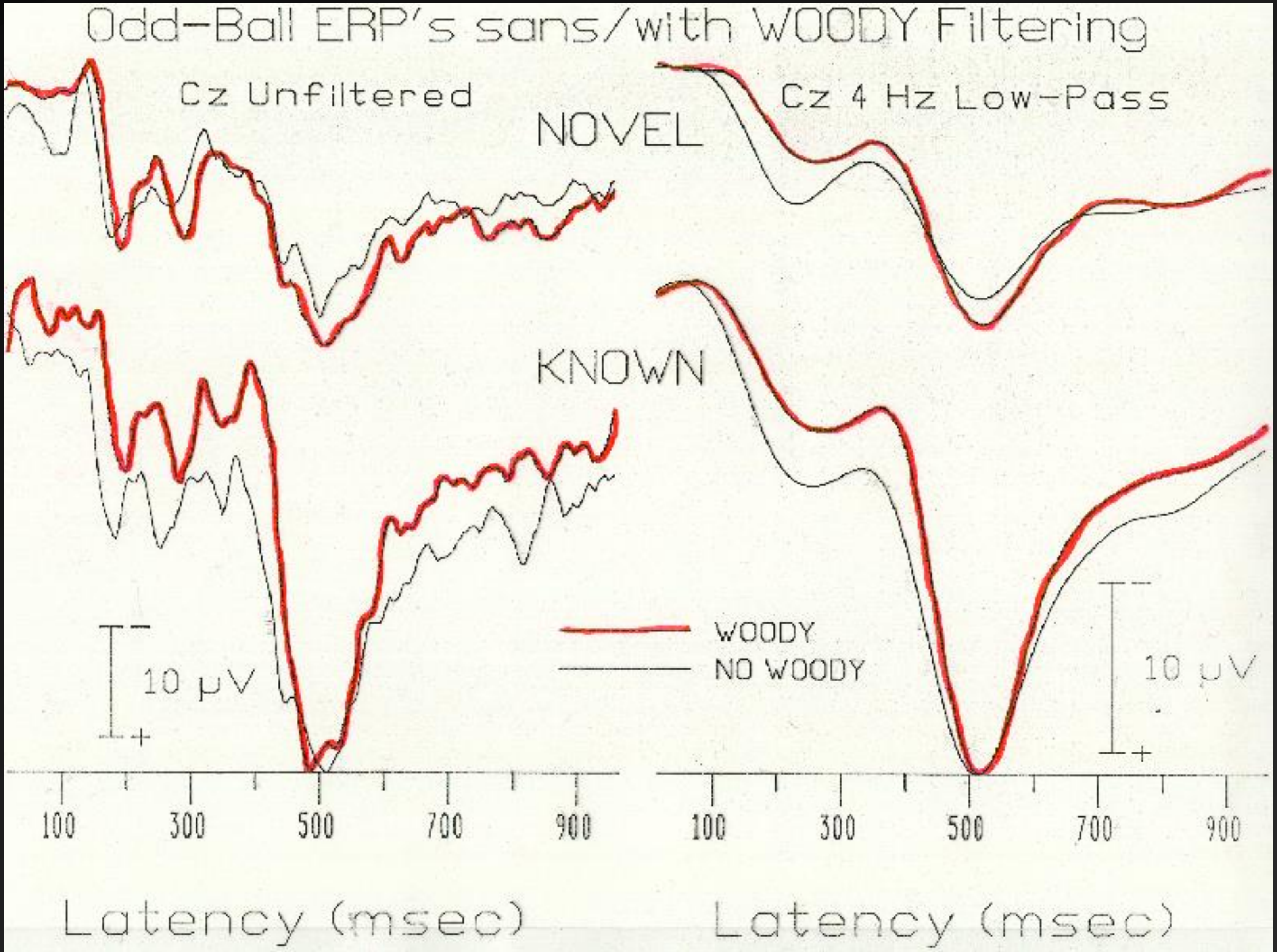
- Can be used as a "template matching" procedure
- Compare running average with raw EEG epochs
- This is a method of single-trial signal detection:
  - First create a template: either predetermined (e.g., sine wave) or empirically determined (e.g., average)
  - Then calculate cross-correlational series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