Advanced Signal Processing I

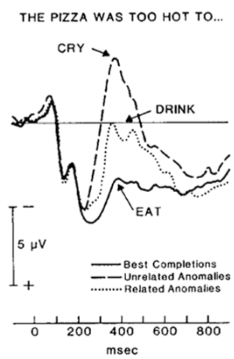
Digital Filters
Time Frequency Approaches
Ocular Artifacts

Announcements

- Research Proposals due next Monday (April 29) no later than 3 pm via email to instructor
  - Word format (DOC or RTF) preferred
  - Use the stipulated format (check website for details)
  - Look at the relevant "guidelines" paper(s) (link on website)
- Take home final distributed next week, due May 7 at noon (hardcopy in my mailbox).
- 3x5s x 2

ERPs … N400, ERN, FRN

N400 and Language



- •Originally reported by Kutas & Hillyard, 1980.
- •Semantic Incongruity is separable from other forms of deviations (e.g. large font)
  - •N400 Semantic Deviation
  - •P300 Physical Deviation
- •Also seen in semantic differentiation tasks (Polich, 1985); APPLE, BANANA, ORANGE, MANGO, *TRUCK*
- •Subject-Object mismatch (the Florida group)
- •NOTE: N400 will appear before P3 (which will be ~P550 in word tasks)

Political Evaluations!

- Morris Squires et al. *Political Psychology* 2003

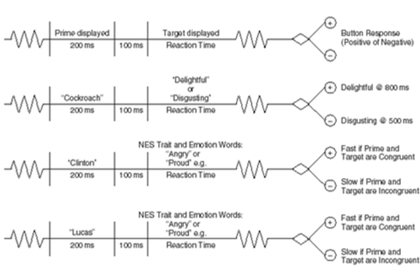


Figure 2. Attitude-priming paradigm and examples of its use.

ERPs and Hot Cognition 739

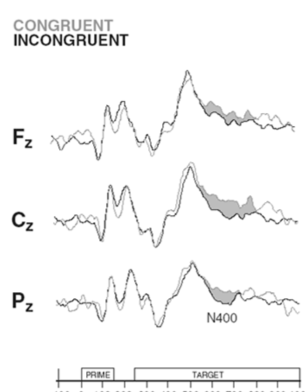
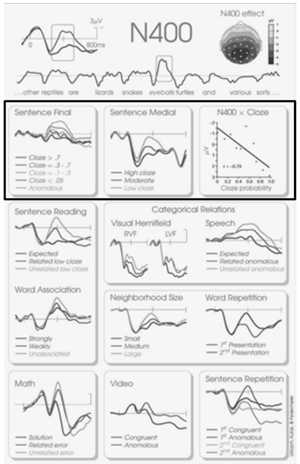


Figure 4. ERPs to congruent and incongruent prime/target pairs.

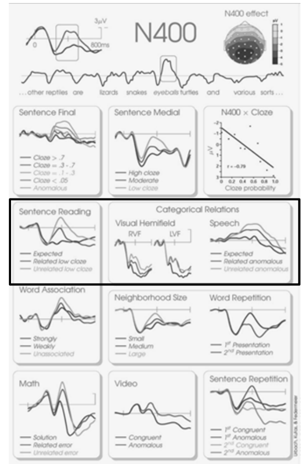
Congruent or incongruent defined based on idiographic data from pretest

Morris Squires et al. *Political Psychology* 2003



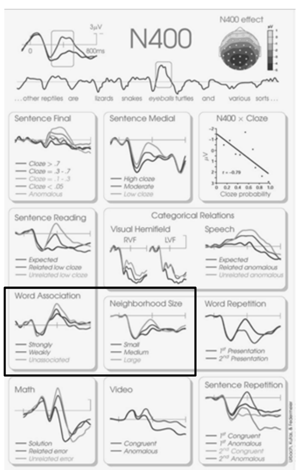
- Cloze probability: proportion of respondents supplying the word as continuation given preceding context
- N400 reflects unexpected word given the preceding context
- This is independent of degree of contextual constraint
- Larger N400
  - Low cloze, Contextual constraint high:
    - *The bill was due at the end of the hour*
  - Low cloze, Contextual constraint low:
    - *He was soothed by the gentle wind*
- *Smaller N400*
  - *The bill was due at the end of the month*

Kutas & Federmeier, 2011



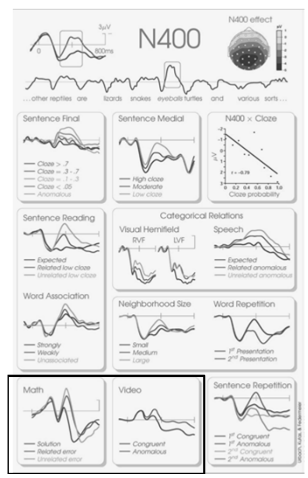
- Sentence completion
  - Best (expected) ending *small*
  - Unexpected but related *larger*
  - Unexpected and unrelated *largest*
- Categorical relations … sentence final word is:
  - an expected category exemplar
  - an unexpected, implausible exemplar from the same category as the expected one (related anomalous)
  - from a different category (unrelated anomalous)
- Note multiple modalities of effect, and graded effect in RVF (LH)

Kutas & Federmeier, 2011



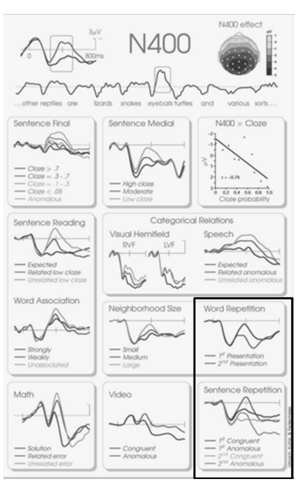
- Word Association, with second word in pair
  - Unrelated to first (*eat door*)
  - Weakly related to first (*eat spoon*)
  - Strongly related to first (*eat drink*)
- Orthographic neighborhood size (among a list of words, pseudowords, and acronyms)
  - Words that share all but one letter in common with particular word
  - Large 'hood (e.g., slop) – *large N400*
  - Small 'hood (e.g. draw) – *small N400*

Kutas & Federmeier, 2011



- Math: (e.g., 5 x 8 = ___)
  - Correct (40) *small*
  - Related (32, 24, 16) *small if close*
  - Unrelated (34, 26, 18) *large*
- Movement and Gestures
  - Typical actions (cutting bread with knife) = *small*
  - Purposeless, inappropriate, or impossible actions = *large*
    - *Cutting jewelry on plate with fork and knife*
    - *Cutting bread with saw*
  - N400 modulated by both:
    - appropriateness of object (e.g., screwdriver instead of key into keyhole)
    - features of motor act per se (e.g., orientation of object to keyhole)

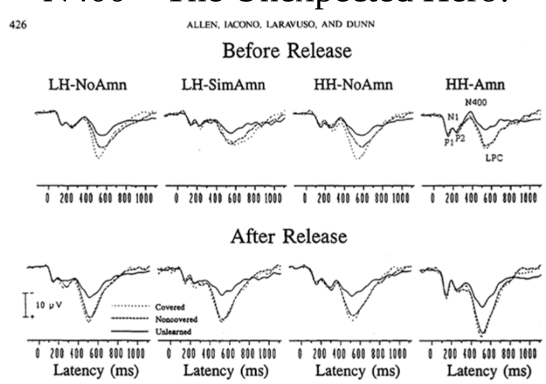
Kutas & Federmeier, 2011



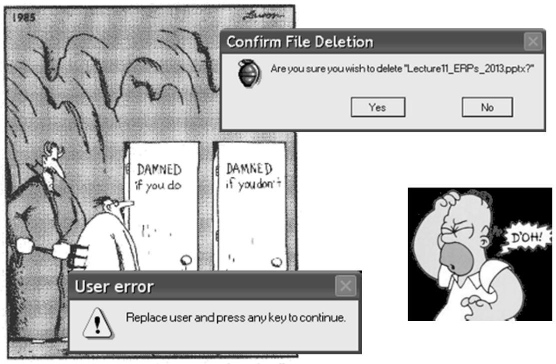
- Repetition effects
  - Repetition creates contextual familiarity, reduced processing demands
  - N400 thus useful in studying memory
  - Appears additive with incongruency effects

Kutas & Federmeier, 2011

N400 – The Unexpected Hero!



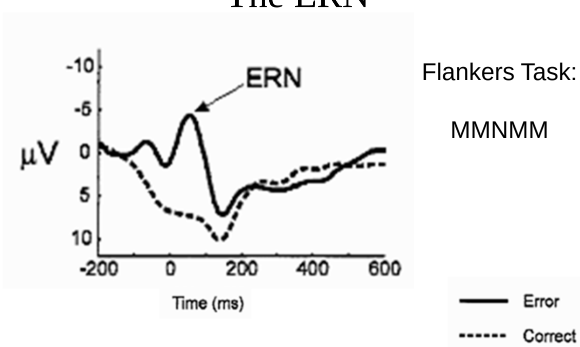
Life is full of choices … and consequences



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

Choices and Feedback

The ERN



Flankers Task:

MMNMM

Also sometimes termed Ne

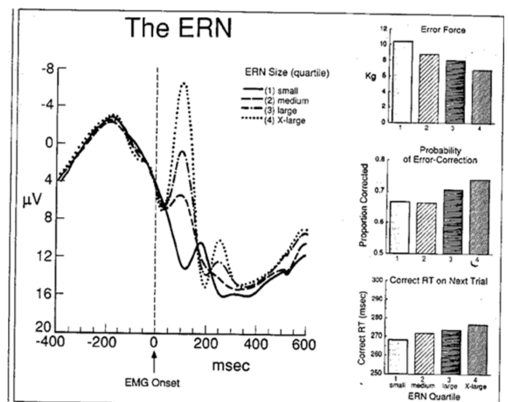


Fig. 3. Relationship between error-related negativity (ERN) amplitude and three measures of compensatory behavior. Left panel: Average event-related potentials at the C_z electrode as a function of the four levels of the posterior probability measure of ERN amplitude. Right panel, top: Error squeeze 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?

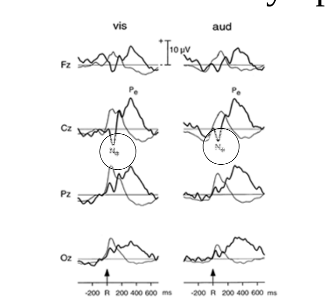
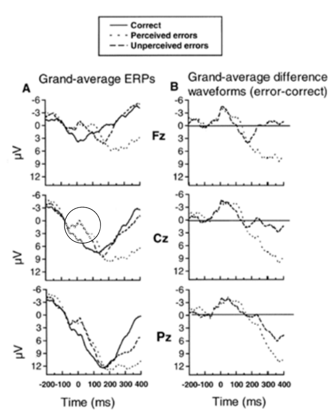


Fig. 1. Grand averages (Experiment 4; $n = 12$) of the RTA for errors (heavy lines) and correct trials (light lines) after visual (vis) and auditory letter stimuli (aud) in a 2-CR task. The error negativity ('Ne') is seen as a sharp negative deflection with central maximum peaking at about 80 ms after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

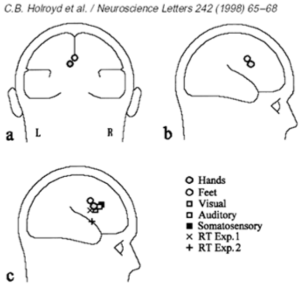


Fig. 2. Source localization of the error-related negativity. Circles represent locations of sources determined for hand and foot responses: (a) coronal view; (b) sagittal view; (c) for comparison, source locations of the ERN determined in previous studies are depicted along with the locations of the 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

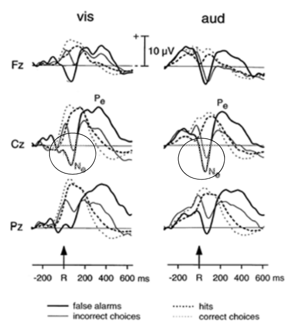


Fig. 5. Grand averages (Experiment 2: $n = 10$) of the RTA for false alarms and hits in Go/Nogo tasks (heavy lines), and choice errors and correct choice trials in two-way choice tasks (thin lines). Errors continuous lines, correct responses broken lines. The Ne is delayed relative to the incorrect key 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

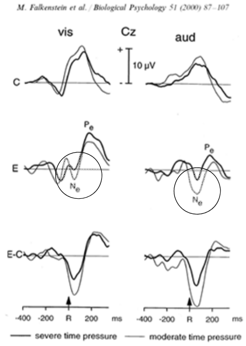


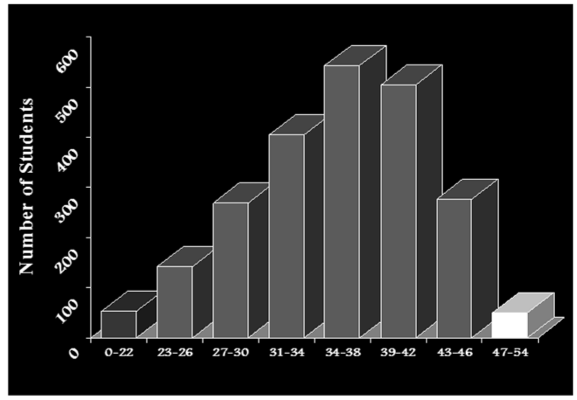
Fig. 4. Grand averages (Experiment 1; $n = 9$) of the RTA for correct responses (C), errors (E), and difference waveshapes (error minus correct: E − C) in a 2-CR task under moderate (light lines) and severe time pressure (heavy lines). The error rates were 15% (moderate) and 30% (severe); the number 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

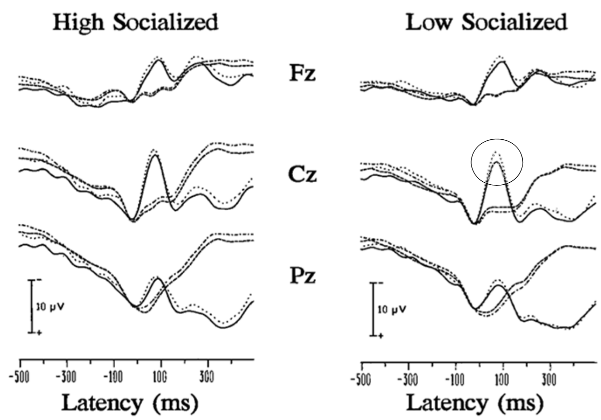


Thirty participants selected: **15 high SO**
15 low SO

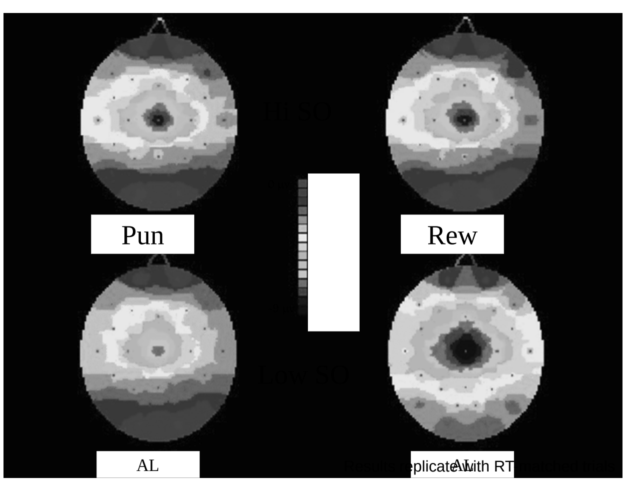
Dikman & Allen, 2000, *Psychophysiology*

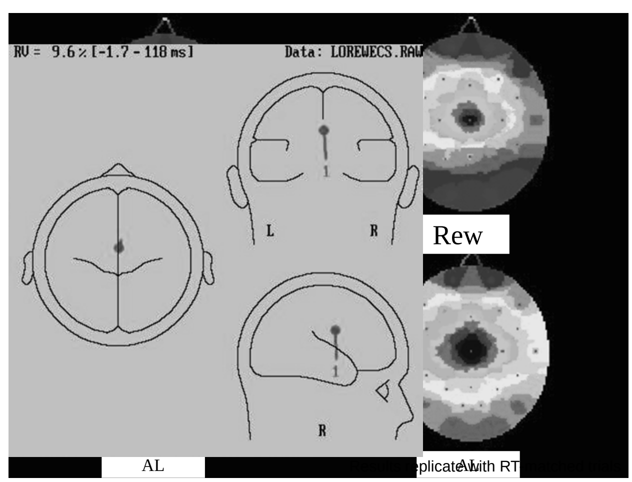
Procedure

- 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*





ERN in OCD

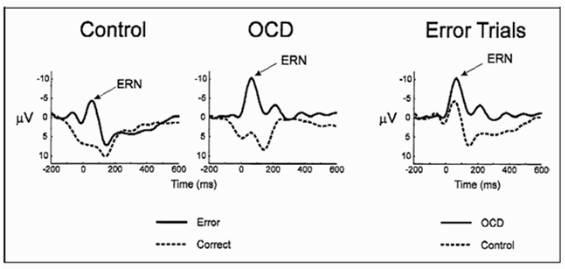
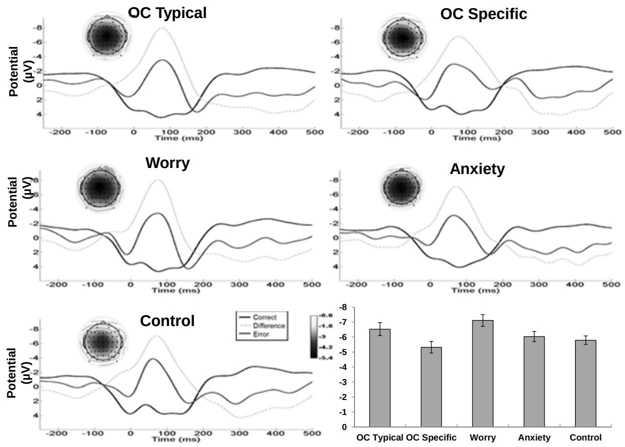


Fig. 1. Response-locked event-related potential waveforms at the Cz electrode location. The left panel compares correct-trial and error-trial waveforms for control participants and for individuals with obsessive-compulsive disorder (OCD). The right panel compares error-trial waveforms for the two groups. 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)



Zambrano-Vazquez & Allen, in progress

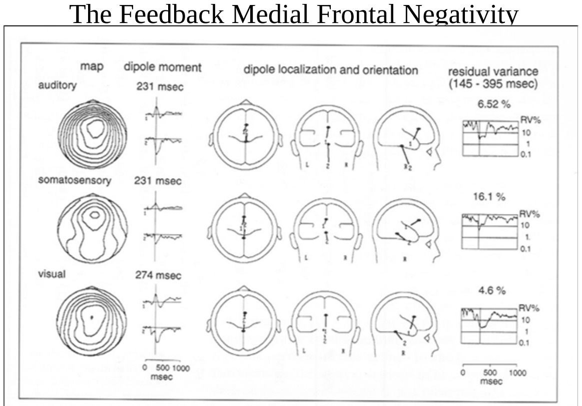
Error Detection Vs. Conflict

- Trials on which errors occur will entail greater response conflict than those without errors
- So, is it error detection, or response conflict?
- Stay tuned…

Errors and Feedback

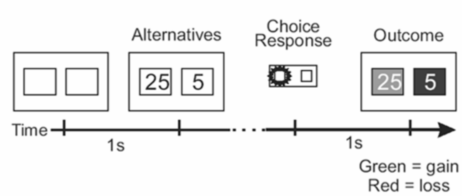
- Endogenous Error Detection
- Exogenous Error Feedback
- Common Mechanism?

The Feedback Medial Frontal Negativity



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

The Gambling Task



Gehring and Willoughby, 2002 *Science*

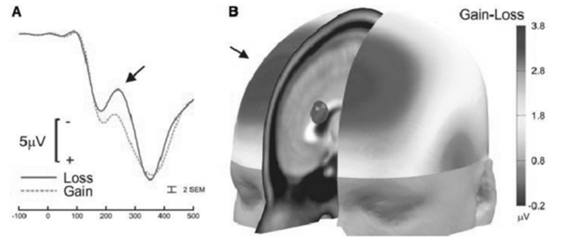
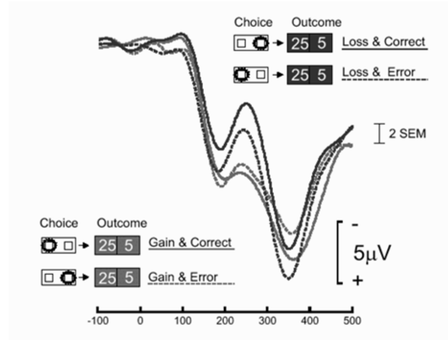


Fig. 2. ERP waveforms, scalp topography, and likely neural generator of the MFN. (**A**) The waveforms are shown at the Fz (frontal) electrode site. The solid red line corresponds to the average ERP waveform for all trials in which the participant lost money. The dashed green line corresponds to those 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).

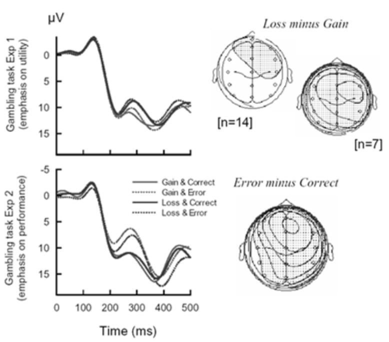
Gehring and Willoughby, 2002 *Science*

Error, or motivation?



Gehring and Willoughby, 2002 *Science*

Effect may depend on *relevant* dimension of feedback



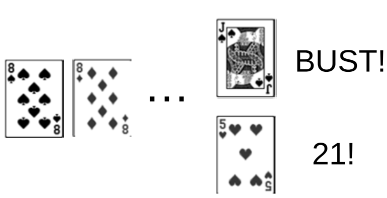
Nieuwenhuis, Yeung, Holroyd, Schurger, & Cohen (2004), Cerebral Cortex

FRN and Problem Gambling

Why do Gamblers Gamble?

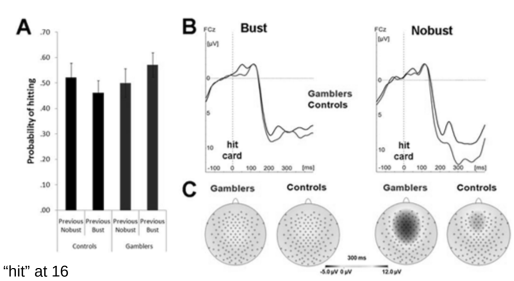
Black Jack Study

- 20 Problem Gamblers, 20 Controls
- Black Jack



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

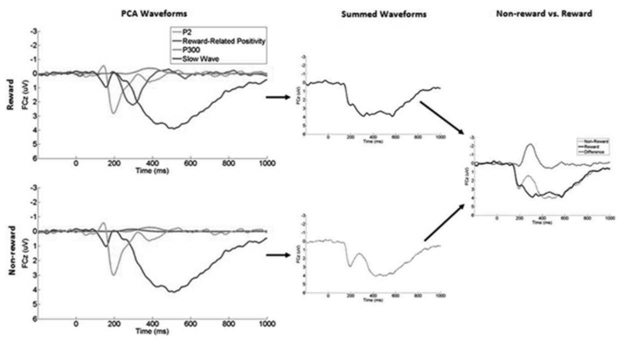
Black Jack Study



Prob "hit" at 16

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

FRN may be absence of Reward Positivity



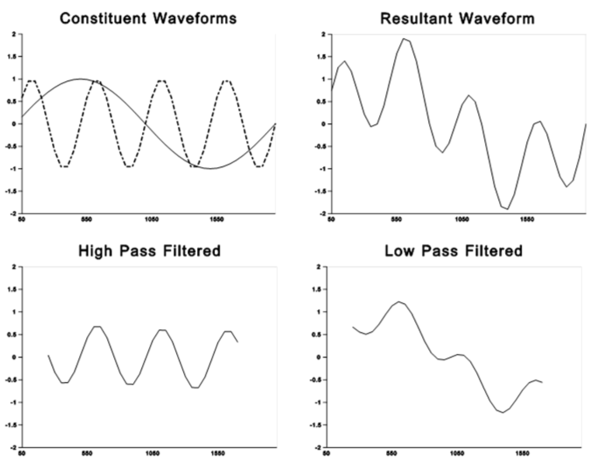
Foti et al. (2011). *HBM*

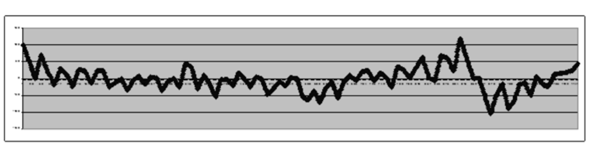
Advanced Signal Processing I

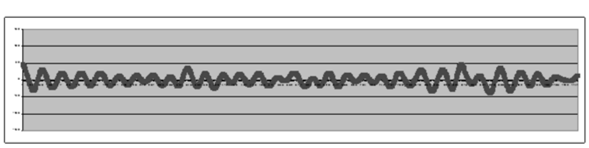
Digital Filters
Time Frequency Approaches
Ocular Artifacts

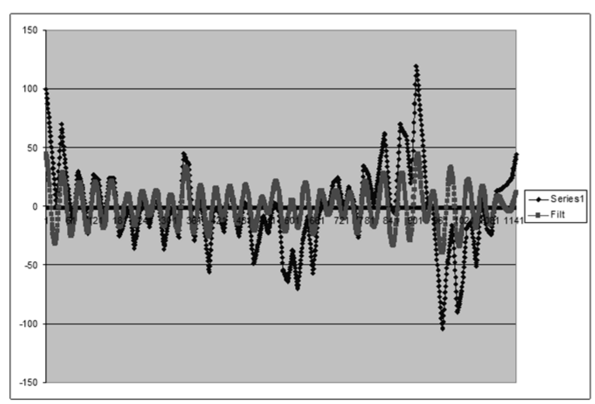
Digital Vs. Analog Filtering

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







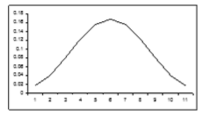


The Details!

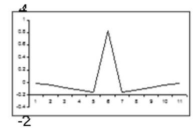
- **Handout on Digital Filtering**

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	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 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

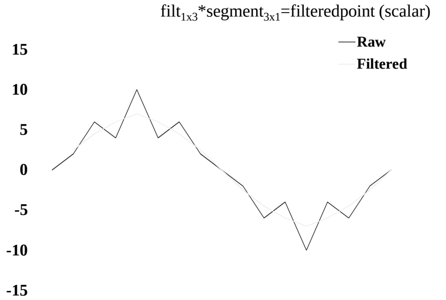
  17.5/200 = x/20 ; x = 1.75 @ 20 Hz Sampling rate

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

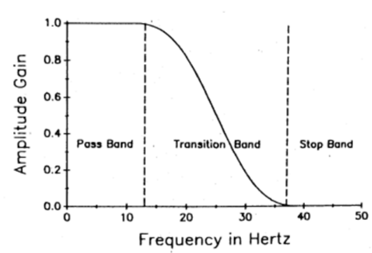
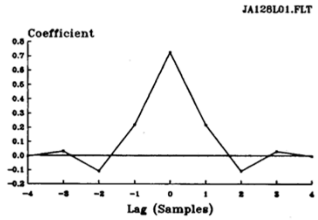


Figure 1. The gain function of a filter is divided into the pass band, transition band, and stop band. The gain function shown is for a low-pass filter.

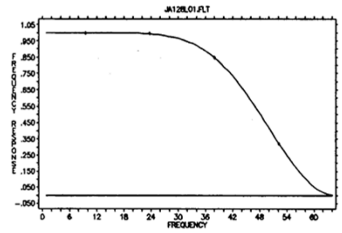
Cook & Miller, 1992

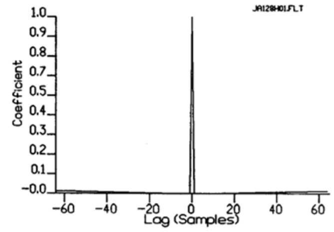


Impulse Response

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

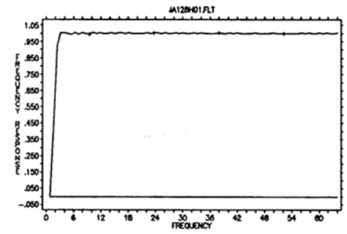
Transfer Function

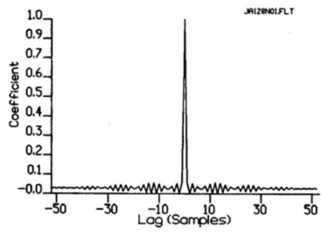




Impulse Response

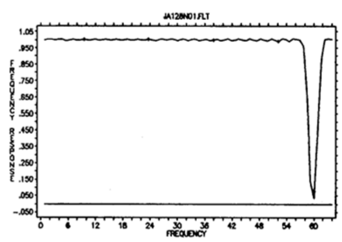
Transfer Function

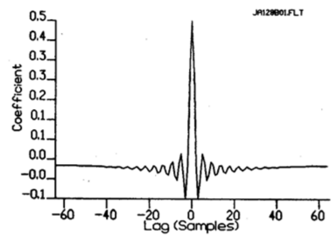




Impulse Response

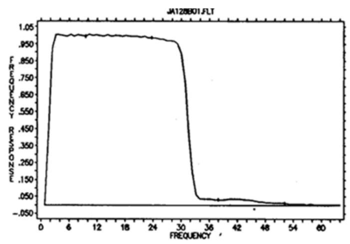
Transfer Function





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

Use in Single Trial Analysis

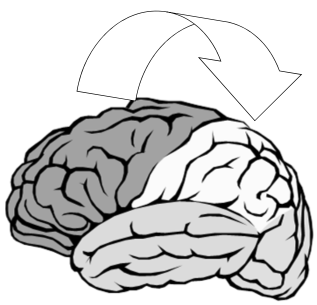
- With stringent digital filtering, you may be able to discern peaks on an individual trial basis

Digital Filtering and More!

A bit more on phase and such

COURTESY OF MIKE COHEN

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

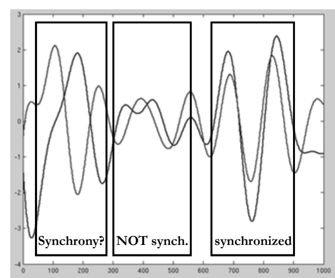


Perhaps through synchronized oscillations!

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

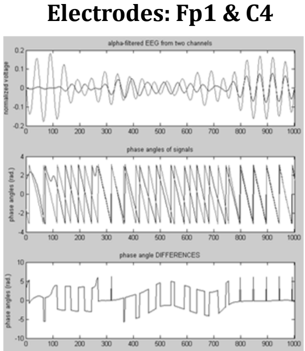
2. How do brain regions "talk" to each other?

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

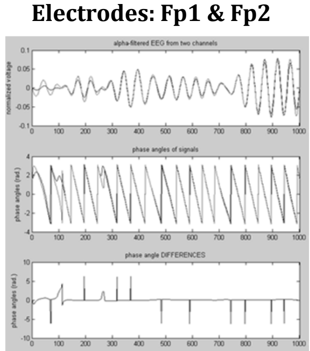


2. Inter-site phase coherence.

Electrodes: Fp1 & C4

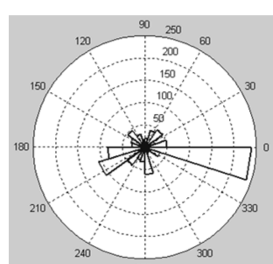


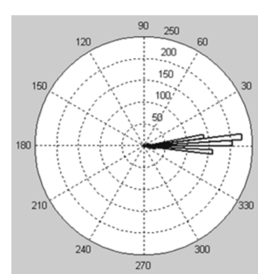
Electrodes: Fp1 & Fp2



2. Inter-site phase coherence?

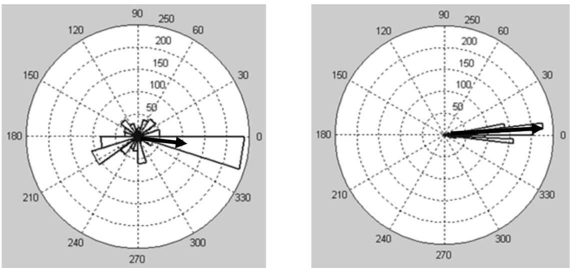
"Polar plot" of phase angle differences.





2. Circular variance.

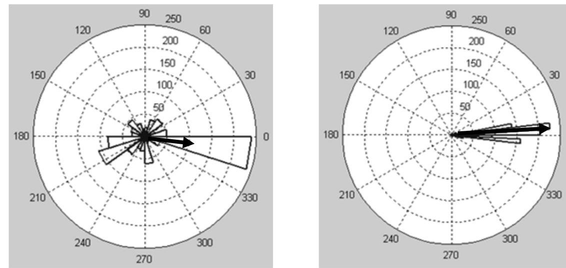
Draw a line through the "average" of vectors.



2. Circular variance.

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

Phase coherence: 0.11 | Phase coherence: 0.94



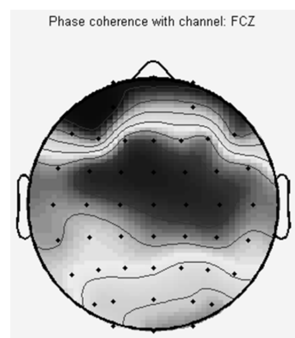
2. Circular variance.

The equation for phase coherence is simple:

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

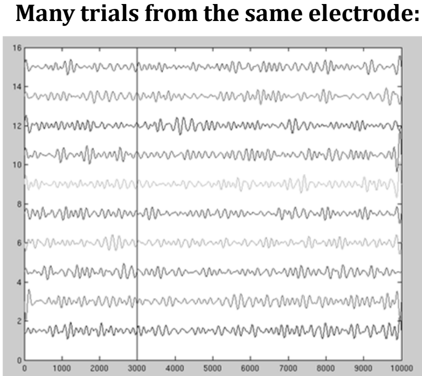
- **Magnitude of vector** (abs)
- **Average across values** (mean)
- **Transform to complex plane** (exp(i*...))
- **Phase angle differences between channels** (angle_differences)

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

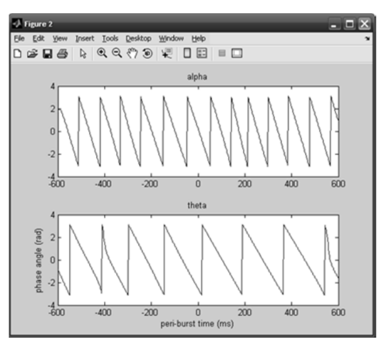


2. Inter-trial phase synchrony within one electrode.

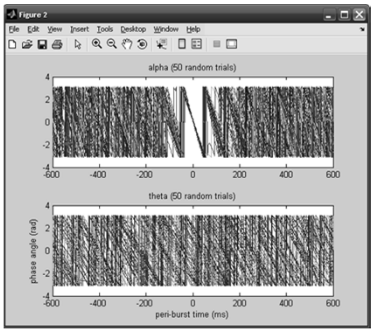
Many trials from the same electrode:



2. Inter-trial phase coherence



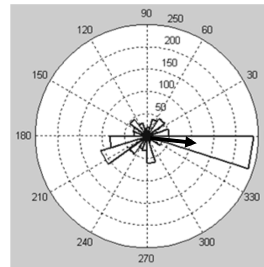
2. Inter-trial phase coherence



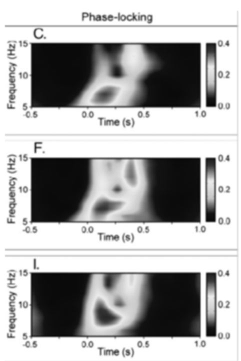
2. Inter-trial phase coherence

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

Power increase in the absence of any phase locking

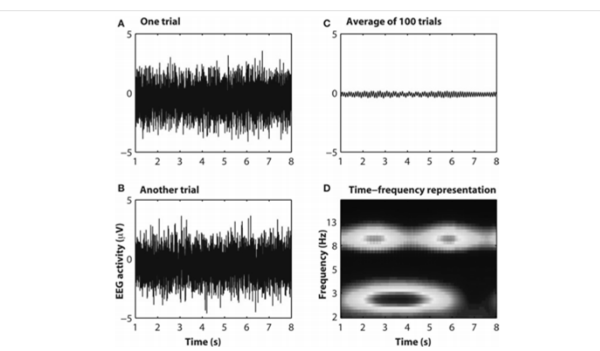
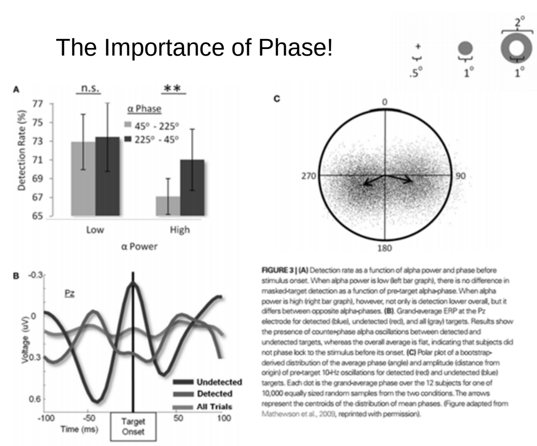


FIGURE 3 | Simulated data showing how information contained in raw EEG data [(A,B): single "trials"] is not apparent in the event-related potential **(C)** but is readily observable in the time–frequency representation **(D)**. Matlab code to run this simulation is available from the author.

Cohen, 2011, *Frontiers in Human Neuroscience*

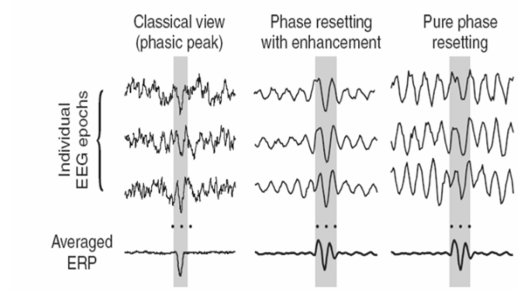
The Importance of Phase!



Matthewson, 2011, *Frontiers in Psychology*

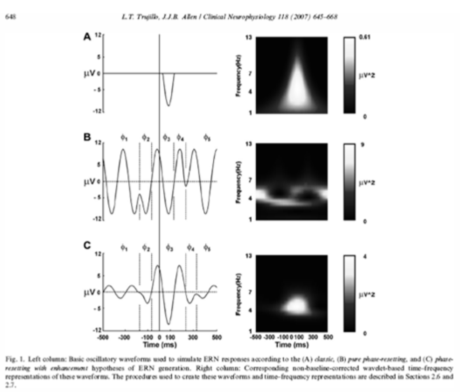
Time-Frequency Approaches to Error Monitoring

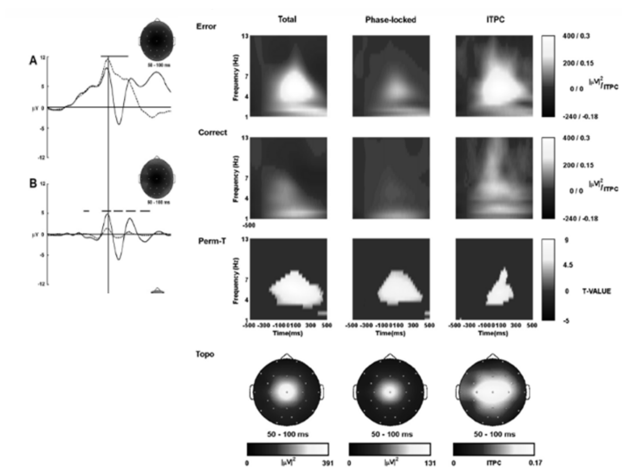
Classic ERPs Vs Phase Resetting

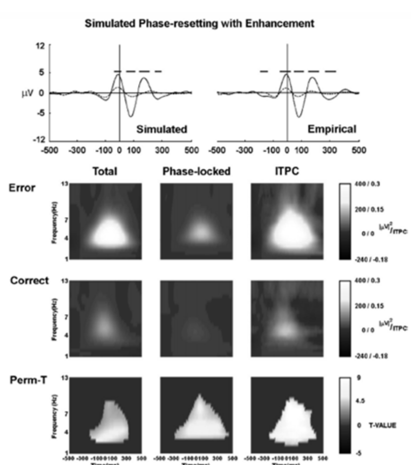


From Yeung et al., *Psychophysiology*, 2004

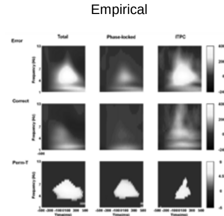
Time-Frequency Representations



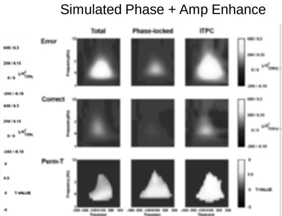




Empirical



Simulated Phase + Amp Enhance



Simulated Classic