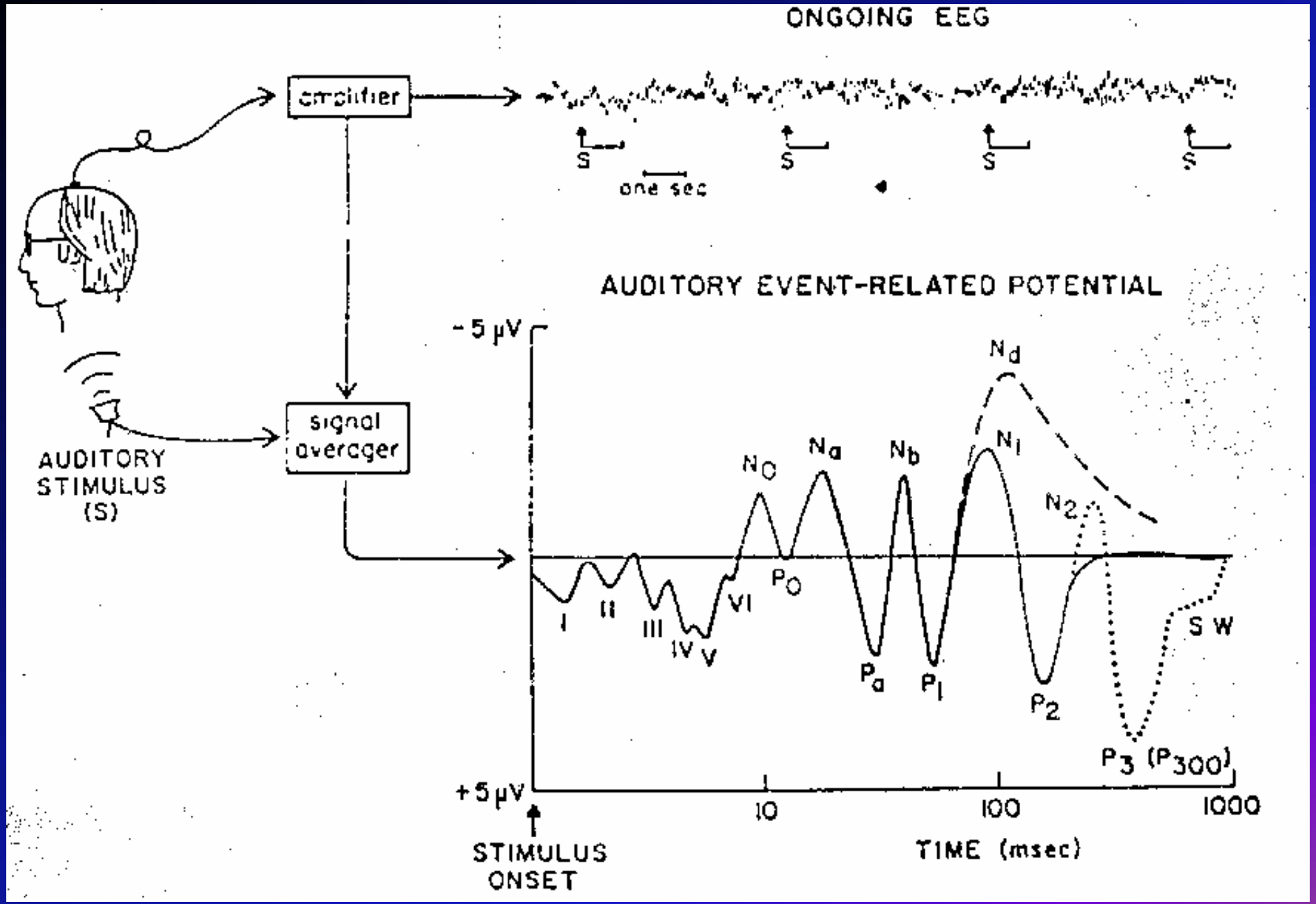
Announcements

- 3x5s for two weeks
- Back to lecture

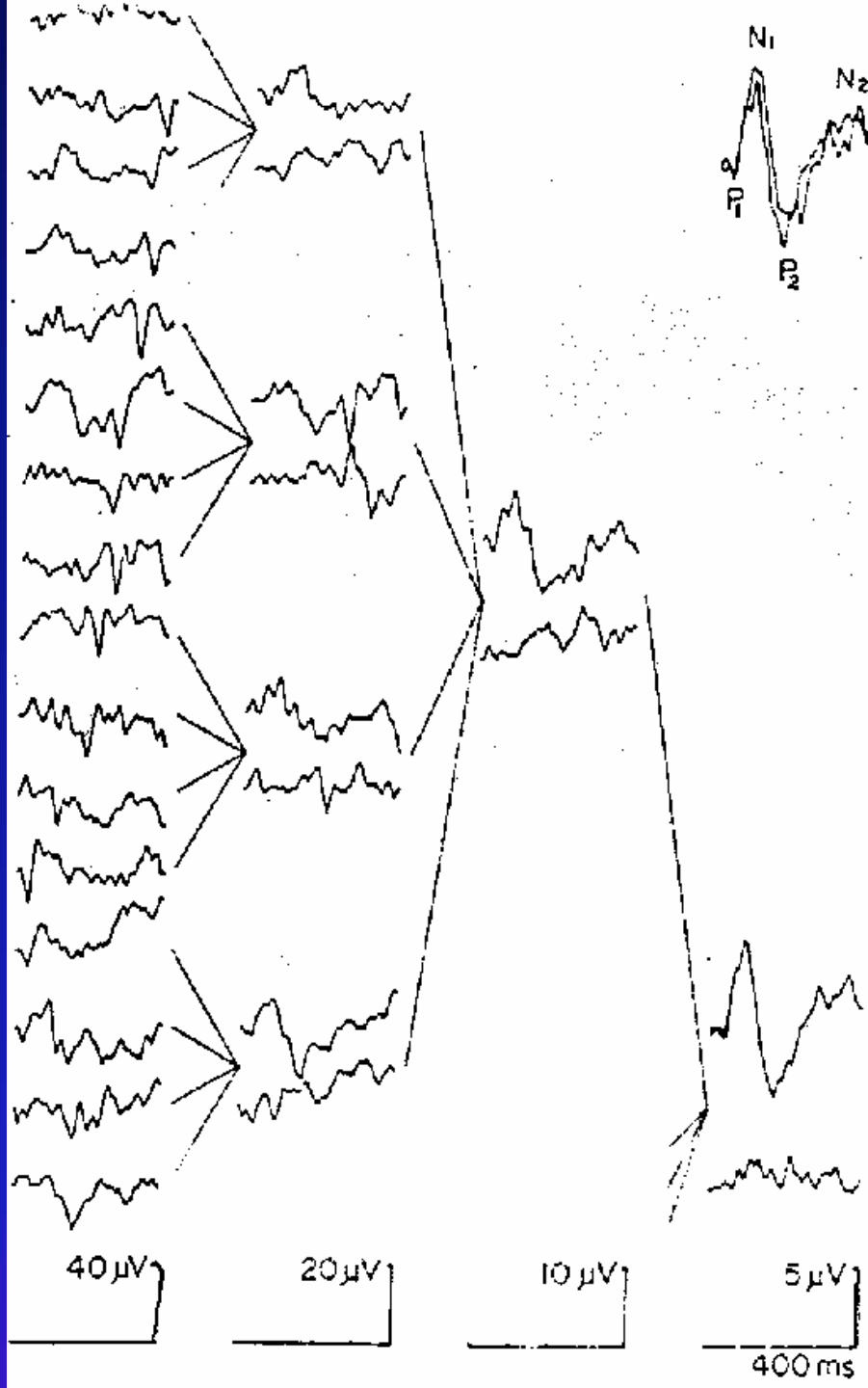
The Event-Related Potential (*aka* the ERP)

Overview

Event-related potentials are patterned voltage changes embedded in the ongoing EEG that reflect a process in response to a particular event: e.g., a visual or auditory stimulus


ONGOING EEG
amplifier
S
one sec
AUDITORY EVENT-RELATED POTENTIAL
-5 μV
+5 μV
signal averager
AUDITORY STIMULUS (S)
N0
Na
Nb
Nd
N1
N2
P0
Pa
P1
P2
P3 (P300)
I
II
III
IV
V
VI
SW
10
100
1000
TIME (msec)
STIMULUS ONSET

Time-locked activity and extraction by averaging



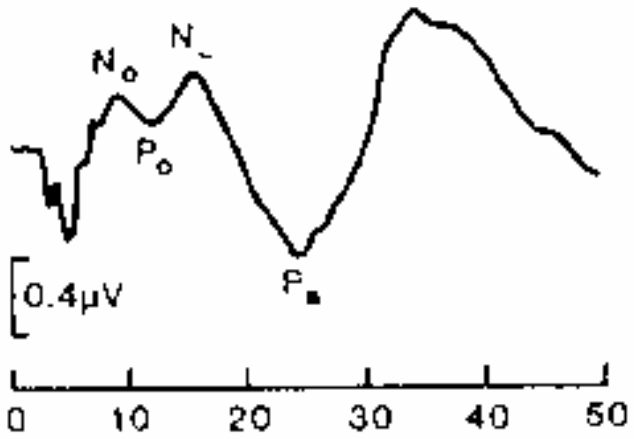
Time-locked activity and extraction by averaging

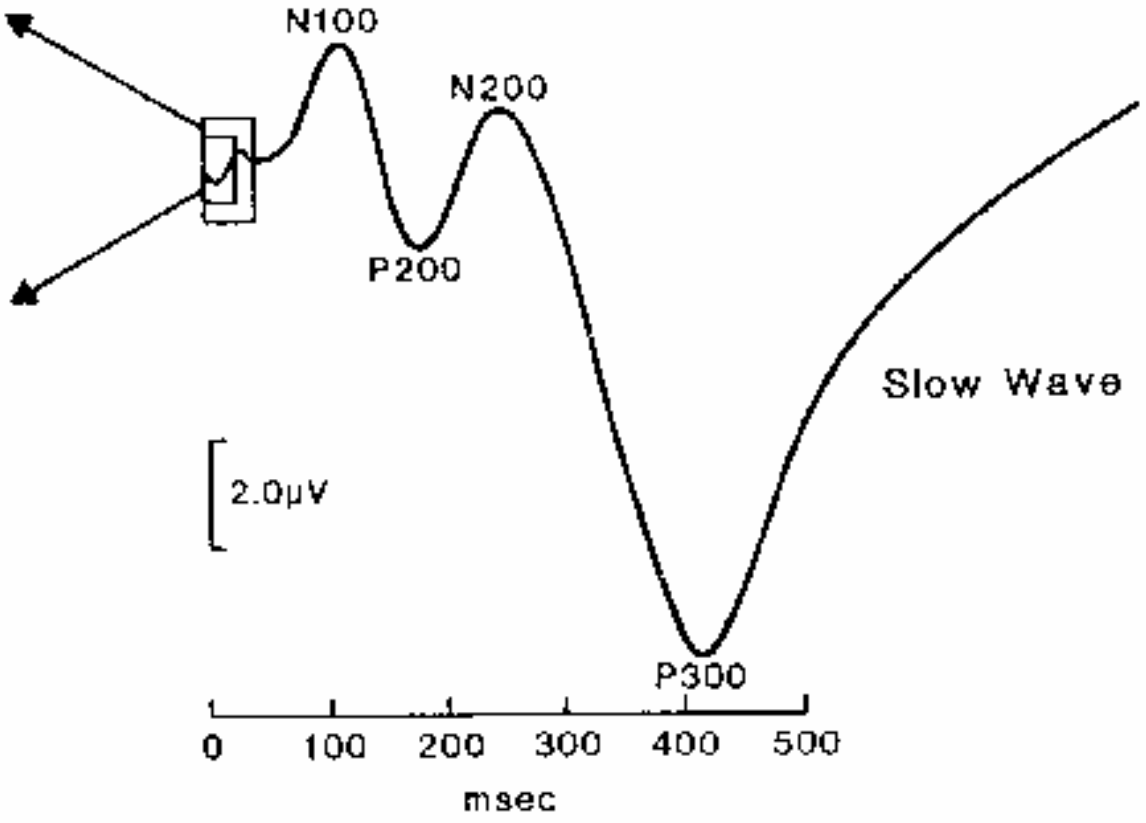
- Ongoing activity reflects "**noise**"
- Activity that reflects processing of a given stimulus **"signal"**
- The signal-related activity can be extracted because it is **time-locked** to the presentation of the stimulus
- Signal Averaging is most common method of extracting the signal
  - Sample EEG for ~1 second after each stimulus presentation & average together across like stimuli
  - Time-locked signal emerges; noise averages to zero
  - Signal to noise ratio increases as a function of the **square root** of the number of trials in the average

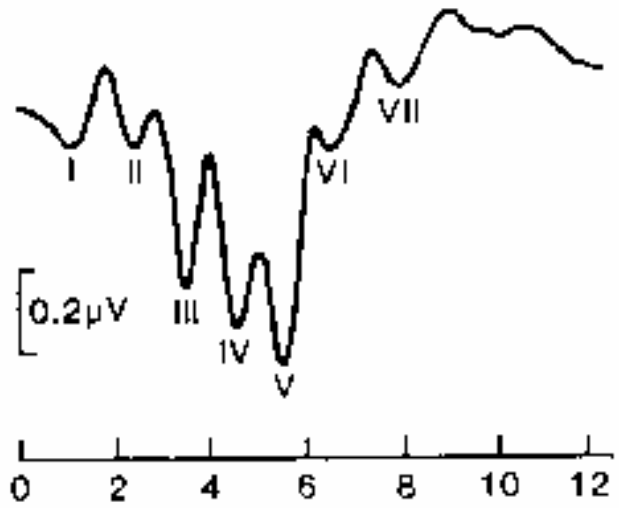
What does the ERP reflect?

- May reflect sensory, motor, **and/or** cognitive events in the brain
- Reflect the synchronous and phase-locked activities of large neuronal populations engaged in information processing

Component is is a "bump" or "trough"

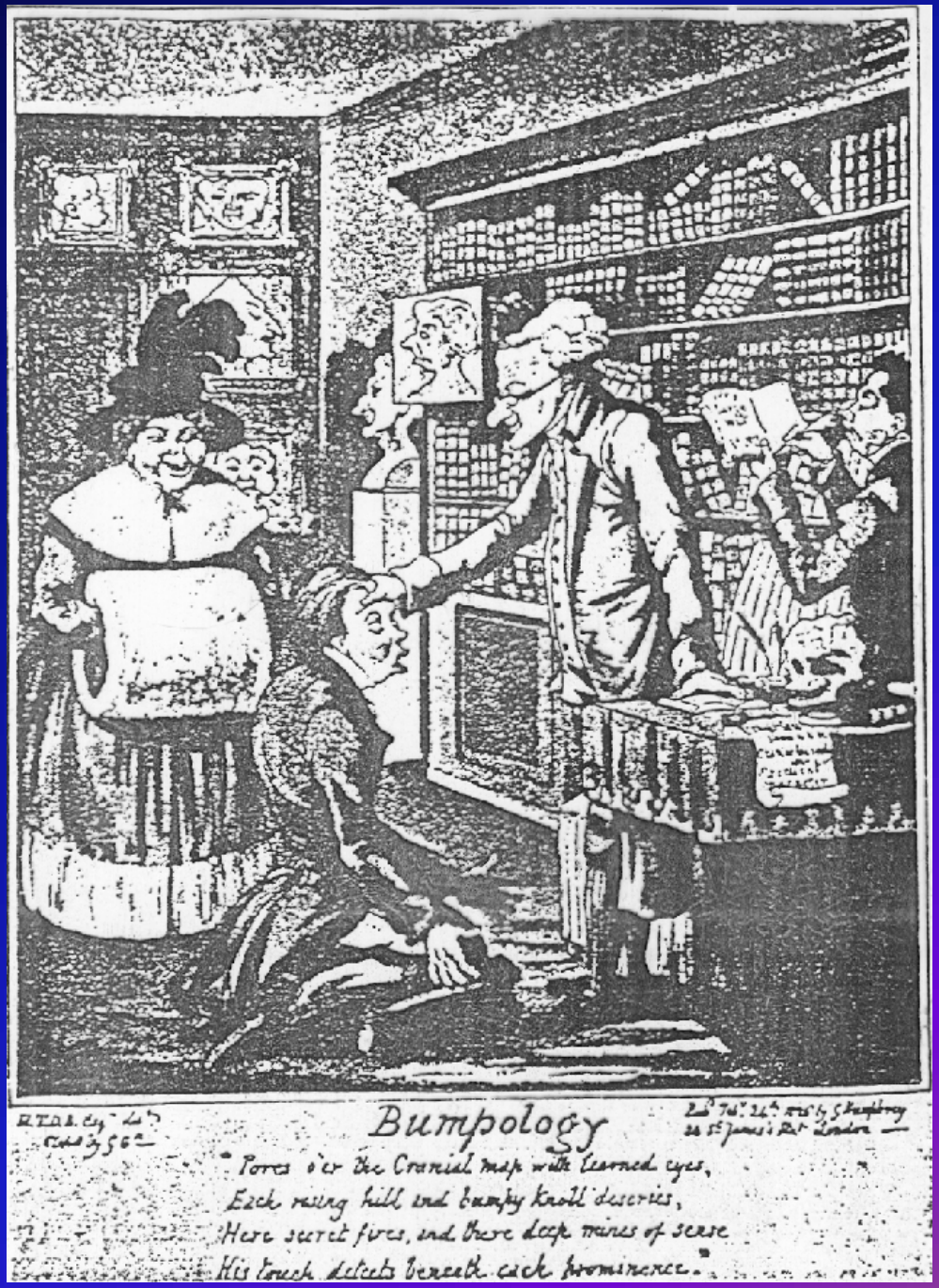






Making Meaning from the bumps

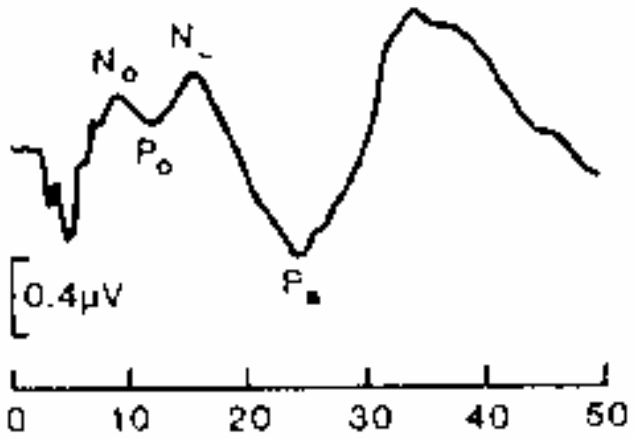
Pores o'er the Cranial map with learned eyes,
Each rising hill and bumpy knoll decries
Here secret fires, and there deep mines of sense
His touch detects beneath each prominence.

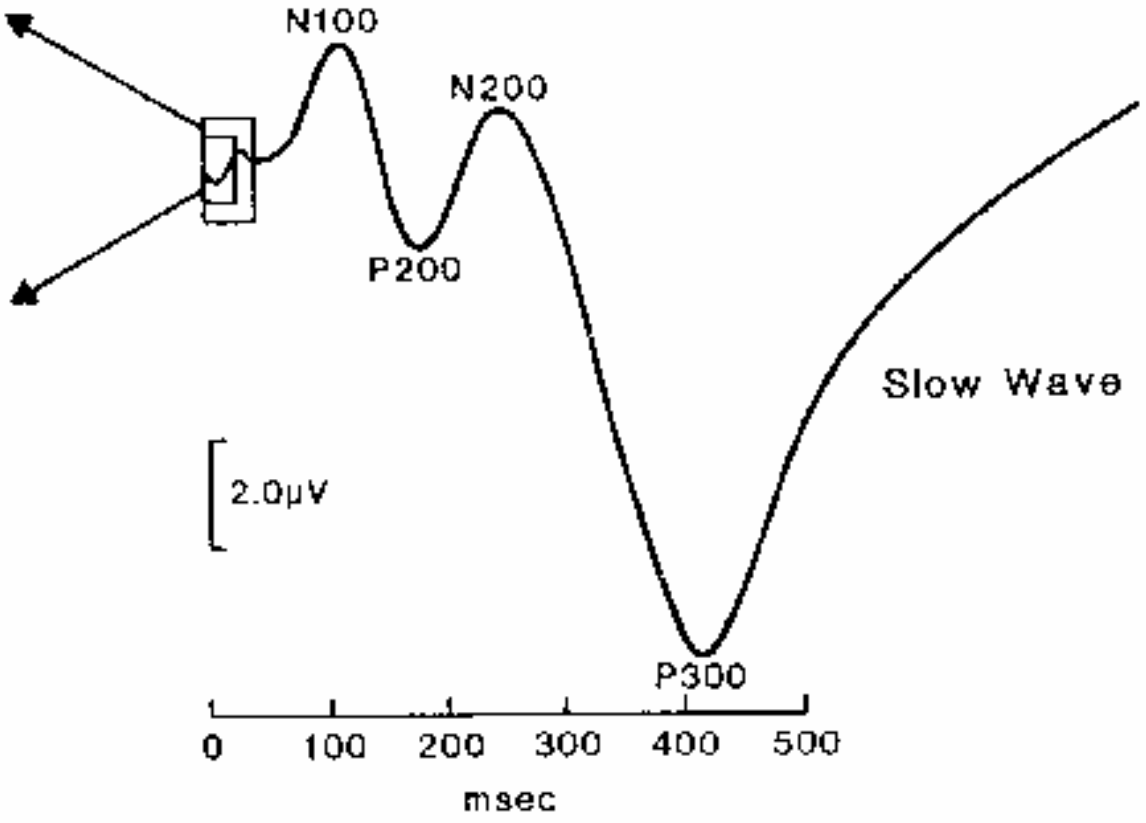


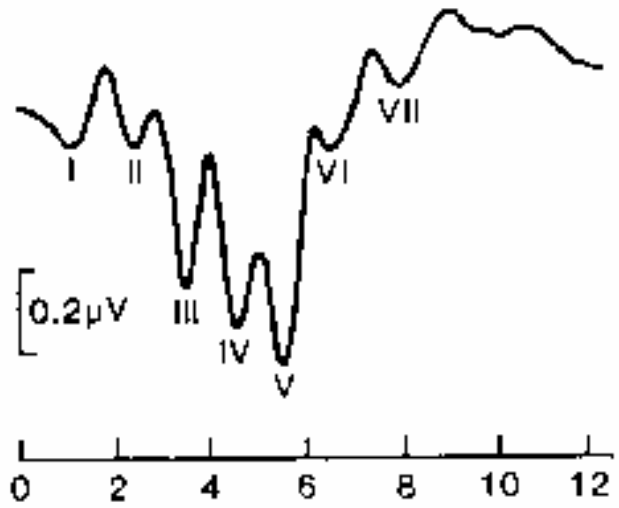
Nomenclature & Quantifying

- Most commonly label peaks and troughs by polarity (P or N) and latency at active recording site
- Quantifying
  - Amplitude
  - Latency
  - Area
  - “String” measure
  - Fancy stuff to be discussed in “advanced” topics

Component is is a "bump" or "trough"







Early Components

- Waves I-VI represent evoked activity in auditory pathways and nuclei of the brainstem
- Early components <60-100 msec
  - occur in **obligatory** fashion
  - are called **Exogenous** = determined "outside" organism
- Even subtle deviations in appearance may be indicative of pathology

Later ERP components

- Highly sensitive to changes in
  - State of organism
  - Meaning of stimulus (NOT physical characteristics)
  - Information processing demands of task
- Therefore termed **Endogenous =** determined “within" organism

Not all components fit neatly into exogenous or endogenous categories

- Both Obligatory but modulated by psychological factors
- “Mesogenous”

Evoked Vs Emitted ERP's

- Evoked are most commonly studied: occur in response to a physical stimulus
- Emitted potentials occur in absence of a physical stimulus (e.g., omission of item in sequence)
- Evoked can have both exogenous and endogenous components; emitted usually have only endogenous

Evoked Vs Emitted Potentials

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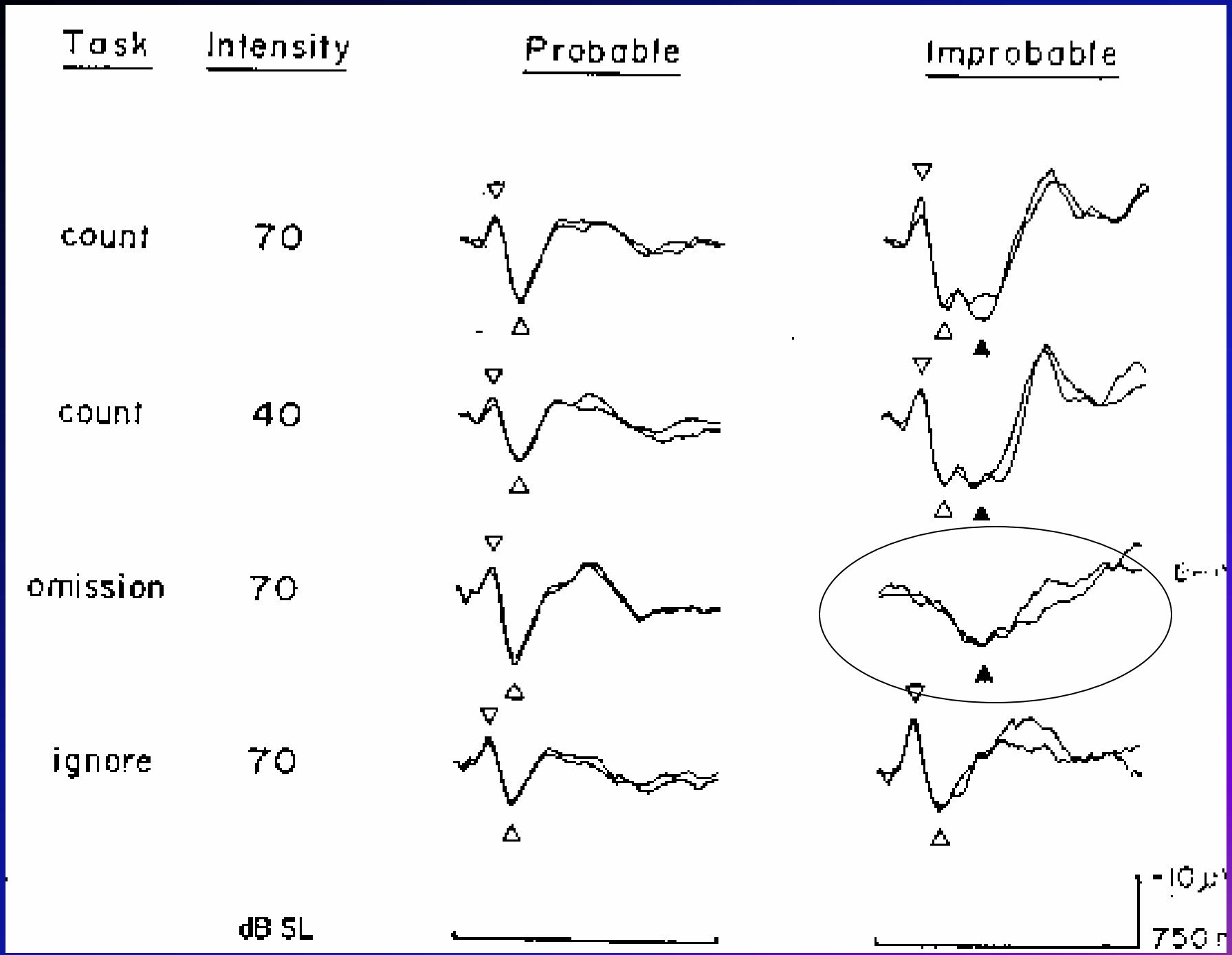
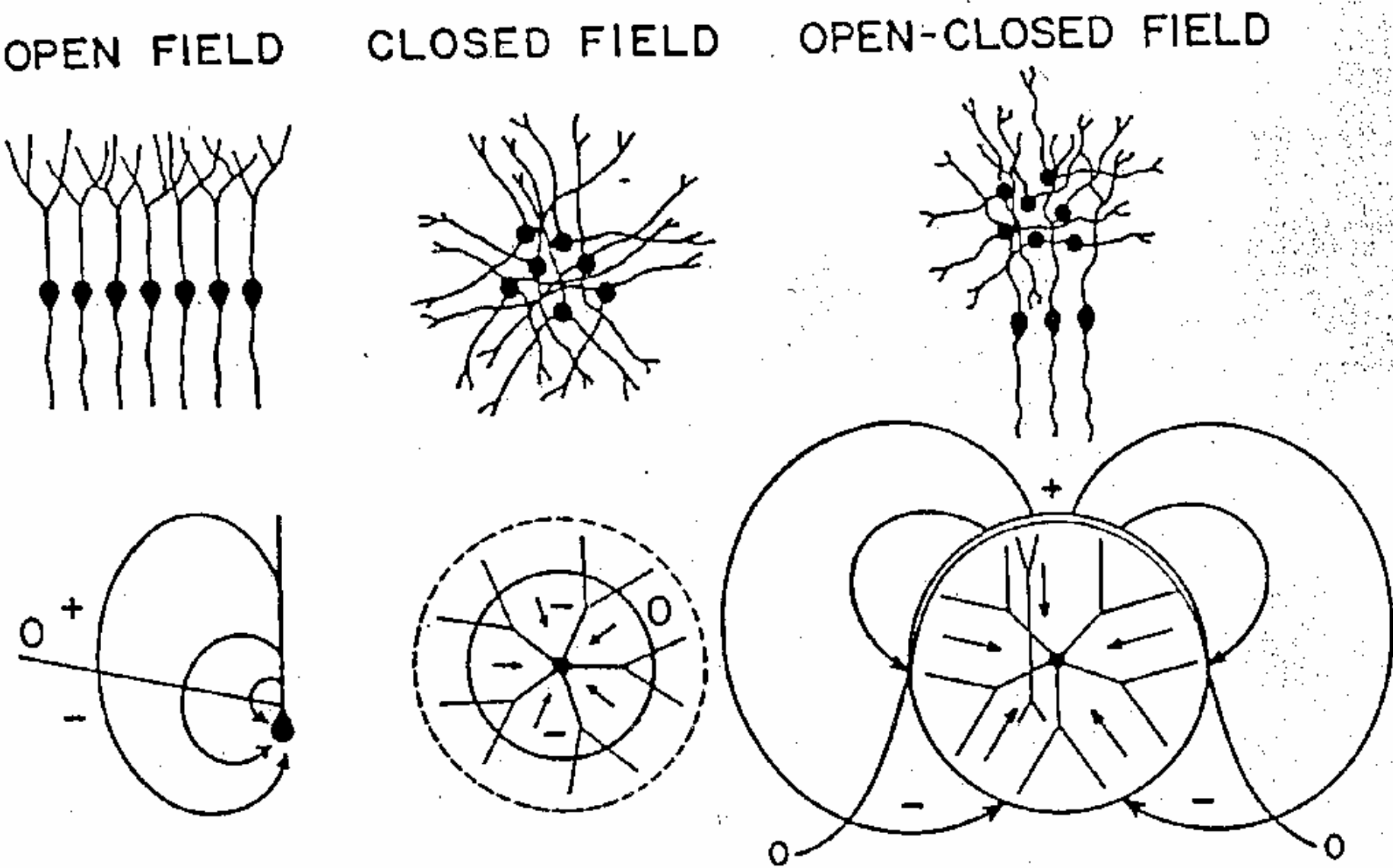

Task
Intensity
Probable
Improbable
count
70
count
40
omission
70
ignore
70
dB SL
- 10 μ
750 m

Comparison to other "windows on the brain"

- Very precise temporal resolution
- Spatial localization is more difficult
  - At the surface, activity of many functional synaptic units recorded
  - ERP's generated only by groups of cells that are synchronously activated in a geometrically organized manner
  - Synchronous activation may occur in one or more than one location
  - Monopolar recording technique most often used
  - Yet localization is not impossible in conjunction with other techniques



After Lorente de Nó, 1947

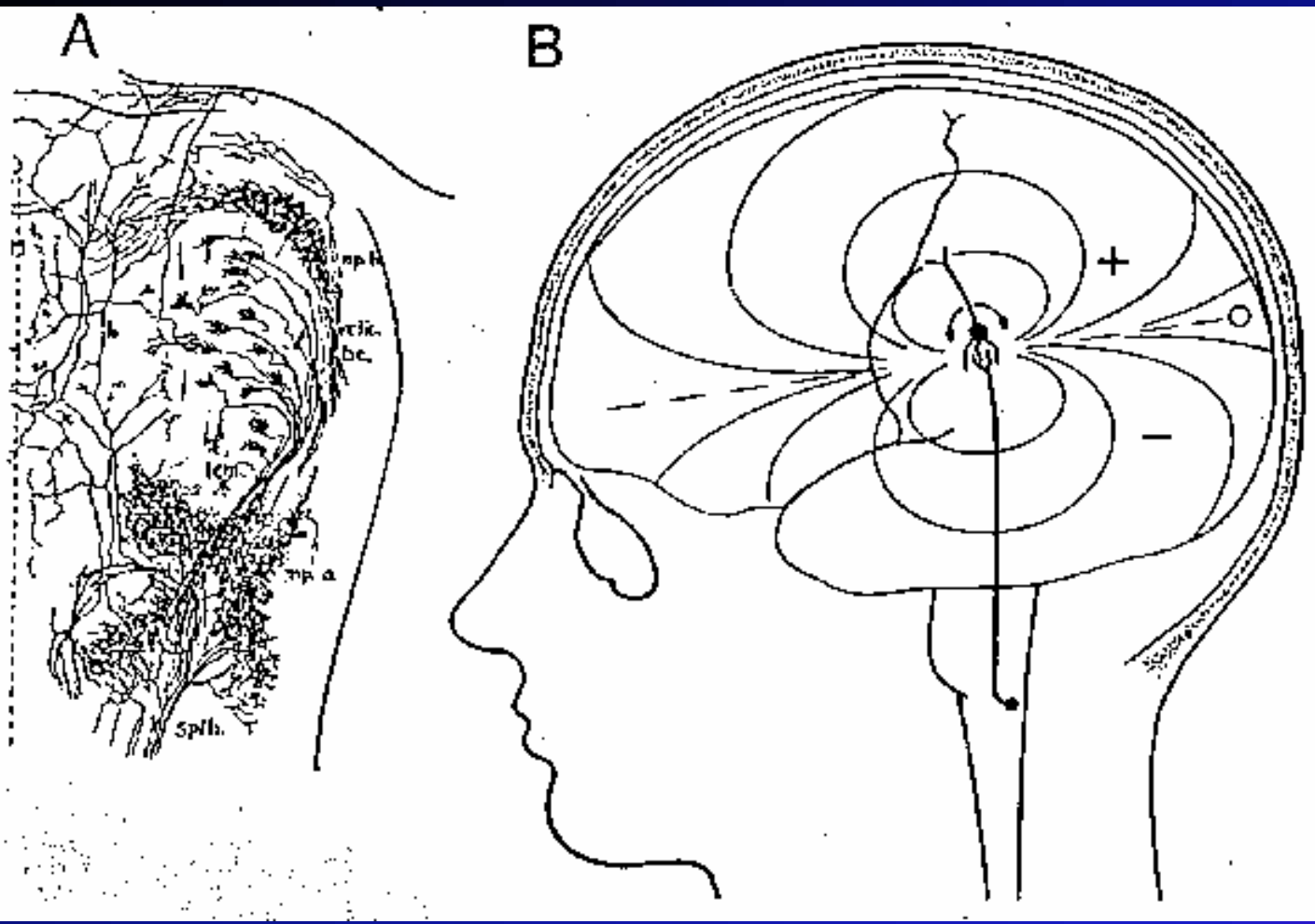


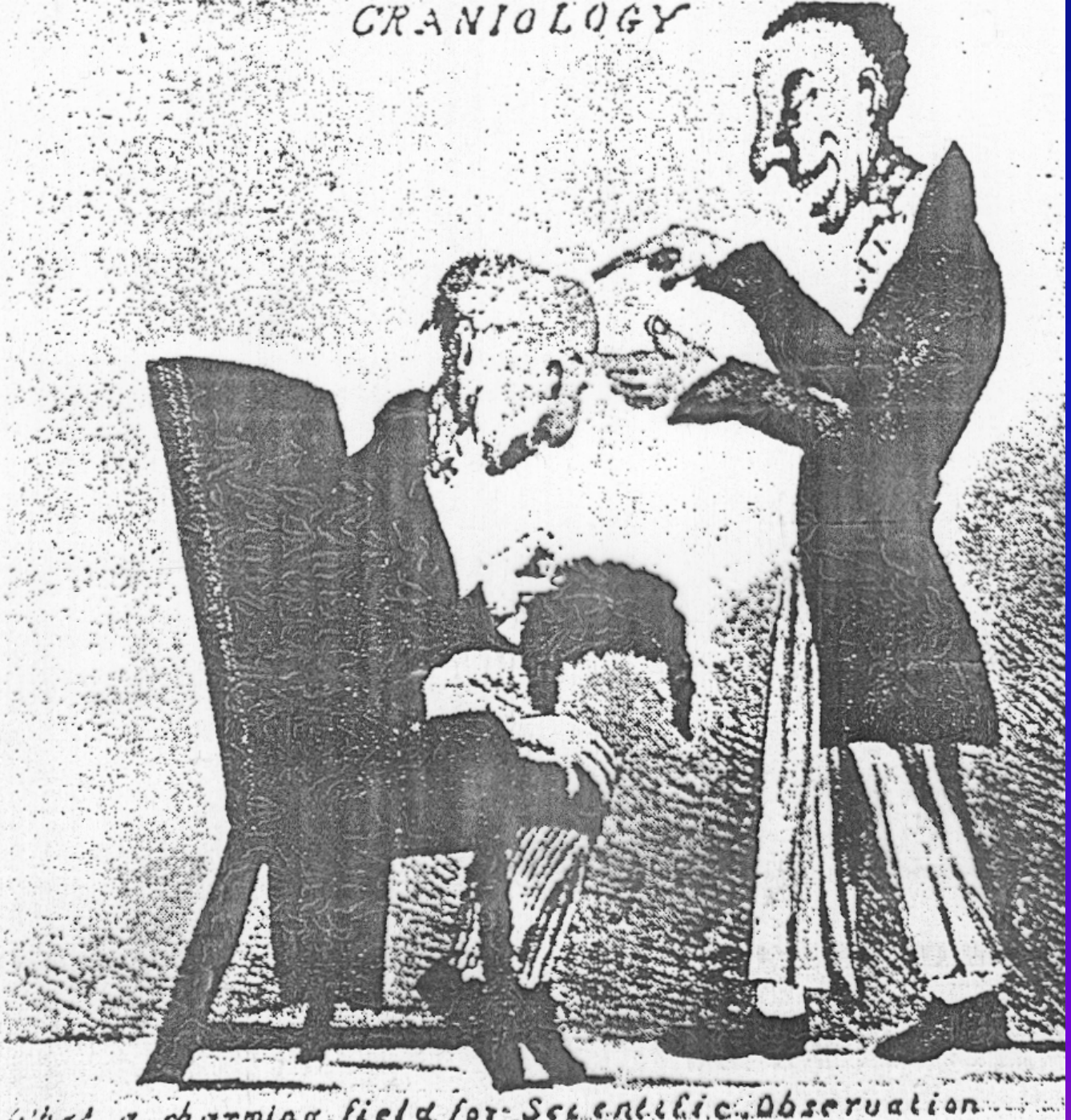
Figure 1-11. Anatomy and electrogenesis of ventroposterior (VP) thalamus. A. Horizontal section showing bushy arborizations of lemniscal (lem) afferents terminating on dendrites of VP relay neurons (g). (From "Patterns of Organization in Specific and Nonspecific Thalamic Fields" by M. E. Scheibel and A. B. Scheibel. In D. P. Purpura and M. D. Yahr [Eds.], *The Thalamus*. New York: Columbia University Press, 1966. Reprinted by permission.) B. Postulated potential field produced by depolarization of VP relay neurons. For clarity, the most intense parts of the field are omitted.

Caveat Emptor

- DO NOT interpret scalp distribution of ERP's as reflect cortical specialization
- Also, DO NOT interpret area of maximum amplitude to suggest that generator lies underneath

Correlate Vs substrate (AGAIN)

- Late ERP components should not be taken to indicate the existence of a neurological substrate of cognitive processing
- Rather should be considered a correlate
- Constructs in search of validation; Process of validation:
  - Determine antecedent conditions under which the ERP component appears and also magnitude and latency of ERP component
  - Develop hypotheses concerning functional significance of the "subroutine" underlying the ERP component
  - Predict consequences of subroutine--validate empirically

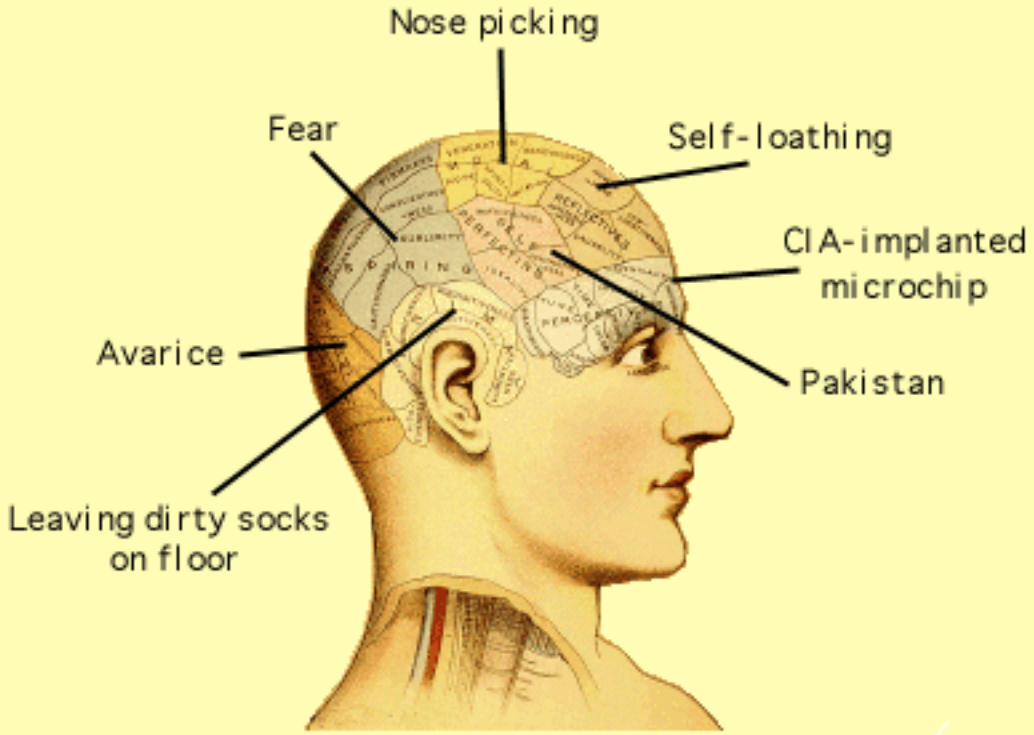

CRANIOLOGY
What a charming field for Scientific Observation

What *IS* Phrenology?

Back a long damn time ago some people thought that you could determine someone's personality by mapping the little bumps on their head to different behaviors. A big bump, I think, meant a predisposition to the corresponding behavior-- a small bump or concavity meant the opposite.

Kinda goofy, really.

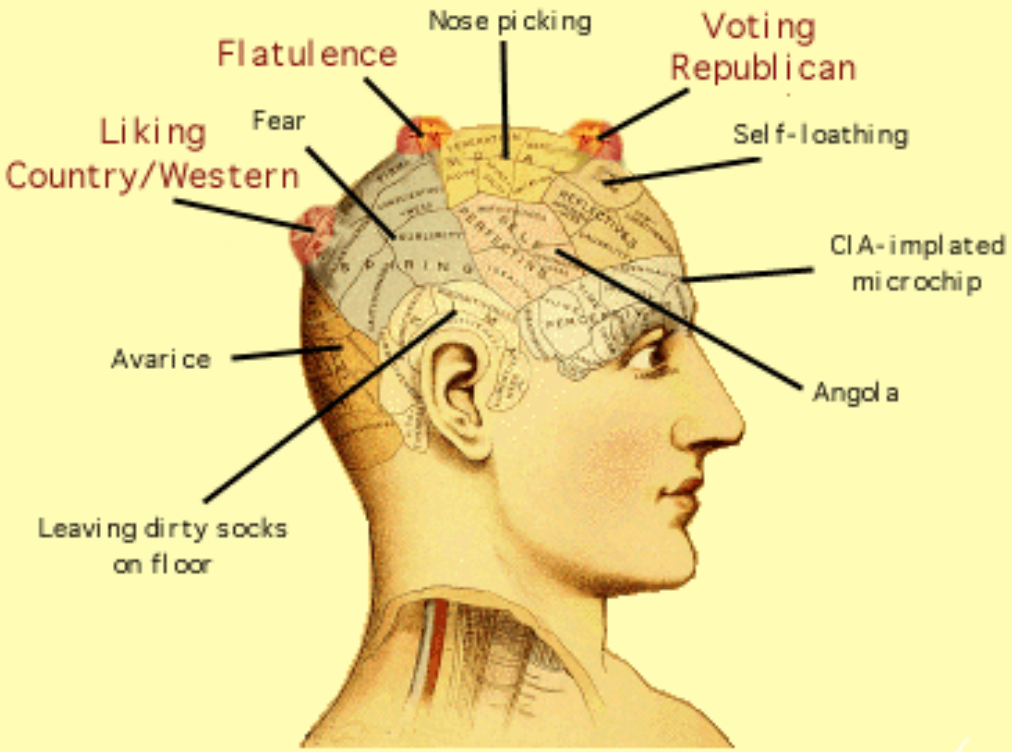
If I believed in it, I'd map the human brain as follows:



From http://triggur.org/phreno.html

What is Phreno*THERAPY*?

It's a bold new discipline (actually I made it up). Whereas phrenology STUDIES the bumps to determine personality, phrenotherapy CHANGES personality by causing NEW bumps. A wooden mallet might work. For example:



Oddly enough, I've been banned by 11 major hospitals from practicing this. I guess they just aren't interested in scientific progress. Losers.

From http://triggur.org/phreno.html

Basic Signal Processing

Paradigms and acquisition

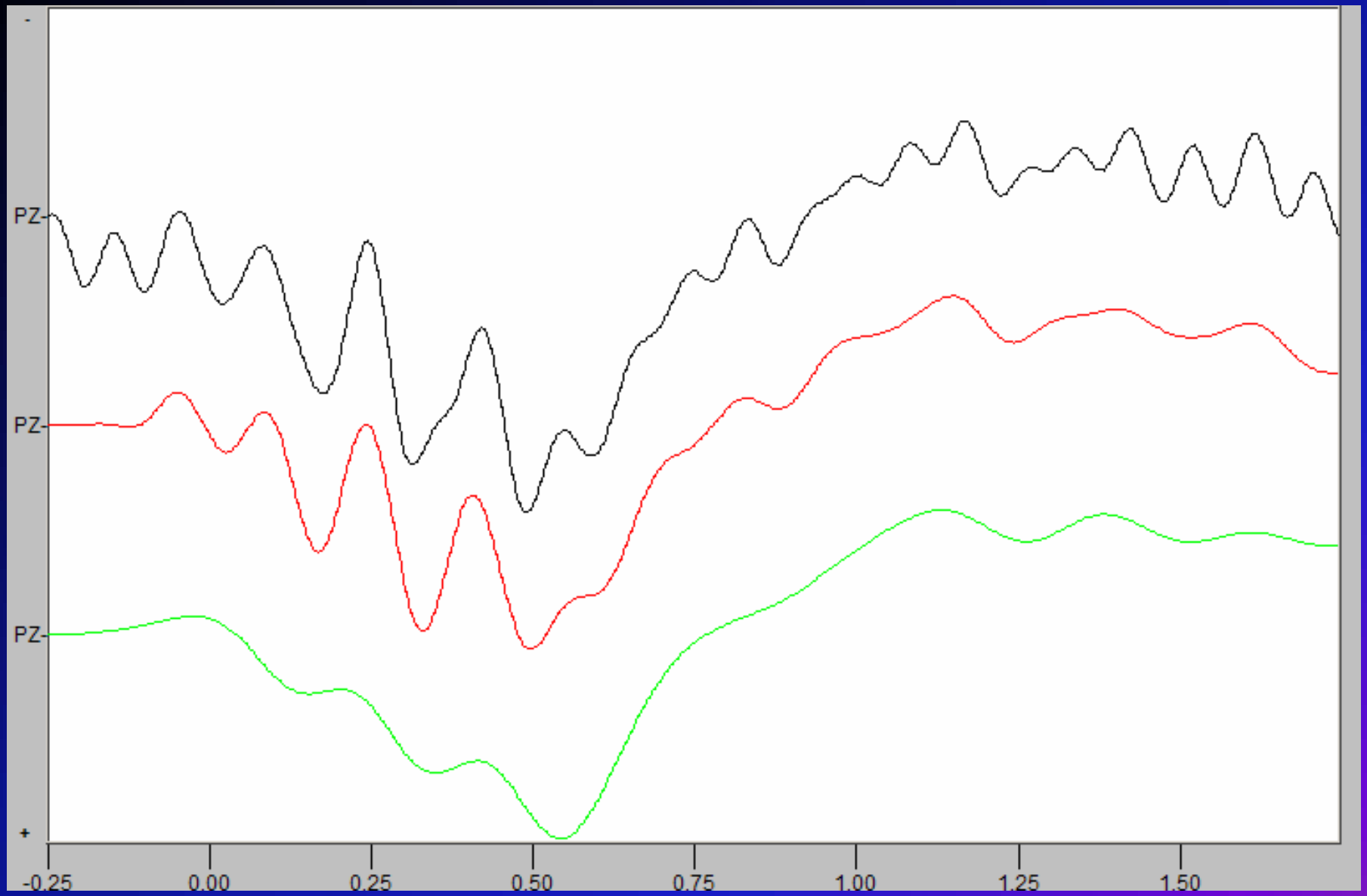
- Precise temporal control over stimulus presentation necessary
  - Requires discrete stimuli
- Individual stimuli are presented numerous times; ERP's generally do not habituate, unlike peripheral measures
- Concurrent with each stimulus, a signal/pulse must be sent to the A/D converter to indicate time of stimulus onset
- A/D converter and sampling
  - sampling either as pulse received, or it may be continuously monitored
  - several pre-onset samples (to provide a baseline for comparison);
  - **epoch** length
- Epochs for like stimuli averaged together to create ERP for that set of stimuli

Assumptions of Averaging methods

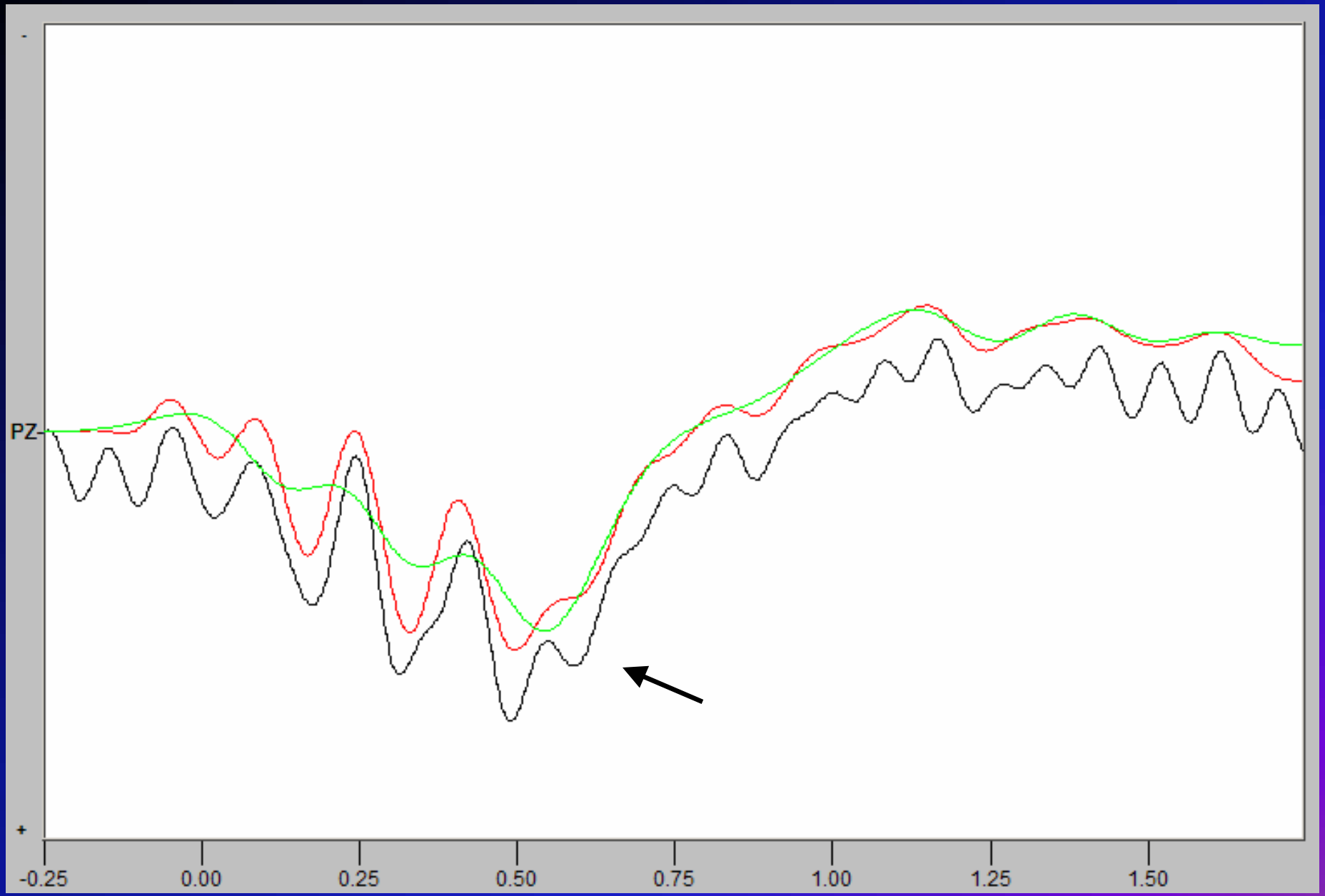
- Signal and noise (in each epoch) sum linearly together to produce the recorded waveform for each epoch (not some peculiar interaction)
- The evoked signal waveshape attributable **solely** to the stimulus is the same for each presentation
- The noise contributions can be considered to constitute statistically independent samples of a random process

Filtering and its influence on the ERP

- Despite many trials and averaging, some noise may remain in the averaged waveform
- If you are only interested in later & slower components, then a low-pass filter may be of interest



Same ERP filtered with 12.5 (black), 8 (red) , and 5 (lime) Hz Low Pass FIR Filter

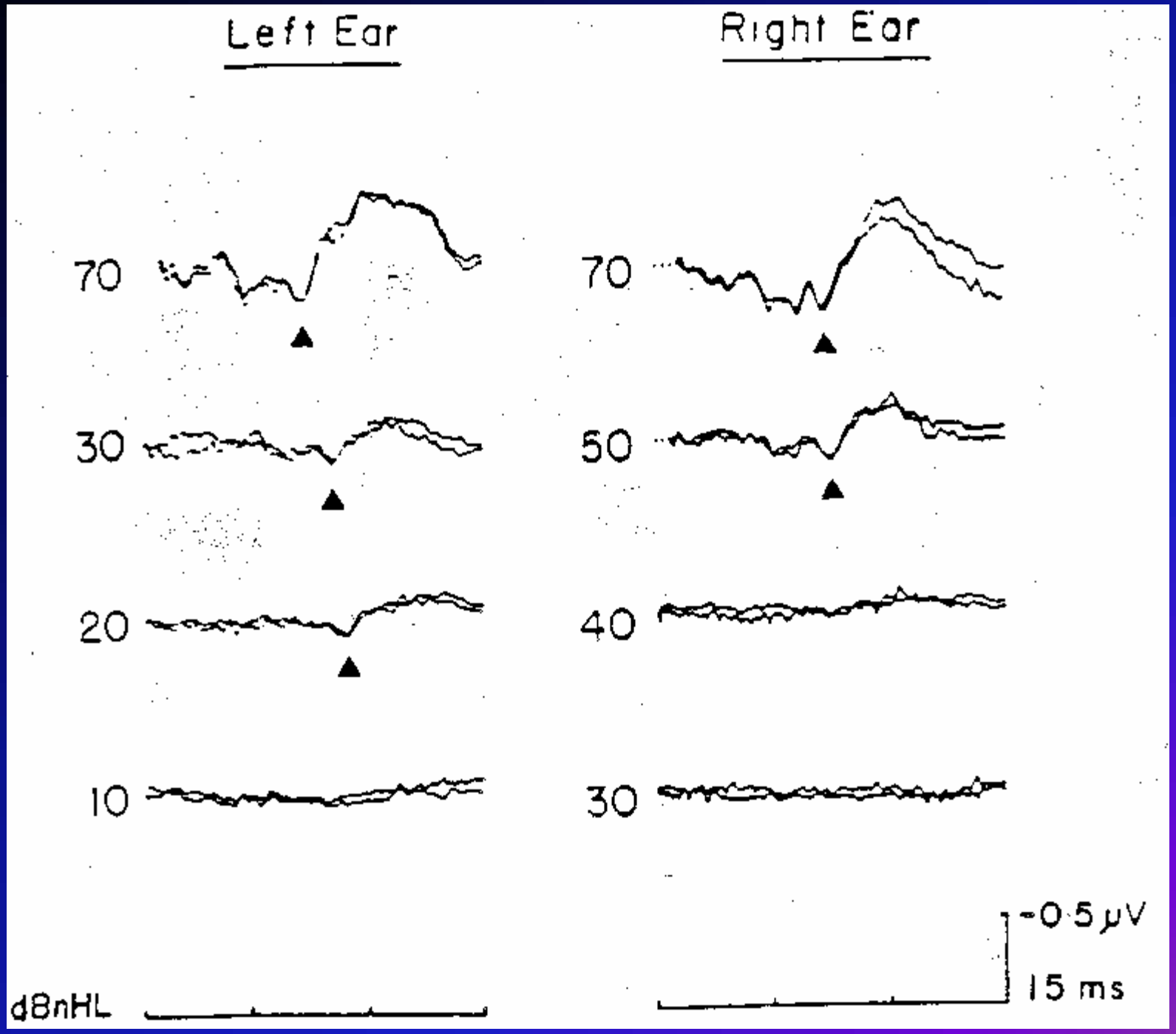


Same ERPs overlaid; note amplitude attenuation in P3 amplitude with stricter filters

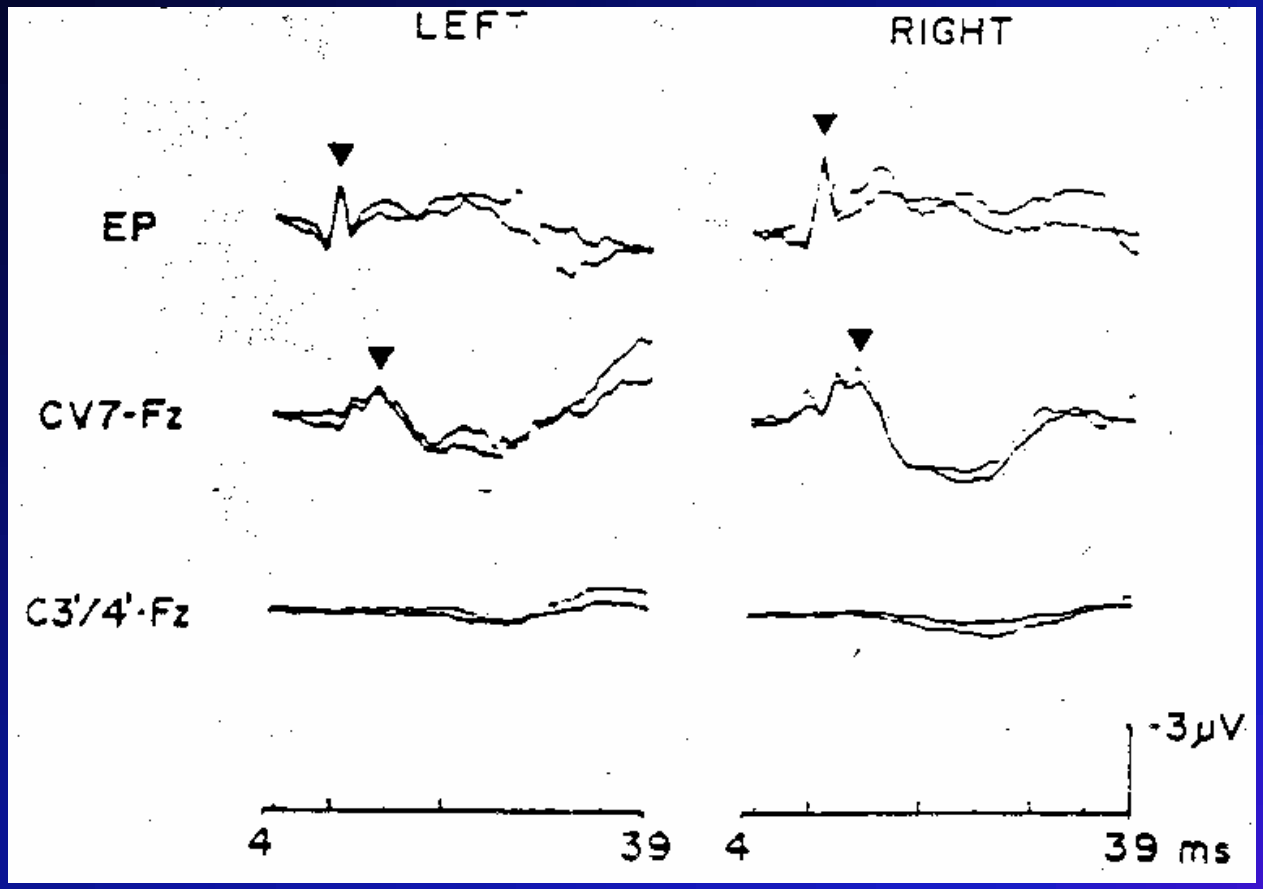
Let’s ERP!

Applications of Early Components

- Neurological evaluation of sensory function; e.g. evaluation of hearing in infants
  - Tones of various dB intensities presented and V wave in auditory brainstem ERP examined
  - Figure 10; 4000 individual trials per average


Left Ear
Right Ear
70
30
20
10
70
50
40
30
0.5 µV
15 ms
dBnHL

Prediction of recovery from coma



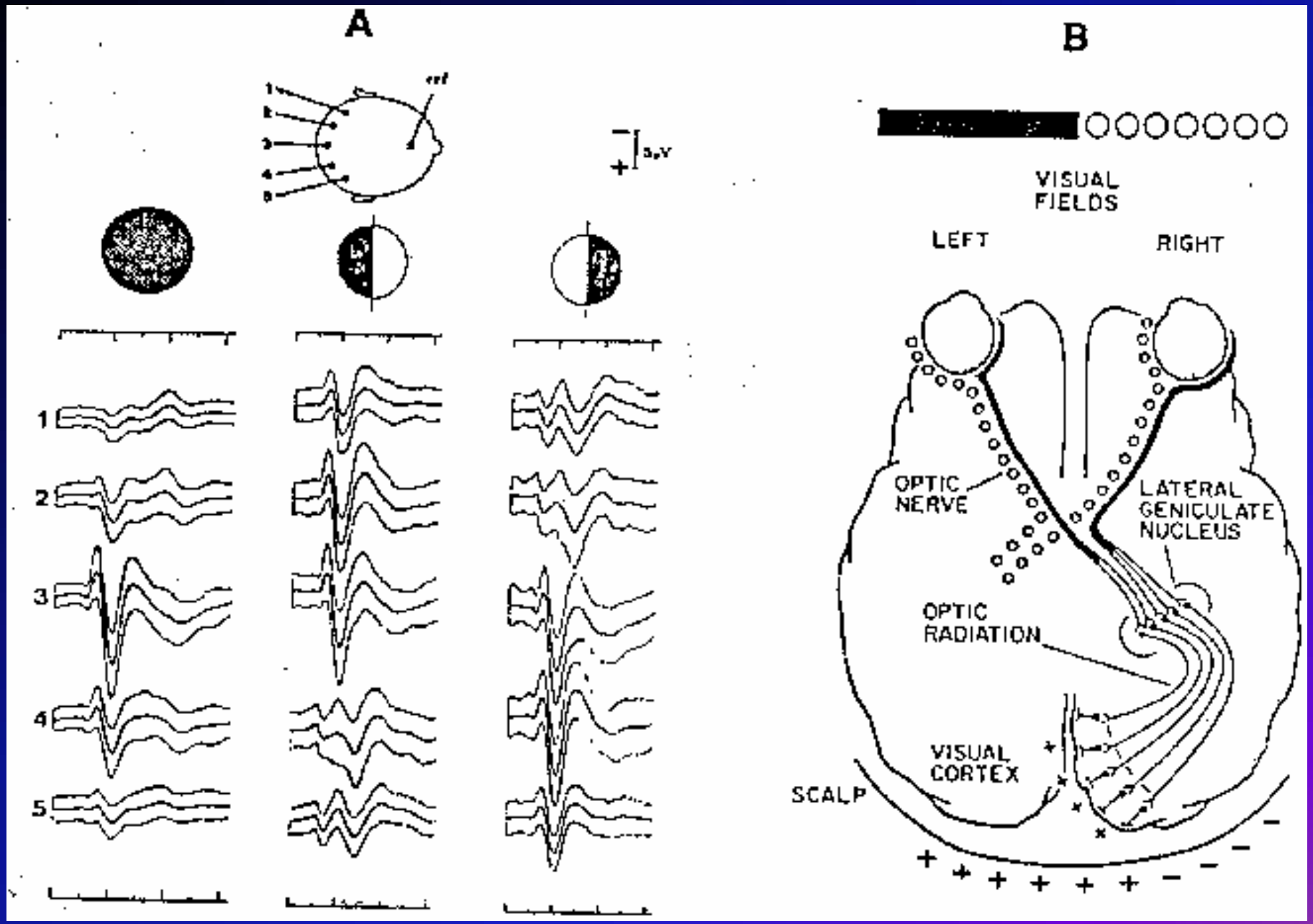
- Somatorsensory evoked potentials were recorded from a patient who was still comatose 1 week after severe closed head injury.
- Responses evoked by electrical stimulation of left and right median nerves
- Normal tracing seen at Erb's point, and from the next over vertebra prominens, but not over C3' of C4'.
- Absense of any cortical response a bad prognostic sign. Patient continued in a chronic vegetative state 1 year after accident

Inter-Hemispheric Transfer Time (IHTT)

- Hypothesized that interhemispheric transfer of information may be abnormal in various disorders (e.g., dyslexia)
- Reaction Time measures contain too much variability not related to Transfer Time
- ERP early components appear promising as a measure of time required to transfer information between hemispheres

IHTT Study (Saron)

- Checkerboards subtending < 1 degree of visual angle presented 2.9 degrees from center
- ERP's recorded at O1 and O2
- Problem of lateralization and Paradoxical results possible; parafoveal regions on banks of calcarine fissure
- P100 wave latency examined; earlier latency in occiput contralateral to presentation
  - Measured by peak picking procedure
  - Also by cross-lagged correlation technique (**DRAW**)
  - Both methods suggest ~15 millisecond IHTT; found to be in expected direction predicted by anatomy for over 90% of subjects
  - Reaction time data from same task showed no reliable differences


A
B
VISUAL FIELDS
LEFT
RIGHT
OPTIC NERVE
LATERAL GENICULATE NUCLEUS
OPTIC RADIATION
VISUAL CORTEX
SCALP
1
2
3
4
5

P1, N1 & selective attention (Luck, Heinze, Mangun, & Hillyard, 1990)

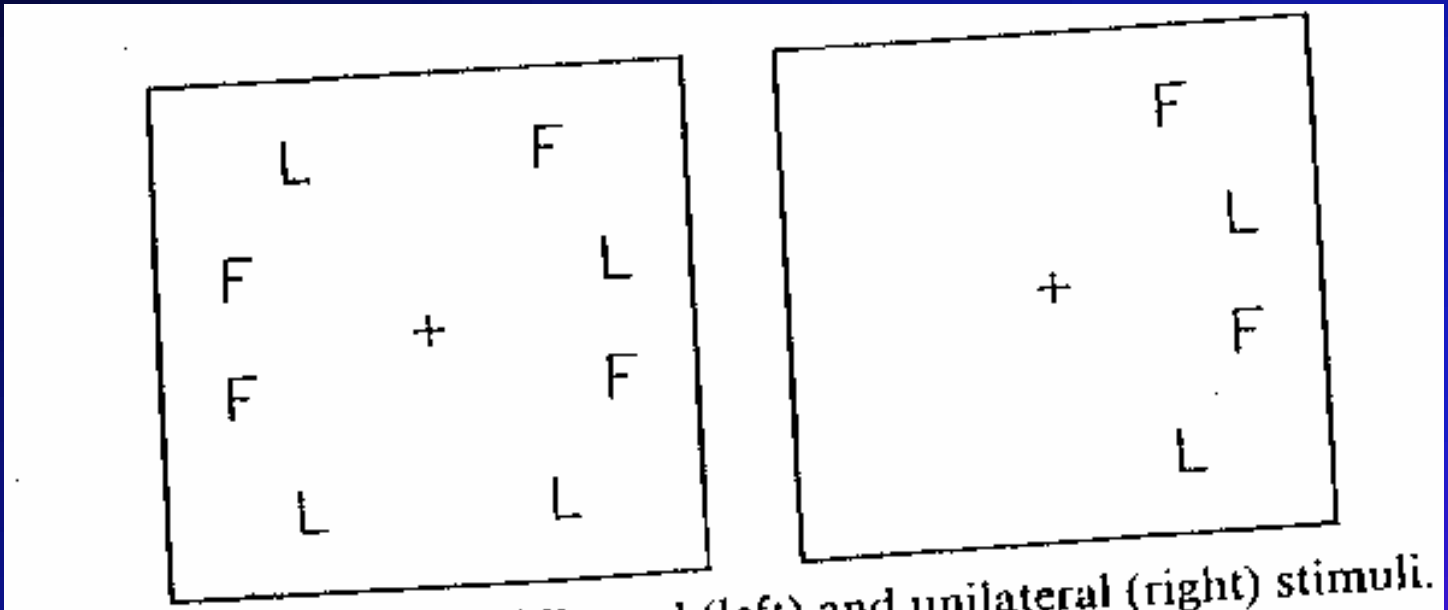


Fig. 1. Examples of bilateral (left) and unilateral (right) stimuli. Each letter was 3° from a fixation point, represented here by the plus symbol.

Visual stimuli presented to one or the other visual field, under two conditions: Bilateral (left) or unilateral (sample on right)

Task and Results

- Subjects instructed to attend either left or right at beginning of each run and to press whenever target letter (T) was identified
  - Accuracy rather than speed was stressed
  - Three main conditions, each run under attend right and attend left instructions:
    - All bilateral
    - all unilateral (50% right, 50% left)
    - or mixed unilateral/bilateral (33% bilateral, 33% right unilateral, 33% left unilateral)
  - When visual stimuli presented to only one visual field
    - P1 component is larger **bilaterally** (but greater contralaterally) in parietal/occipital regions during attended vs unattended stimuli
    - N1 component is larger in parietal region **contralateral** to field of presentation, to attended stimuli
  - When visual stimuli presented bilaterally, however,
    - P1 is enhanced contralateral to attended stimuli
    - N1 is reduced relative to unilateral presentations
  - Hillyard and associates interpret the modulation of this component to reflect gating or filtering of information at an early stage of processing

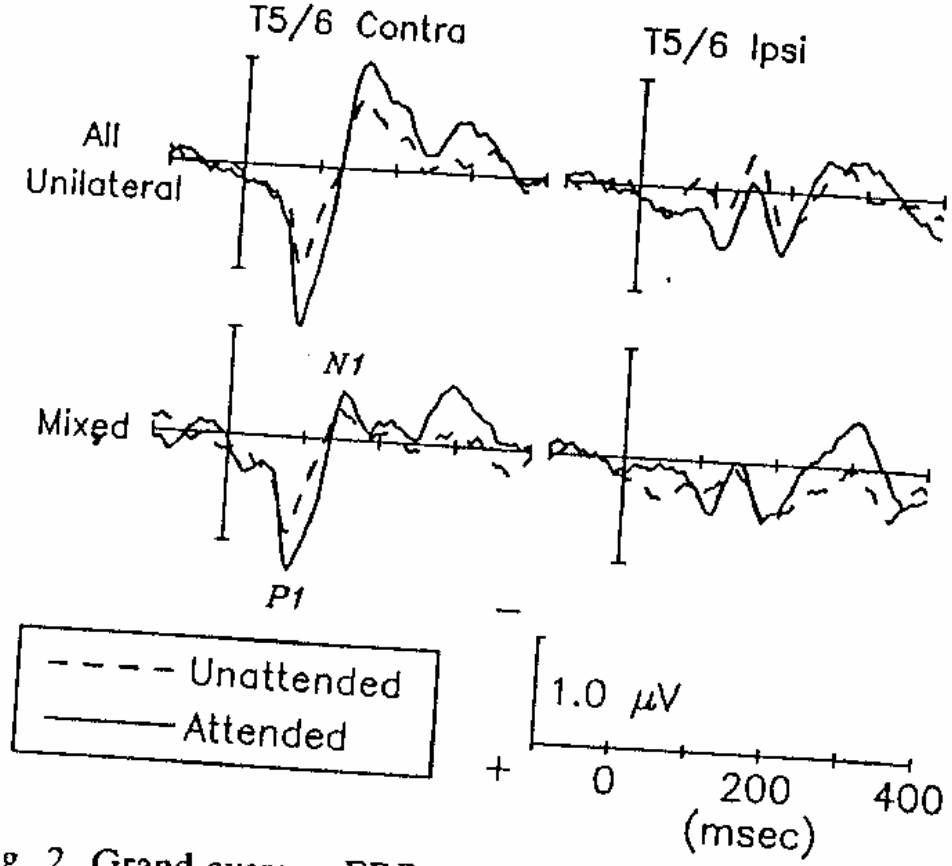
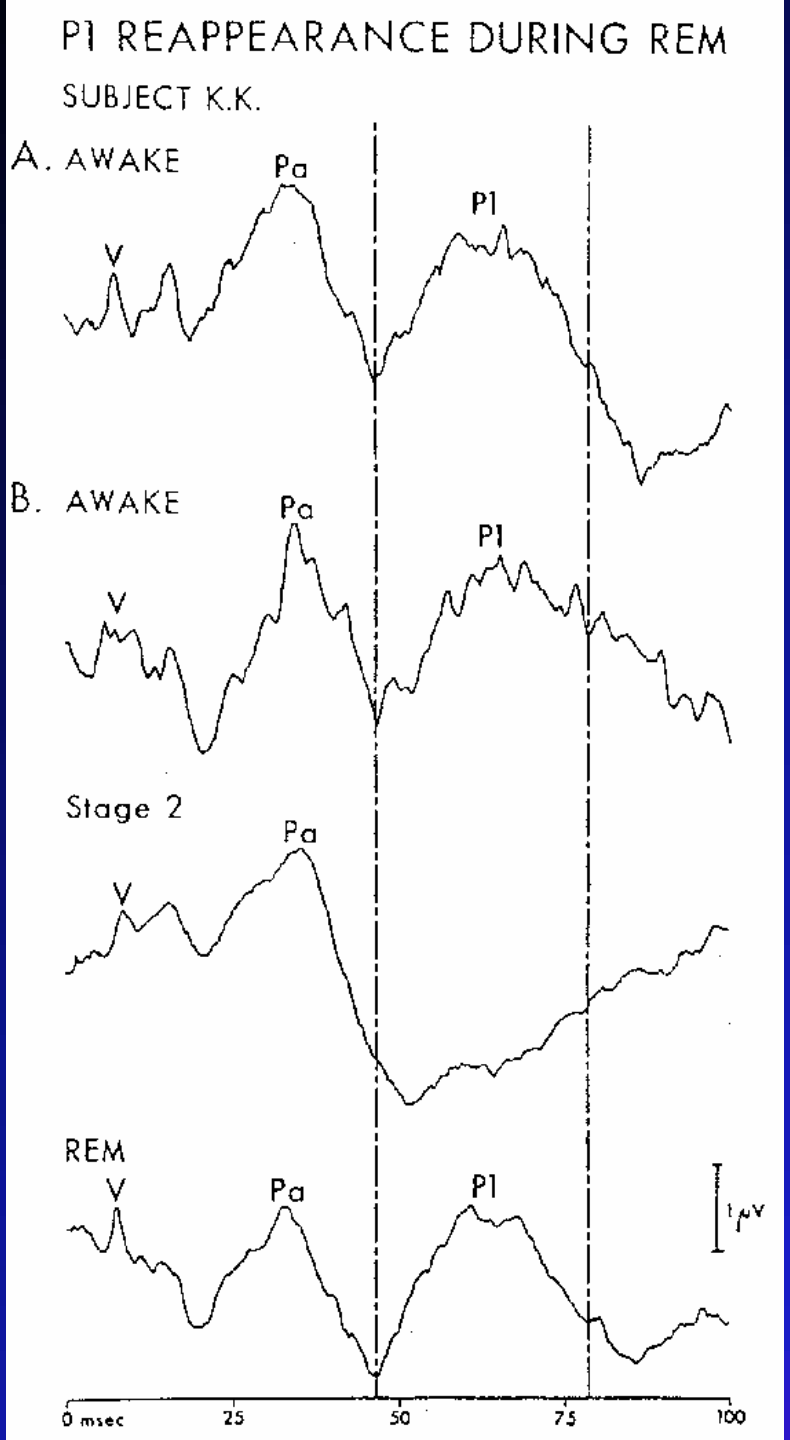


Fig. 2. Grand-average ERPs elicited by unilateral non-target stimuli in all-unilateral sequences (top row) and mixed sequences (bottom row). ERPs for unattended stimuli are plotted with dashed lines and ERPs for attended stimuli are plotted with solid lines. The left column displays ERPs from temporal electrodes contralateral to the position of the stimulus and the right column displays ERPs from ipsilateral temporal electrodes.



Note P1 disappears in Stage 2 sleep, but reemerges in REM sleep

Construct Validity of P300 (P3, P3b)

- First observed by Sutton, Braren, Zubin, & John (1965)
- P300 Amplitude; Johnson's model is

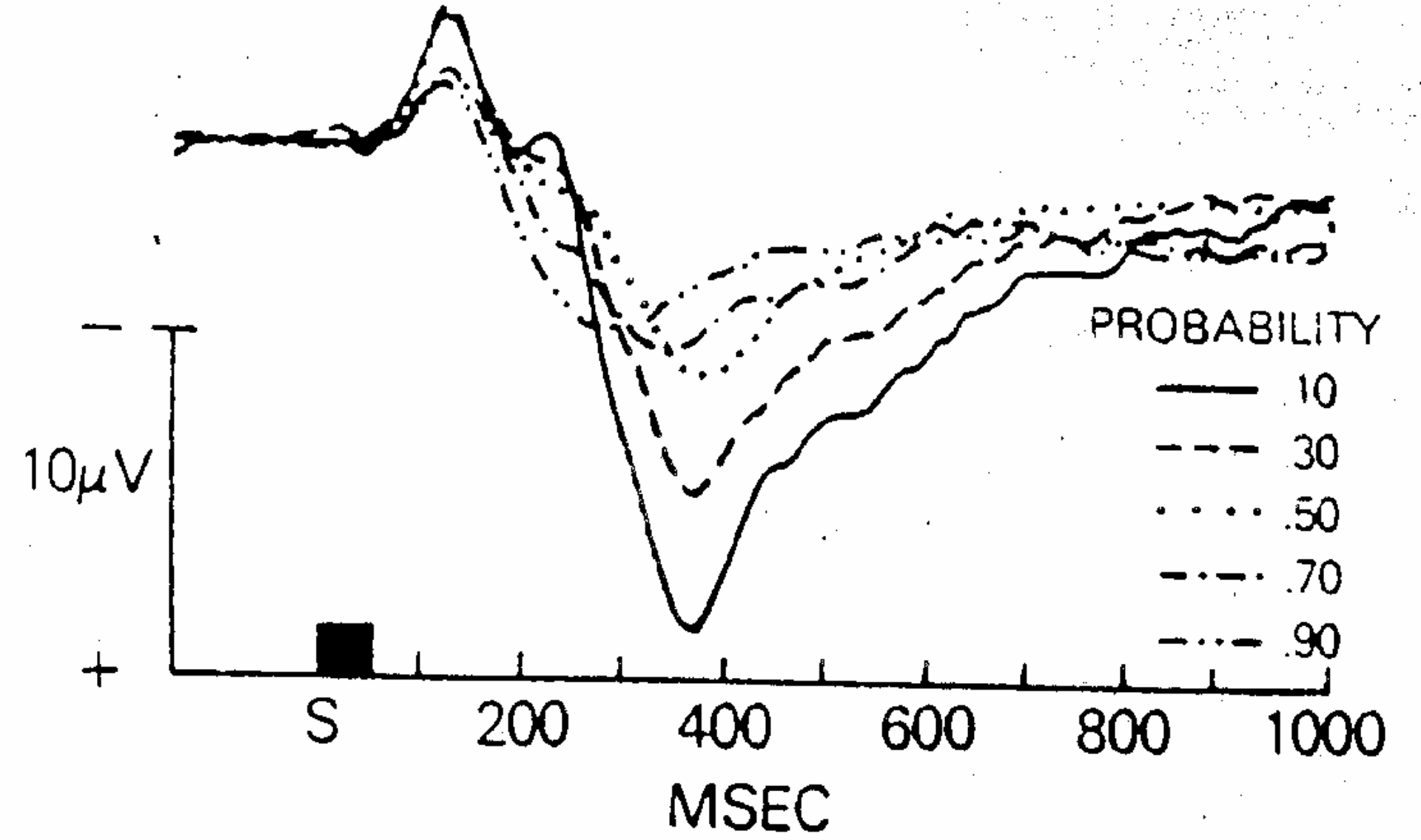
$$\text{P300 Amplitude} = f[T \times (1/P + M)]$$

where

  - P = probability of occurrence,
  - M = Stimulus meaning, &
  - T = amount of information transmitted

Aspects of the Model

- Rarity
  - The P300 is observed in variants of the "oddball paradigm"
  - The rare stimulus almost invariantly elicits a P300: largest at parietal, then central, and then frontal sites
  - **Subjective probability**
- Stimulus meaning
  - Actually composed of three dimensions
    - task complexity
    - stimulus complexity
    - stimulus value
- Information Transmission (proportion 0 to 1; more shortly)


PROBABILITY
.10
.30
.50
.70
.90
10μV
−
+
S
200
400
600
800
1000
MSEC

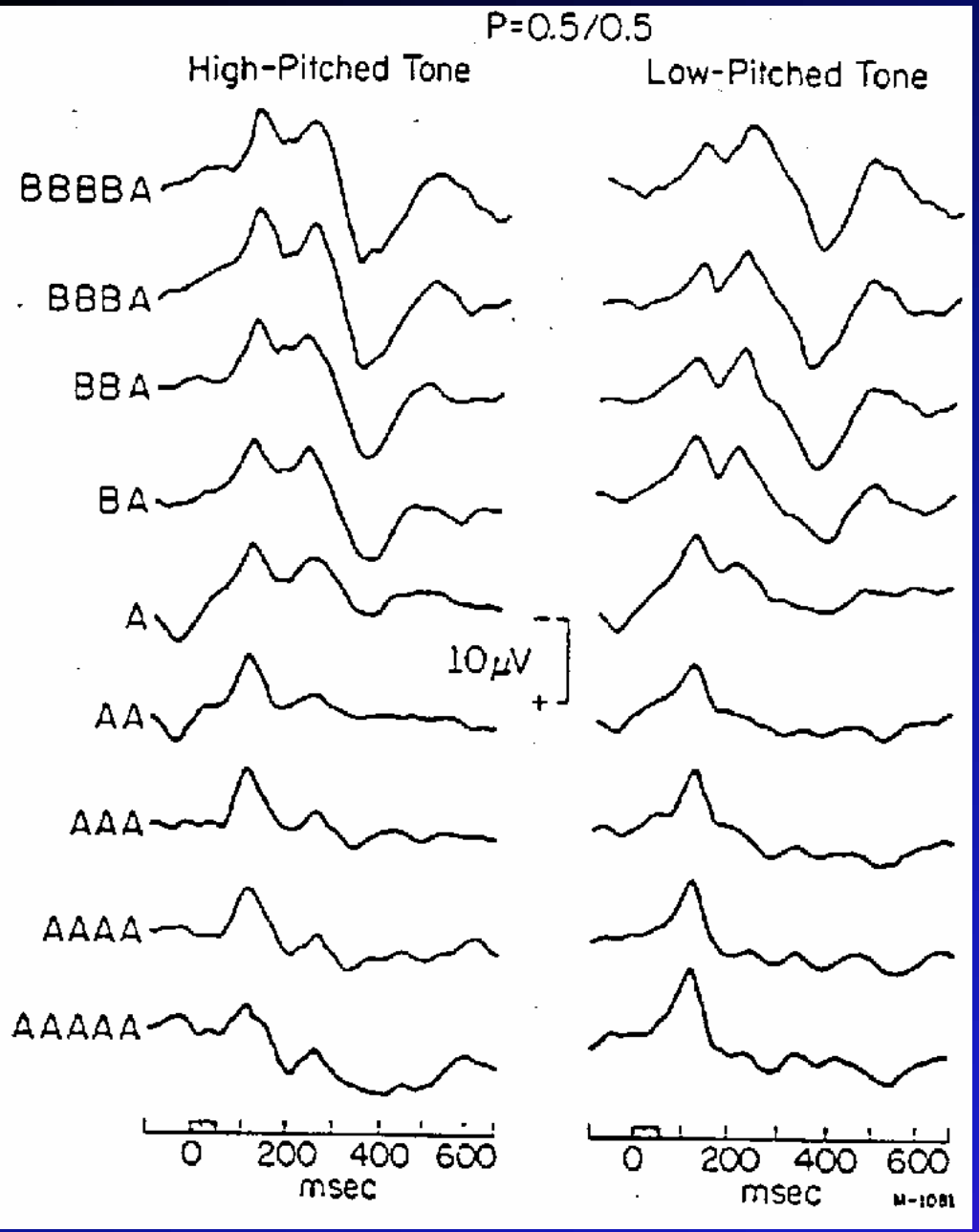


Figure 12-1. The ERPs in each column were elicited by the same physical tone; high-pitched tones were used for the left column and low-pitched tones for the right column. Both were presented in a Bernoulli series in which the probability of the two stimuli were equal. In the middle of each column (labeled "A") is the ERP elicited by all the presentations of the stimulus. The curve labeled "AA" was obtained by averaging together all the tones of one frequency that were preceded on the previous trial by tones of the same frequency. On the other hand, the curves labeled "BA" were elicited by stimuli preceded on the previous trial by the tones of different frequency. Similar sorting operations were applied to all other curves in this figure. It can be seen that the same physical tone elicited quite different ERPs, depending on the events that occurred on the preceding trials. Whenever a tone terminated a series of tones from the other category, a large P300 was elicited, and its magnitude was a function of the length of the stimulus series. (From "Effect of Stimulus Sequence on the Waveform of the Cortical Event-Related Potential," by K. C. Squires, C. D. Wickens, N. K. Squires, and E. Donchin. *Science*, 1976, 193, 1142–1146. Copyright 1976 by the AAAS.

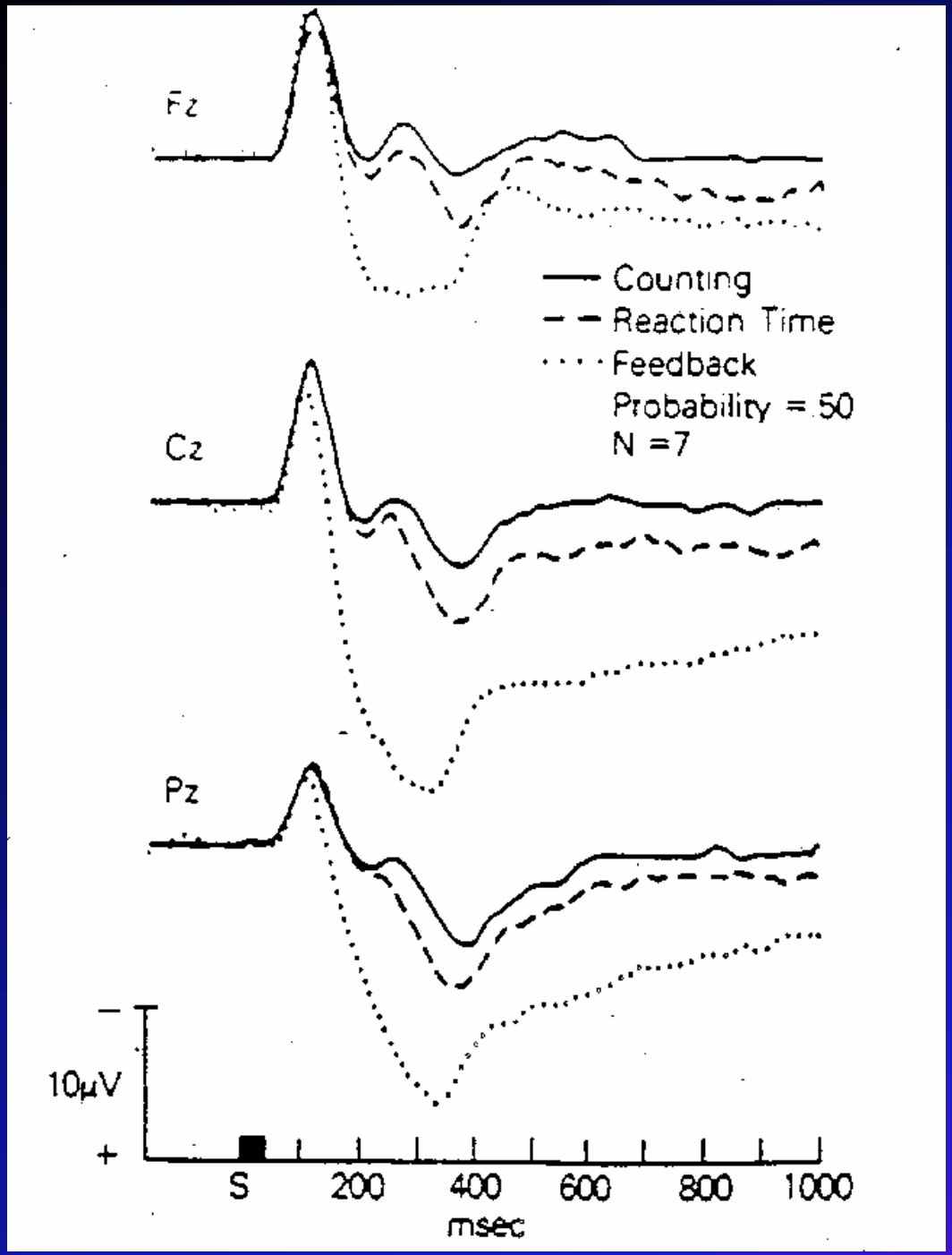
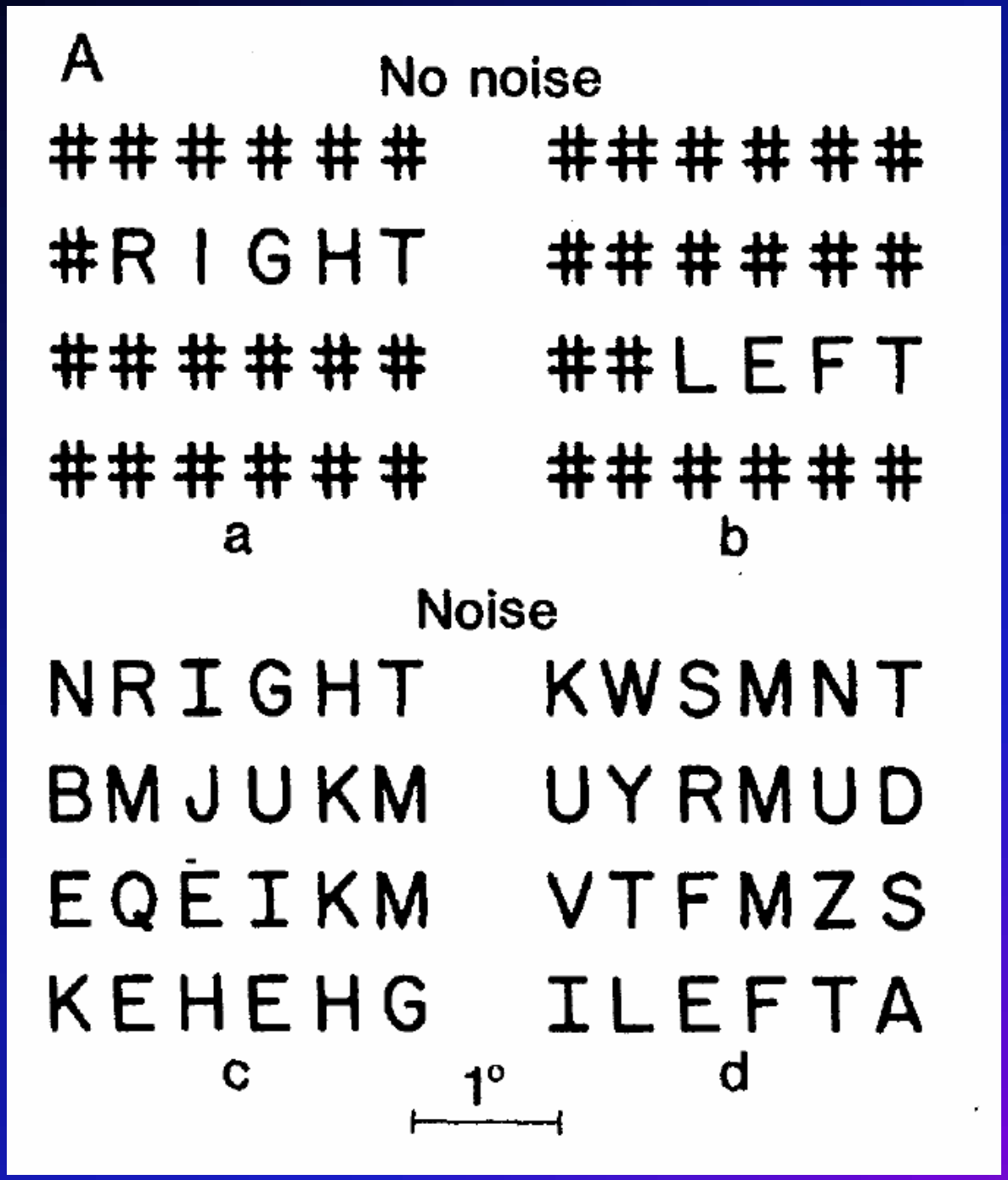
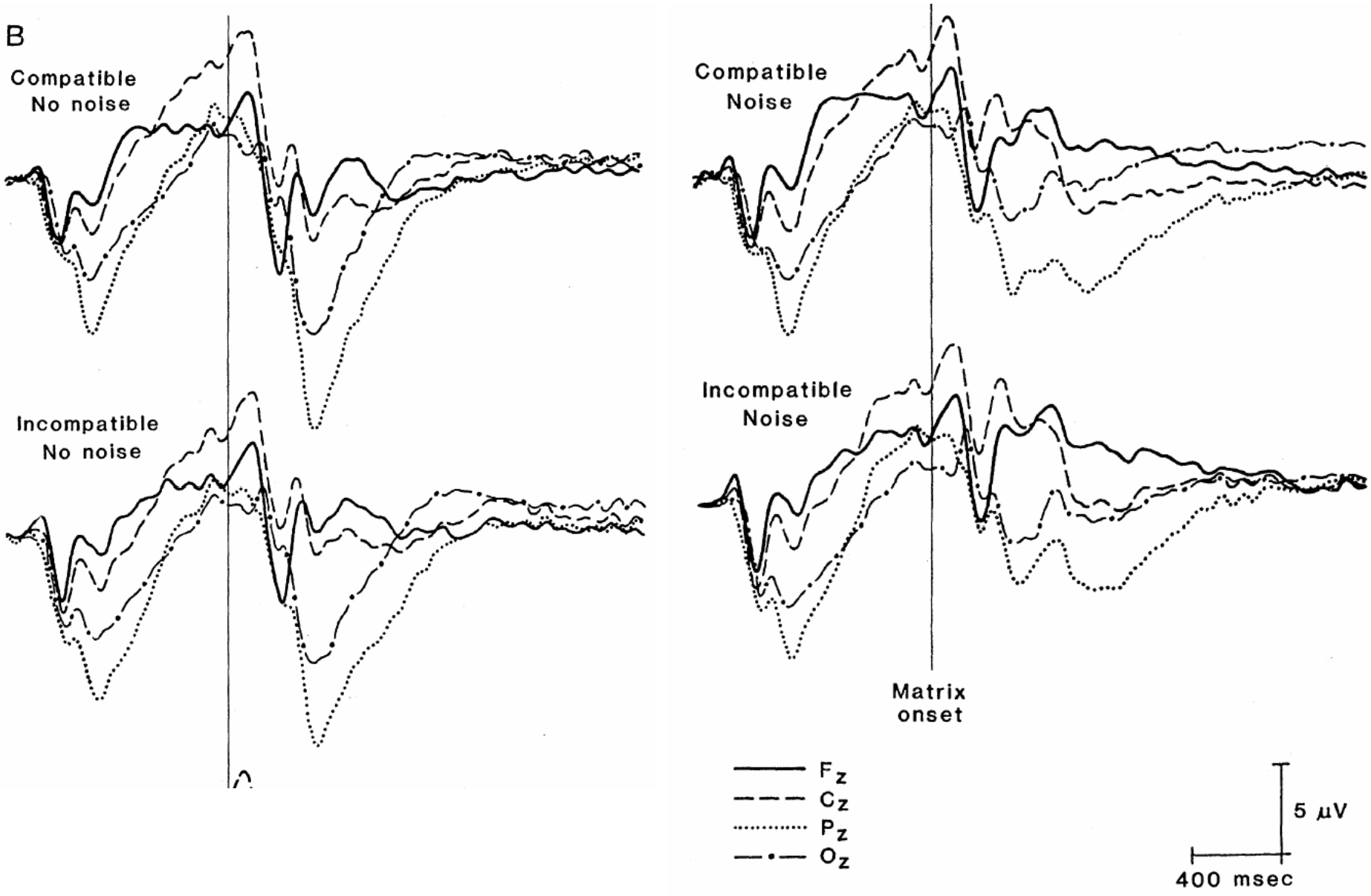


Figure 2. Grand-mean waveforms (N = 7) from F_z, C_z, and P_z from three different tasks. The ERPs elicited in an oddball paradigm run under two different task conditions, Counting (solid line) and Reaction Time (dashed line), are superimposed on the ERP elicited when the same stimulus signified correct performance in a feedback paradigm (dotted line). The waveforms were all elicited by a 1000 Hz, 50dB SL tone ($p = .50$).

P3 Latency

- An index of processing time, independent of response requirements
  - RT measures confounds the two
  - McCarthy & Donchin (1981) experiment:
    - The words "RIGHT" or "LEFT" embedded in a matrix of letters of X's
    - Compatible condition: respond with hand indicated in matrix; Incompatible condition: respond with opposite hand (e.g., LEFT signals right hand response);
    - Results:
      - P300 latency delayed when discriminability more difficult
      - Response compatibility had no effect on P300 latency
      - **Note amplitude reduction as function of noise--information transmission)**


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


B
Compatible
No noise
Incompatible
No noise
Compatible
Noise
Incompatible
Noise
Matrix
onset
Fz
Cz
Pz
Oz
5 μV
400 msec

Construct Validity?

- What, then, does the P300 mean in very general terms?
  - A stimulus (or class of stimuli) is "important"; denotes information that is necessary or useful to the task
  - Stimulus is meaningful, important, noticeable
- The P3a (Squires, Squires, and Hillyard, 1975): P3-like component with a frontal maximum and occurs to improbable stimuli in the "to-be-ignored" class of stimuli; a novelty response.

ERPs and Memory

- Sensitive to both Recognition
  - Likely episodic recollection
- Sensitive to Encoding

Repetition Priming Effects

- Robust effect that repeated items produce an enhanced late positivity across a broad latency range
- Magnitude of effect related to strength of memory trace

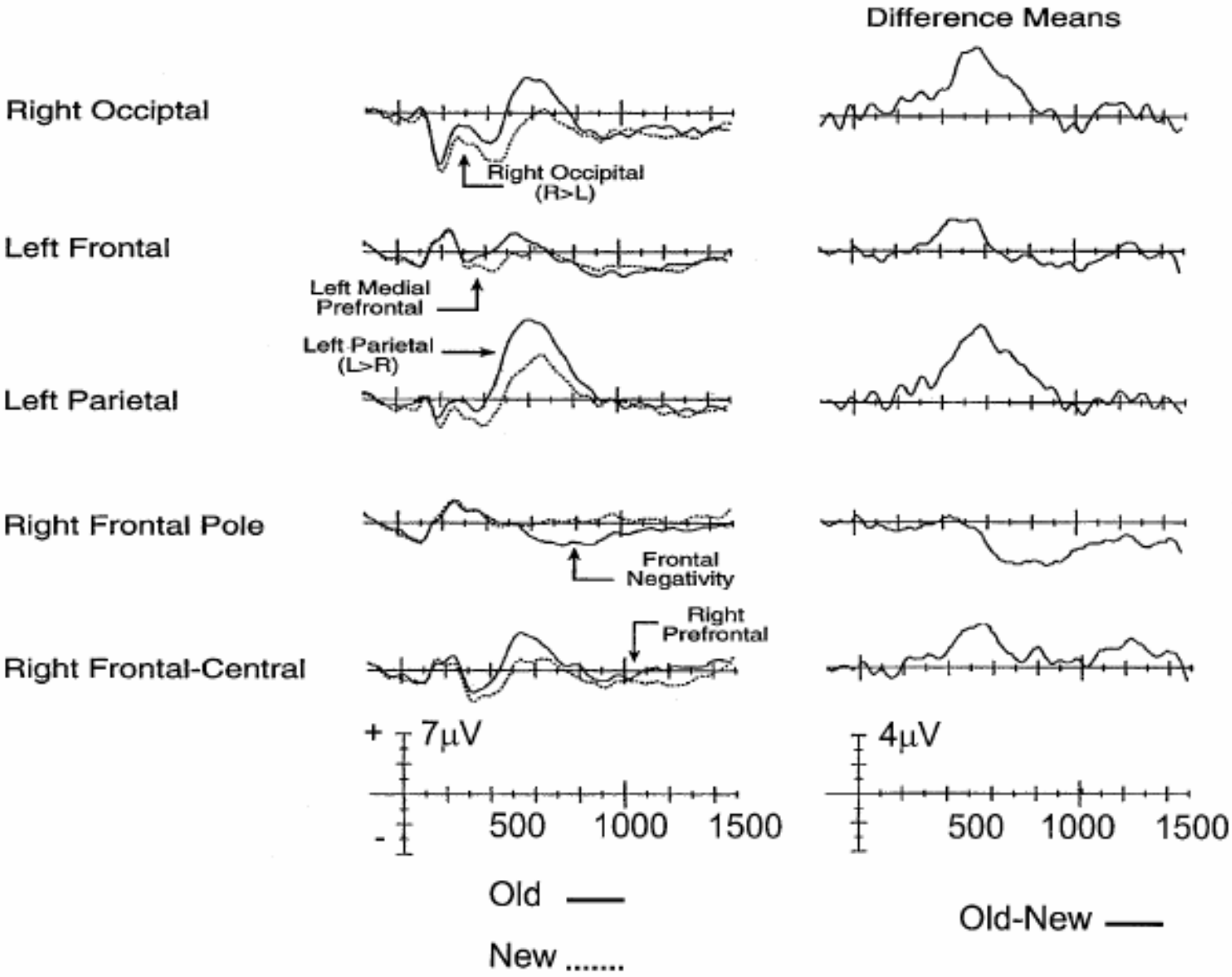
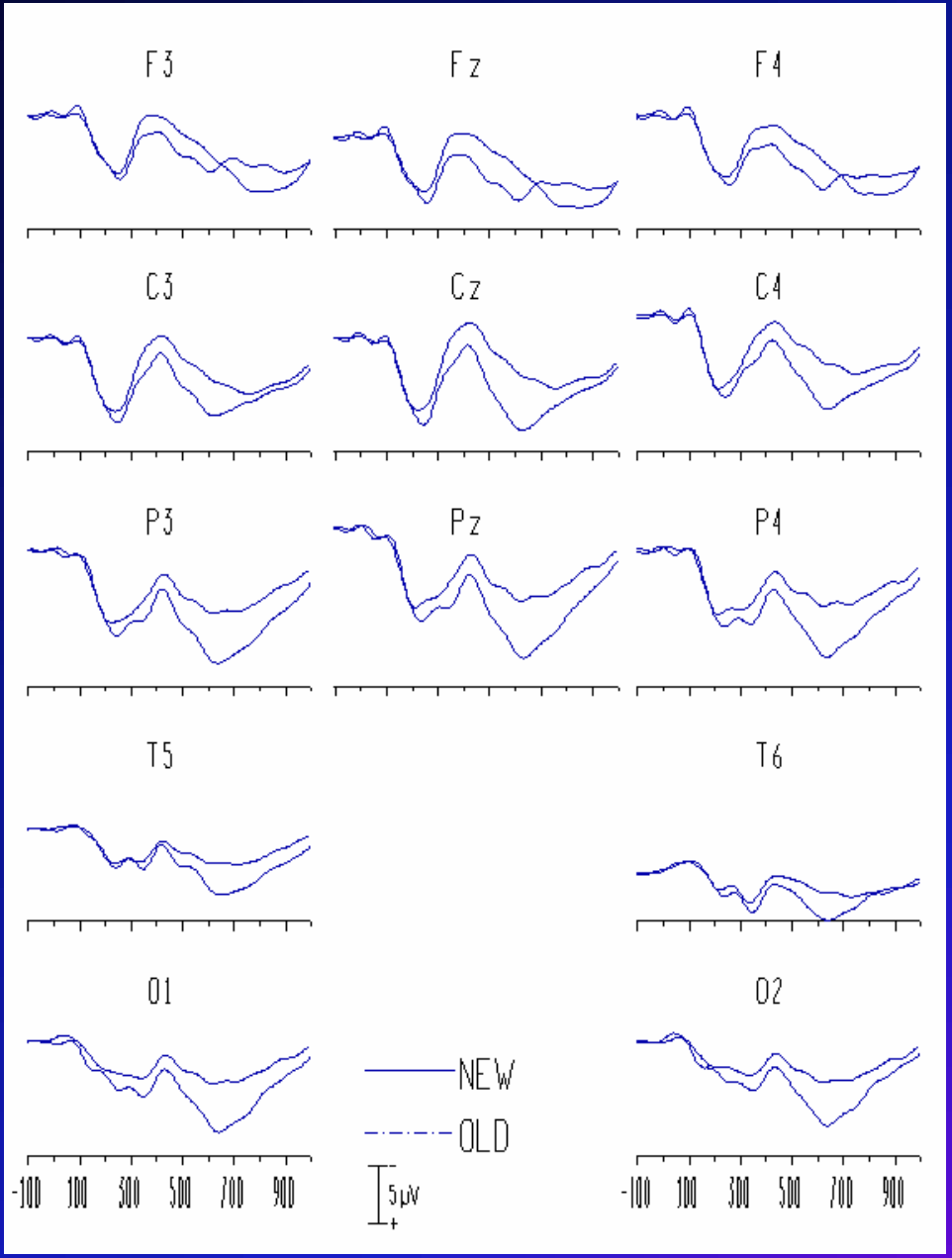
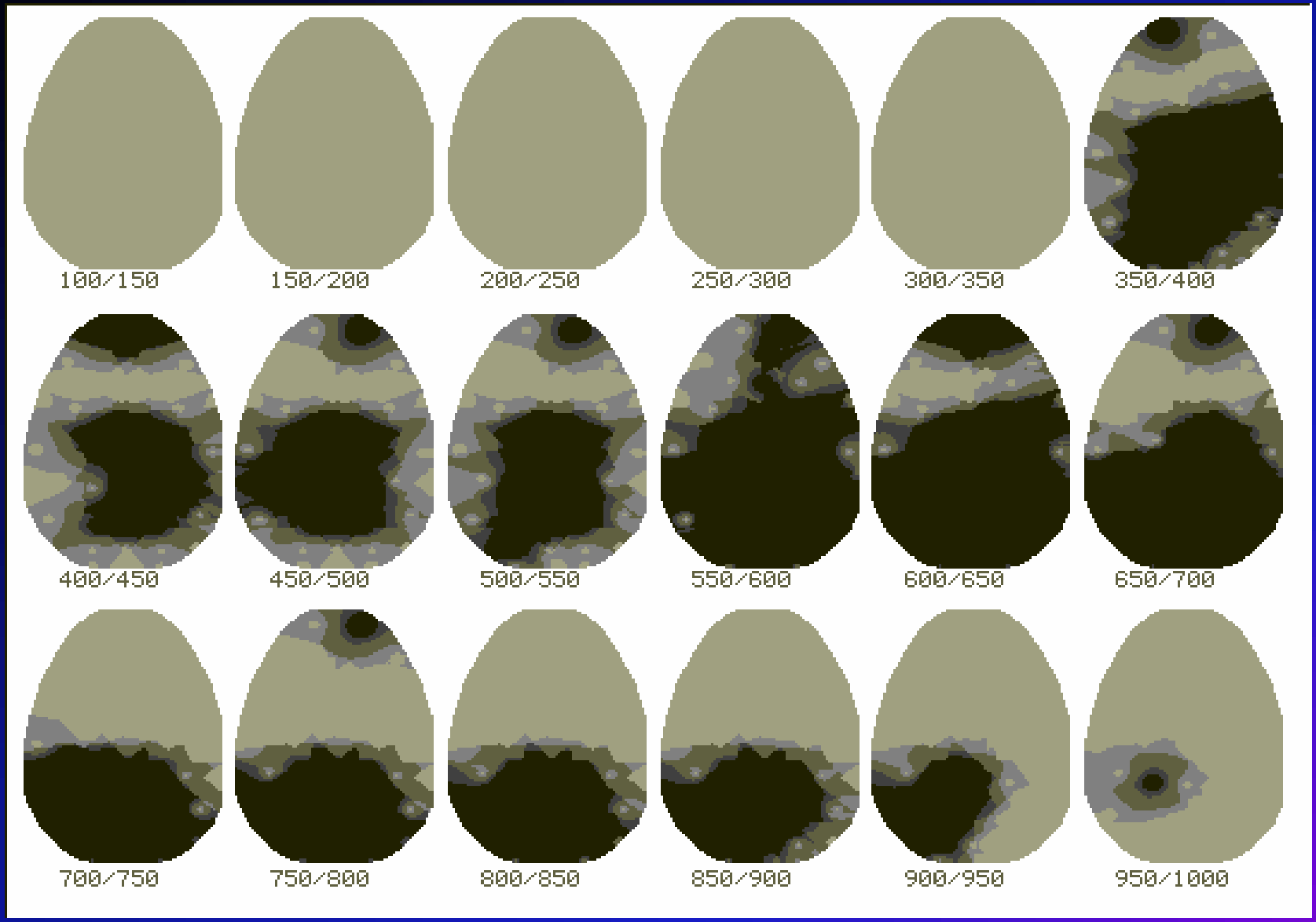


Fig. 4. Grand mean ERP waveforms elicited by correctly recognized old and correctly rejected new items from Johnson et al. (1998a). The left column depicts the old and new waveforms at the electrode site and hemiscalp where that subcomponent was largest. Repoduced from Johnson et al. (1998a) with permission of the publisher.

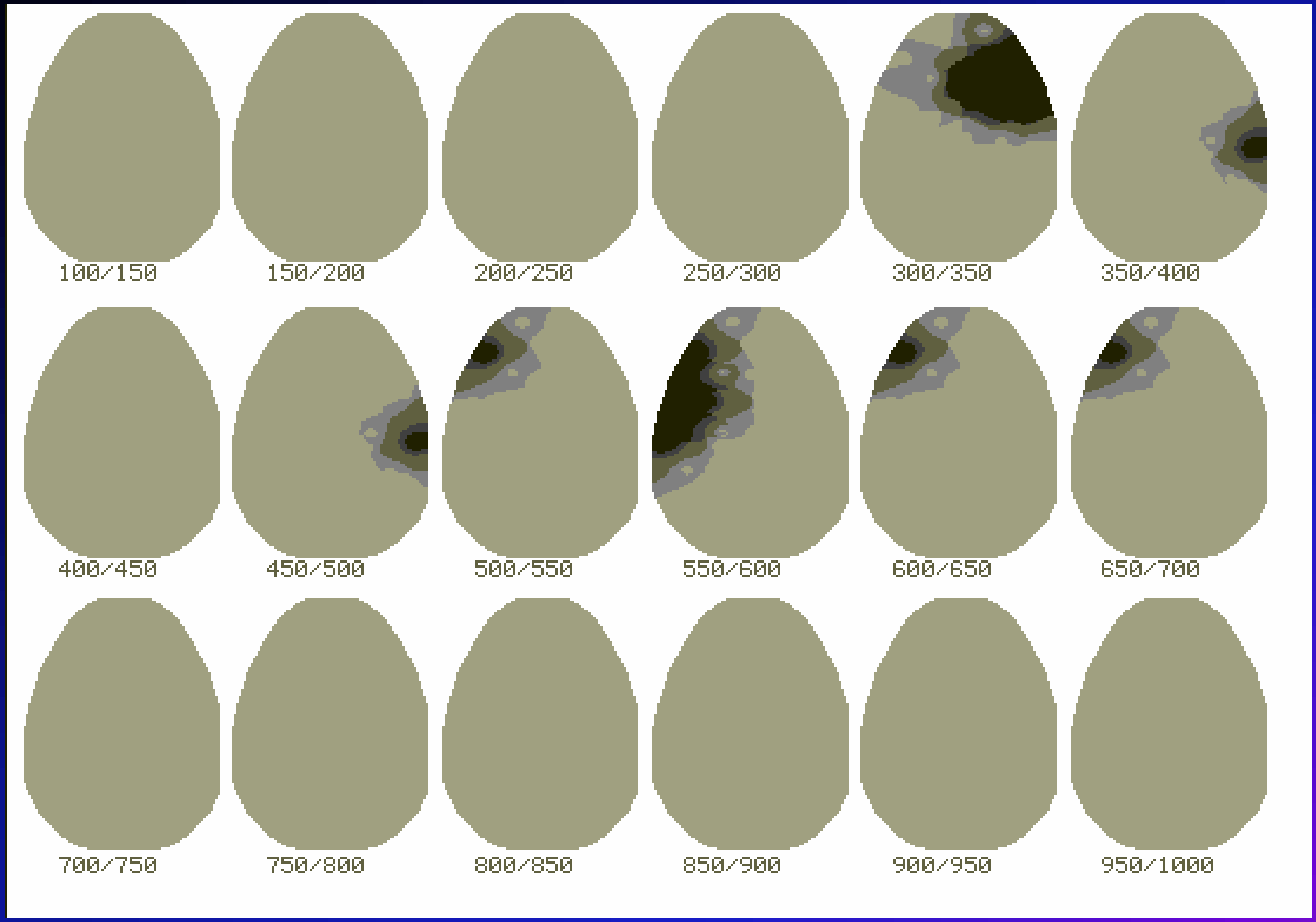
Repetition Priming

- Are there repetition effects that do not depend on the subjective awareness of the subject?
  - Can use Mask Priming to examine (Schnyer, Allen, Forster, 1997)

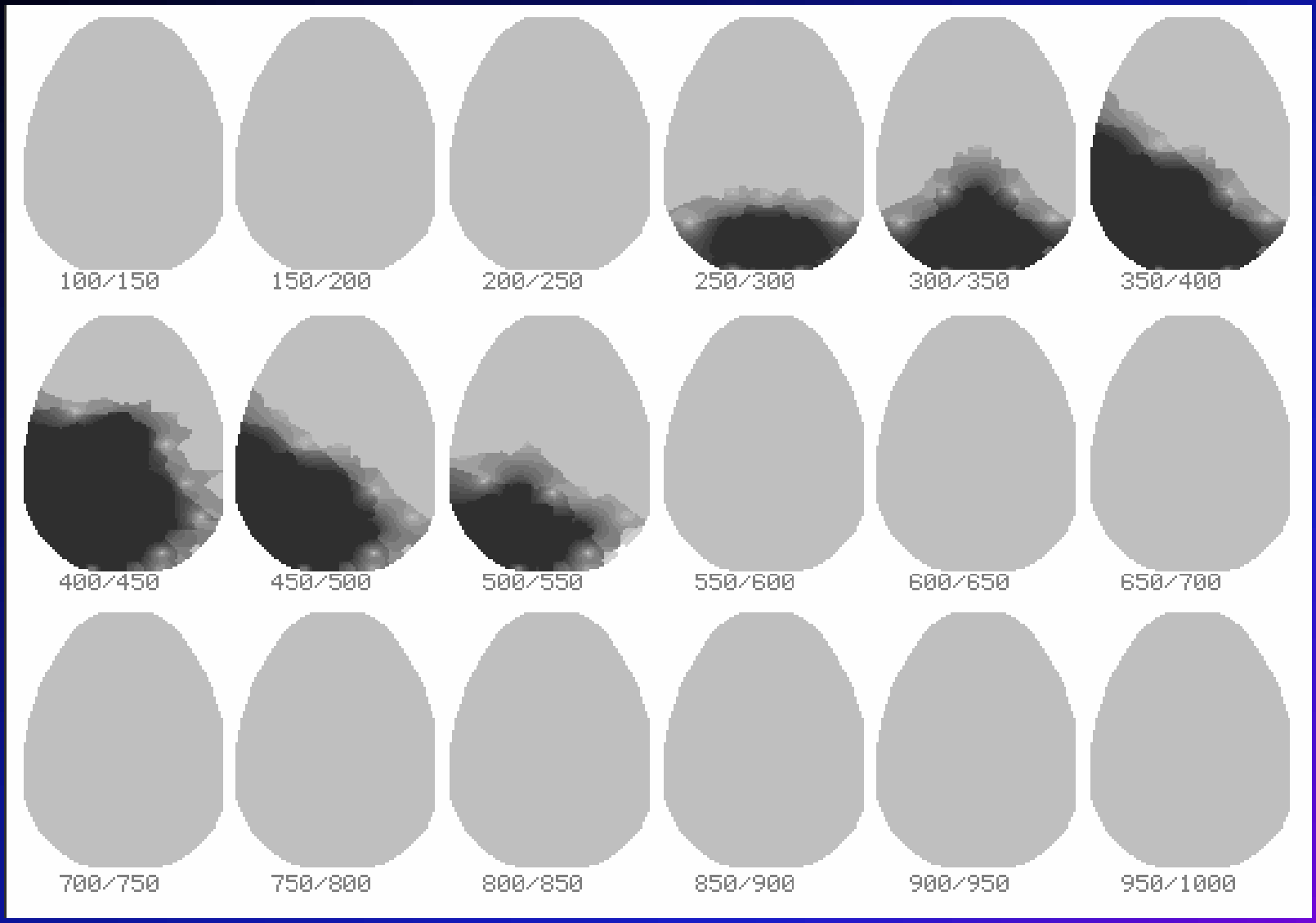

F3
Fz
F4
C3
Cz
C4
P3
Pz
P4
T5
T6
O1
O2
NEW
OLD
5μV
-100
100
300
500
700
900



Standard Repetition Effect for Words Seen Unmasked in Previous Blocks
Task is to make OLD-NEW decision



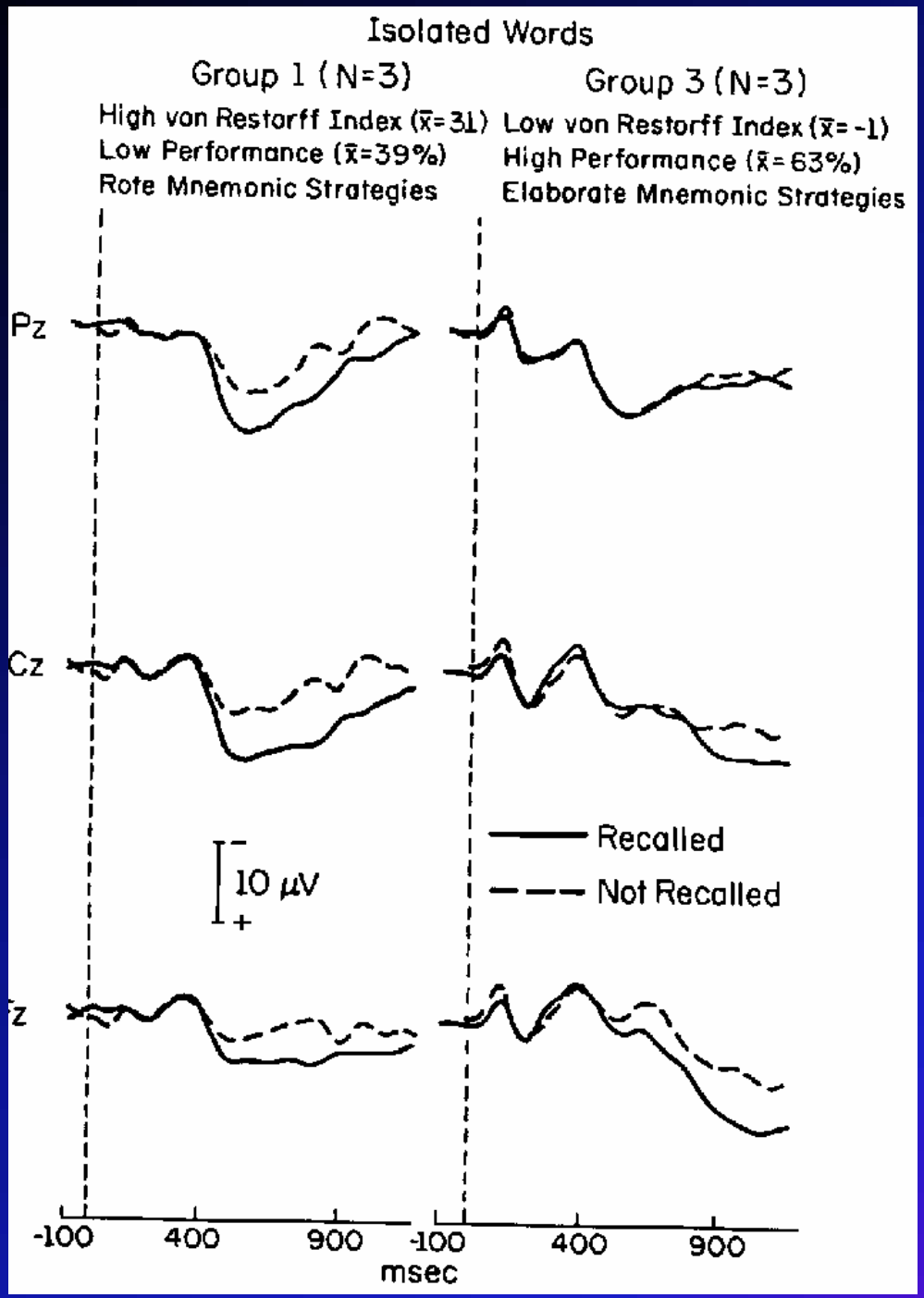
Standard Repetition Effect for Words Seen Unmasked in Previous Blocks
But Task is to make WORD-NONWORD decision



Masked Repetition Priming Effect for Words Presented only a Trial Previously

Memory Encoding

- Words subsequently remembered show enhanced positivity at encoding
- Strategy interacts, however



Note prototypic DM effect on left, but not on right for those that used elaborative strategies. Note enhancement over frontal lead for these latter subjects.

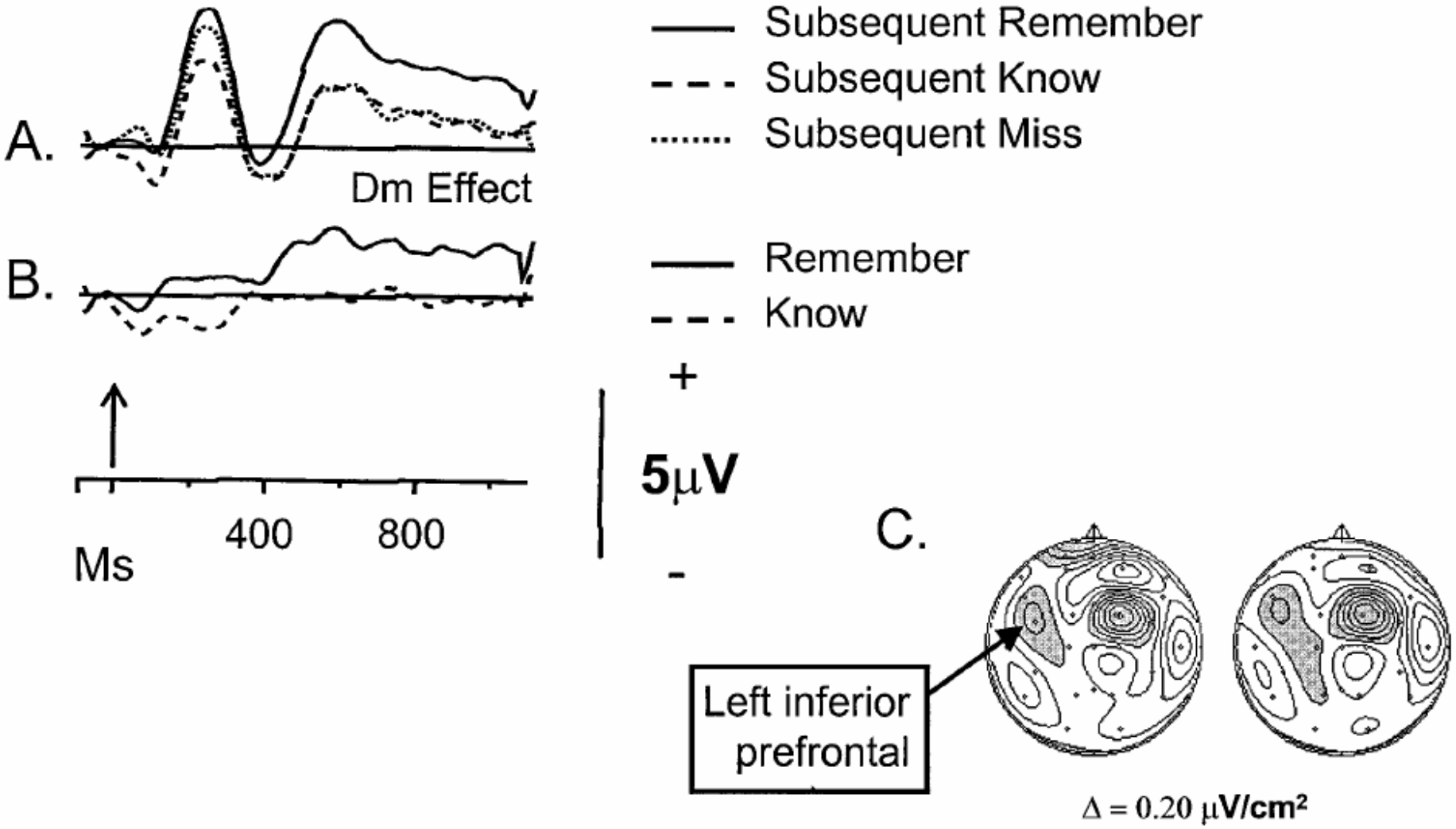


Fig. 3. **A:** Grand mean ERPs elicited by study items that were subsequently associated with remember or know judgments (hits) or were unrecognized (misses) during the subsequent recognition test. **B:** Grand mean difference waveforms computed by subtracting the ERPs to study items subsequently missed from those that were subsequently associated with either a remember or know judgment (Modified from Friedman and Trott, 2000). **C:** CSD maps for 2 intervals (500–800; 810–1,100 ms) measured in the Dm waveform associated with a subsequent Remember judgment. Data in A and B recorded at a left inferior prefrontal scalp site.

Indirect Assessments of Recognition

- Can the ERP detect recognition, independent of subjects' overt responses?
- Two applications
  - Clinical Malingering
  - Forensic Assessment

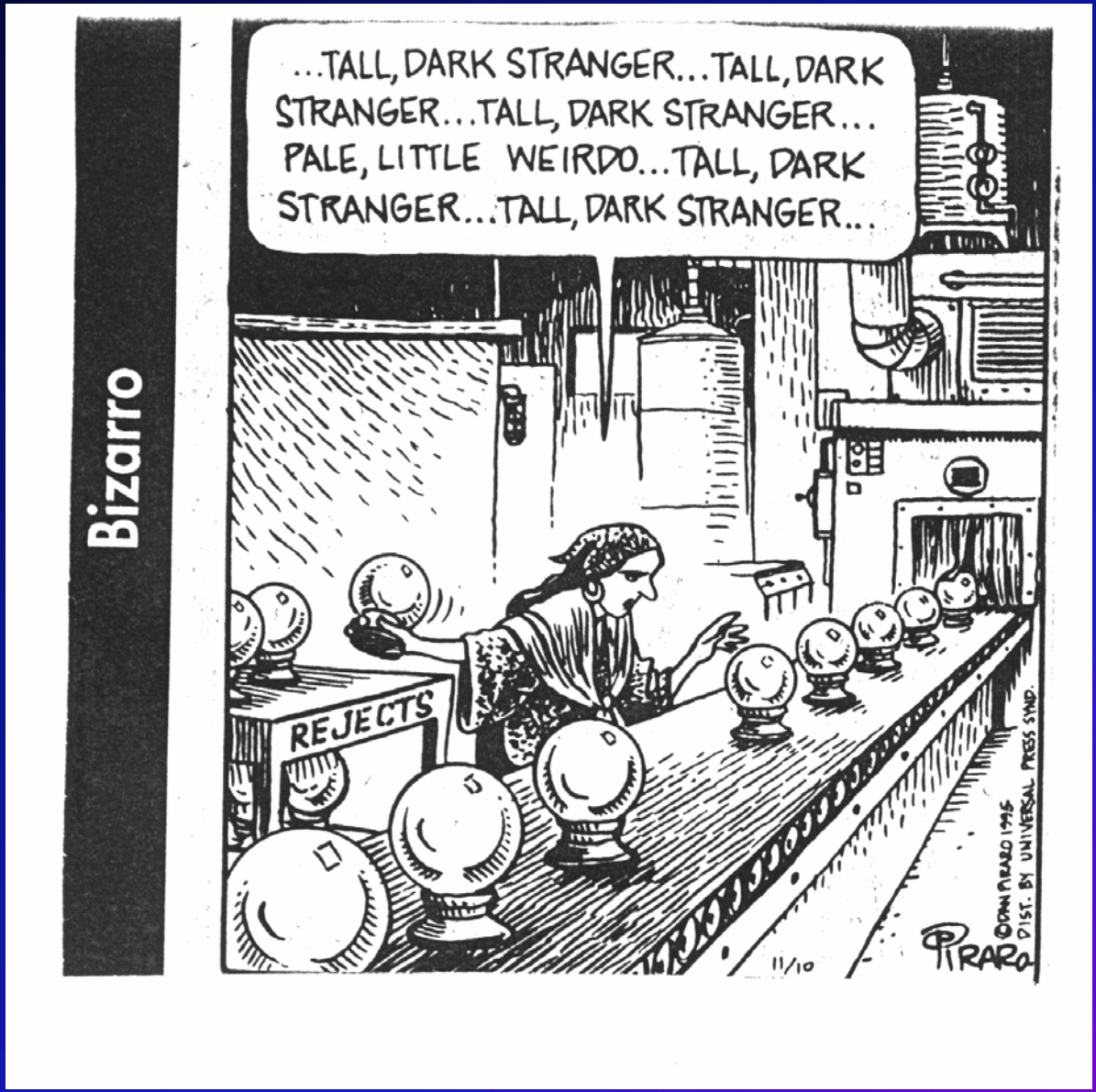
ERP Memory Assessment Procedures

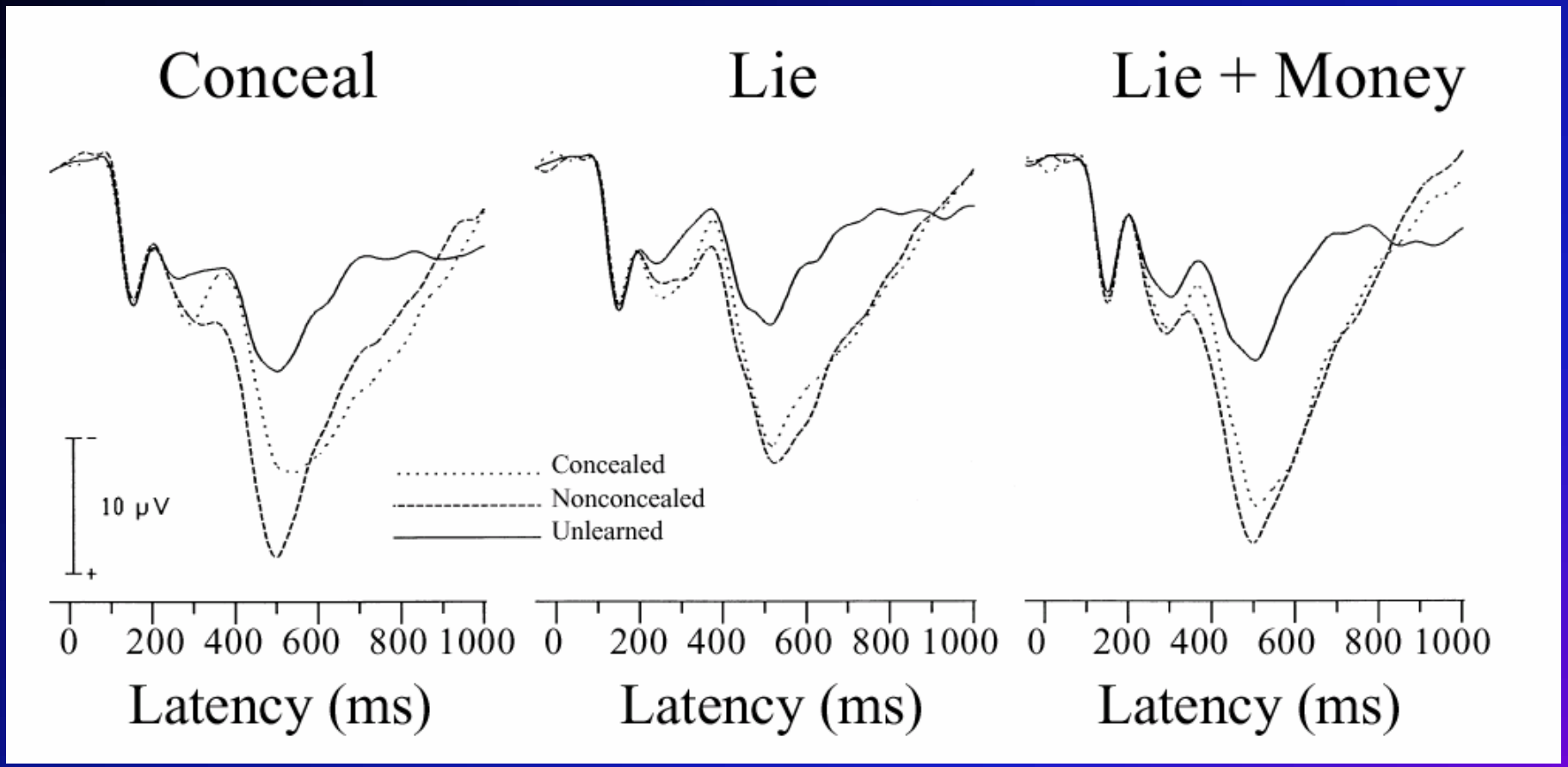
- Learn a list of words
- Learn a second list of words
- Task: Concealed (1st list) and Nonconcealed (2nd list) words appear infrequently

Item Type	Probability	Response	P3 Amplitude
Nonconcealed	1/7	"Yes"	Large
Concealed	1/7	"No"	Large if Recognized Small if not Recognized
Unlearned	5/7	"No"	Small

- Similar to procedures by Rosenfeld et al, Farwell & Donchin

The Classic Oddball Experiment





After Allen & Iacono, 1997

Brain Fingerprinting:
A New Paradigm in Criminal Investigations and Counterterrorism

Executive Summary

Farwell Brain Fingerprinting is a revolutionary new technology for investigating crimes and exonerating innocent suspects, with a record of 100% accuracy in research on FBI agents, research with US government agencies, and field applications.

The technology is proprietary and patented. Brain Fingerprinting fulfills an urgent need for government, law enforcement agencies, corporations, and individuals. Over a trillion dollars are spent annually on crime fighting worldwide.

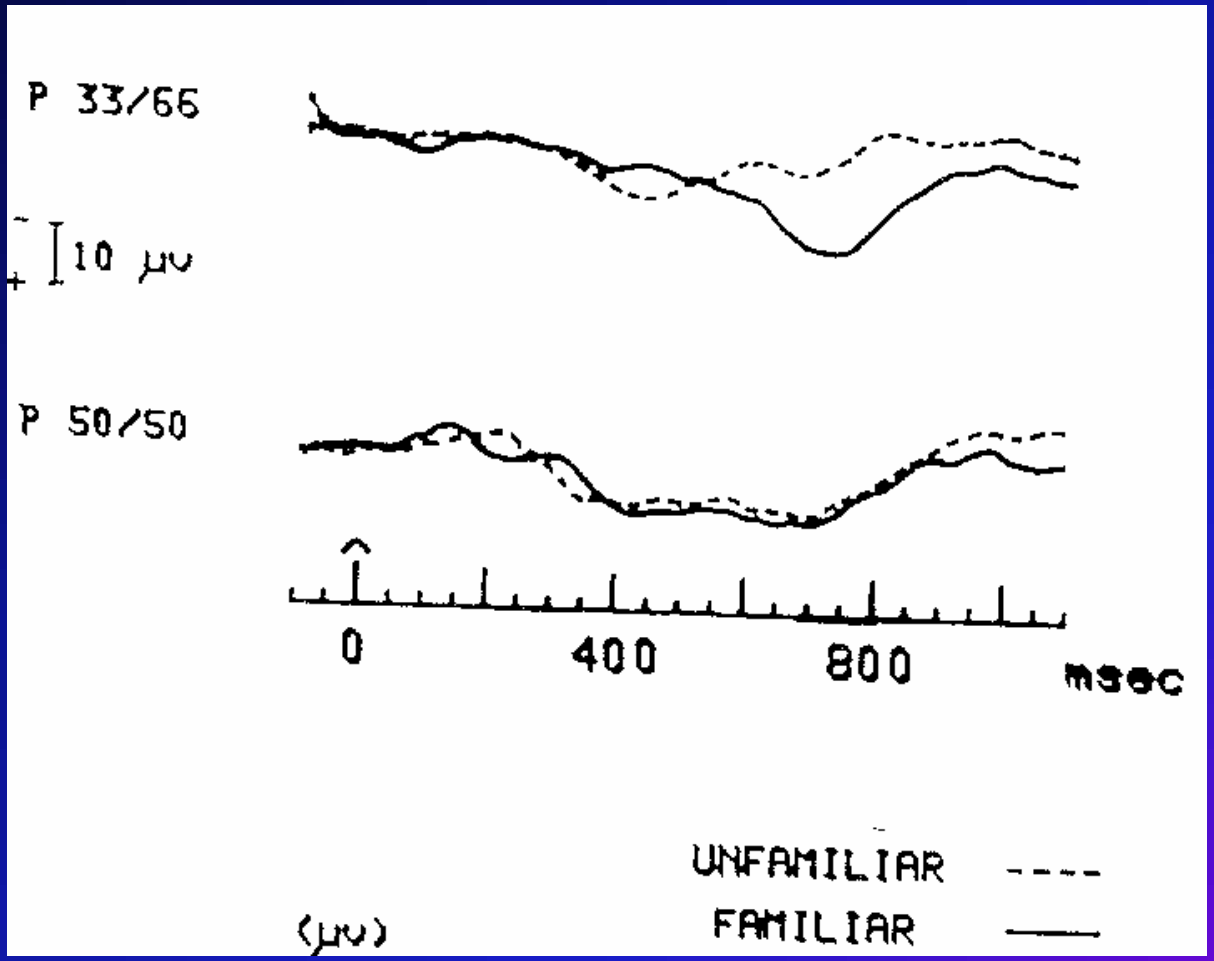
Brain Fingerprinting solves the central problem by determining scientifically whether a suspect has the details of a crime stored in his brain. It has received extensive media coverage around the world. The technology is fully developed and available for application.

Brain Fingerprinting is a powerful tool for the investigation of suspected terrorists. Measuring the brain wave activity while suspects are shown words or pictures related to specifics of the September 11, 2001 attacks can help determine if they are members of terrorist cells. Brain Fingerprinting can identify trained terrorists before they strike

Larry Farwell, PhD

Chairman & Chief Scientist
Brain Wave Science
Human Brain Research Laboratory, Inc.

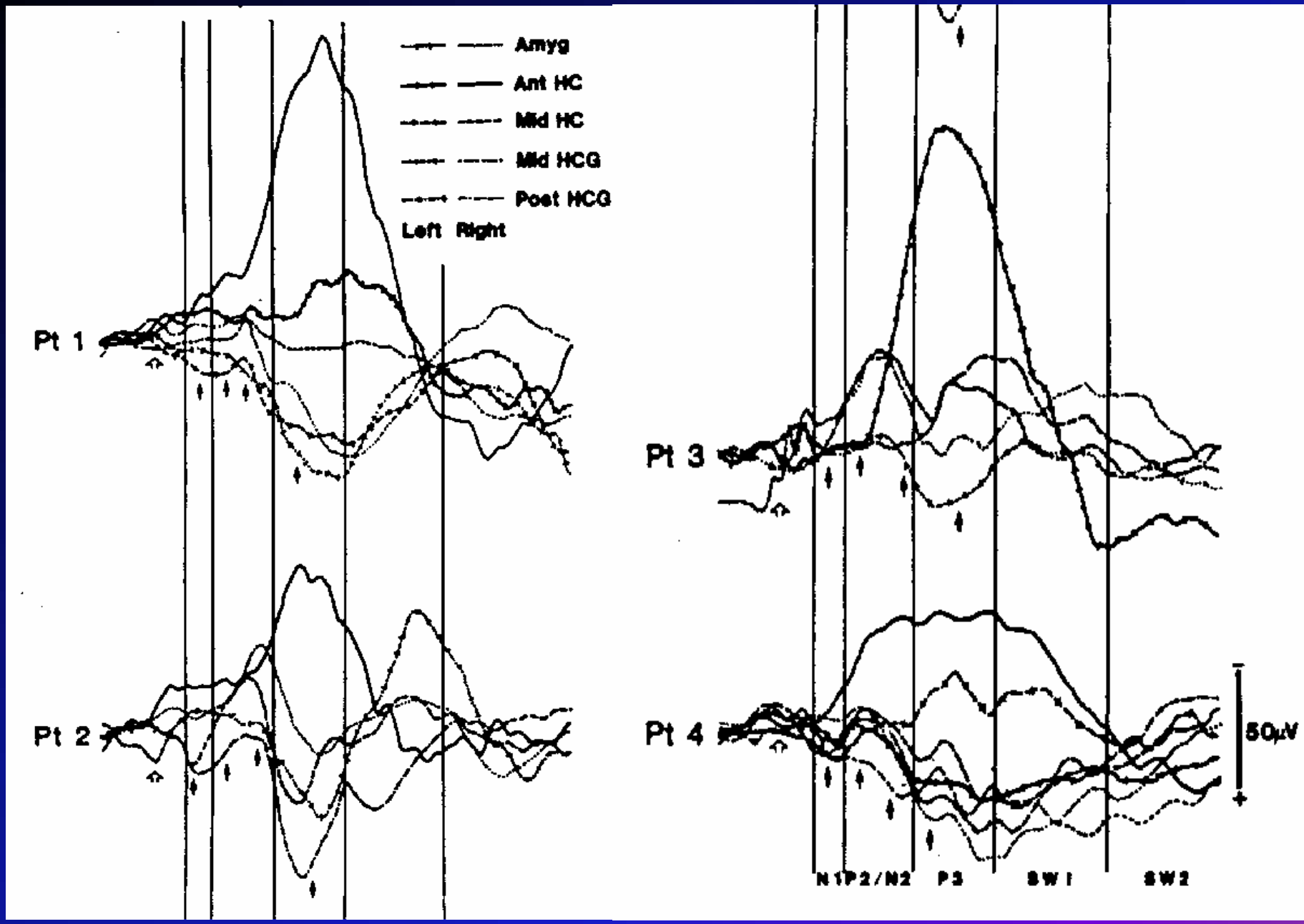
Assessing Recognition in Prosopagnosia



Renault et al.

Sources of P3

- Likely distributed
- Candidates found in:
  - bilaterally in the anterior superior temporal gyrus
  - inferior and middle frontal gyrus
  - inferior and superior parietal lobules
  - anterior and posterior cingulate
  - thalamus
  - Caudate
  - Amygdala/hippocampal complex
  - Insula
  - Among others!


Amyg
Ant HC
Mid HC
Mid HCG
Post HCG
Left Right
Pt 1
Pt 2
Pt 3
Pt 4
50μV
N1P2/N2
P3
SW1
SW2

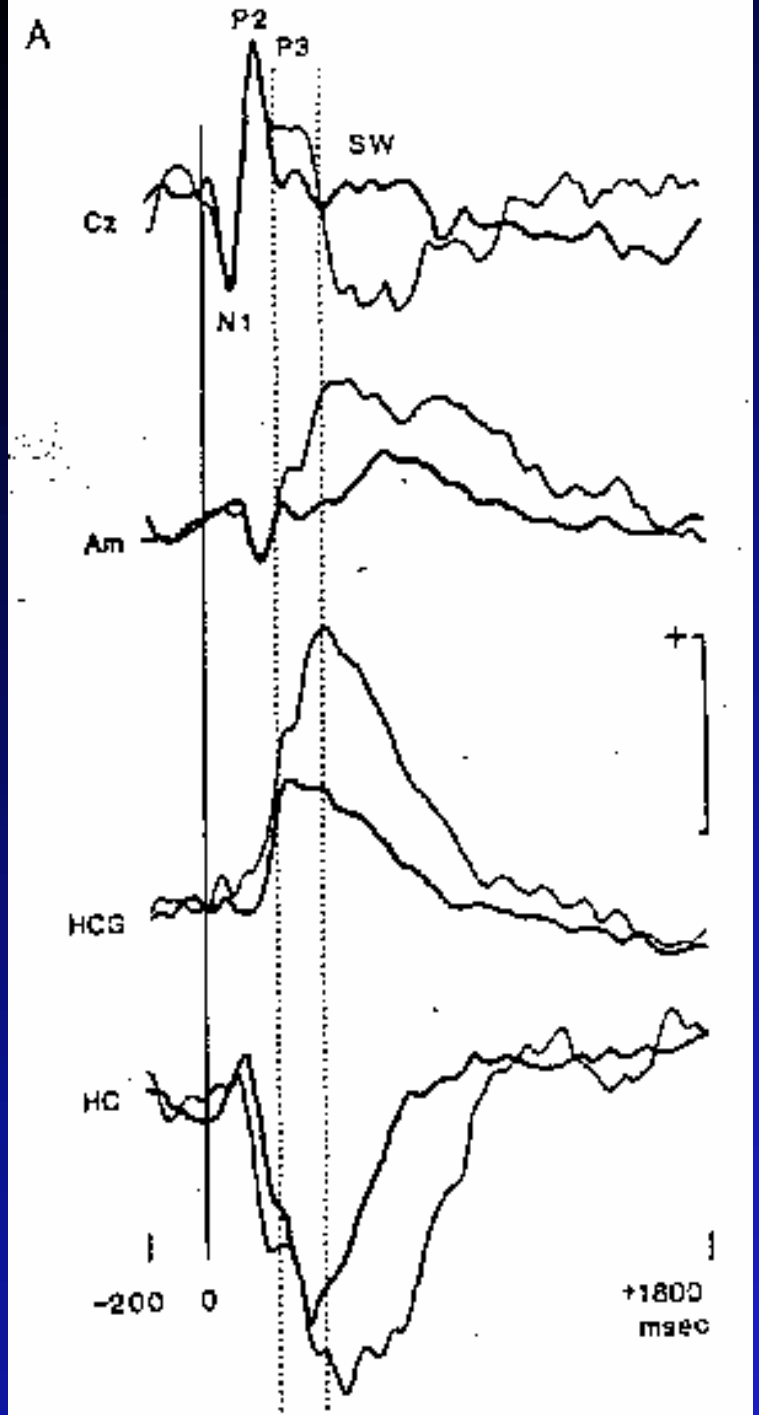
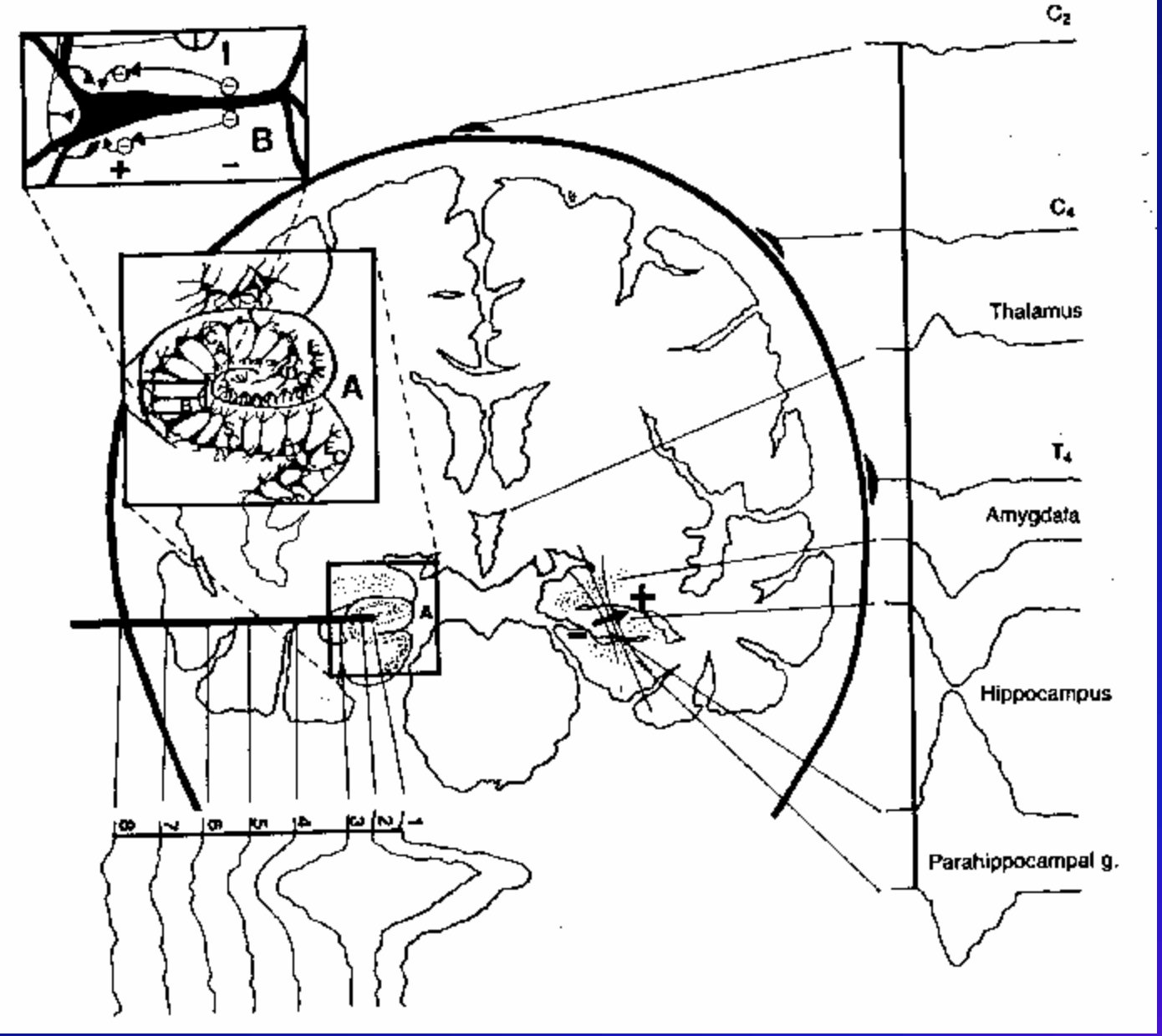


Fig. 1 (left). (A) Characteristic potentials evoked in limbic sites during an auditory paradigm (*3*). The largest negative potential was recorded in the hippocampus (*HC*) after rare tone bursts. Phase reversal occurred 9 mm posteromedial in the hippocampal gyrus (*HCG*) and 26 mm anterior in the amygdala (*Am*). The vertical dotted lines, 265 and 430 msec after stimulus onset, indicate the approximate onsets of the P3 and slow wave (*SW*) at the vertex (*Cz*). In all graphs, the thin lines represent the average of 35 to 45 responses evoked by rare stimuli, and the thick lines the averages to 155 to 165 frequent stimuli (*15*). Scale: 100 μV depth; 25 μV scalp.



Note polarity reversal as enter and exit the hippocampus

Yet hippocampus not likely to be a major contributor to surface-recorded P3

Polich and Squires (1993) find P3 in patients with bilateral hippocampal lesions!

Distributed sources likely

How Many P3s?

- The Classic P3/P300
  - Parietal Central Maximum
  - Largest when stimuli rare and task-relevant
- The P3a (Squires et al., 1975) or Novelty P3 (Courchesne et al., 1975)
  - More anterior scalp distribution
  - Slightly earlier latency
  - Responsive to rare, unexpected, unattended stimuli

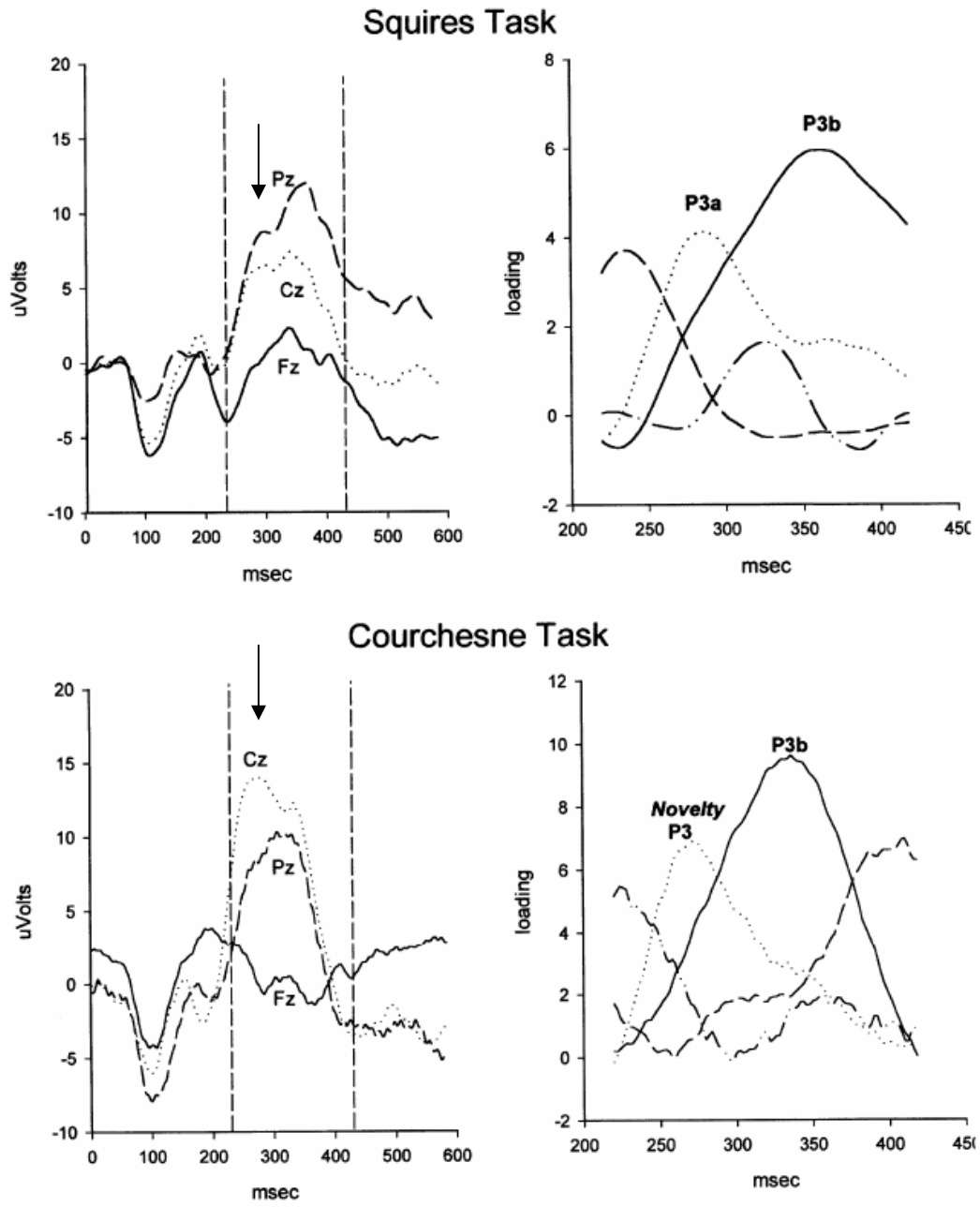


Fig. 1. ERP waveforms (left) and PCA basis waves (right) obtained from infrequent targets during the Squires (top) task and infrequent nontargets/novels during the Courchesne (bottom) task. PCA was conducted during the 220–420 ms epoch following stimulus onset and four factors were extracted from each data set.

Simons et. al, 2001

- Squires Task was tones (two tones)
- Courchesne task was digitized speech (“me” “you” and collection of naturally occurring sounds
- In all cases subjects merely counted Tones

P3a – Can you see it?

- Some inconsistencies in finding P3a following the initial Squires, Squires and Hilyard 1975 report
- Comerchero & Polich (1998) may have resolved the enigma
  - P3a highly dependent on foreground discrimination

Table 1
Stimulus type (probability) for each task condition and modality (auditory = frequency and intensity, visual = area and shape-color)

Modality	Auditory		Visual	
Nontarget distinctiveness	Low	High	Low	High
Target (0.10)	2000 Hz	2000 Hz	12.57 cm^2	12.57 cm^2
	75 dB	75 dB	● Blue	● Blue
Standard (0.80)	1940 Hz	1940 Hz	10.18 cm^2	10.18 cm^2
	75 dB	75 dB	● Blue	● Blue
Nontarget (0.10)	500 Hz	4000 Hz	12.57 cm^2	12.57 cm^2
	75 dB	90 dB	■ Blue	■ Fuchsia

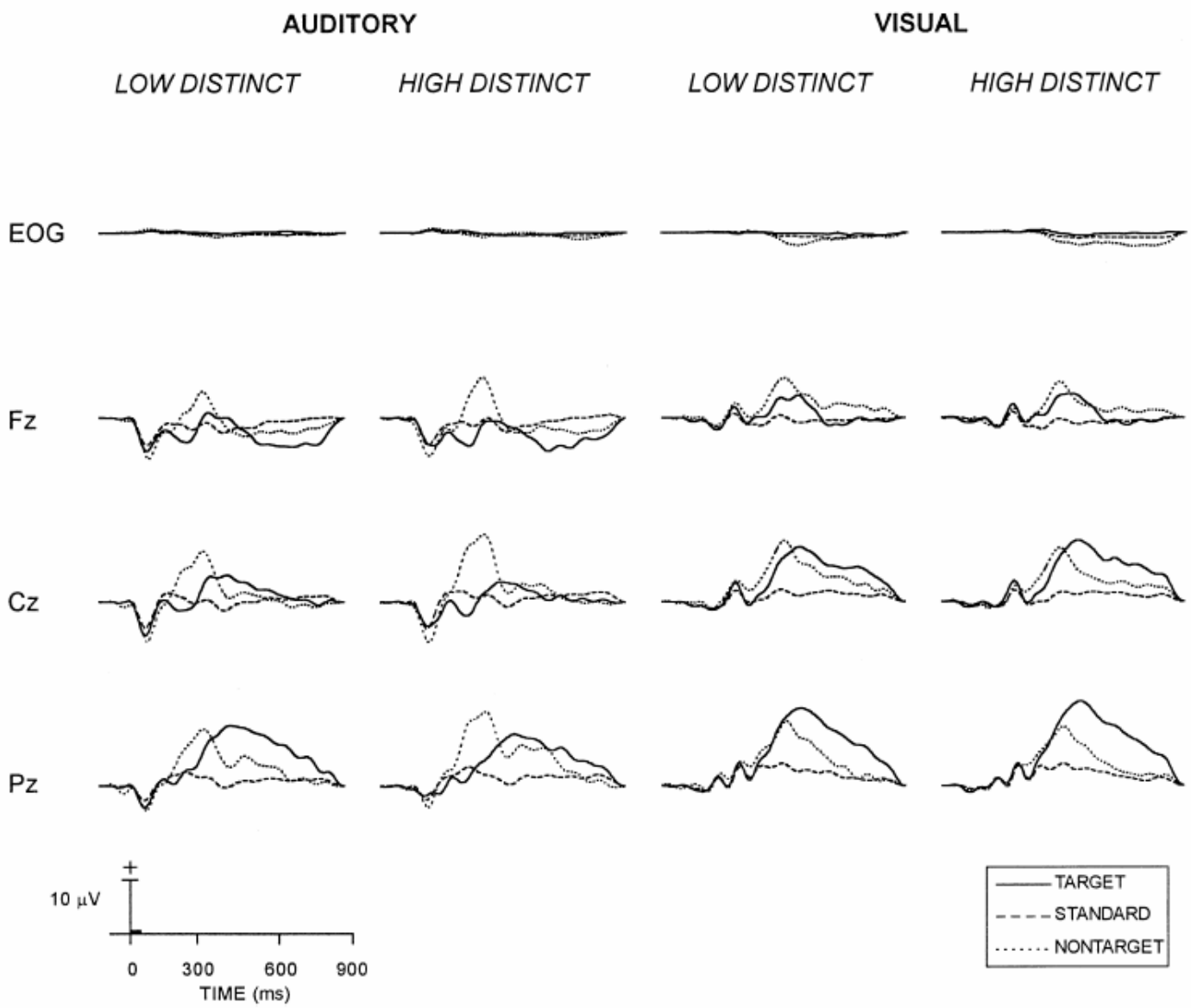


Fig. 1. Grand averaged ERPs for each stimulus type, auditory and visual modalities, distinctiveness condition, and recording site ($n = 16$).

Note: Nontarget peak amplitude was earlier and larger at the frontal electrodes than those from the target stimuli for both auditory and visual stimuli. In the High distinct conditions, same pattern and auditory nontarget stimuli elicited a P300 P3a that was appreciably larger than the target P300 P3b over all sites.

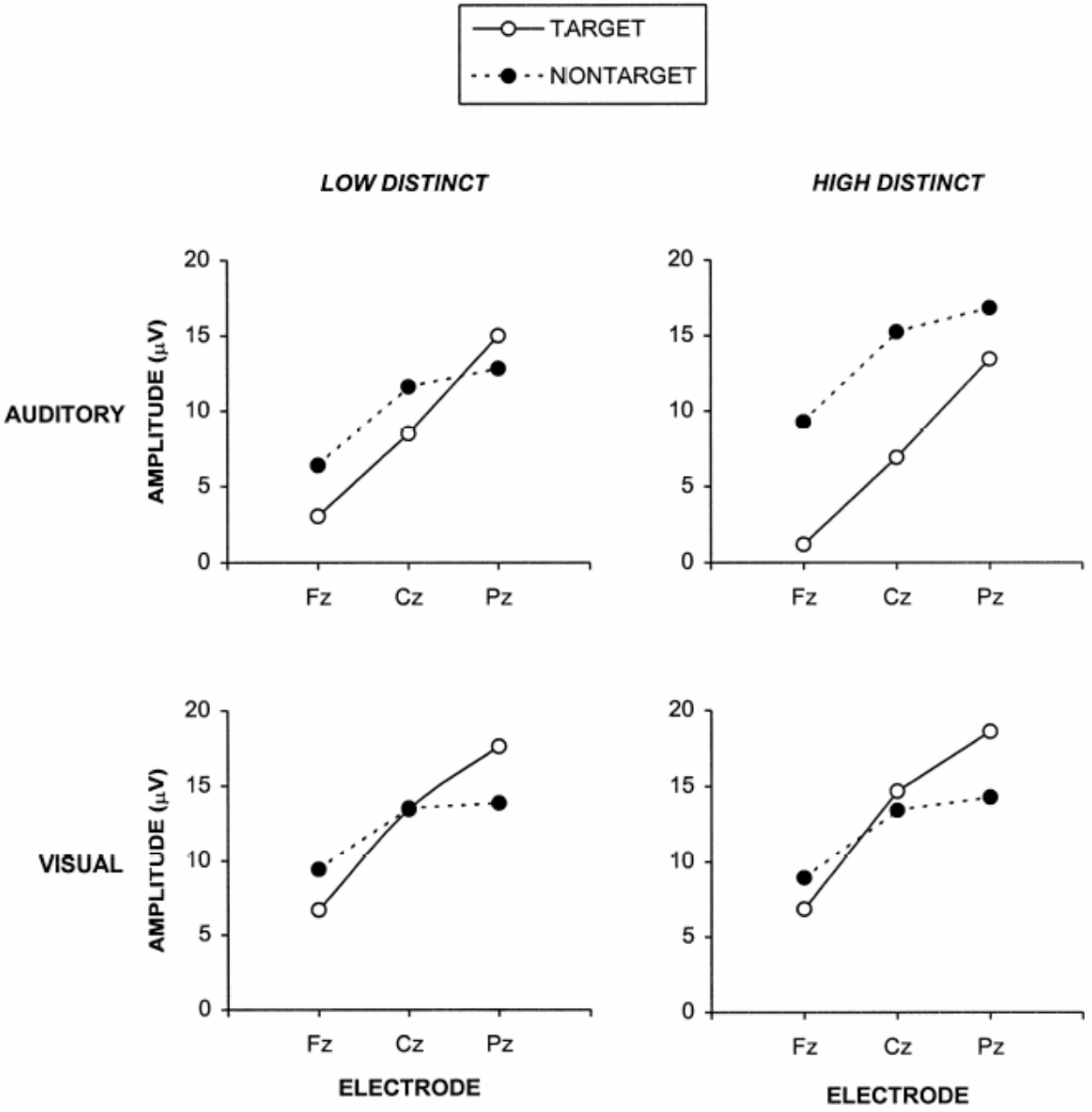


Fig. 2. Mean P300 amplitude from the target and nontarget stimuli for each modality and distinctiveness condition as a function of midline electrode site.

Synopsis

"…the manipulation of target-standard stimulus discriminability produced a stimulus environment in which the infrequently occurring nontarget engaged focal attention in a manner similar to that observed previously for 'novel' stimuli.

However, all stimuli in the present study were employed because of their 'typical' characteristics, so that the results imply that an anterior P3a component can be produced without using 'novel' stimuli per se.

If stimulus context is defined primarily by a difficult targetrstandard discrimination, attentional redirection to the nontarget would occur because of the frontal lobe activation that generates P3a."

Comerchero & Polich 1998, p. 47

ERPS and Affective Processing

- IAPS = International Affective Picture System
  - Pleasant, Neutral, Unpleasant
  - Vary in Arousal: Pleasant and Unpleasant tend to be more arousing
- Predict more significant stimuli produce larger P3

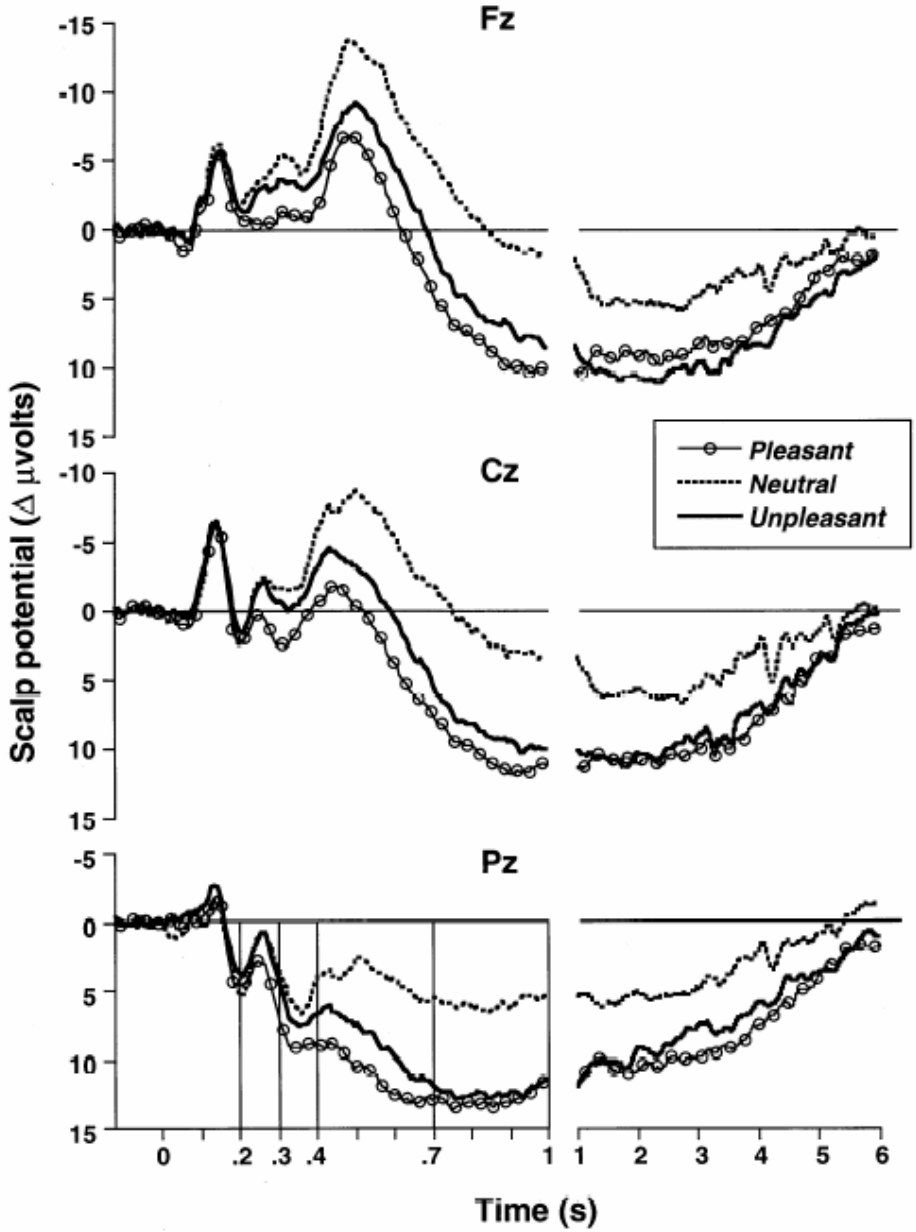


Fig. 1. Stimulus synchronized grand average ERP waveforms for Fz, Cz, and Pz electrodes during viewing of affective pictures, separately for each valence category (pleasant, neutral and unpleasant). The left panel illustrates the picture onset potentials on a finer time scale, and the vertical lines at Pz illustrate the time areas subjected to statistical analysis (i.e. 200–300, 300–400, 400–700, 700–1000 ms). The right panel shows the subsequent 5 s of slow potential change.

Long (6 sec)
Presentation Duration

Schupp et al (2000),
Psychophysiology

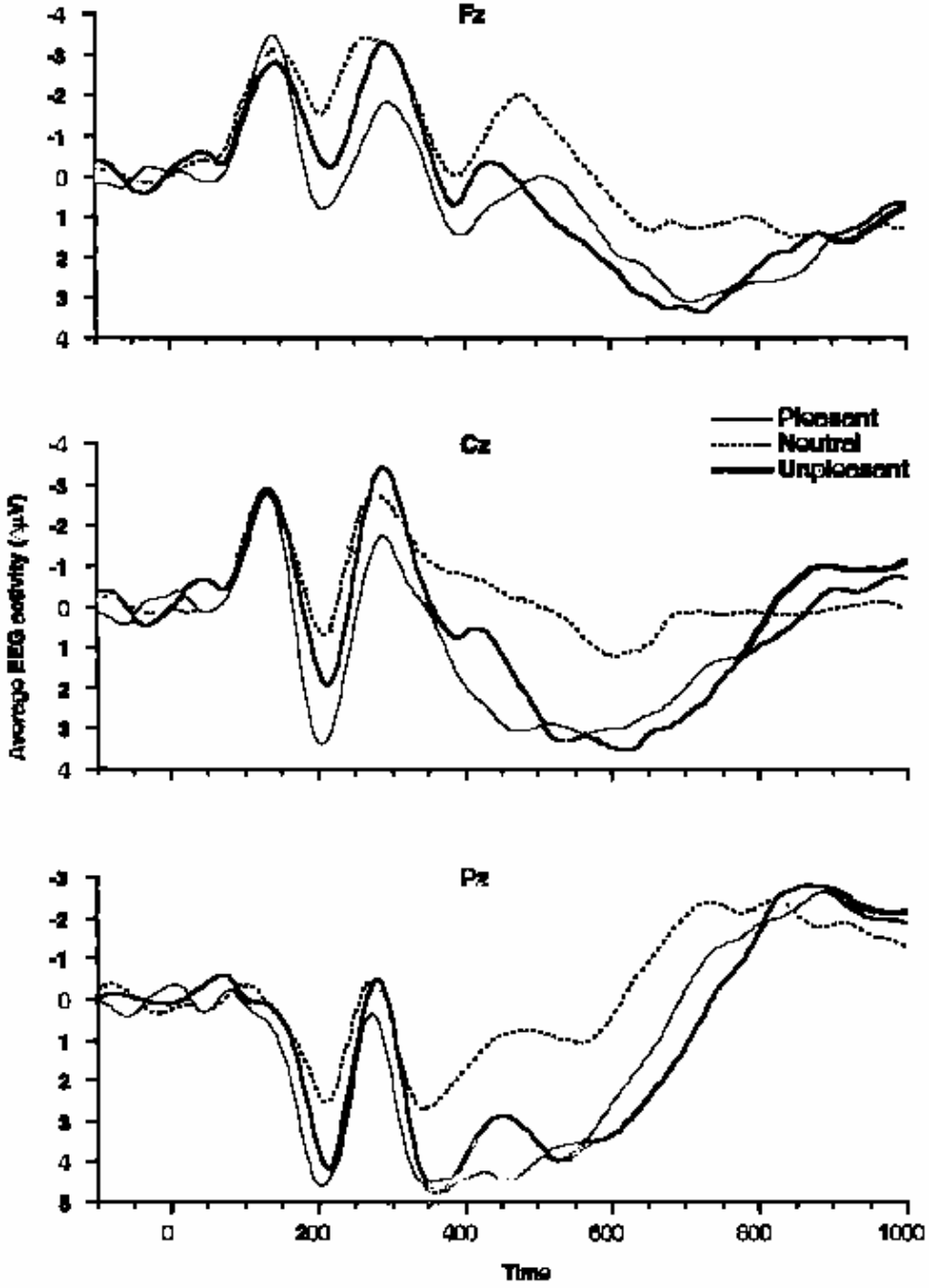
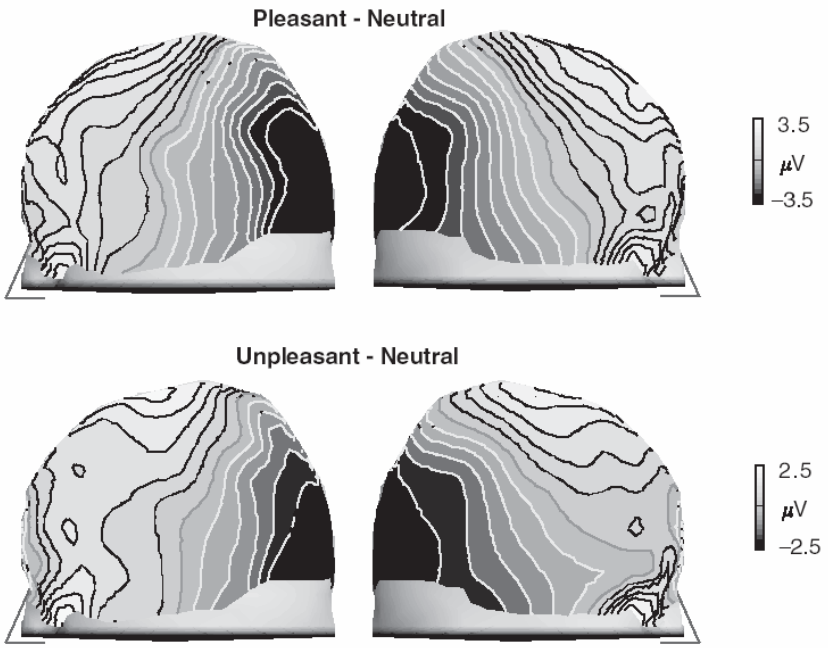


Figure 1. Picture onset synchronized grand-average event-related potential (ERP) waveforms for each valence category (pleasant, neutral, and unpleasant) from midline electrodes Fz, Cz, and Pz.

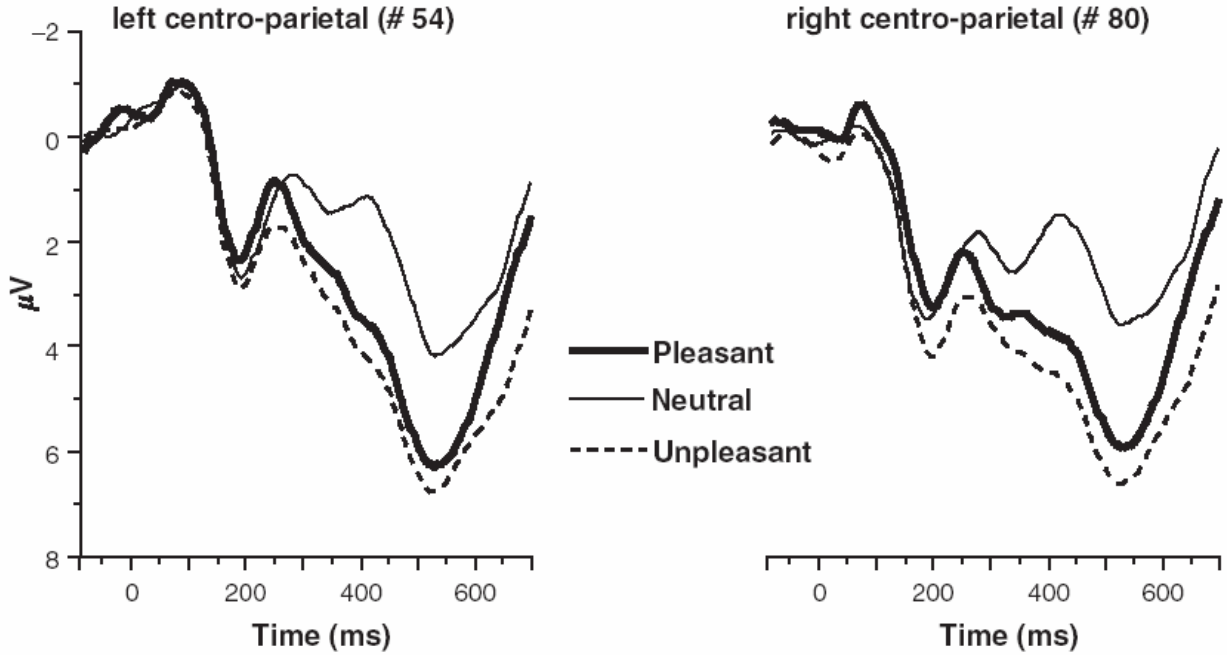
1.5 sec Presentation Duration

Cuthbert et al (2000), *Biological Psychology*



120 msec Presentation Duration

Schupp et al (in press), *Psychophysiology*



ERPS and Implicit Affective Processing

- Ito & Cacioppo (2000) *JESP*
  - Evaluative Processing (positive vs negative)
  - Nonevaluative (people vs no-people)

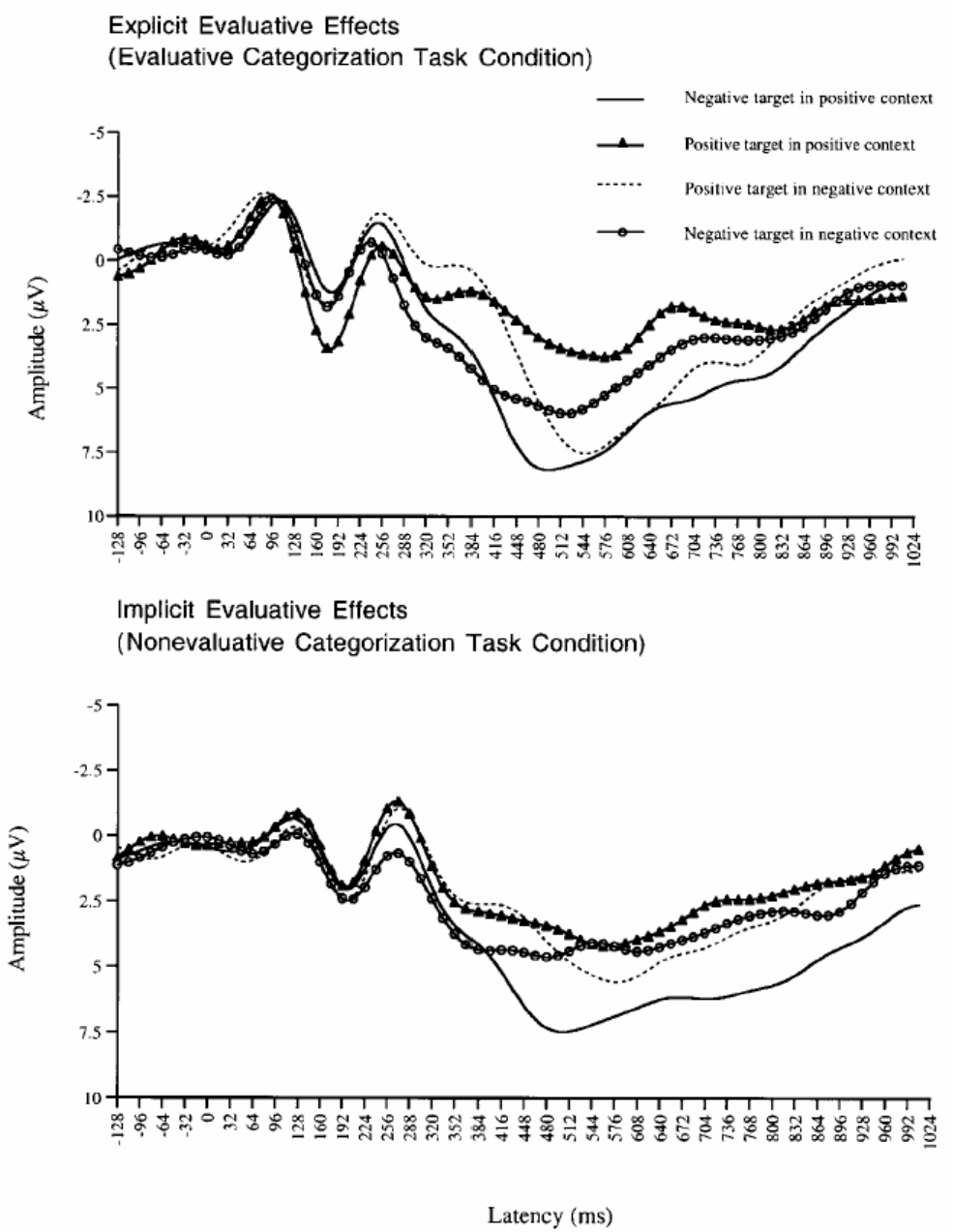


FIG. 2. Averaged event-related potential waveforms at electrode Pz as a function of target and context valence. The top panel depicts explicit evaluative categorization effects (data from participants in the evaluative task condition). The bottom panel depicts implicit evaluative categorization effects (data from participants in the nonevaluative task condition). The late-positive potential is the positive (downward) deflection peaking at approximately 450–550 ms.

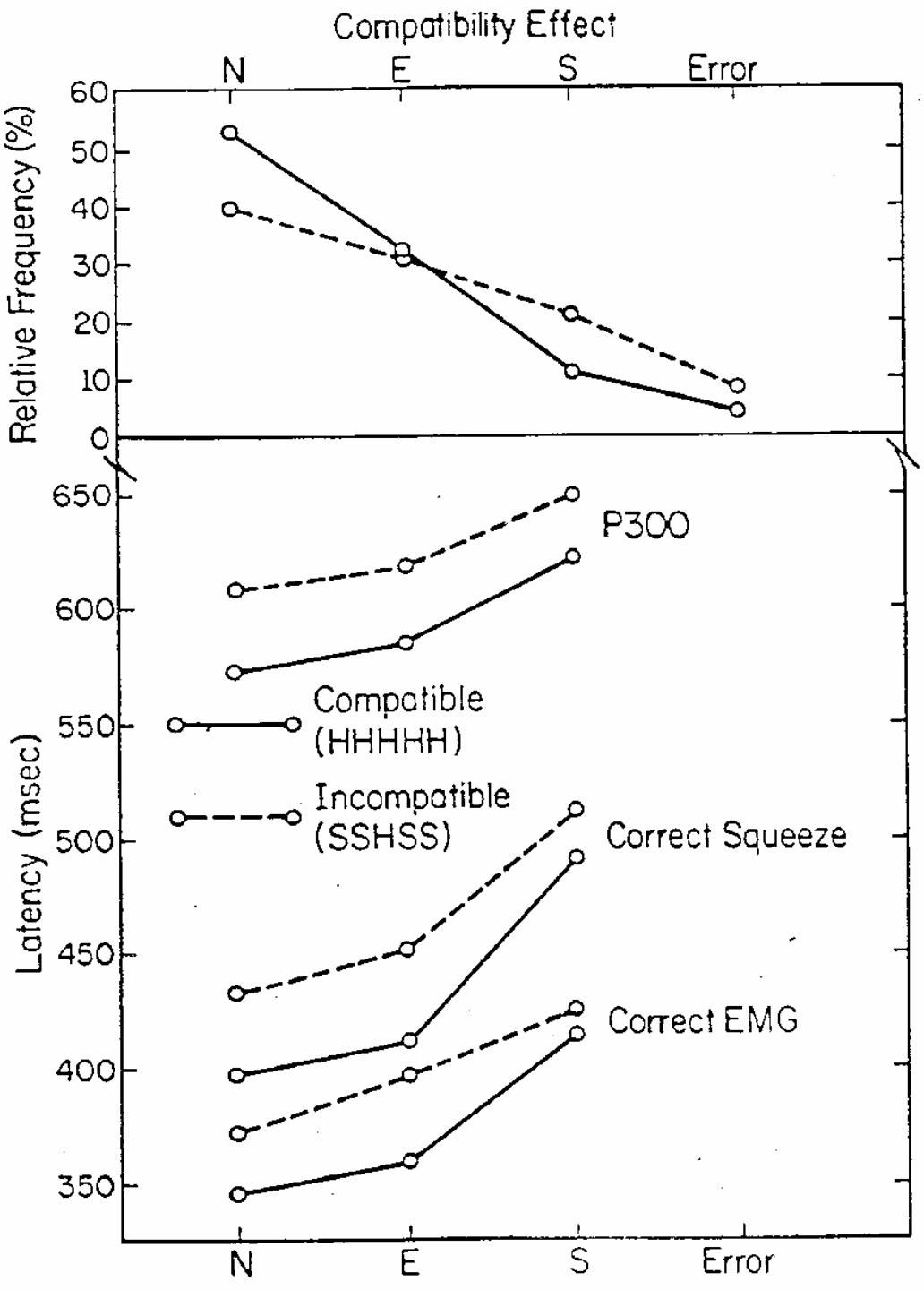
Ito & Cacioppo (2000) *JESP*

ERPs and Mental Chronometry

- "Correctness" not dichotomous
- The continuous flow model of human information processing (Coles, Bashore, Eriksen, & Donchin, 1985)
- Measure response using hand dynamometer and EMG activity to compatible and incompatible arrays:

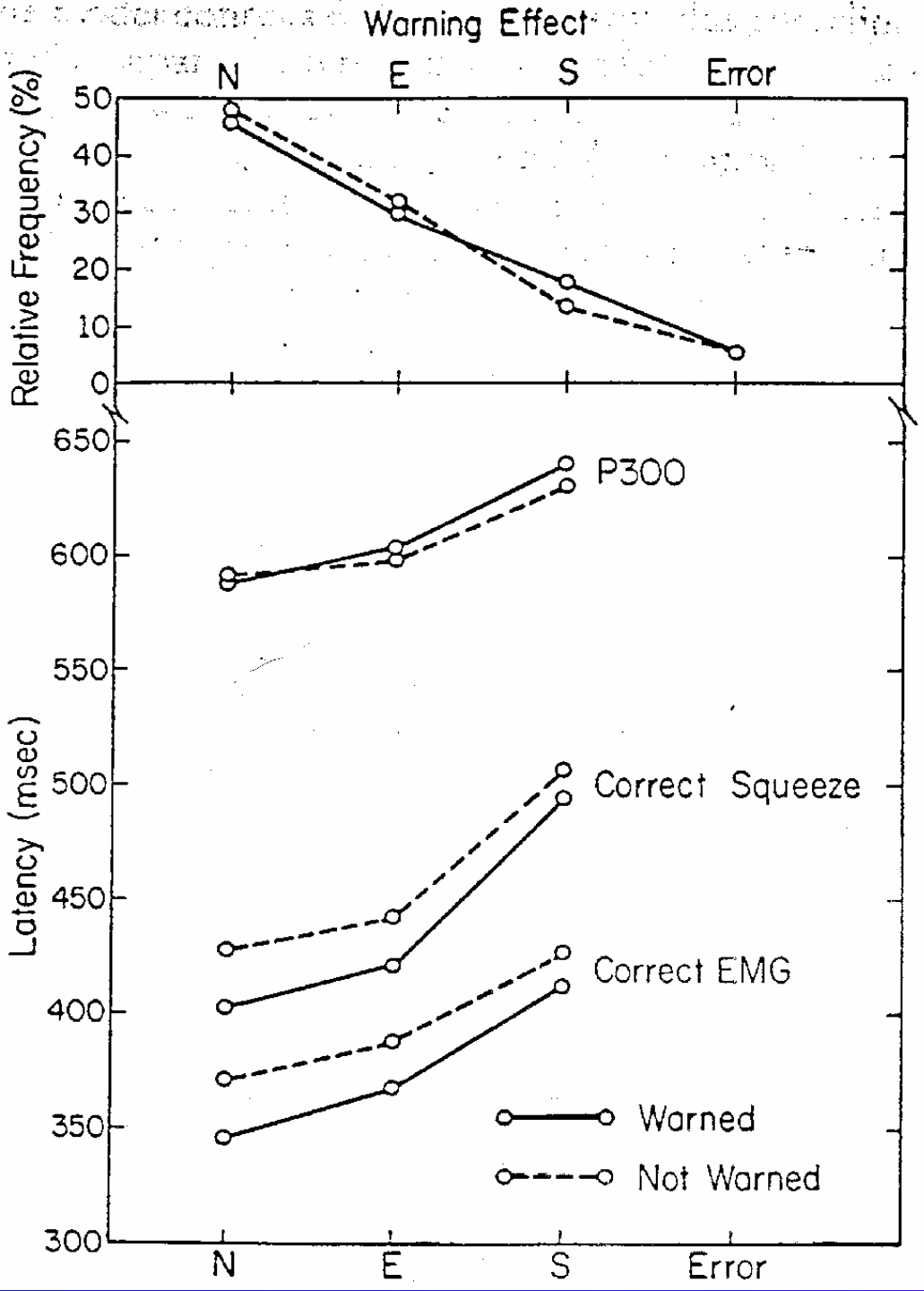
HHHHH Vs HHSHH

SSSSS Vs SSHSS



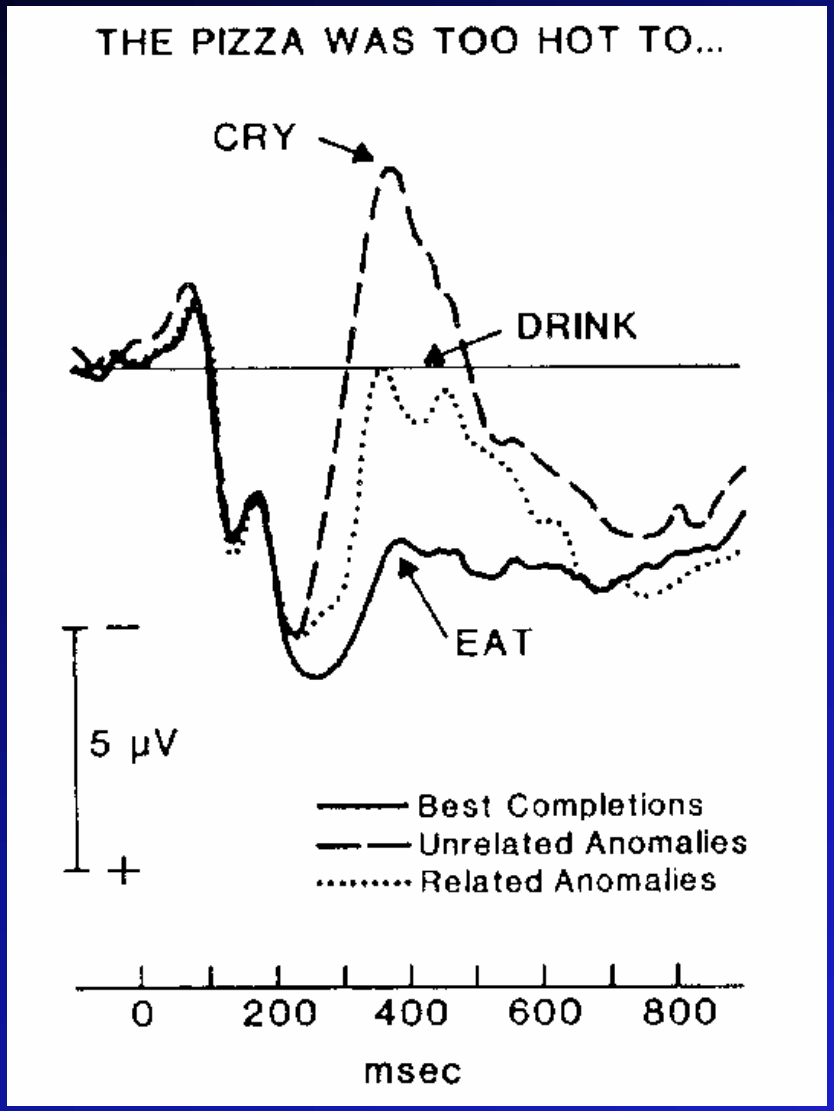
N = No Incorrect Activity
E = Some EMG activity on incorrect response channel
S = EMG and squeeze on both correct and incorrect channels
Error = no correct response, may be some EMG in correct channel

Latency of activity on correct side increased as a function of activity on incorrect side



Effect of Warning seen only in response measures, but not central evaluation

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

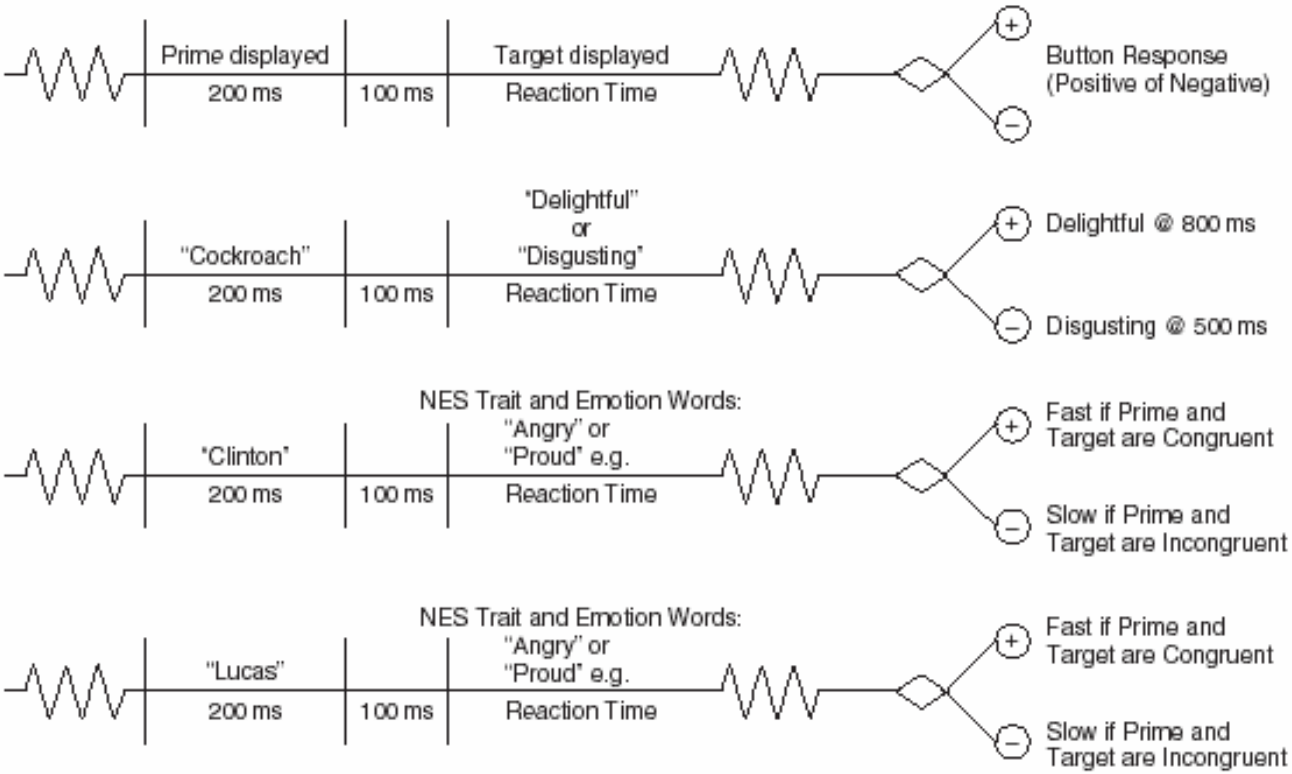


Figure 2. Attitude-priming paradigm and examples of its use.

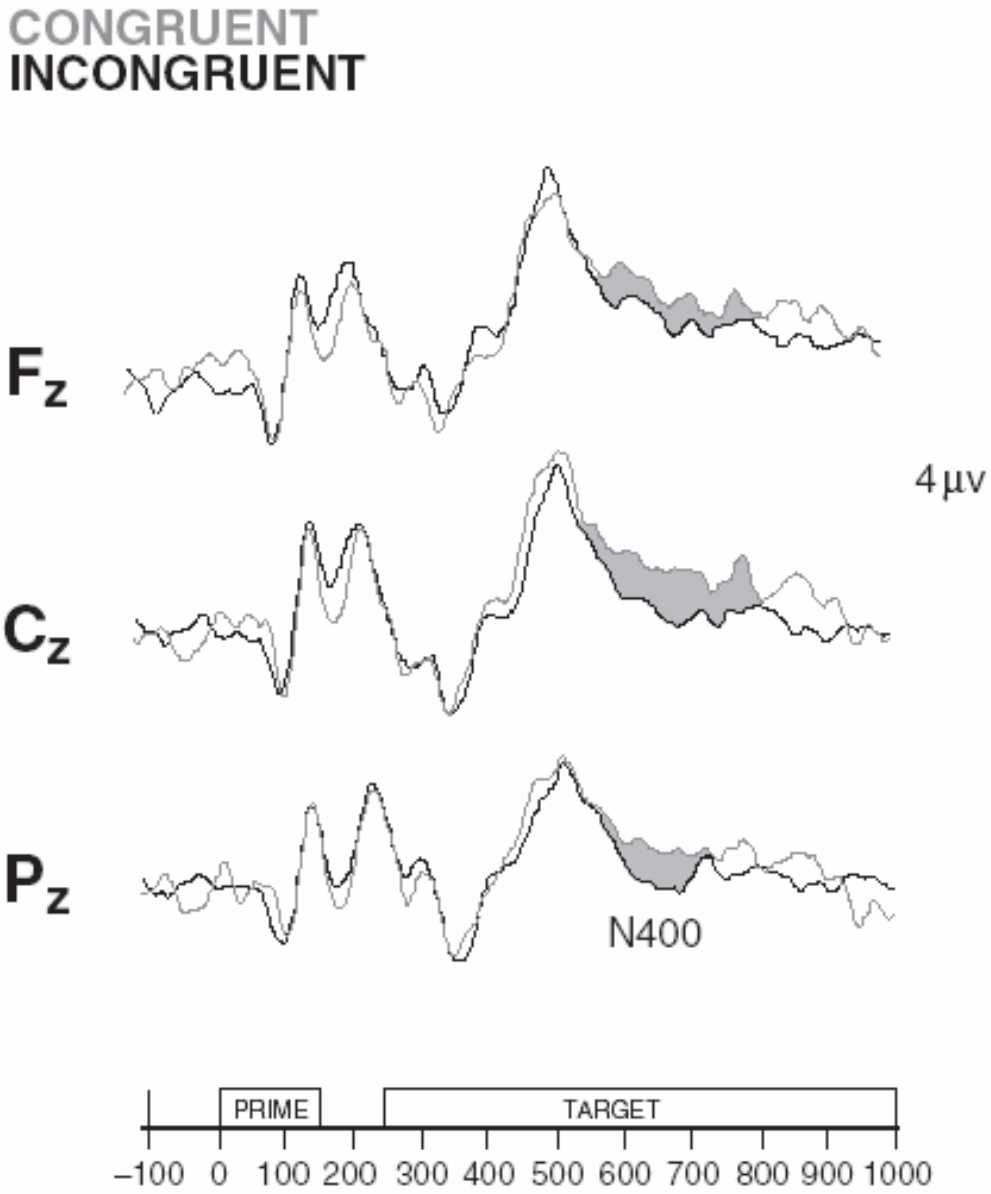
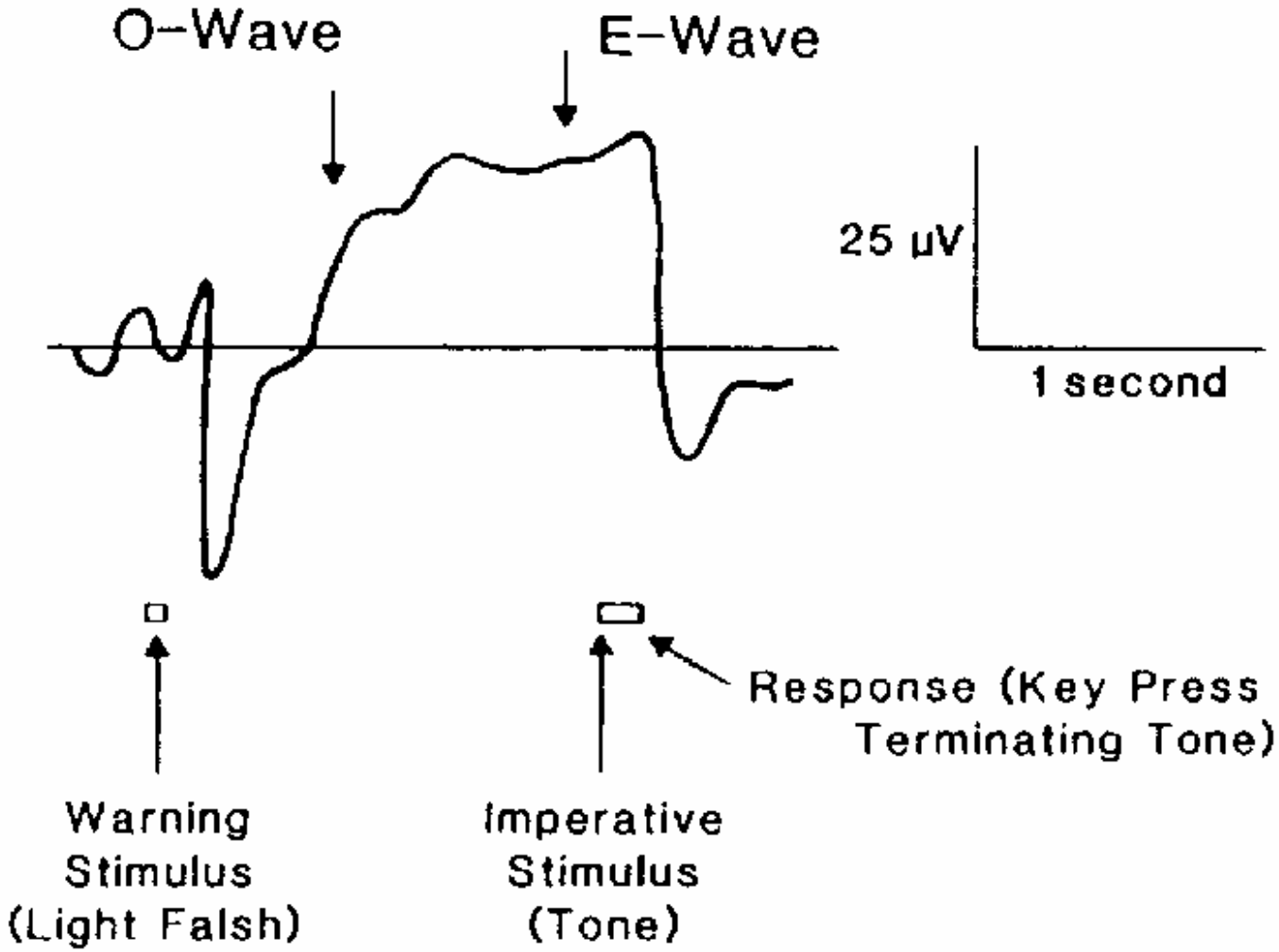


Figure 4. ERPs to congruent and incongruent prime/target pairs.

Morris Squires et al. *Political Psychology* 2003

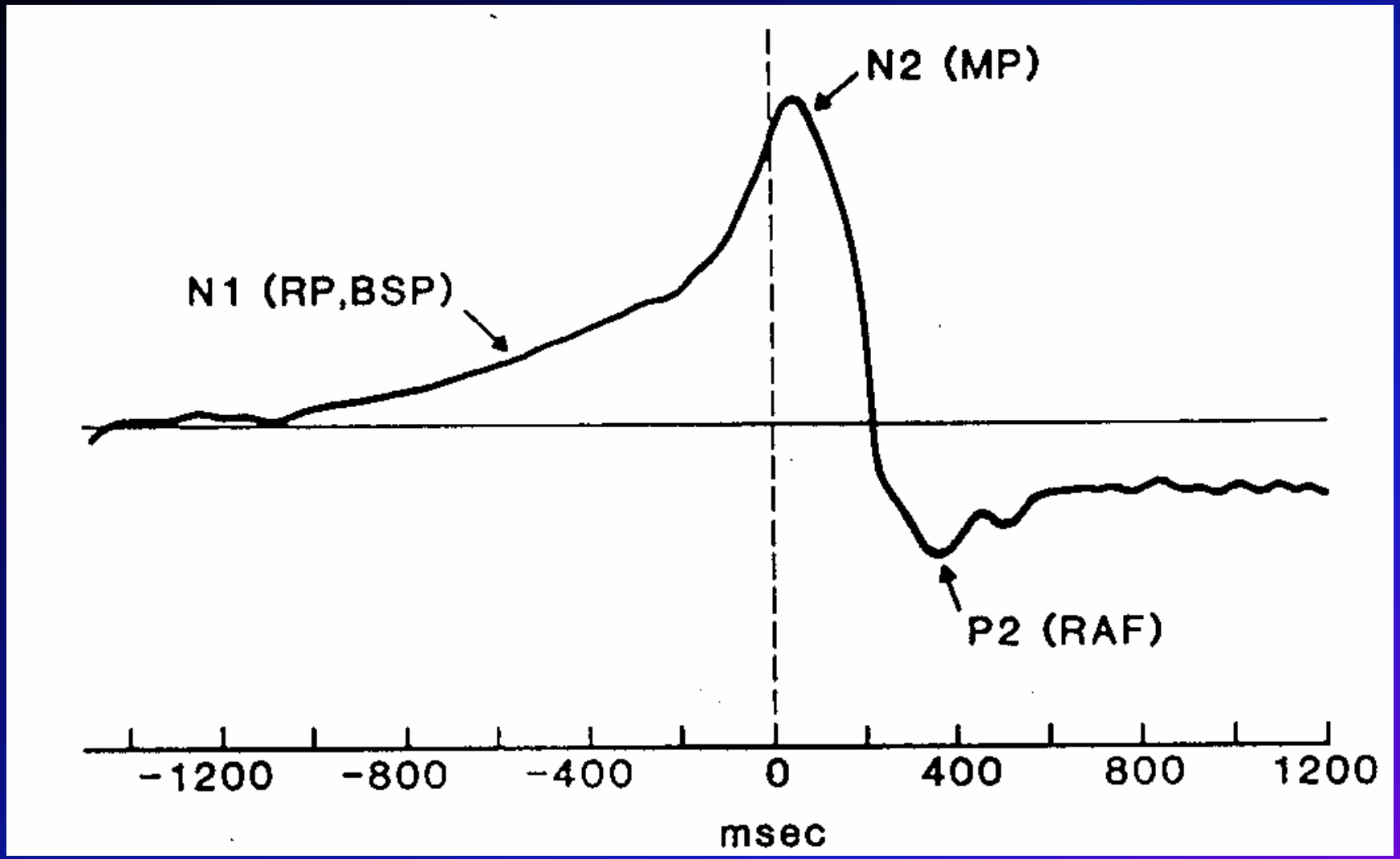
Contingent Negative Variation



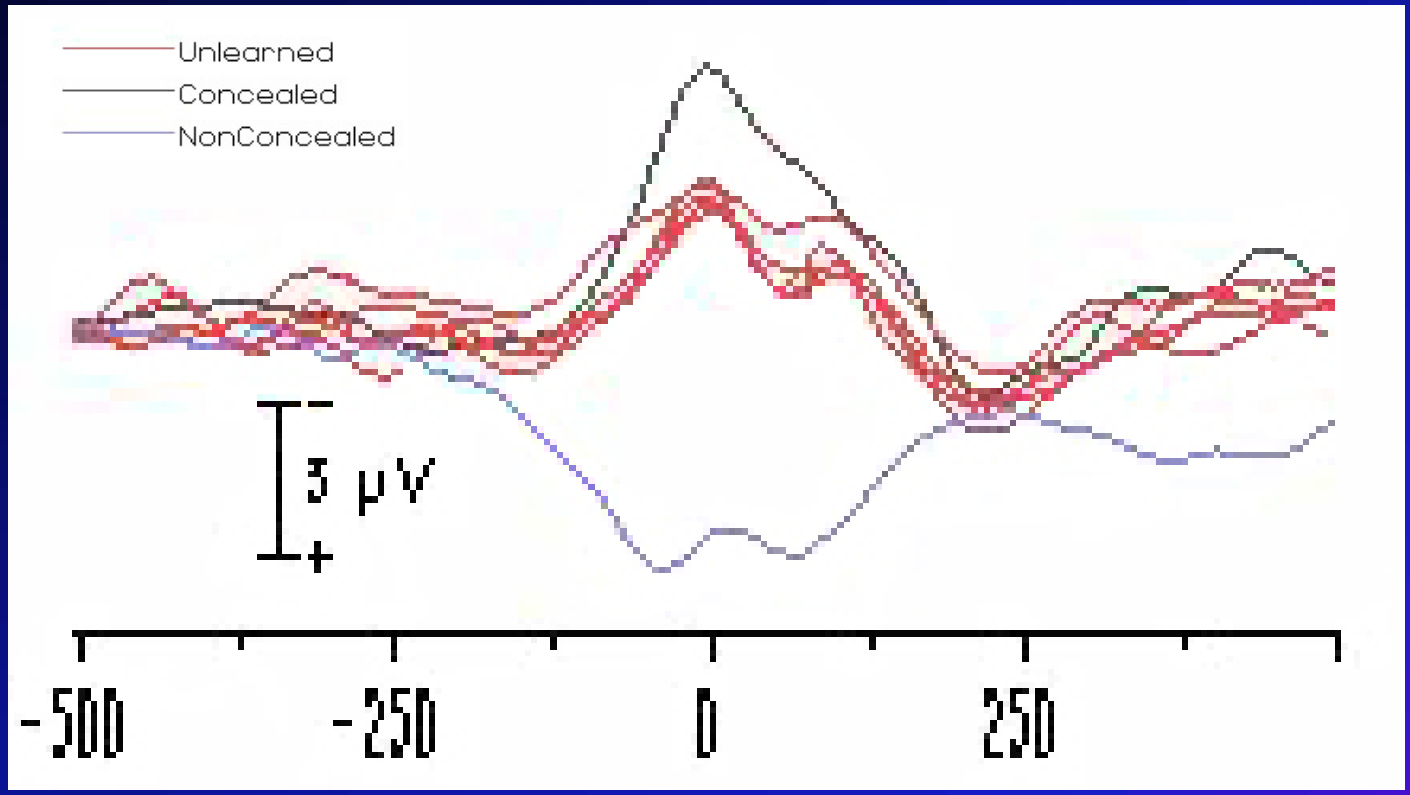
O-wave = Orienting; E-Wave = Expectancy, arguably motor-related

Response-locked potentials

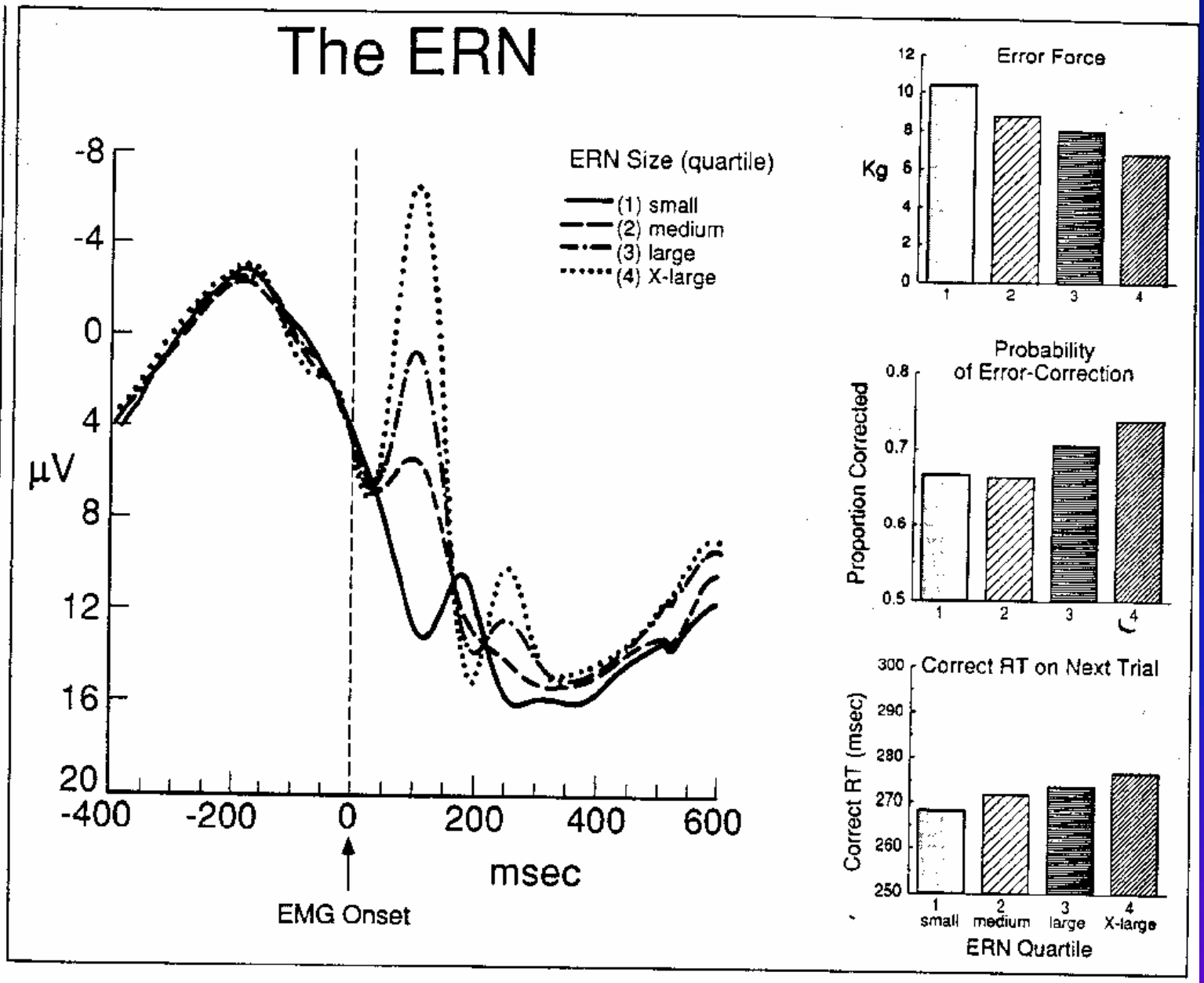
- Lateralized Readiness Potential (LRP), a special case of movement-related potentials
- Error-related Negativity (ERN, aka N_E)



Typical Movement-related Potential. Recorded over central sulcus, with voluntary hand movement at time 0. RP= Readiness Potential, BSP-Bereitschoftspotential; MP=Motor Potential; RAF=Reafferent potential

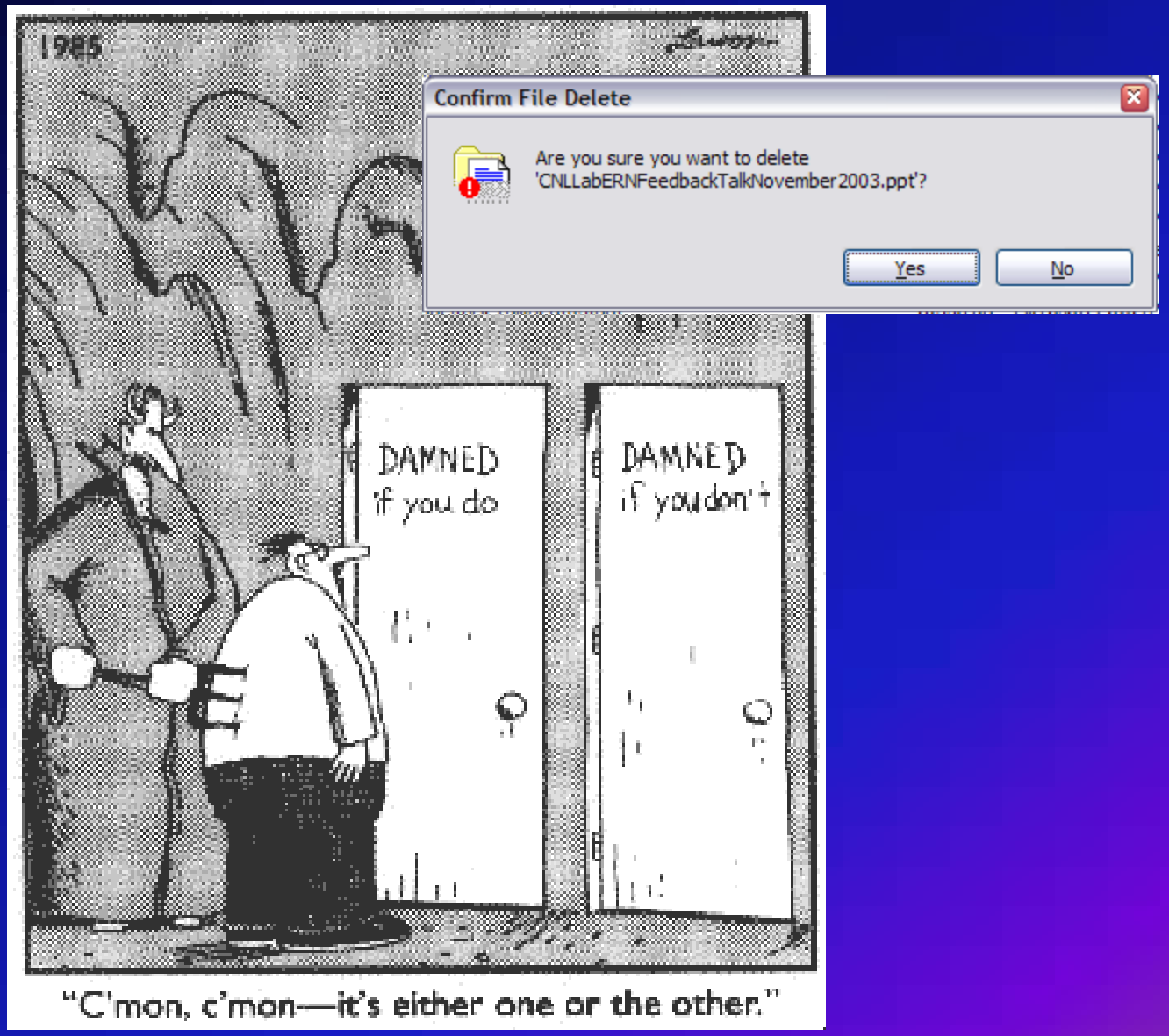


The Lateralized Readiness Potential in the Deception Detection Paradigm. Waveform is C3-C4; Correct response to nonconcealed is right button press; correct response to all others is left button press



Gehring et al., 1993

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.


1985
DAMNED if you do
DAMNED if you don't
Confirm File Delete
Are you sure you want to delete 'CNLLabERNFeedbackTalkNovember2003.ppt'?
Yes
No
"C'mon, c'mon—it's either one or the other."

Modality Specific?

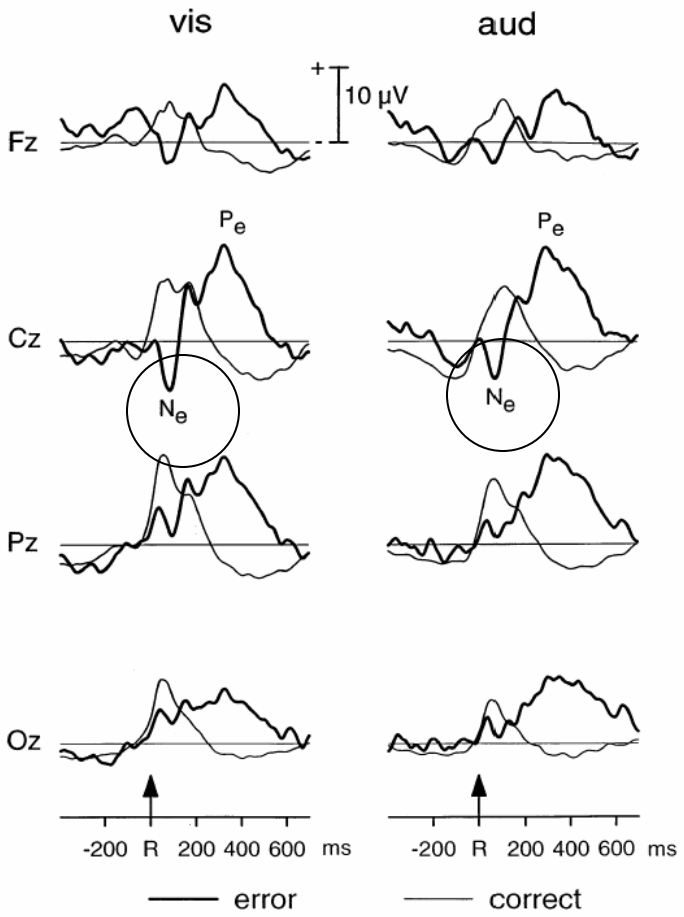
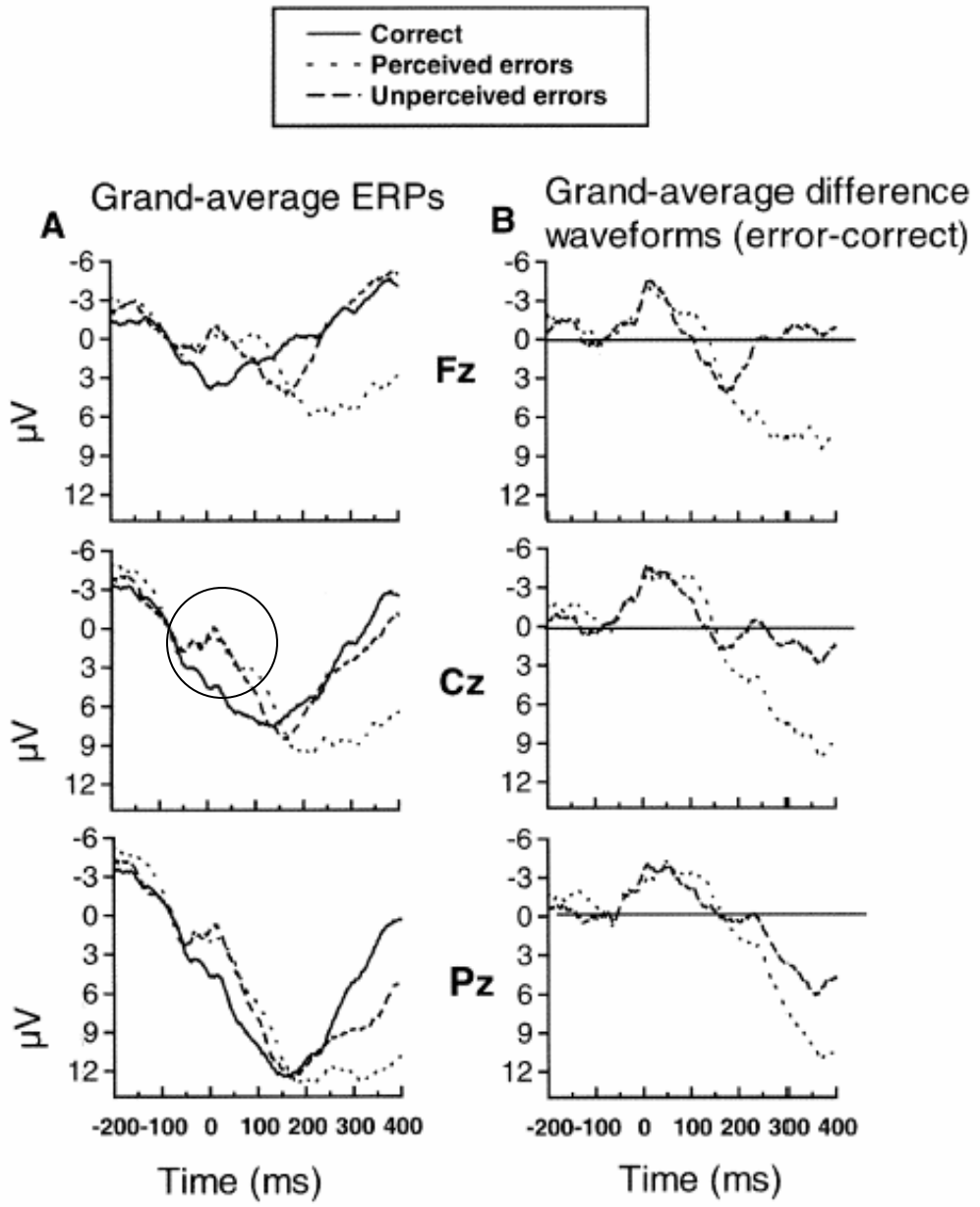


Fig. 1. Grand averages (Experiment 4; $n = 12$) of the RTA for errors (heavy lines) and correct trials (light lines) after visual (vis) and auditory letter stimuli (aud) in a 2-CR task. The error negativity ('Ne') is seen as a sharp negative deflection with central maximum peaking at about 80 ms after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

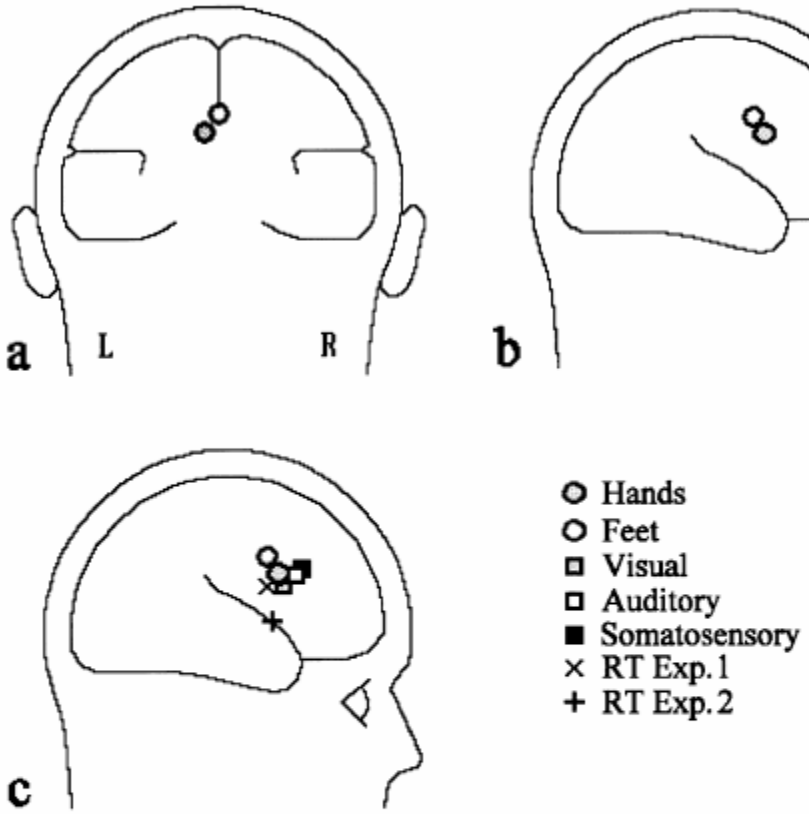


Fig. 2. Source localization of the error-related negativity. Circles represent locations of sources determined for hand and foot responses: (a) coronal view; (b) sagittal view; (c) for comparison, source locations of the ERN determined in previous studies are depicted along with the locations of the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

Theoretical Squabble #1: 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…

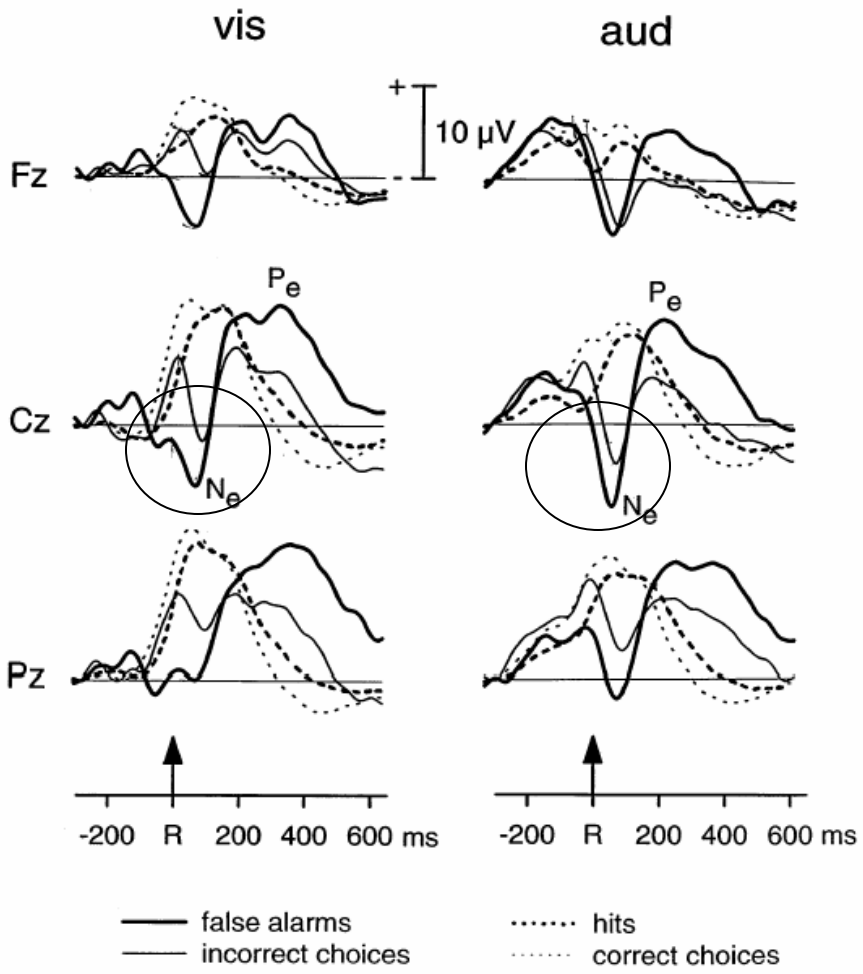


Fig. 5. Grand averages (Experiment 2; $n = 10$) of the RTA for false alarms and hits in Go/Nogo tasks (heavy lines), and choice errors and correct choice trials in two-way choice tasks (thin lines). Errors continuous lines, correct responses broken lines. The Ne is delayed relative to the incorrect key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

Theoretical Squabble #2: 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

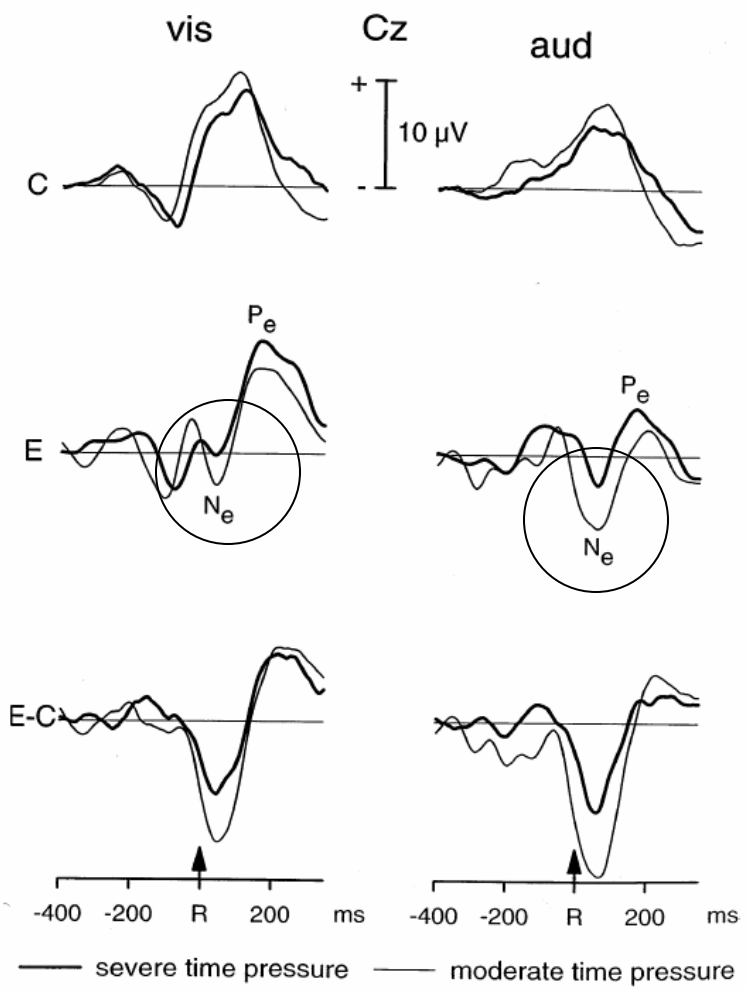


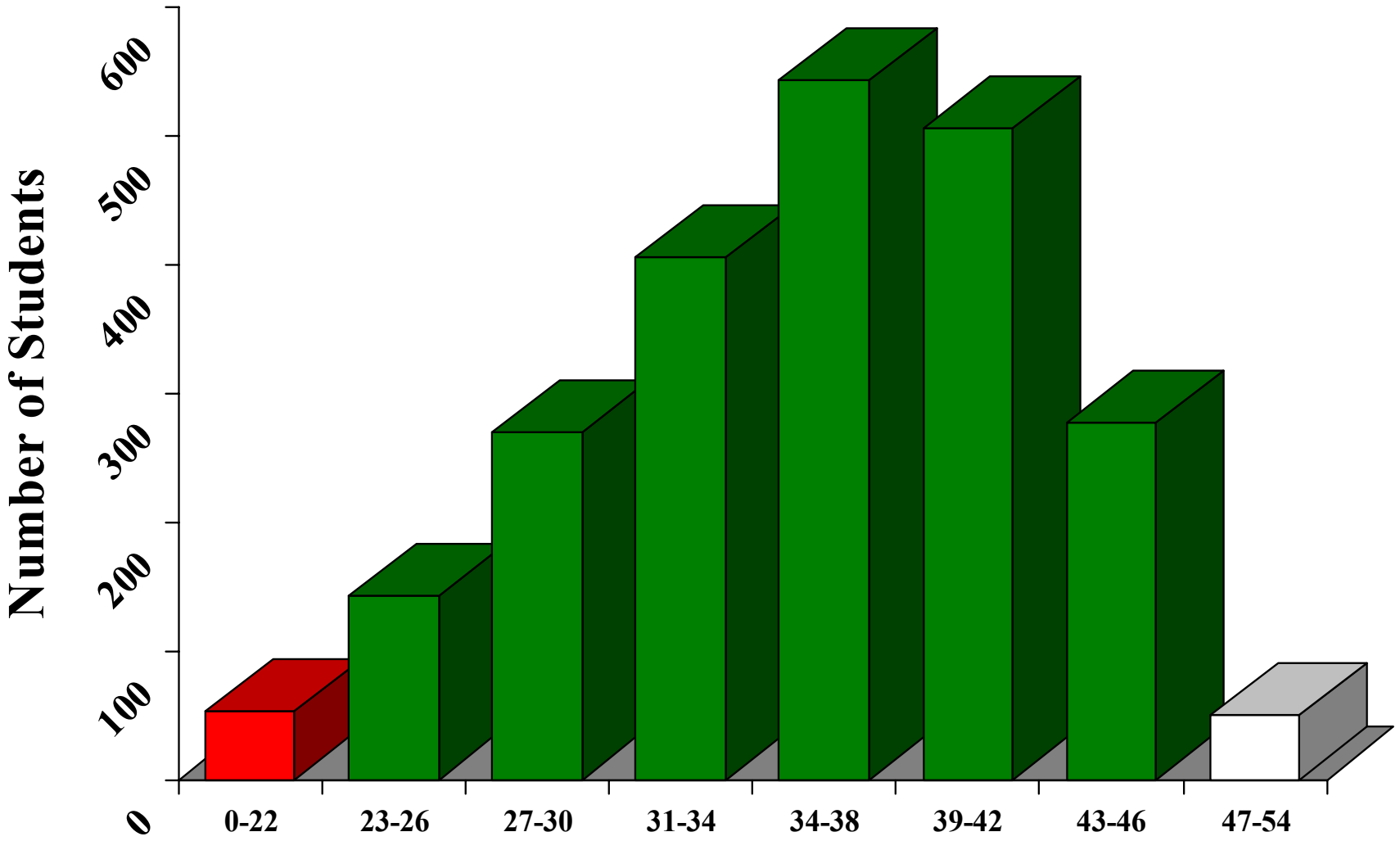
Fig. 4. Grand averages (Experiment 1; $n = 9$) of the RTA for correct responses (C), errors (E), and difference waveshapes (error minus correct; E − C) in a 2-CR task under moderate (light lines) and severe time pressure (heavy lines). The error rates were 15% (moderate) and 30% (severe); the number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



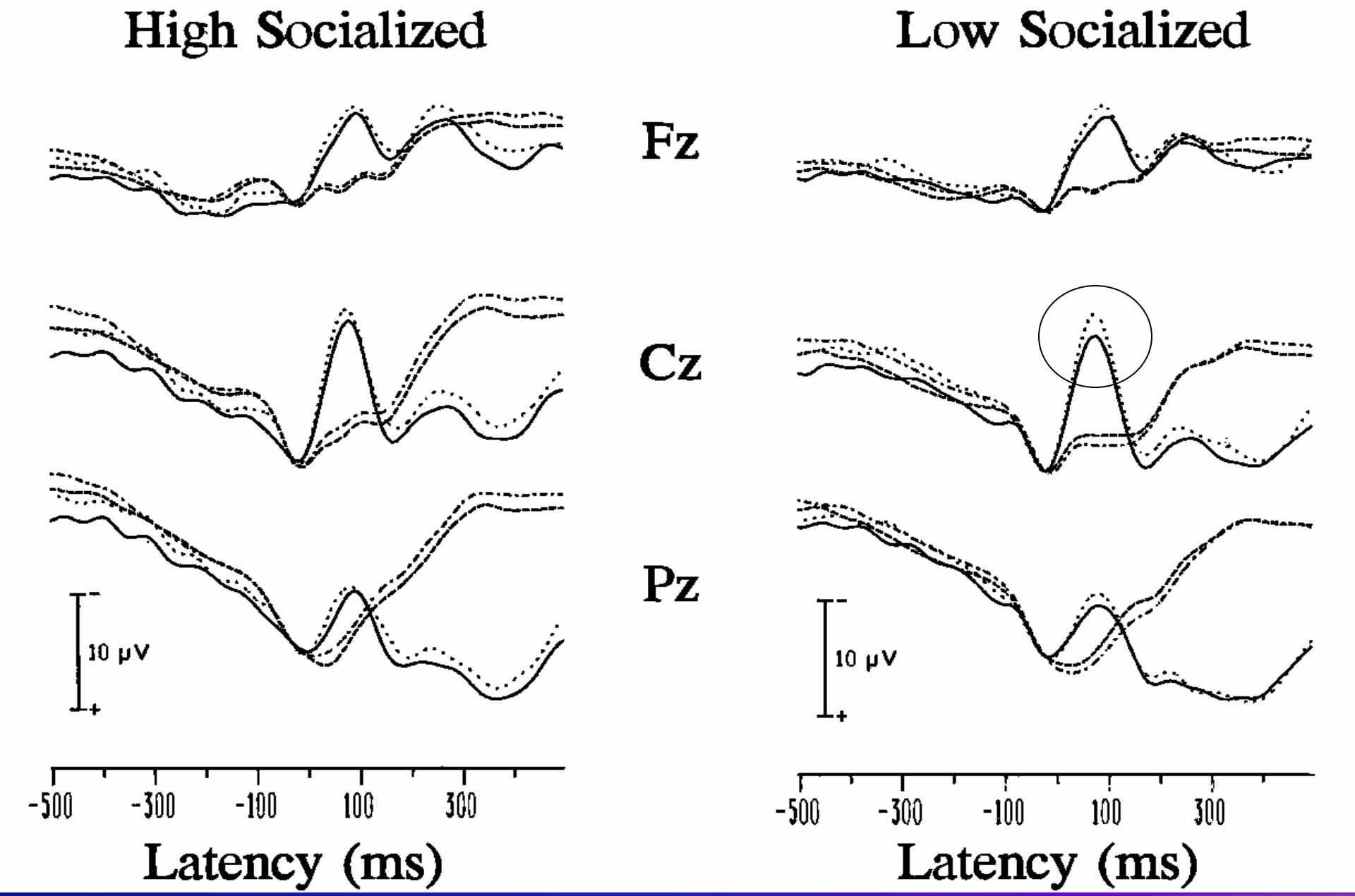
Thirty participants selected: **15 high SO**

15 low SO

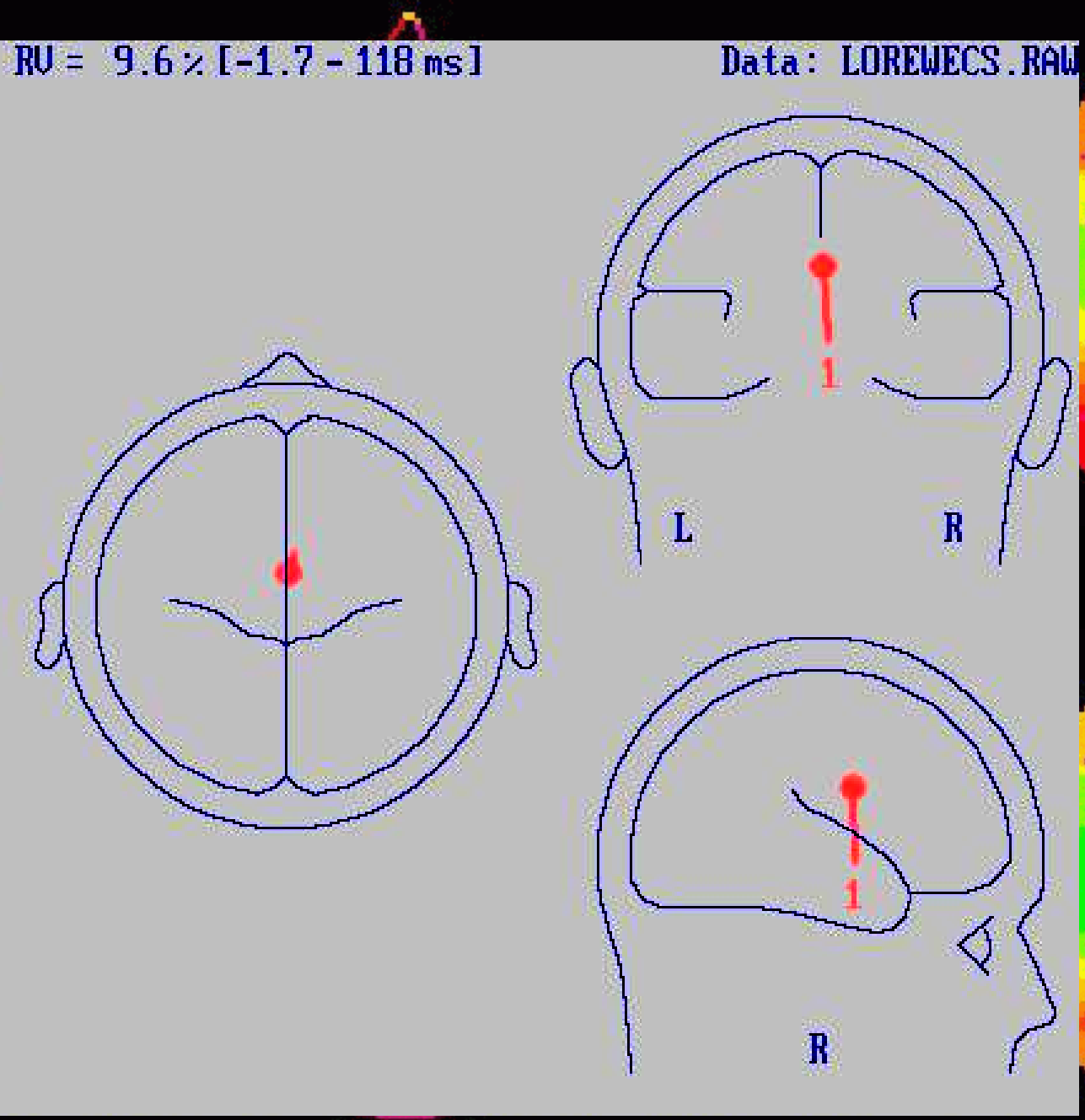
Dikman & Allen, 2000, *Psychophysiology*

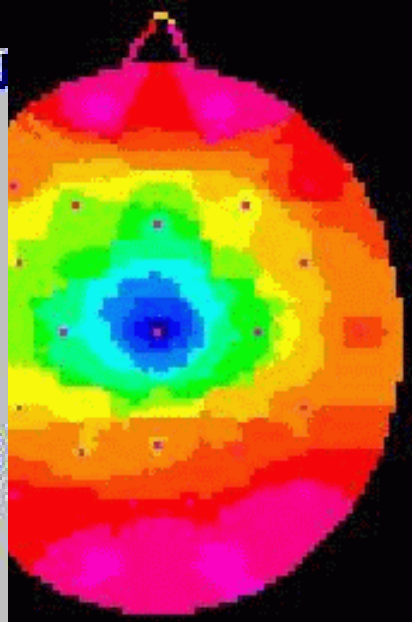
Procedure

- 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

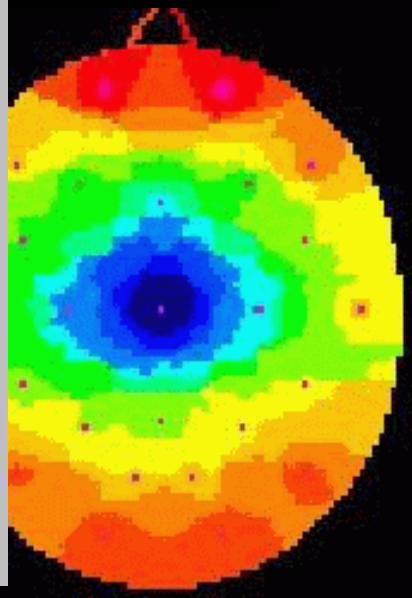


Dikman & Allen, 2000, *Psychophysiology*





Rew



Results replicate with RT-matched trials

ERN in OCD

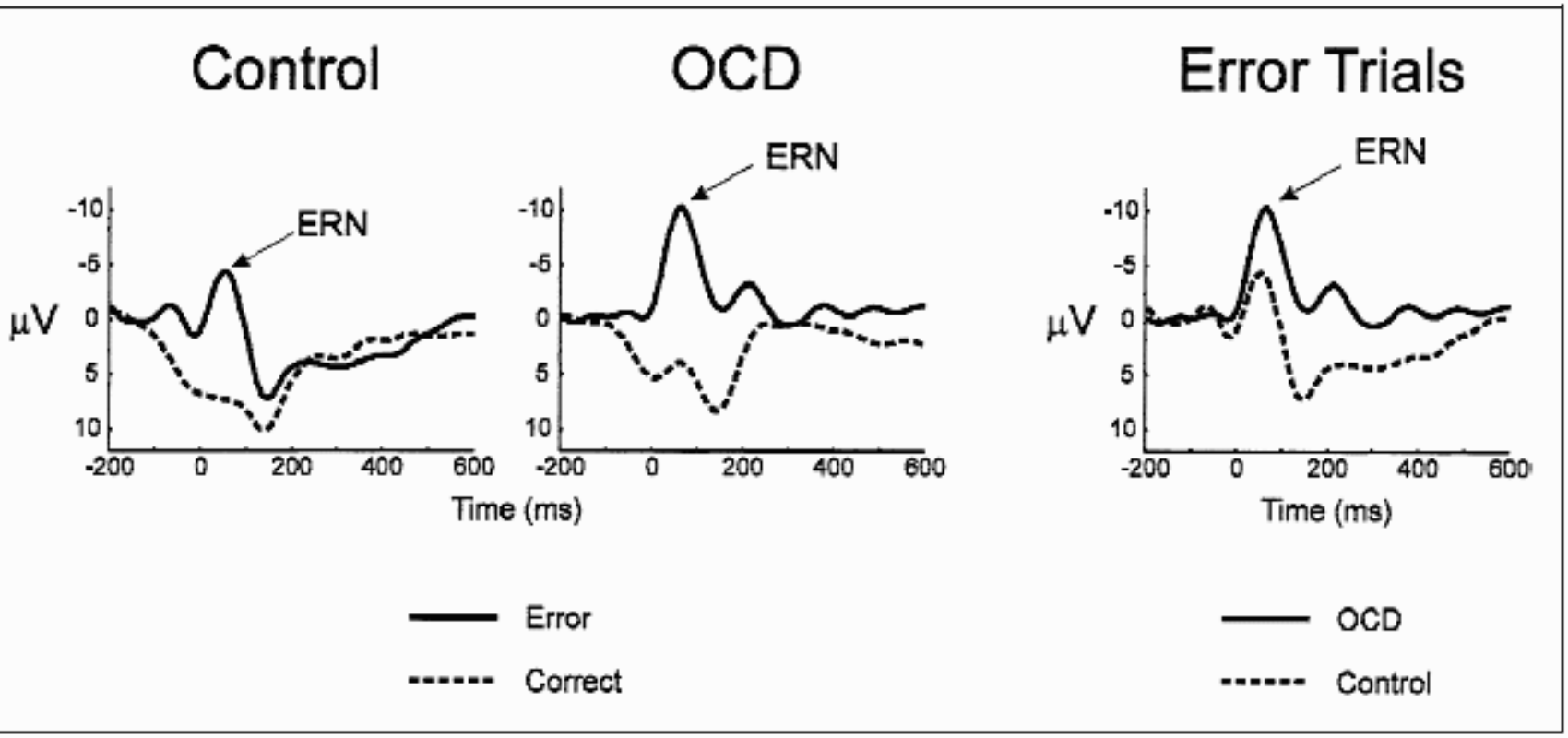


Fig. 1. Response-locked event-related potential waveforms at the Cz electrode location. The left panel compares correct-trial and error-trial waveforms for control participants and for individuals with obsessive-compulsive disorder (OCD). The right panel compares error-trial waveforms for the two groups.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

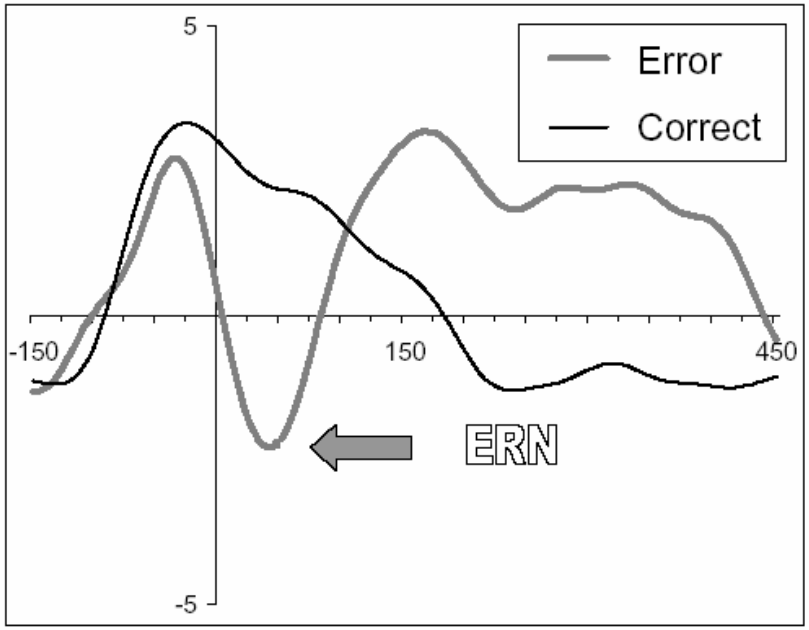
And amplitude of ERN correlates with Symptom severity (correlation magnitude ~.50); Gehring et al. (2000)

Theoretical Squabble #3: Error Detection Vs. Conflict

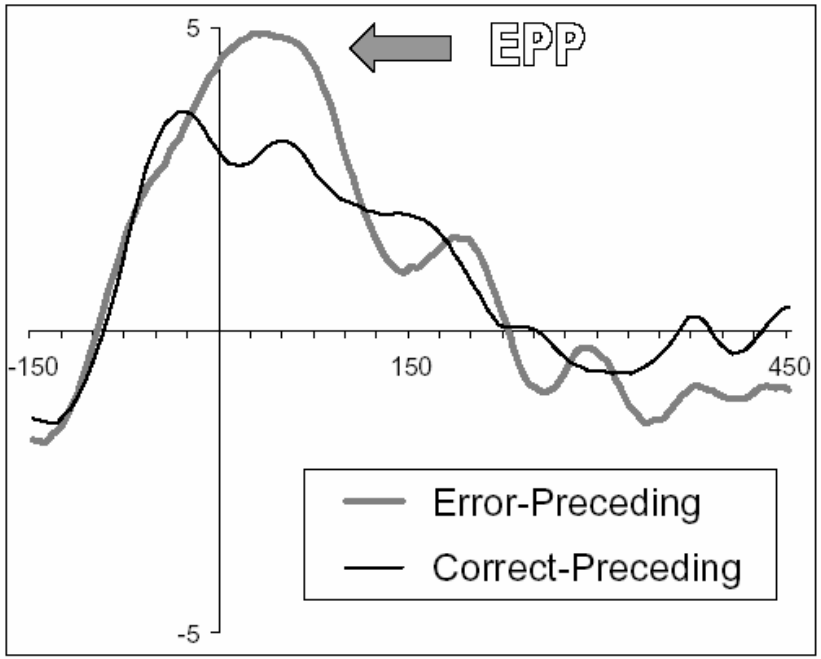
- Trials on which errors occur will entail greater response conflict than those without errors
- So, is it error detection, or response conflict?
- Stay tuned…

Theoretical Wrinkle yet Unnumbered

- Performance Errors are foreshadowed on the trial preceding the error
- Precognition?!!



Fz



Ridderinkhof, Nieuwenhuis, Bashore, *Neuroscience Letters*, 2003

Arrow Flanker Task

← ← → ← ←

Performance errors are foreshadowed in a modulation of brain activity that is thought to reflect a cingulate-based action monitoring system.

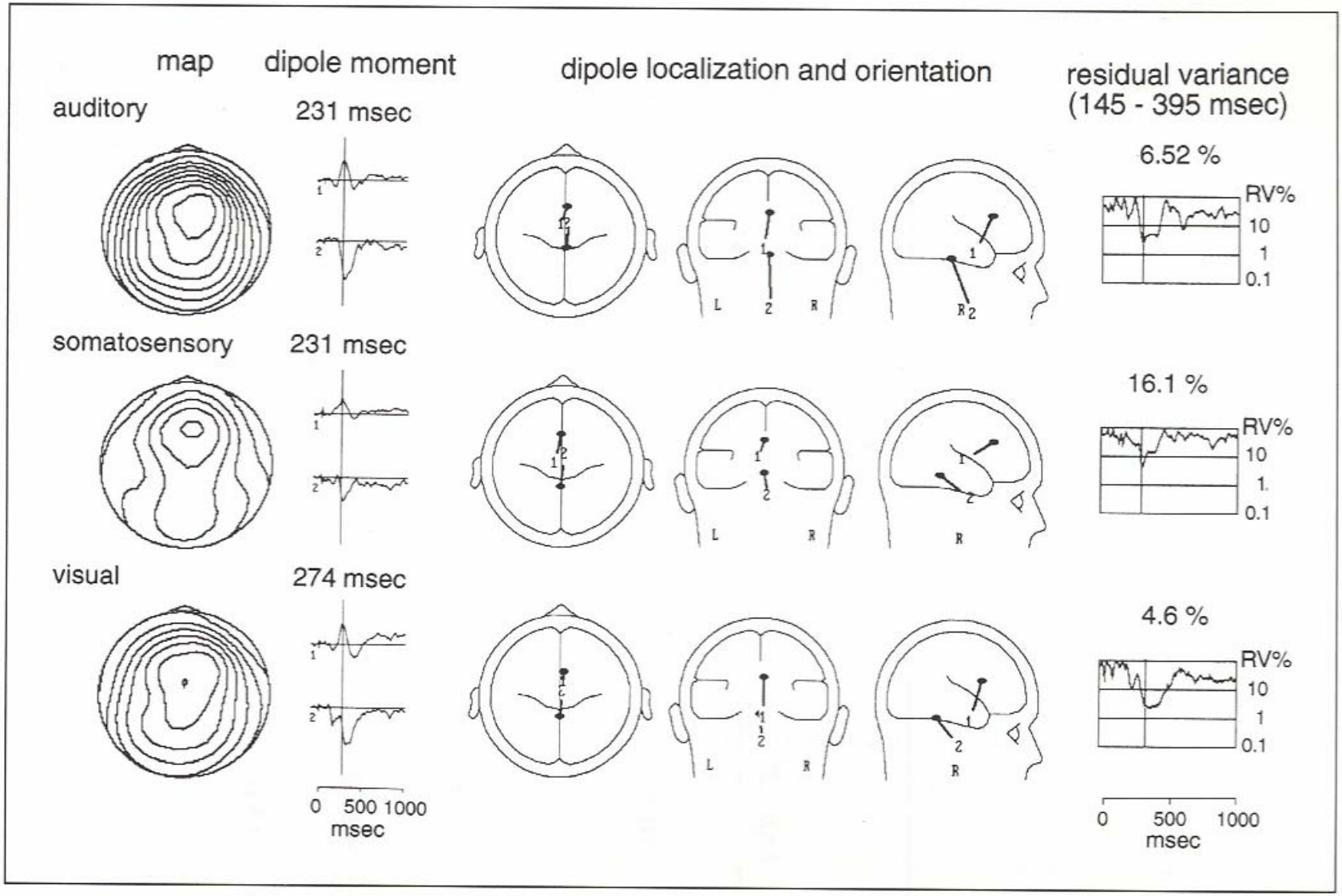
Ridderinkhof et al. propose that this modulation reflects fluctuations in the efficiency of the action monitoring system, which may occasionally compromise subsequent performance and thus comprise a prelude to performance errors.

Note: Not a function of subsequent error trial being faster than subsequent correct trial

Errors and Feedback

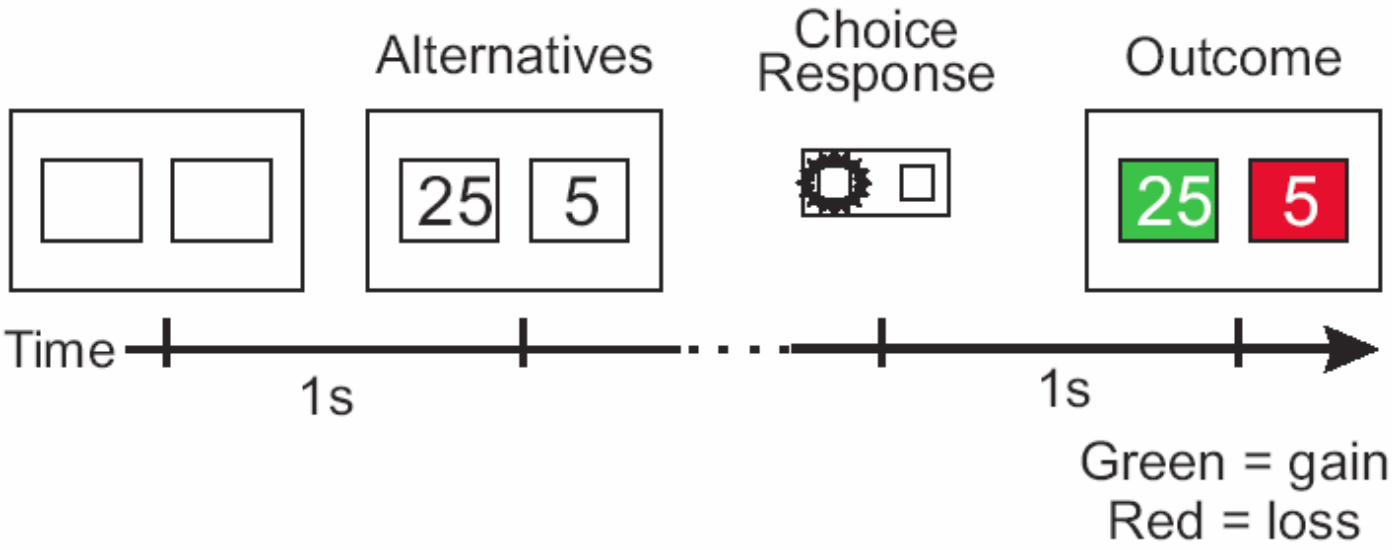
- Endogenous Error Detection
- Exogenous Error Feedback
- Common Mechanism?

The Feedback Medial Frontal Negativity



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

The Gambling Task



Gehring and Willoughby, 2002 *Science*

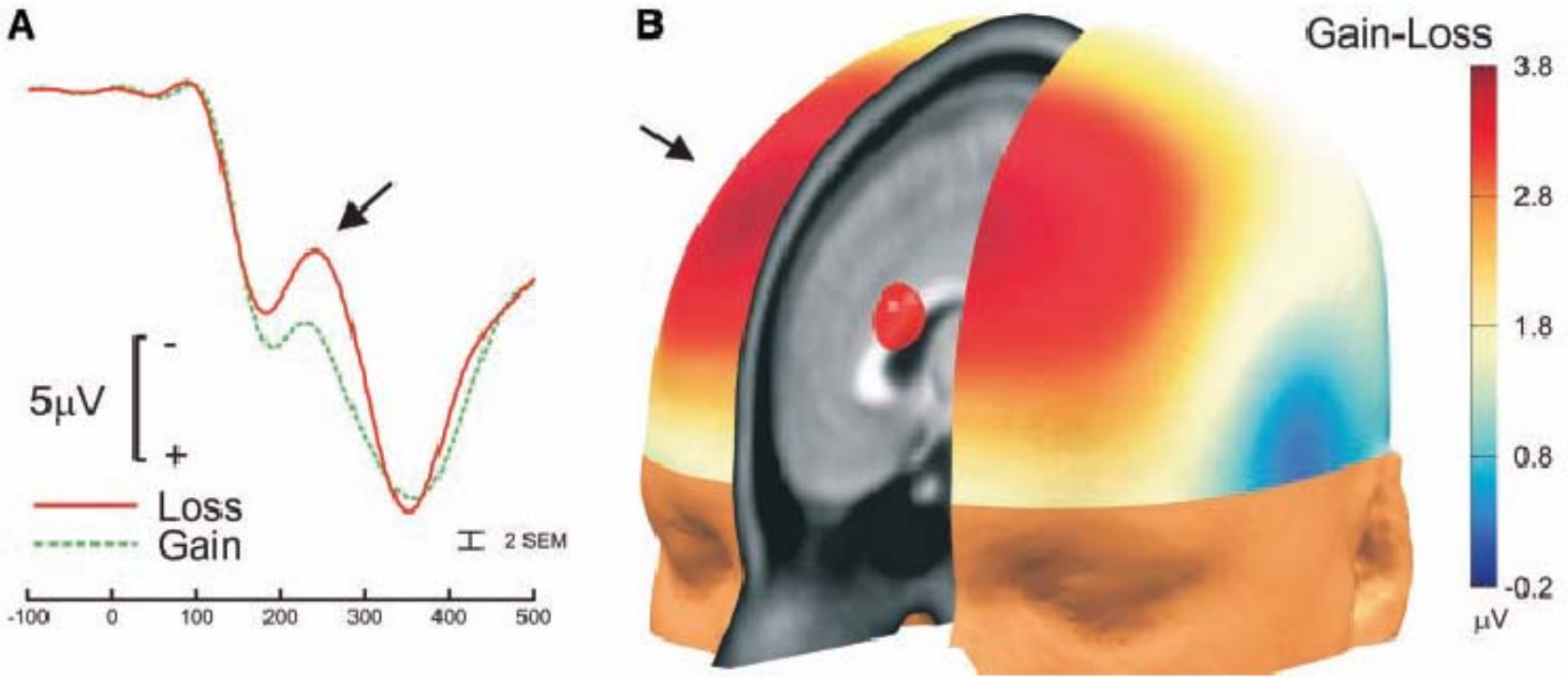


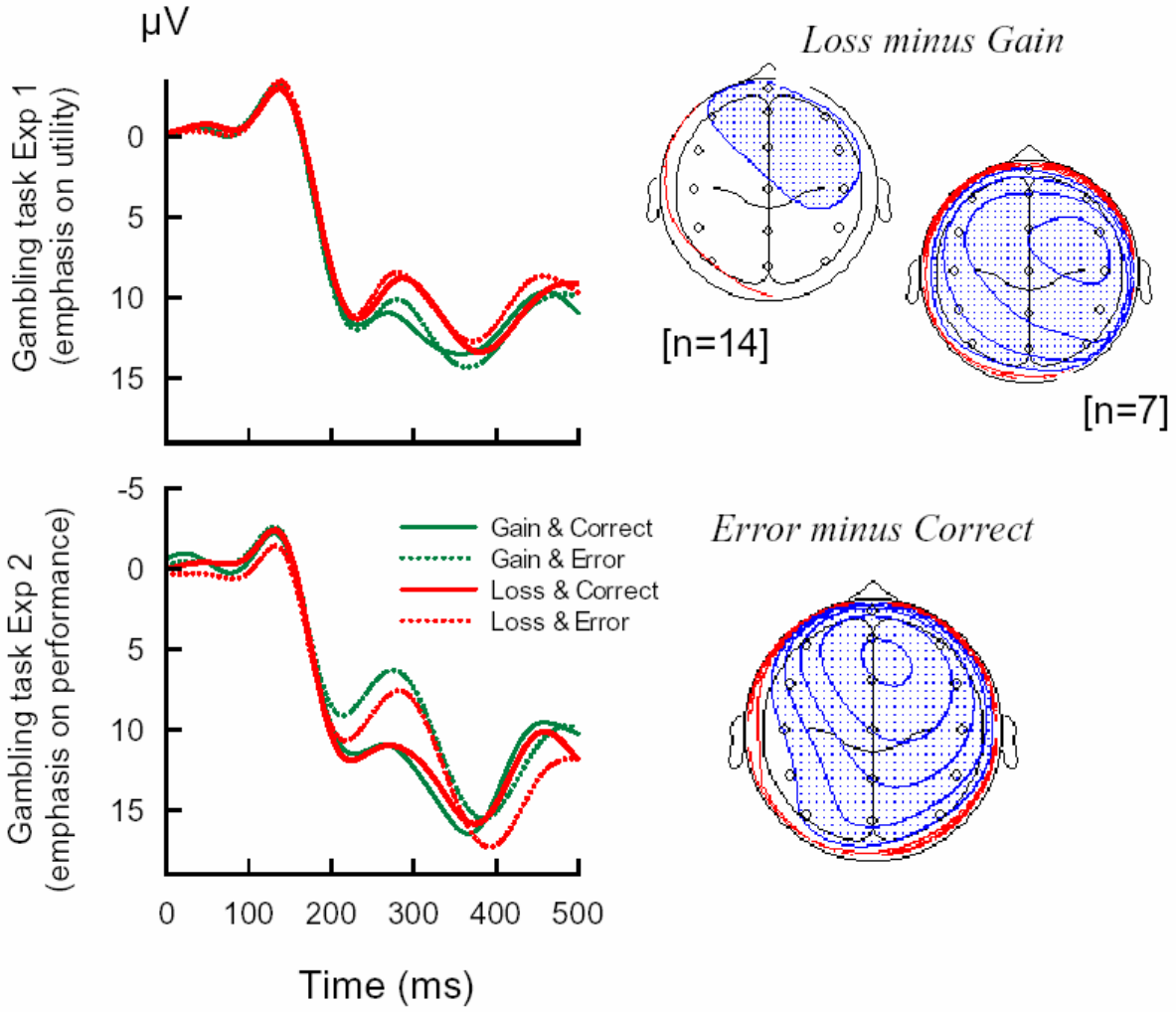
Fig. 2. ERP waveforms, scalp topography, and likely neural generator of the MFN. (**A**) The waveforms are shown at the Fz (frontal) electrode site. The solid red line corresponds to the average ERP waveform for all trials in which the participant lost money. The dashed green line corresponds to those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