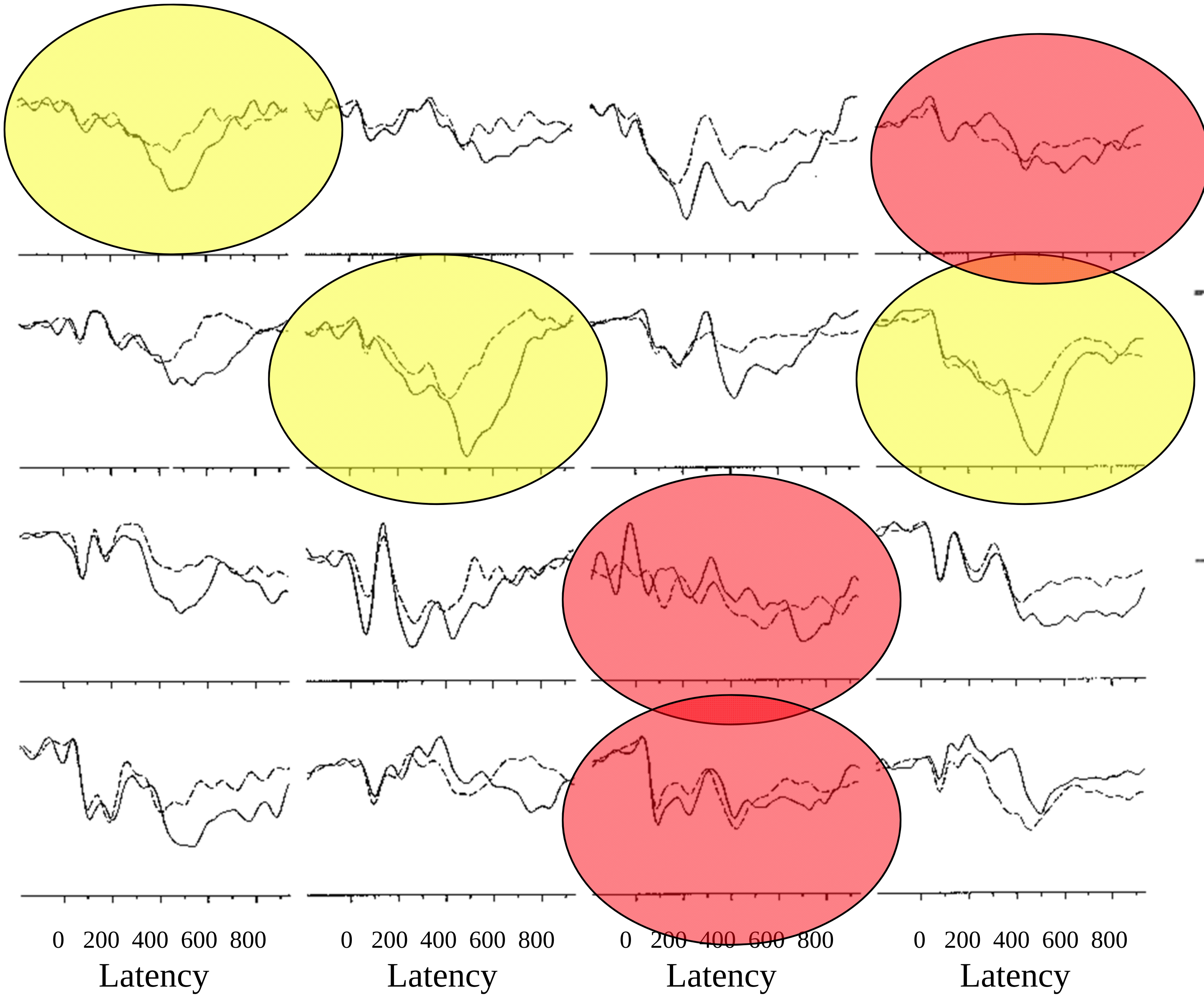
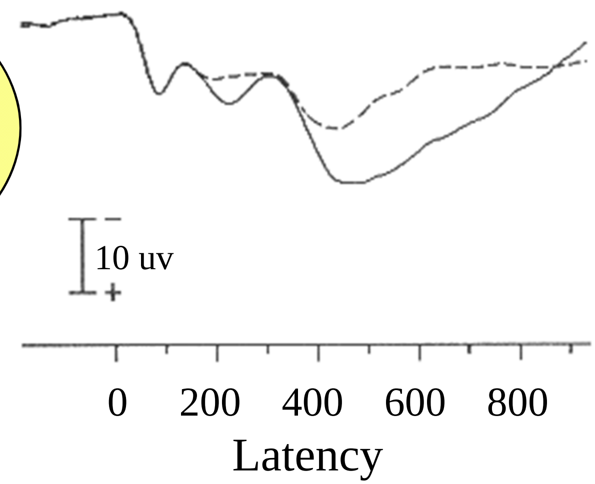
The Event-Related Potential (*aka* the ERP)

A continuation…

Individual Subjects' ERPs do not Resemble the Grand Average ERP





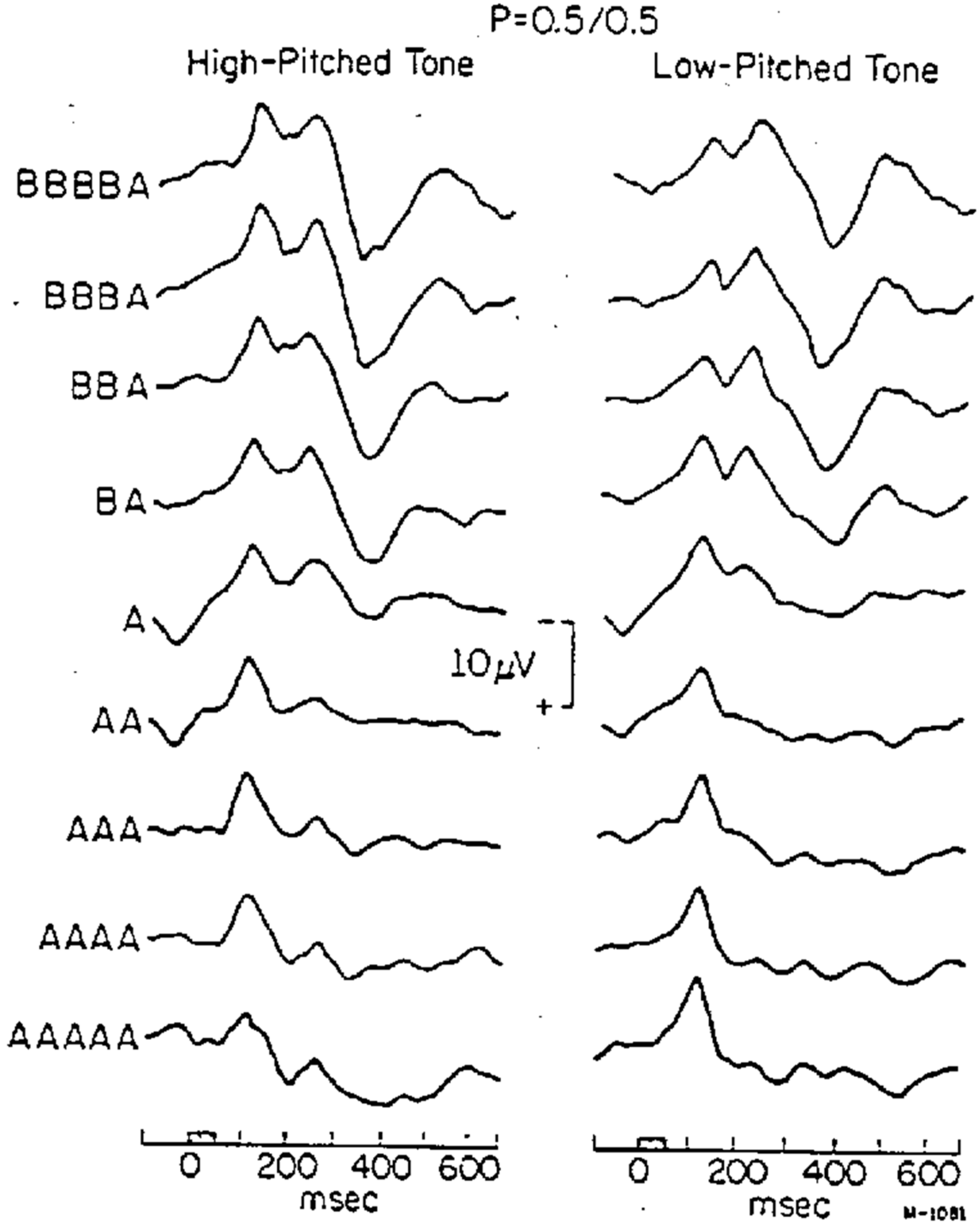
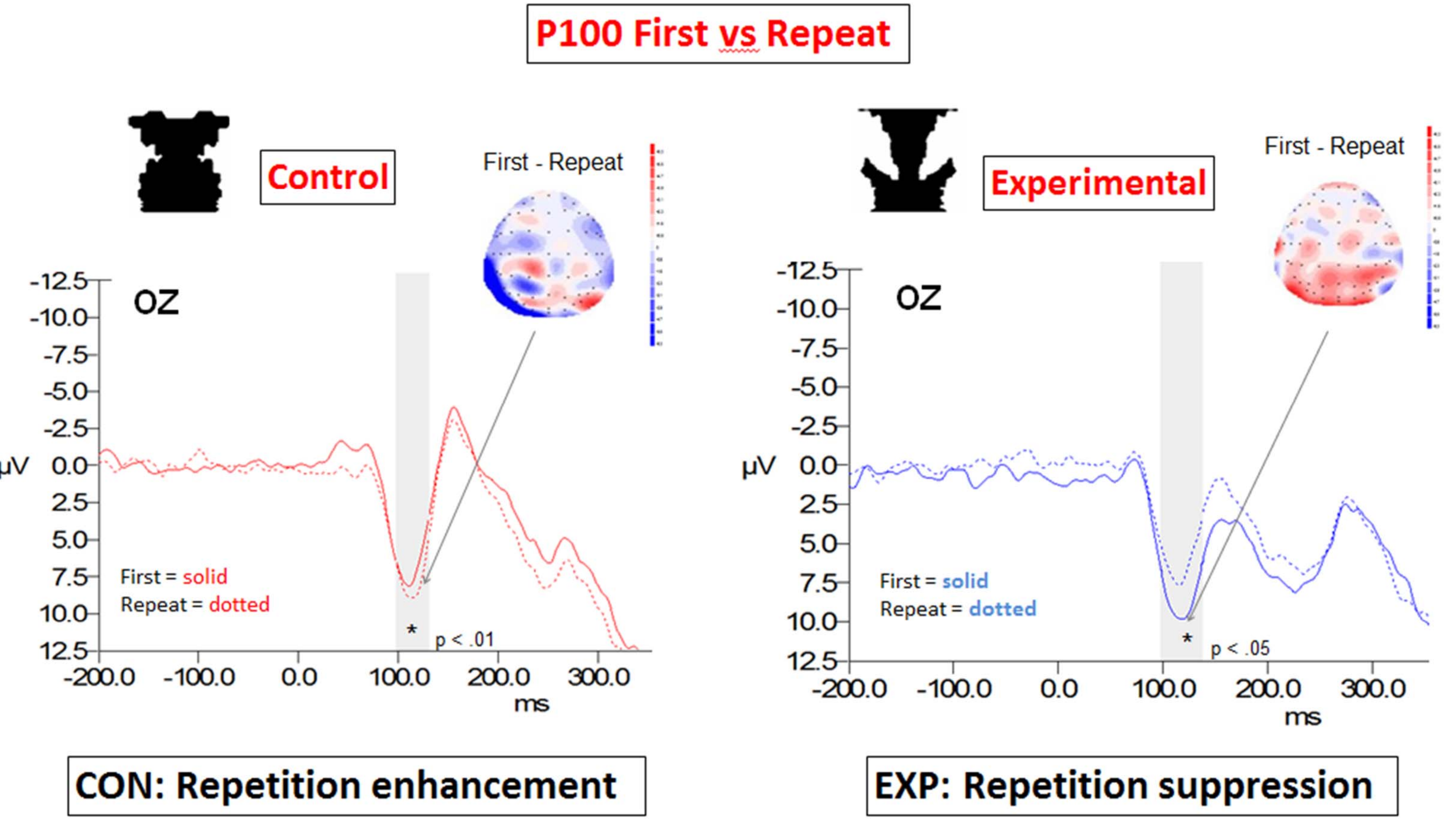


Figure 12-1. The ERPs in each column were elicited by the same physical tone; high-pitched tones were used for the left column and low-pitched tones for the right column. Both were presented in a Bernoulli series in which the probability of the two stimuli were equal. In the middle of each column (labeled "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.



P100 First vs Repeat
Control
First - Repeat
OZ
μV
First = solid
Repeat = dotted
*
p < .01
ms
Experimental
First - Repeat
OZ
μV
First = solid
Repeat = dotted
*
p < .05
ms
CON: Repetition enhancement
EXP: Repetition suppression

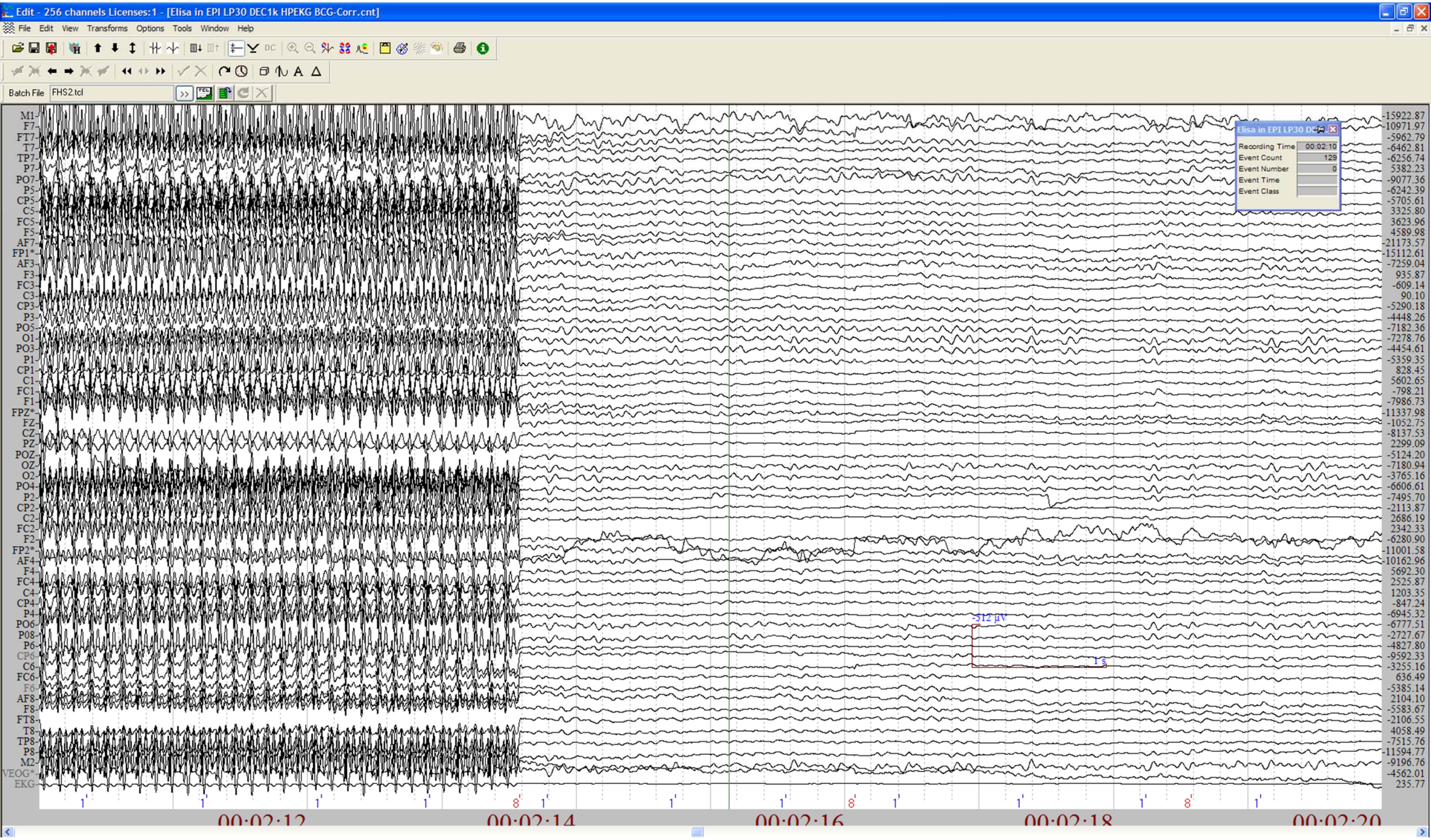
Recording EEG in fMRI environments: Oodles of Issues

- EEG can be bad for fMRI
  - Wires and electrodes can be ferromagnetic = TROUBLE
  - Wires and electrodes can be paramagnetic = less trouble
  - Solution: Non-paramagetic cap
- MRI and fMRI can be bad for EEG
  - RF pulse creates huge artifact for EEG
  - Movement in Magnetic fields creates current in any conductive medium (e.g. wires!)
  - High frequency current can make wires HOT and RF is 127.68 MHz at 3T – that's fast, and can create mega-hurts!

Next

Carbon fiber Cap

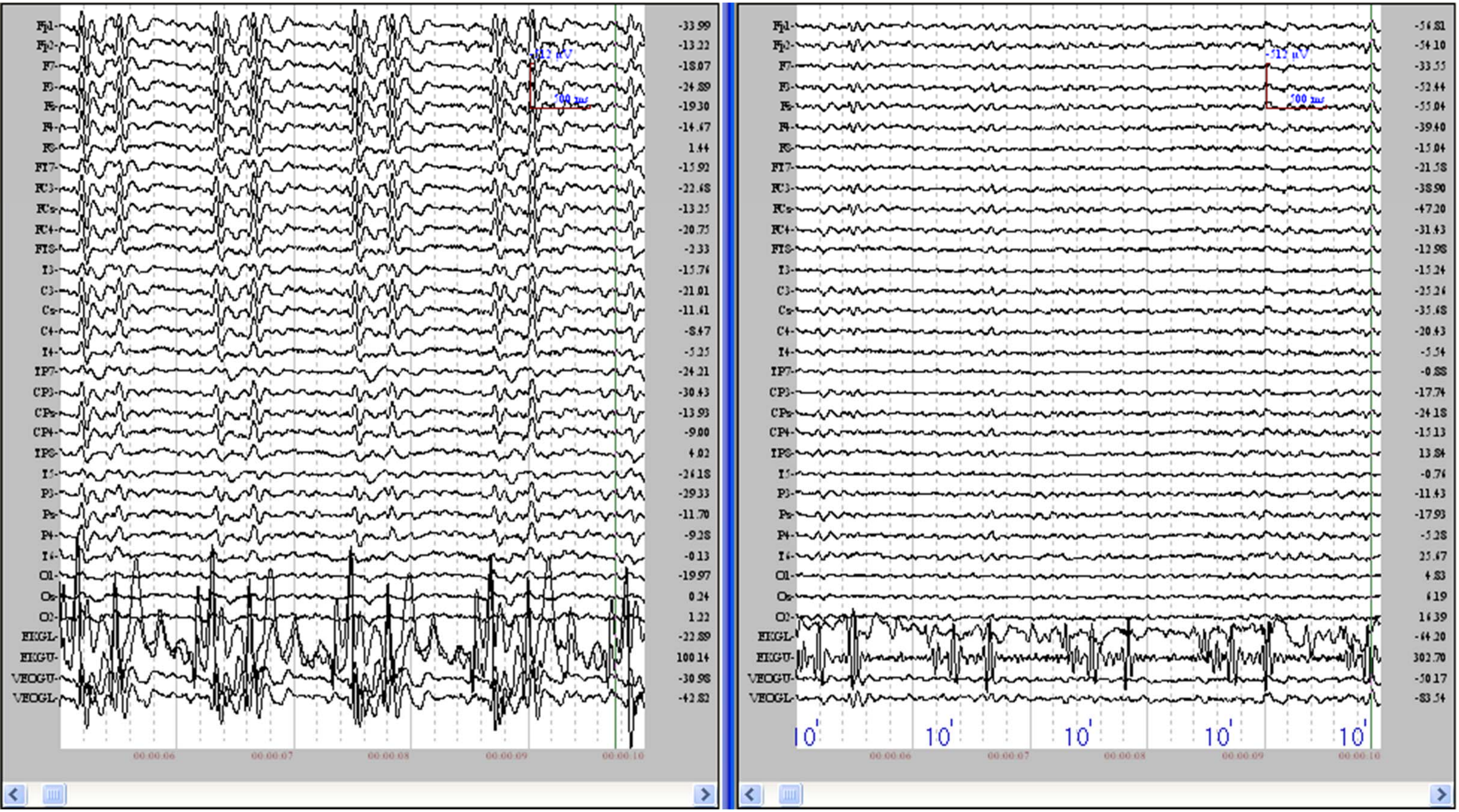
- Conductive
- Will not heat up
- Will not pose hazard in strong magnetic field
- Includes 5Kohm inline resistor to prevent any induced current from reaching the subject
- Includes Styrofoam head at no charge



Spontaneous EEG data obtained from a 3T scanner, with data on the left side shown prior to correction for the rf-pulse, and data on the right reflecting the correction.

By linking the trigger for the rf pulse with the EEG acquisition system, and knowing the rf pulse sequence parameters, software can model and remove the artifact, with the EEG signal preserved despite the large artifact that appears to overwhelm it.

Other artifact: Movement in the Magnetic Field



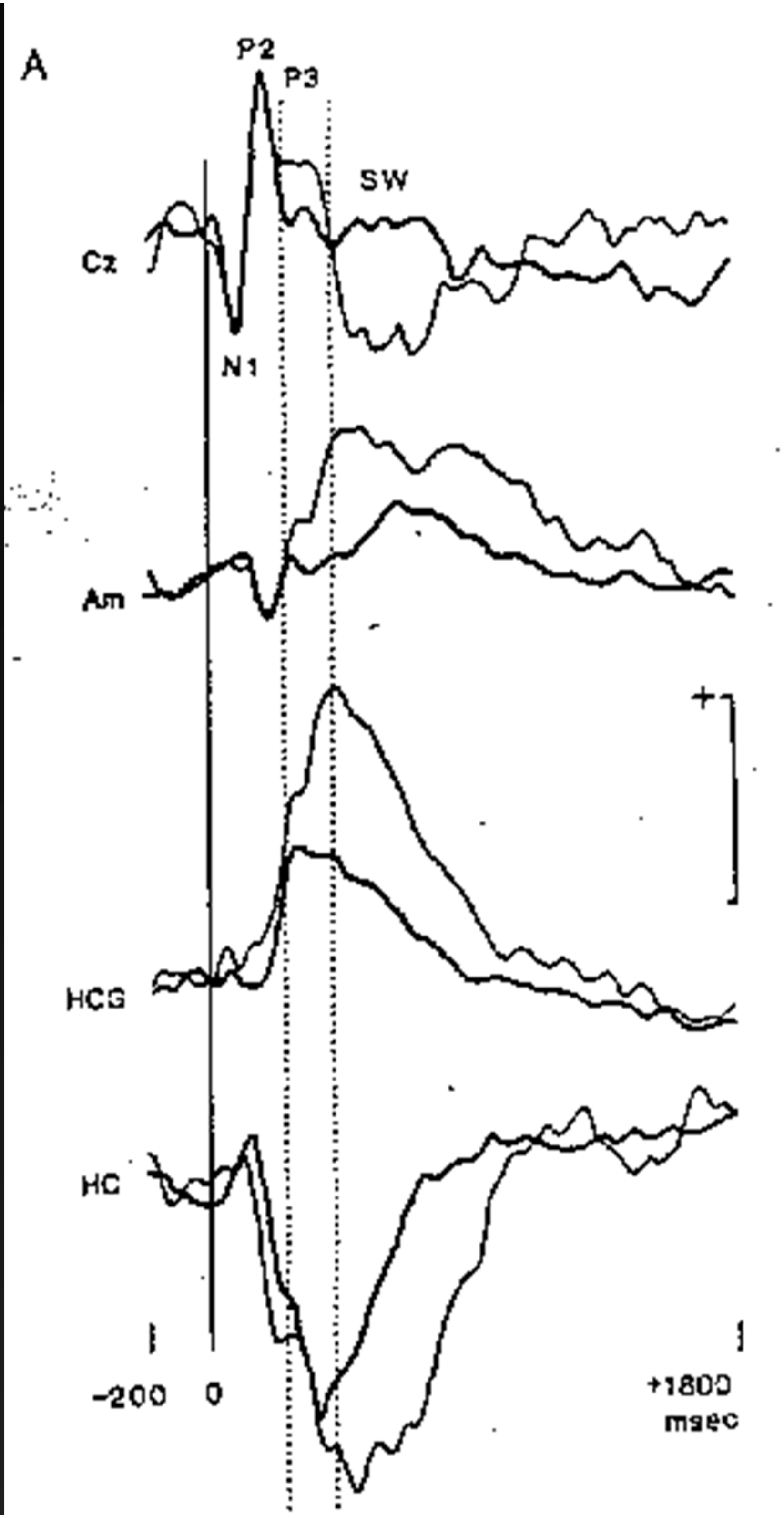
Pulsatile changes in blood flow with each heart beat create motion in the strong magnetic field that induces electrical current. Uncorrected spontaneous EEG data displayed on the left show clear ballistocardiogram artifact. On right, same data following ballistocardiogram artifact reduction. Note uncorrected EKG channel near the bottom of the panel.

Returning to ERP Lecture

New Handout

Sources of P3

- Likely distributed
- Candidates found in (nonexhaustive list):
  - 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!



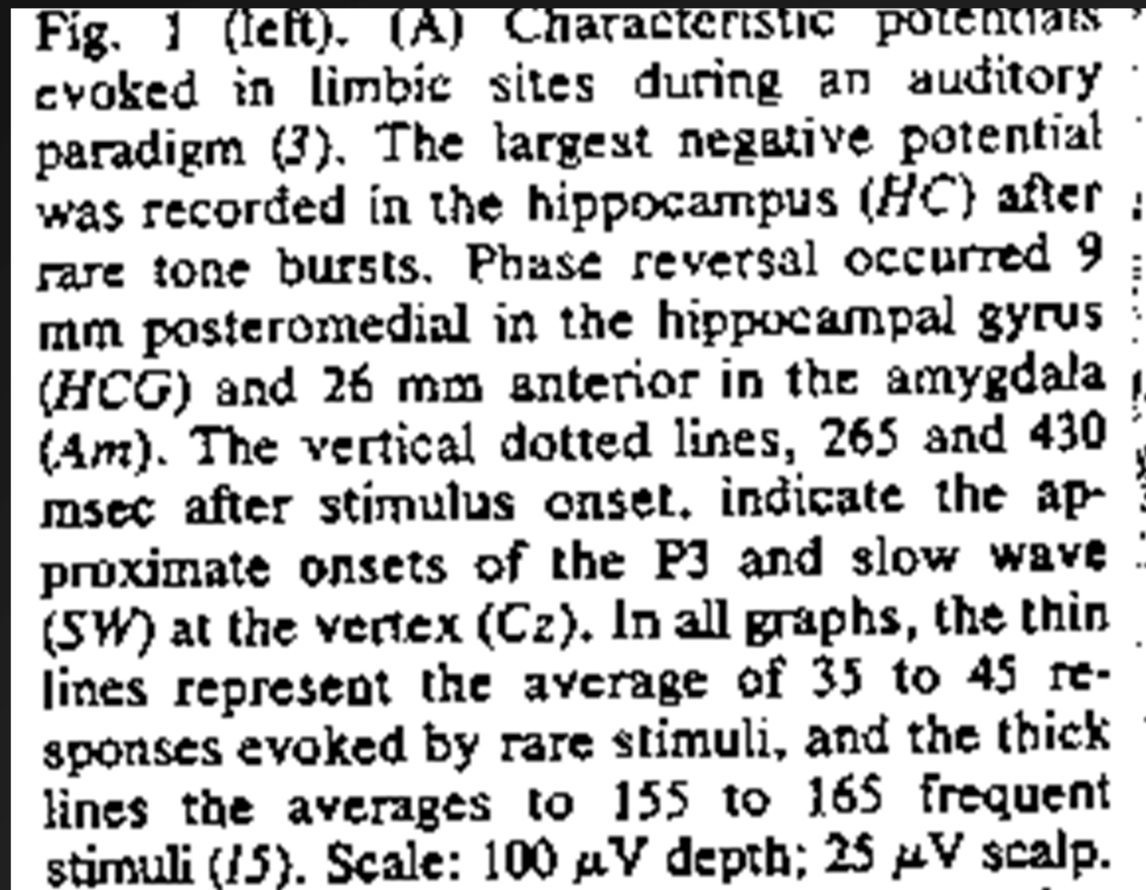
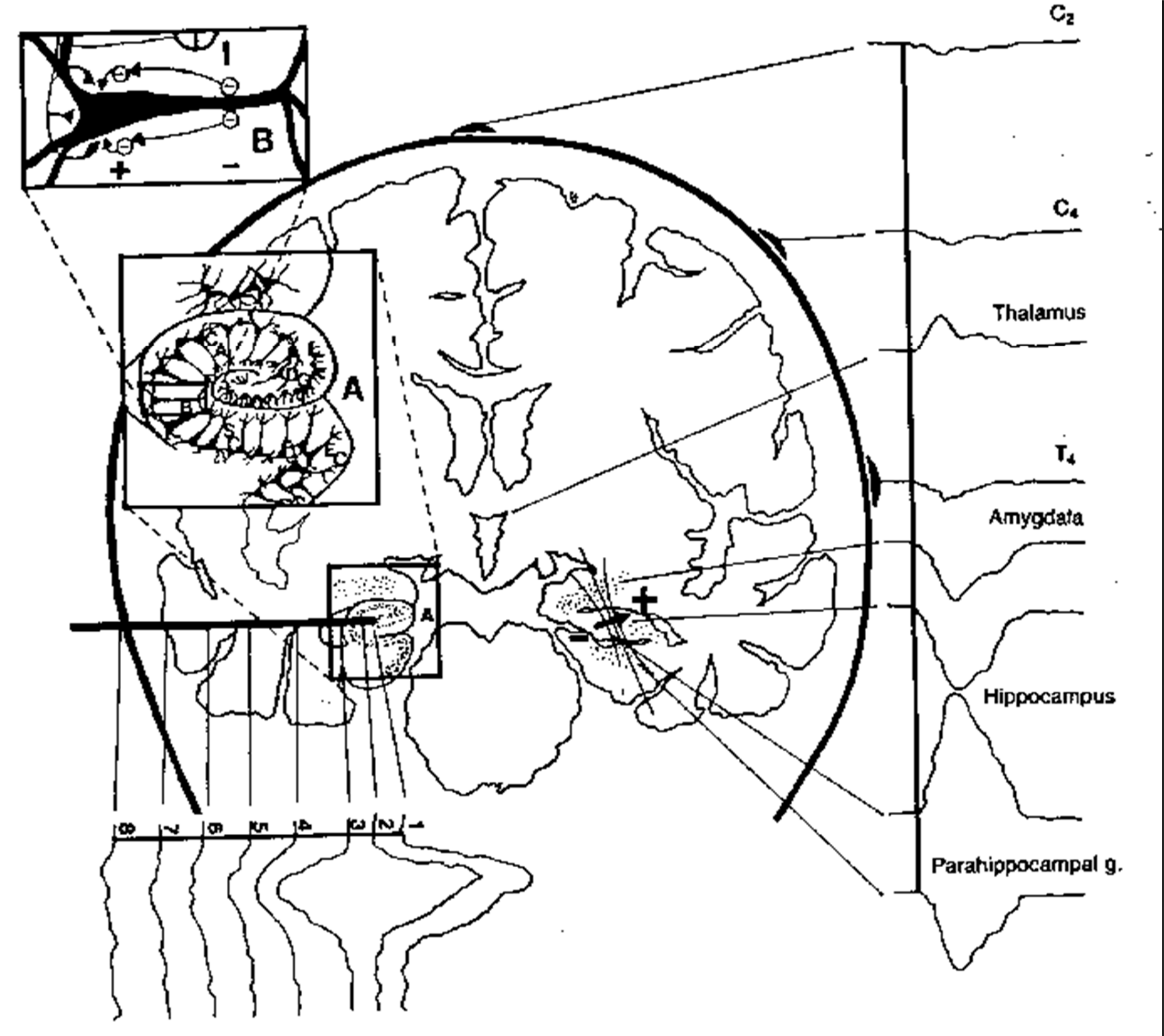


Fig. 1 (left). (A) Characteristic potentials evoked in limbic sites during an auditory paradigm (3). The largest negative potential was recorded in the hippocampus (*HC*) after rare tone bursts. Phase reversal occurred 9 mm posteromedial in the hippocampal gyrus (*HCG*) and 26 mm anterior in the amygdala (*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.

Halgren, *Science*, 1980



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

Electroencephalography and clinical Neurophysiology, 86 (1993) 408–417

EEG 92168

P300 from amnesic patients with bilateral hippocampal lesions

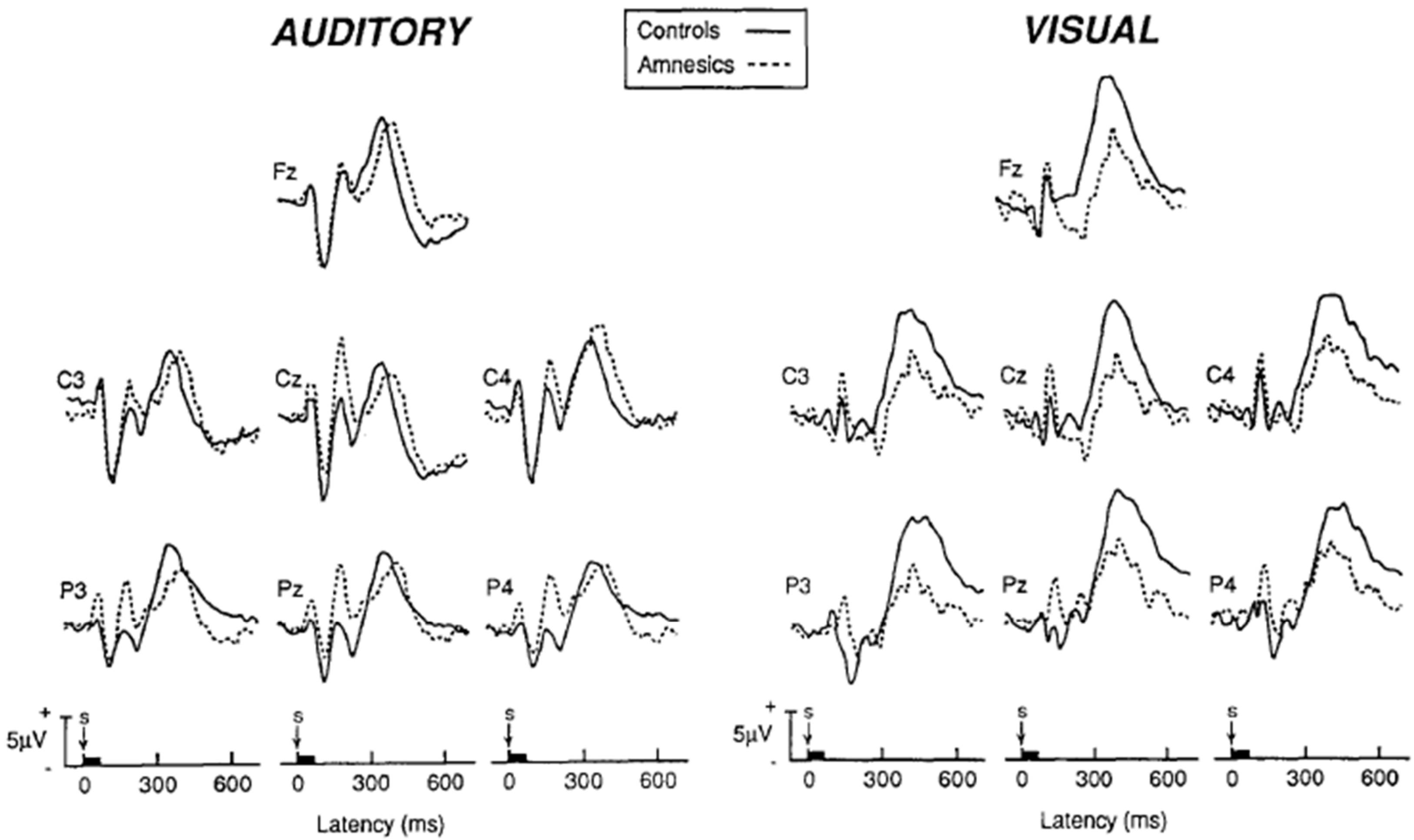
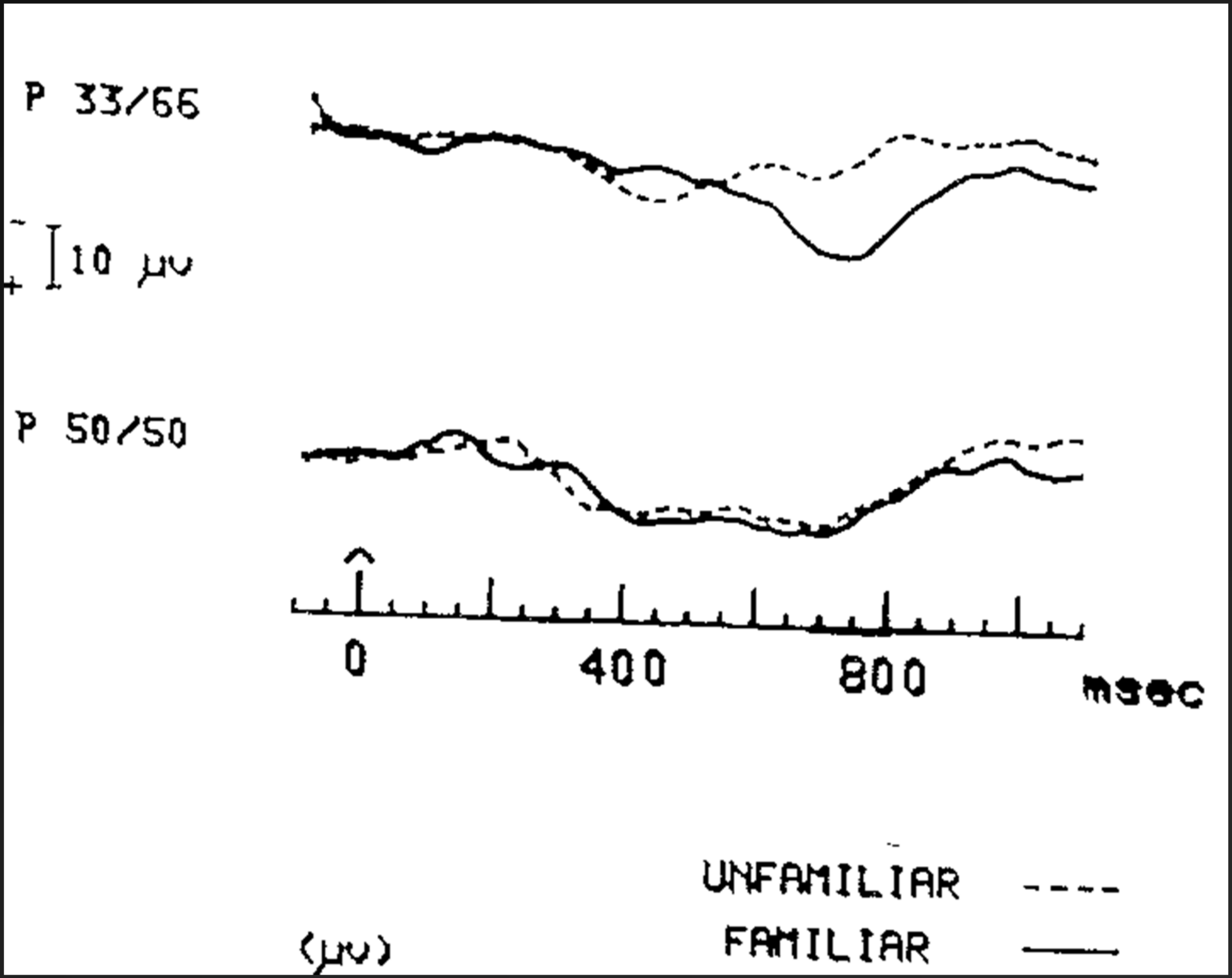


Fig. 2. Grand average ERPs from amnesic patients (n = 5) and control subjects (n = 20) obtained for each stimulus modality and electrode position. For bottom row, S is stimulus onset and the black bar denotes stimulus duration.

P3 without awareness? Assessing Recognition in Prosopagnosia



Renault et al.

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

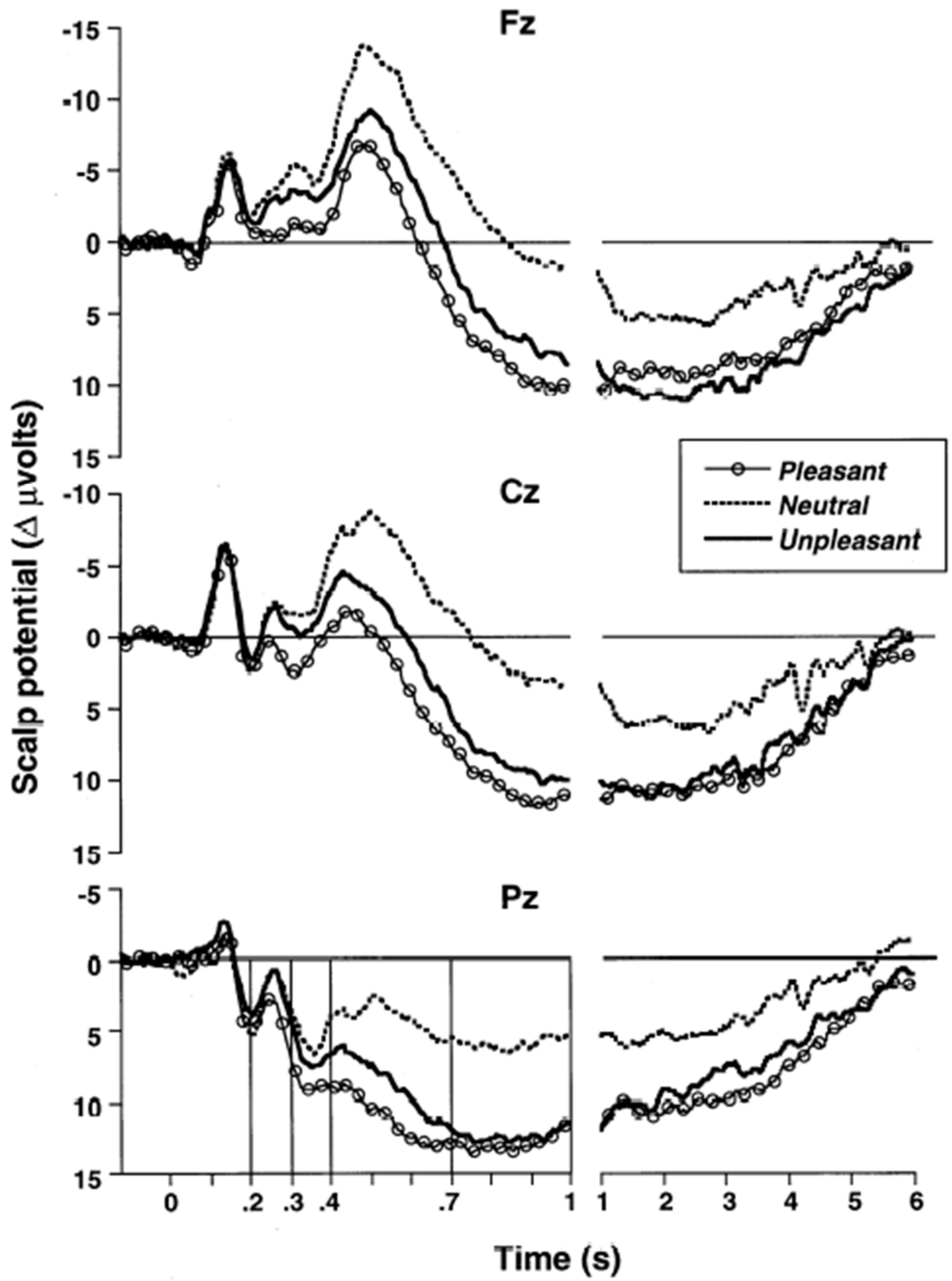


Fig. 1. Stimulus synchronized grand average ERP waveforms for Fz, Cz, and Pz electrodes during viewing of affective pictures, separately for each valence category (pleasant, neutral and unpleasant). The left panel illustrates the picture onset potentials on a finer time scale, and the vertical lines 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),
Psycholophysiology

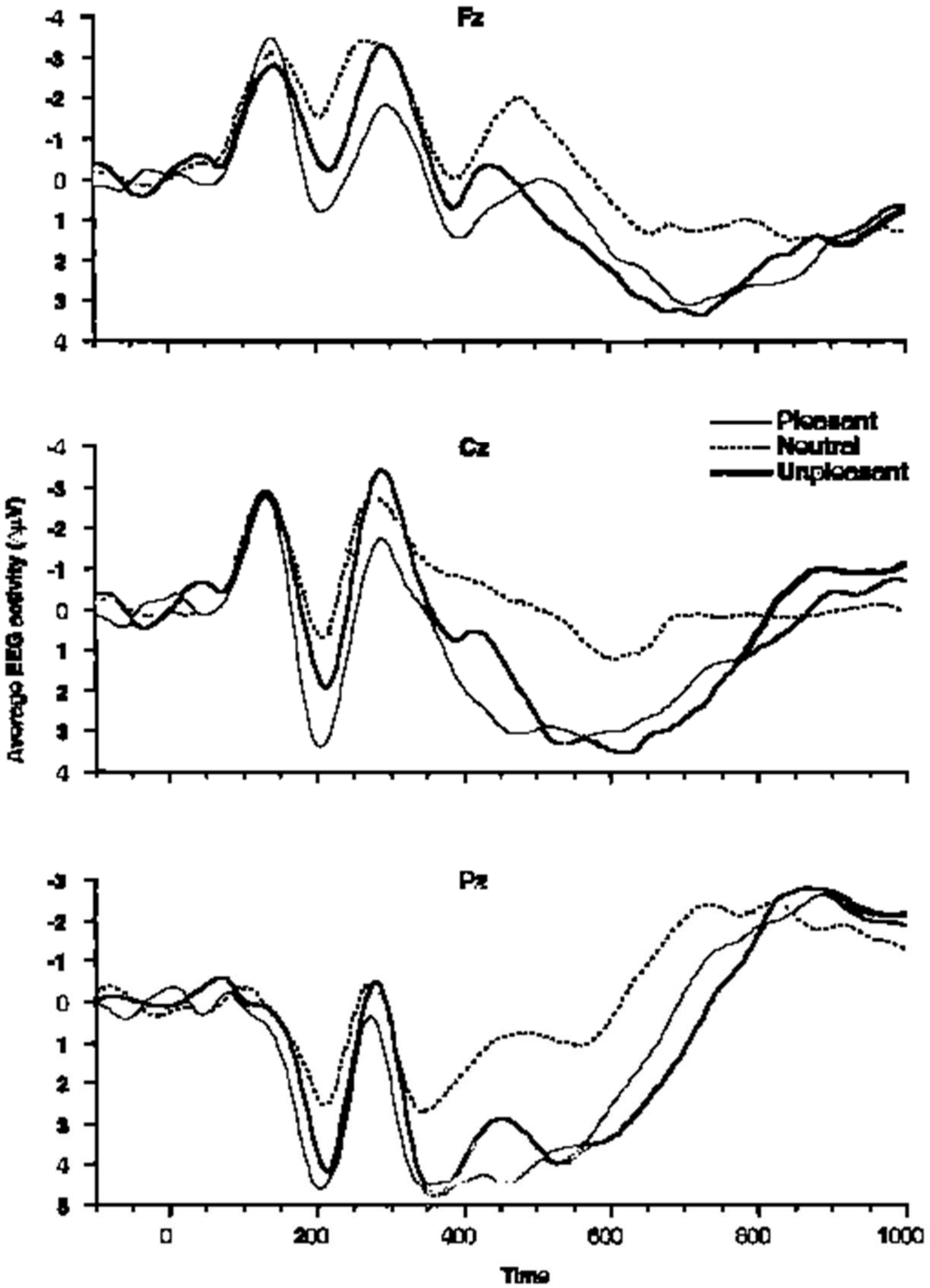
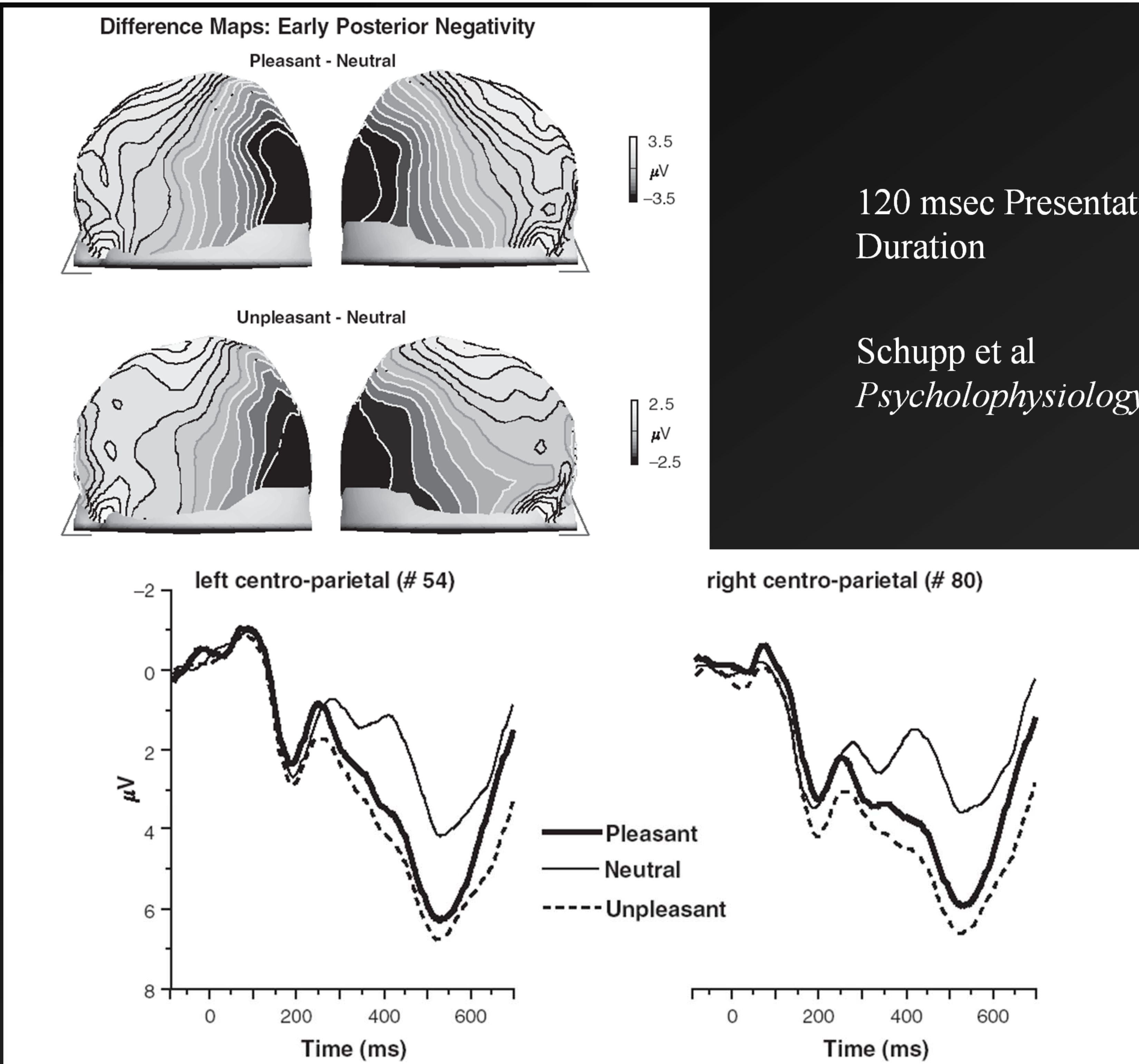


Figure 1. Picture onset synchronized grand-average event-related potential (ERP) waveforms for each valence category (pleasant, neutral, and unpleasant) from midline electrodes Fz, Cz, and Pz.

1.5 sec Presentation Duration

Cuthbert et al (2000), *Biological Psychology*



120 msec Presentation Duration

Schupp et al
Psycholophysiology

ERPS and Implicit Affective Processing

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

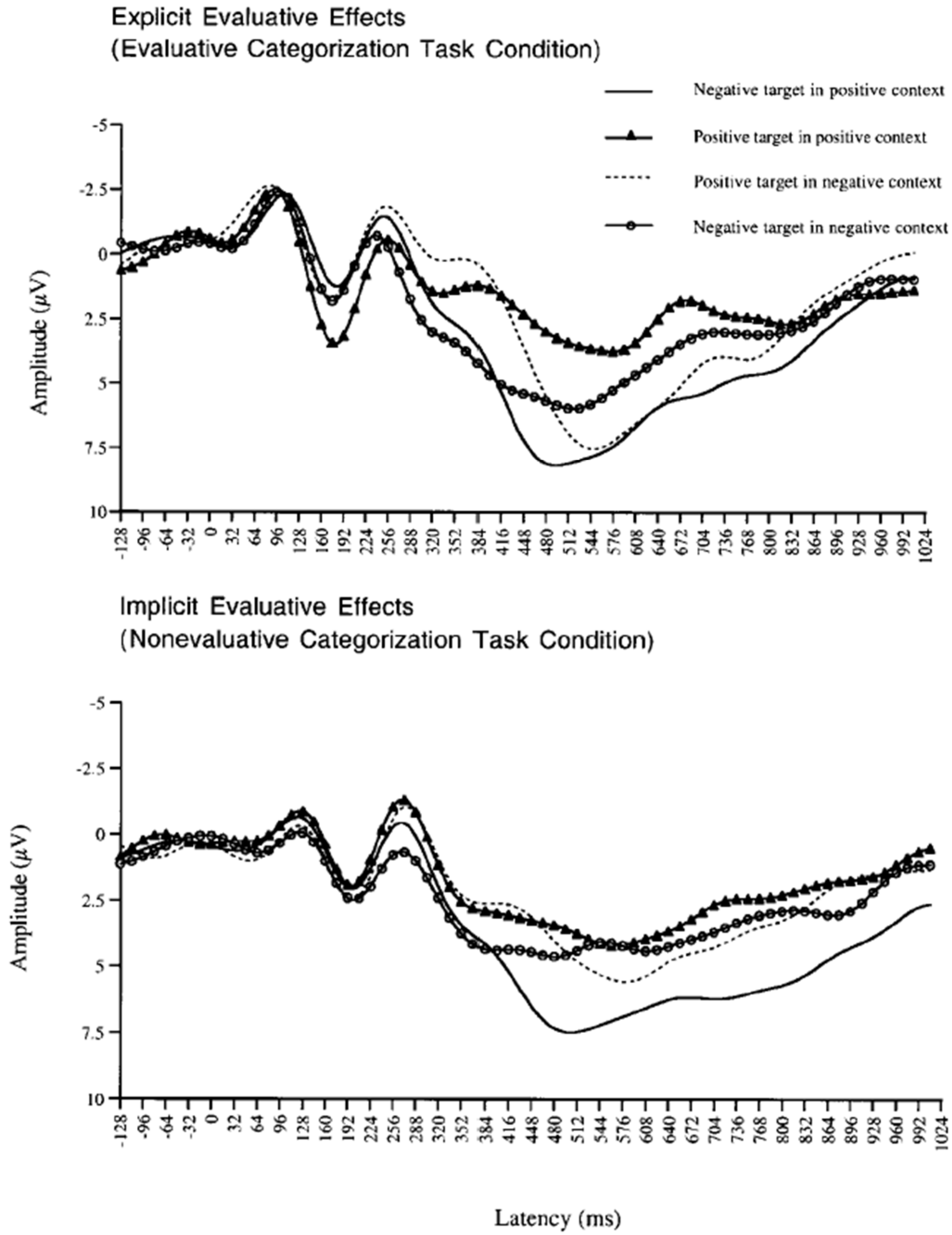


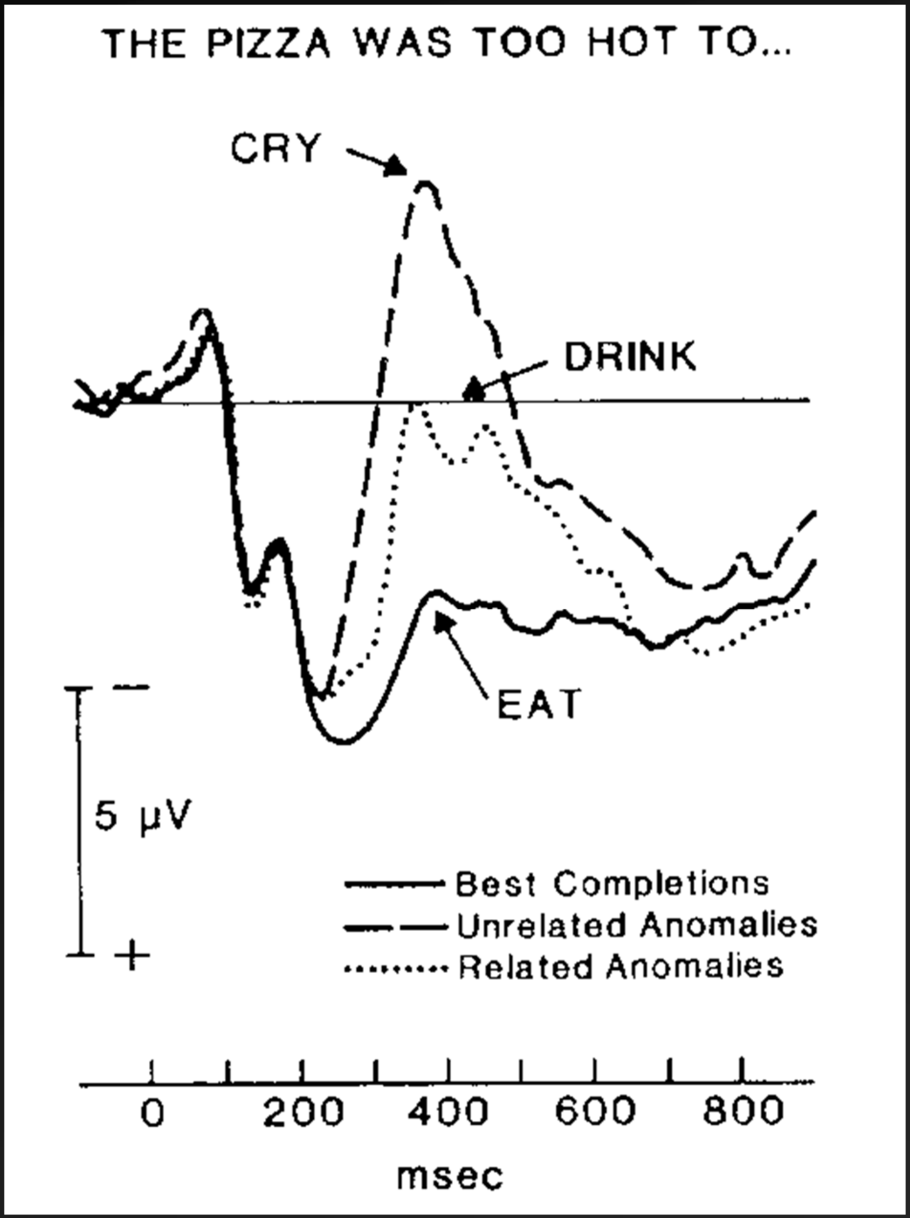
FIG. 2. Averaged event-related potential waveforms at electrode Pz as a function of target and context valence. The top panel depicts explicit evaluative categorization effects (data from participants in the evaluative task condition). The bottom panel depicts implicit evaluative categorization effects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

Explicit – categorize as positive or negative

Implicit – categorize as with or without people

Ito & Cacioppo (2000) *JESP*

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

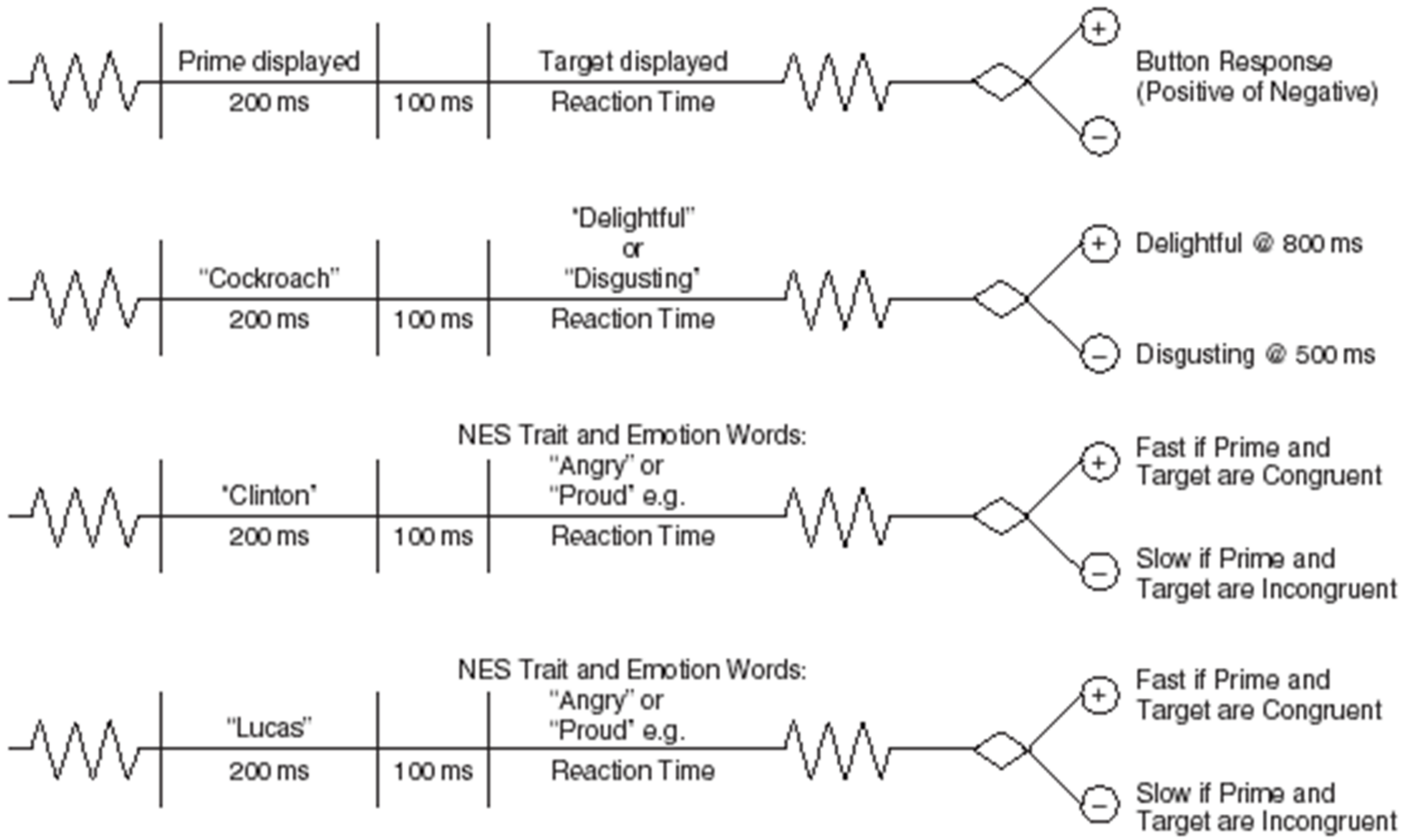


Figure 2. Attitude-priming paradigm and examples of its use.

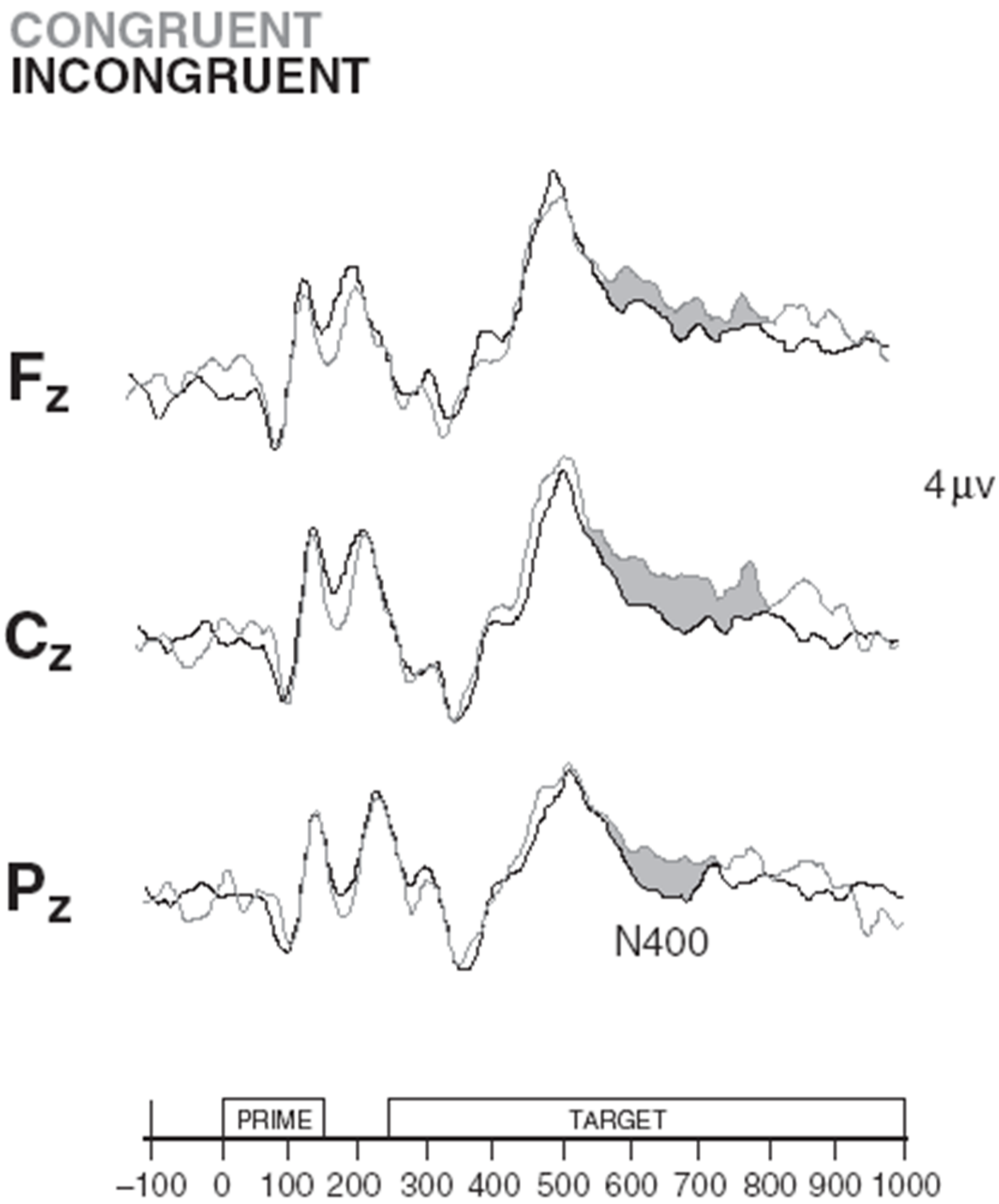
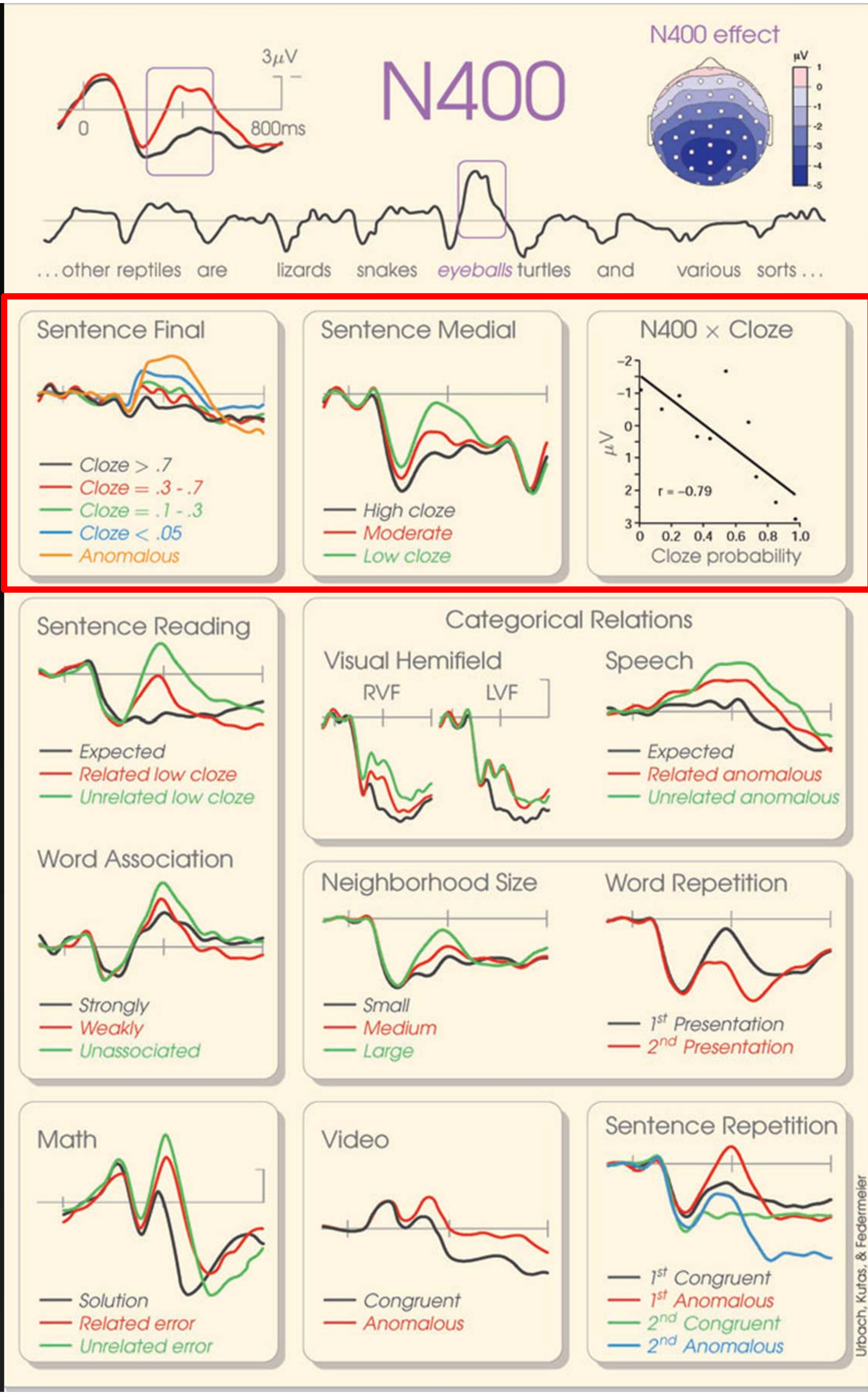


Figure 4. ERPs to congruent and incongruent prime/target pairs.

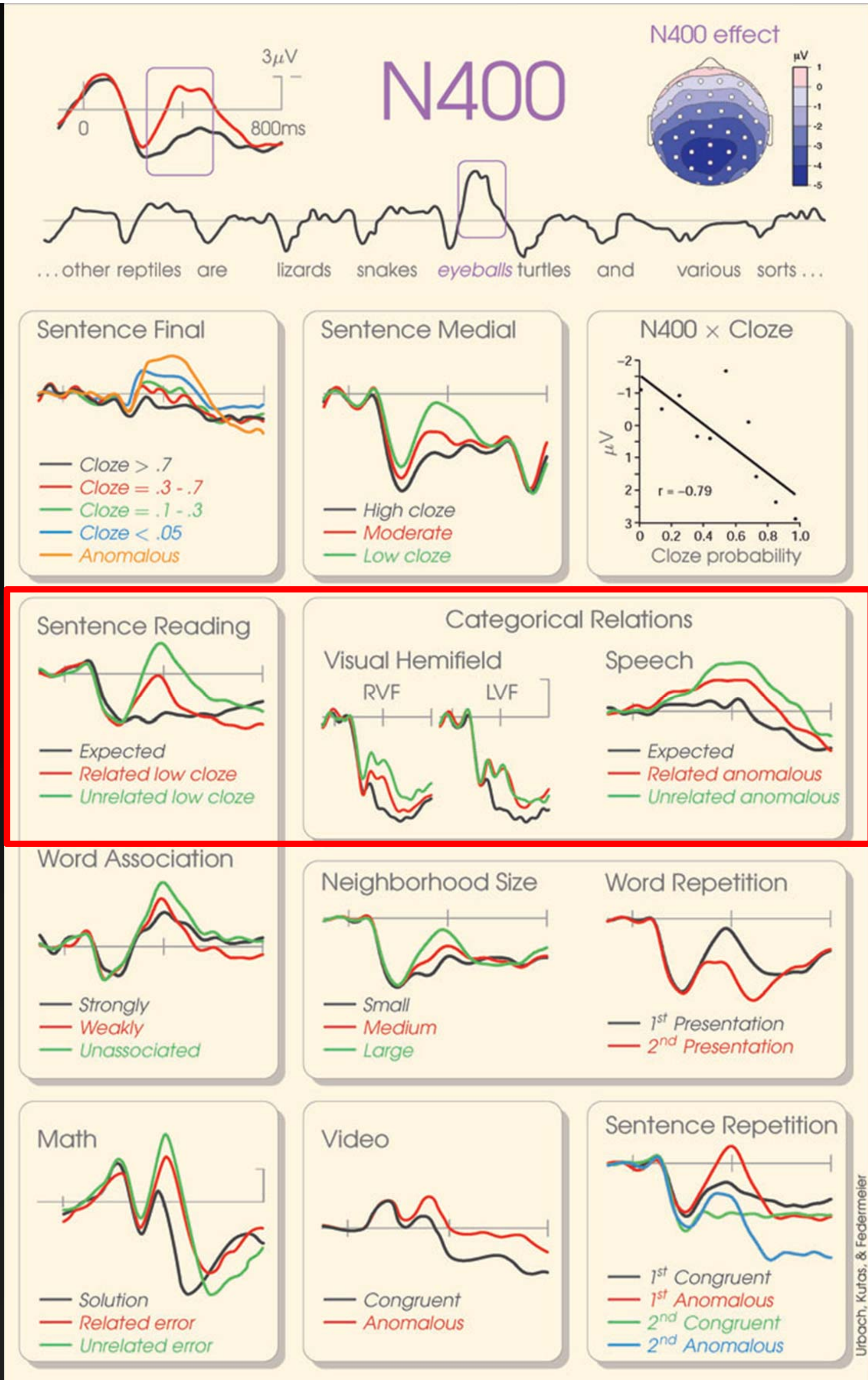
Congruent or incongruent defined base in idiographic data from pretest

Morris Squires et al. *Political Psychology* 2003



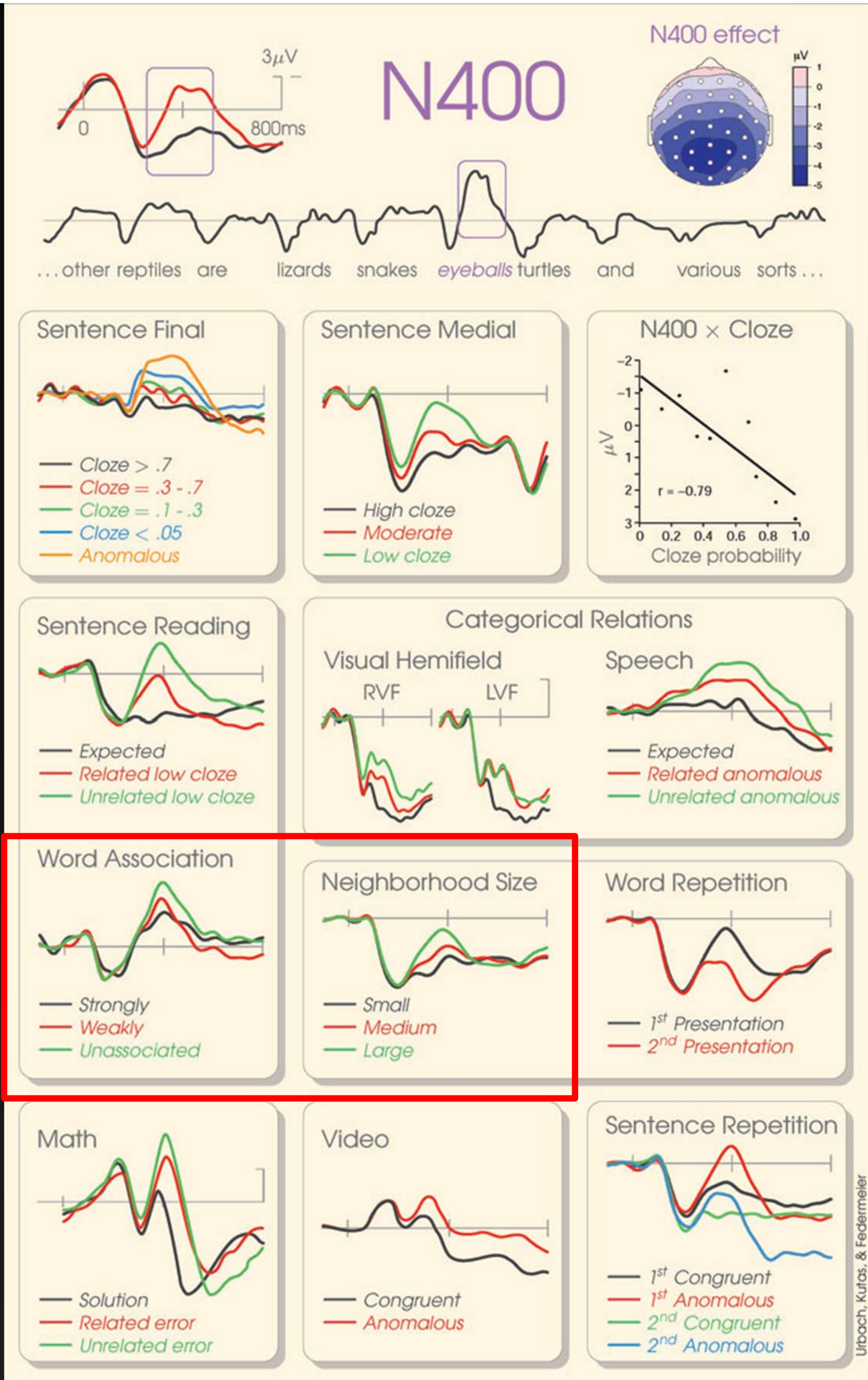
- Cloze probability: proportion of respondents supplying the word as continuation given preceding context
- N400 reflects unexpected word given the preceding context
- This is independent of degree of contextual constraint
- Larger N400
  - Low cloze, Contextual constraint high:
    - *The bill was due 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



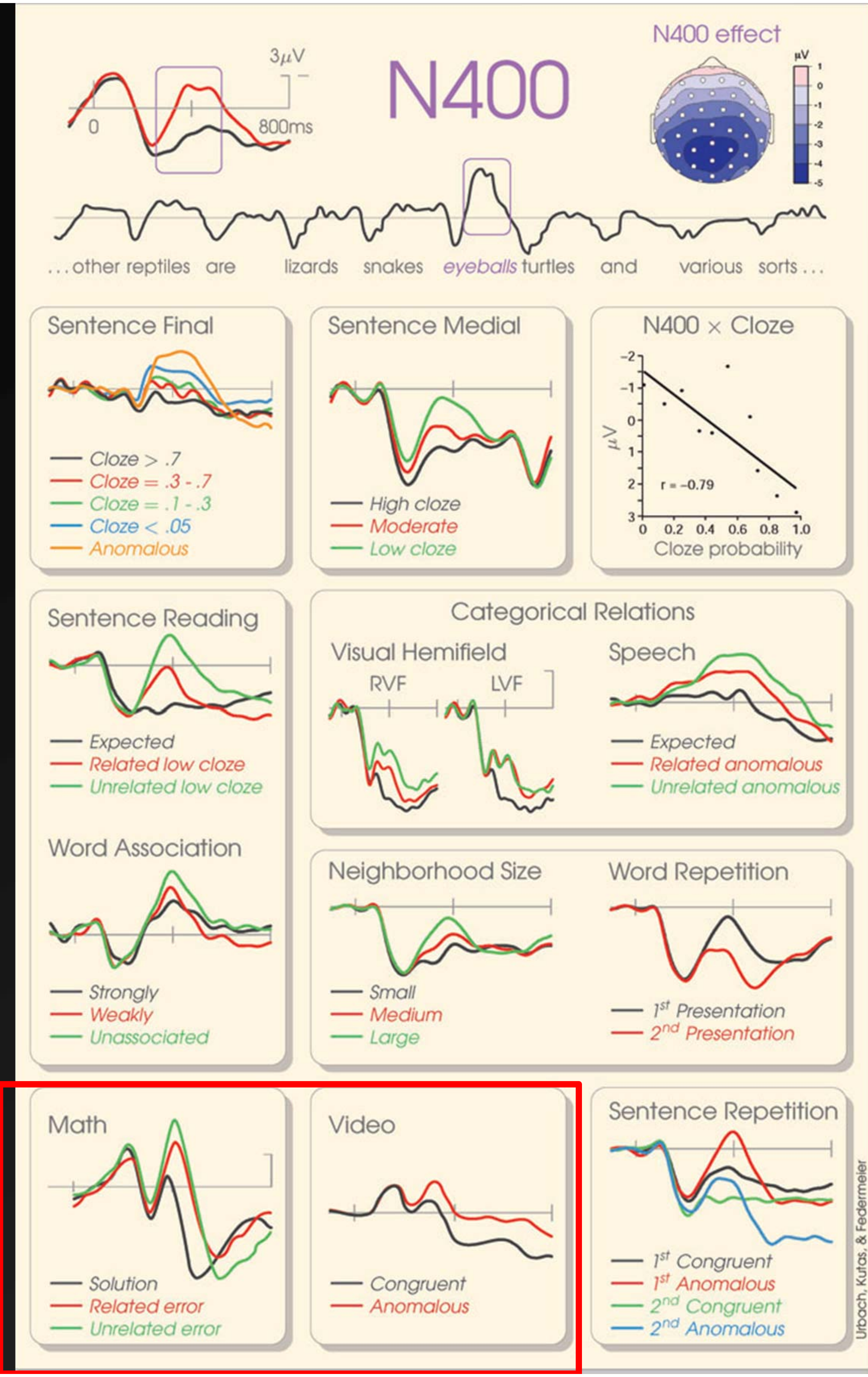
- Sentence completion
  - Best (expected) ending *small*
  - Unexpected but related *larger*
  - Unexpected and unrelated *largest*
- Categorical relations … sentence final word is:
  - an expected category exemplar
  - an unexpected, implausible exemplar from the same category as the expected one (related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

Kutas & Federmeier, 2011



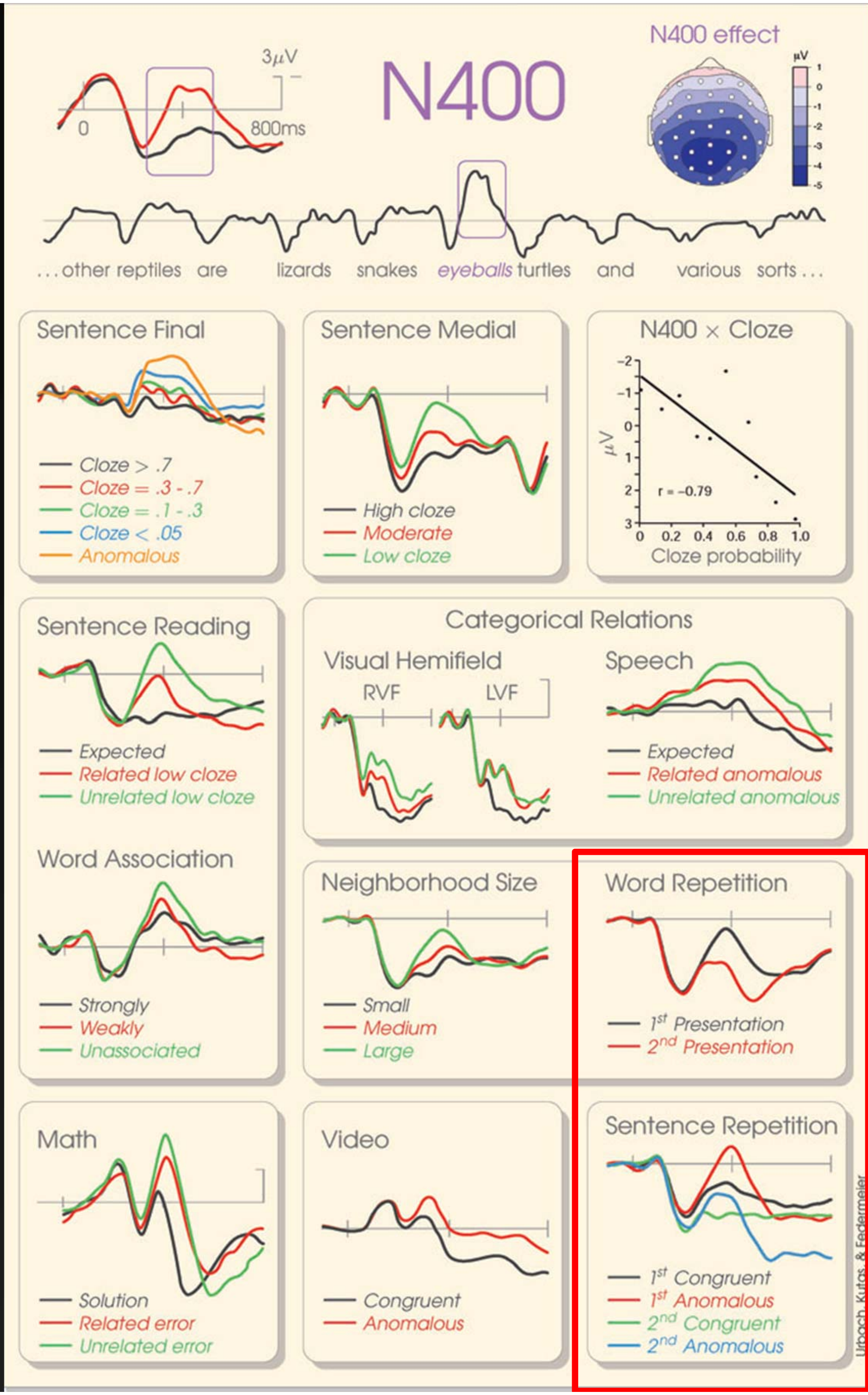
- Word Association, with second word in pair
  - Unrelated to first (*eat door*)
  - Weakly related to first (*eat spoon*)
  - Strongly related to first (*eat drink*)
- Orthographic neighborhood size
  - Words that share all but one letter in common with particular word
  - Large ‘hood (e.g., slop) – *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



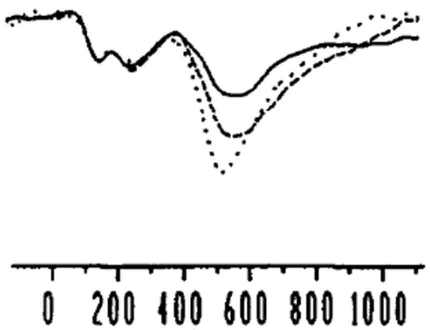
- Repetition effects
  - Repetition creates contextual familiarity, reduced processing demands
  - N400 thus useful in studying memory
  - Appears additive with incongruency effects

Kutas & Federmeier, 2011

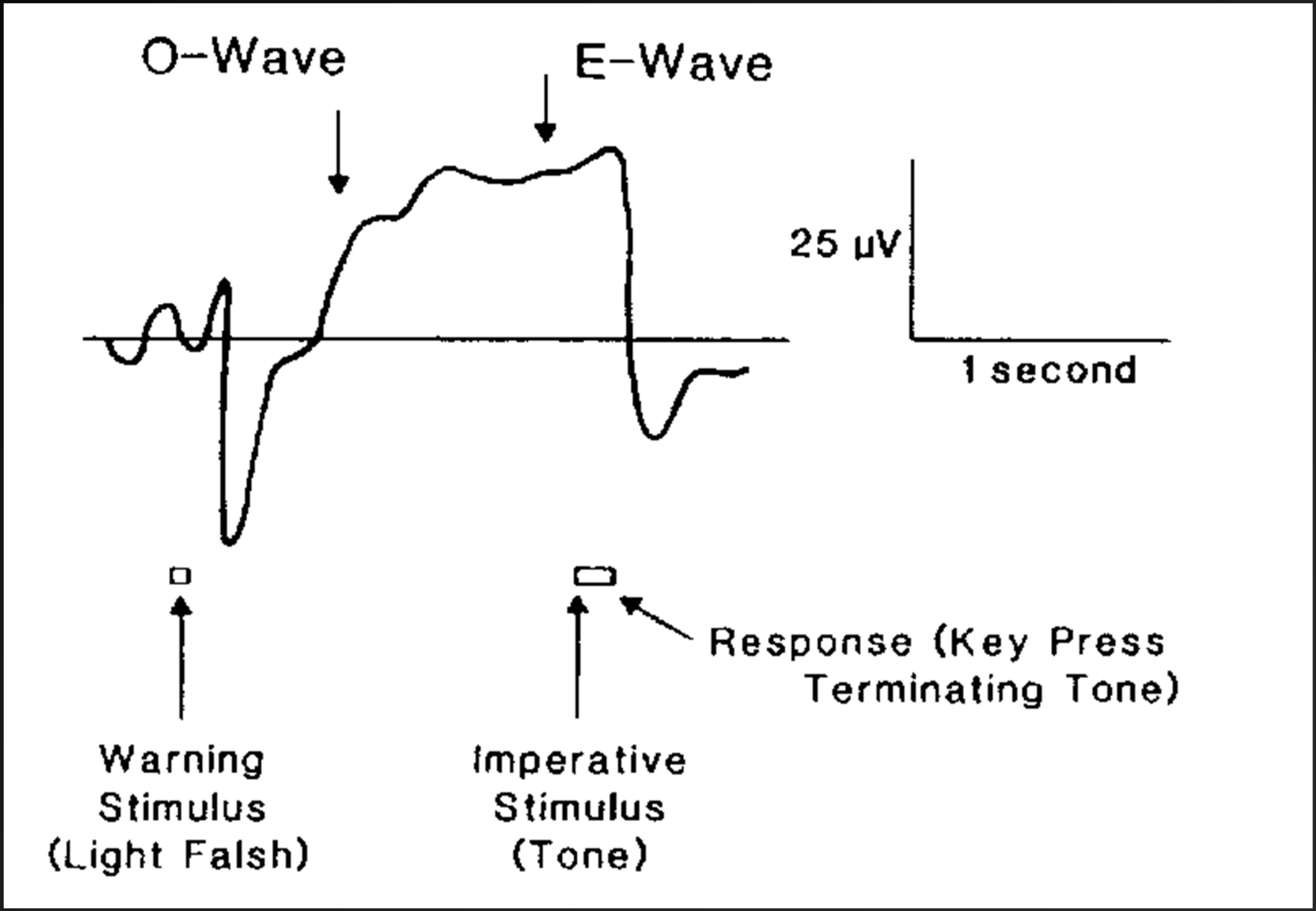
N400 – The Unexpected Hero!

Before Release

LH-NoAmn LH-SimAmn HH-NoAmn HH-Amn



Contingent Negative Variation



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

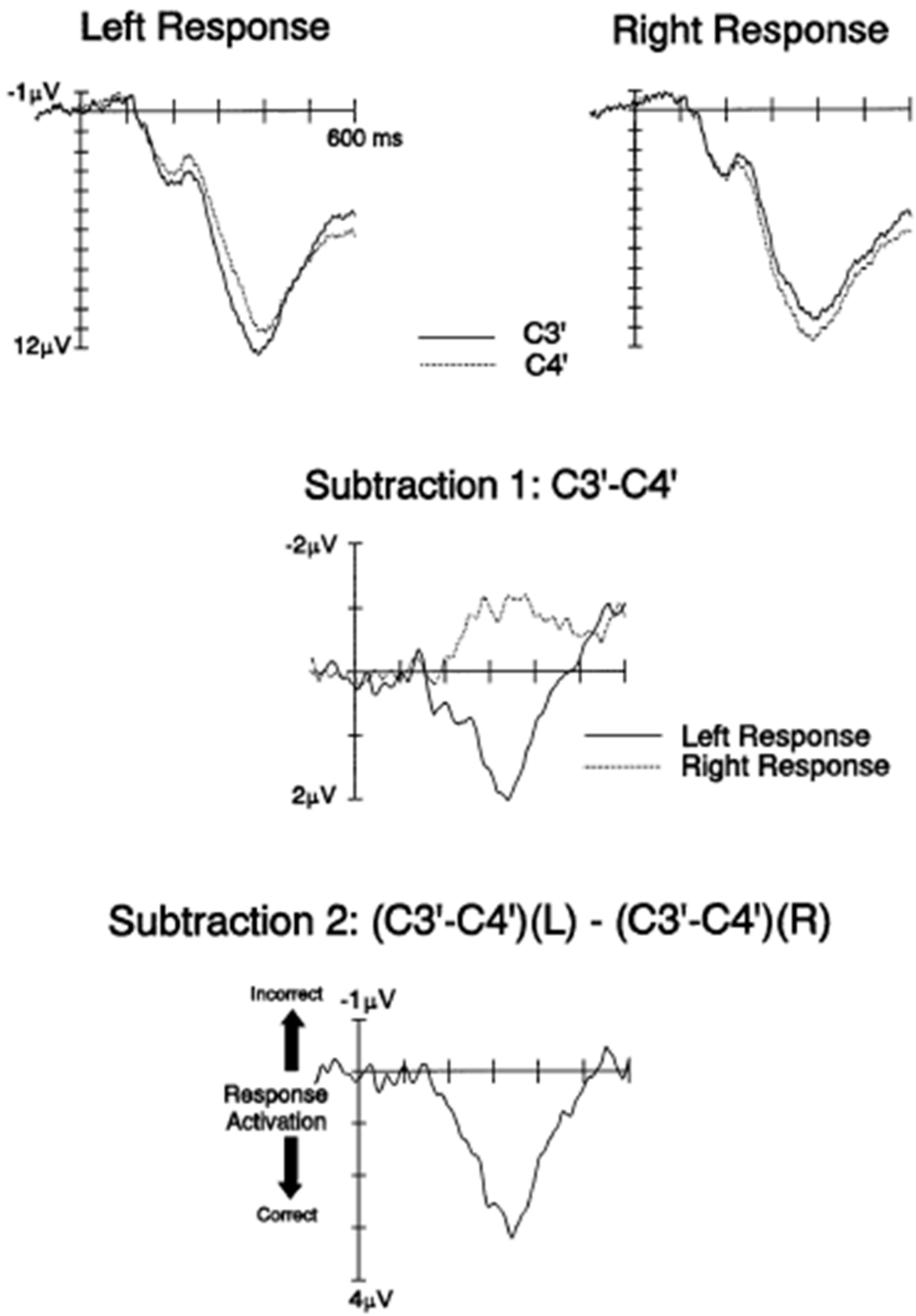
Response-locked potentials

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

148 EIMER

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

Response conflict in the LRP

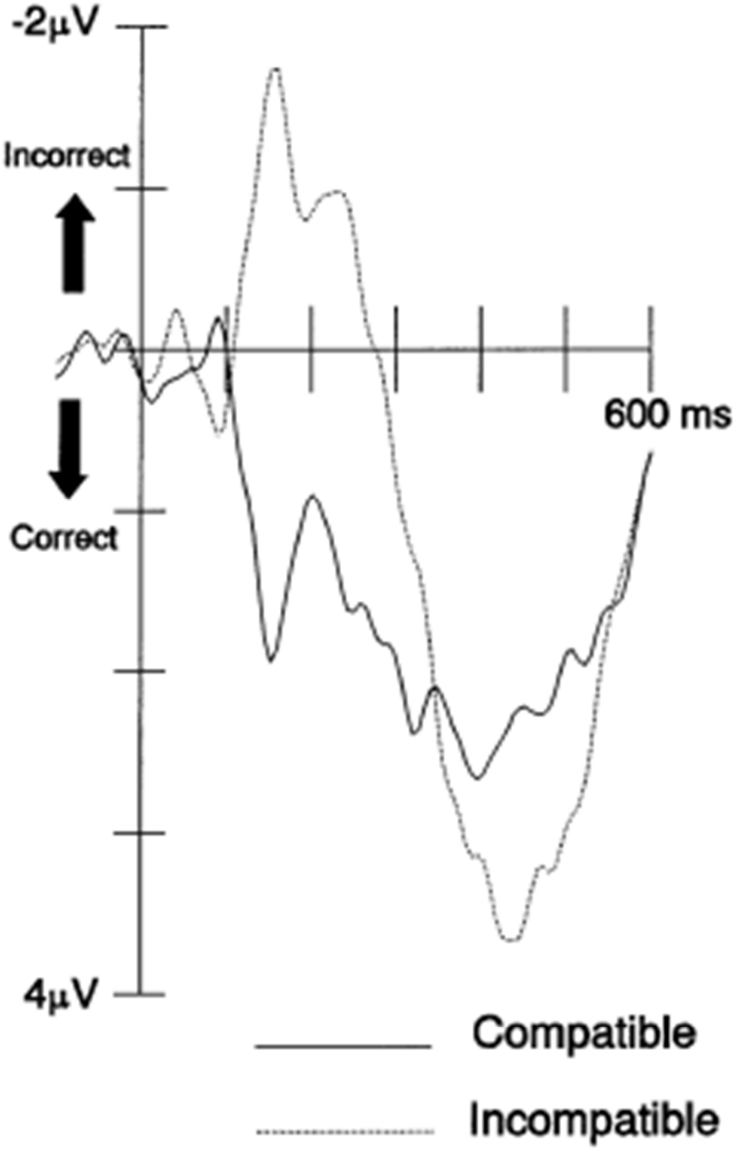


Figure 2. Top: Examples of stimulus displays in an experiment on spatial stimulus–response compatibility (Eimer, 1993, Experiment 1a) in which stimulus and response sides could either be compatible (left side) or incompatible (right side). Bottom: Grand-averaged LRP waveforms from 10 subjects, elicited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

Eimer 1998, *Beh Res Methods*

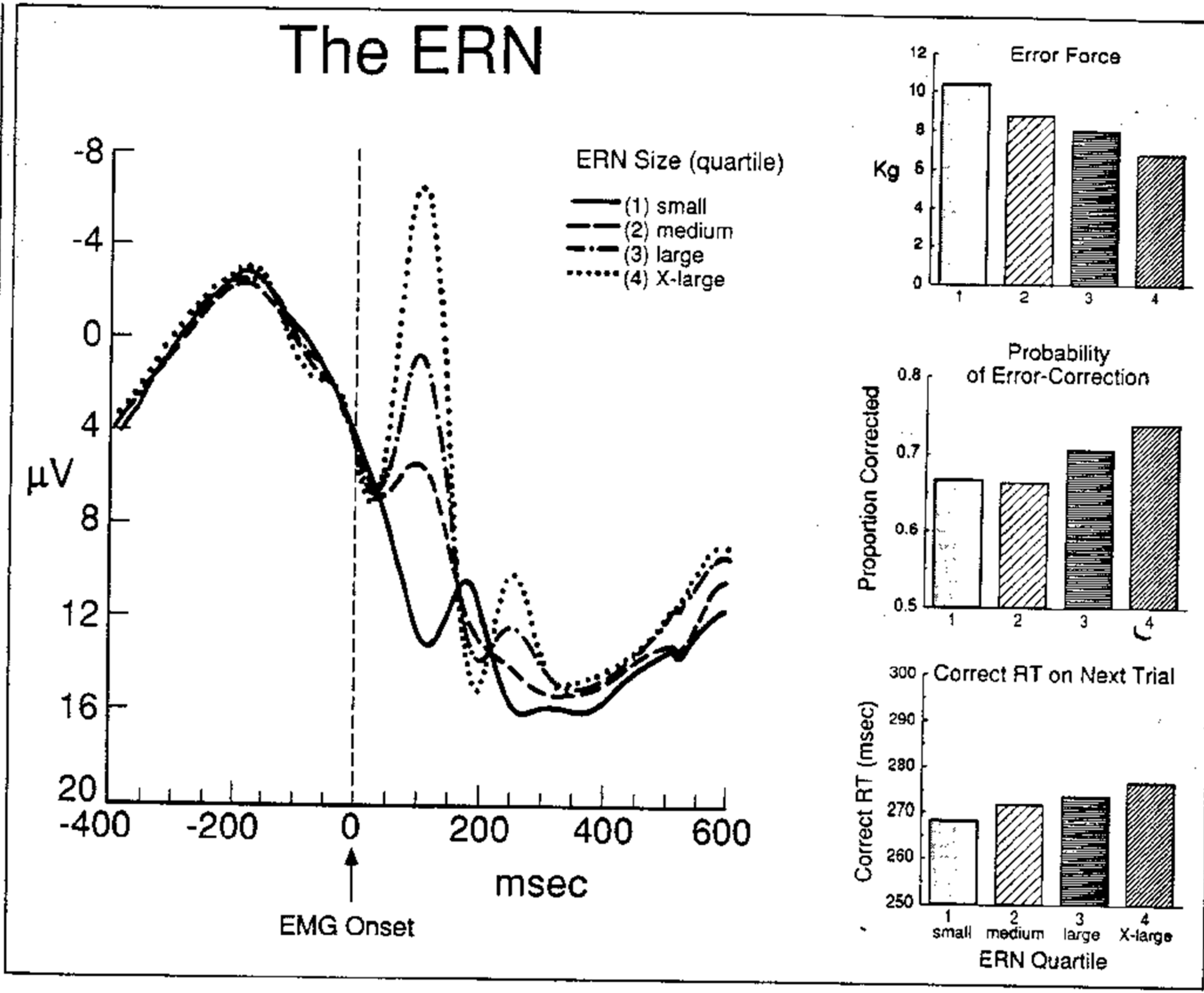


Fig. 3. Relationship between error-related negativity (ERN) amplitude and three measures of compensatory behavior. Left panel: Average event-related potentials at the C_z electrode as a function of the four levels of the posterior probability measure of ERN amplitude. Right panel, top: Error squeeze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

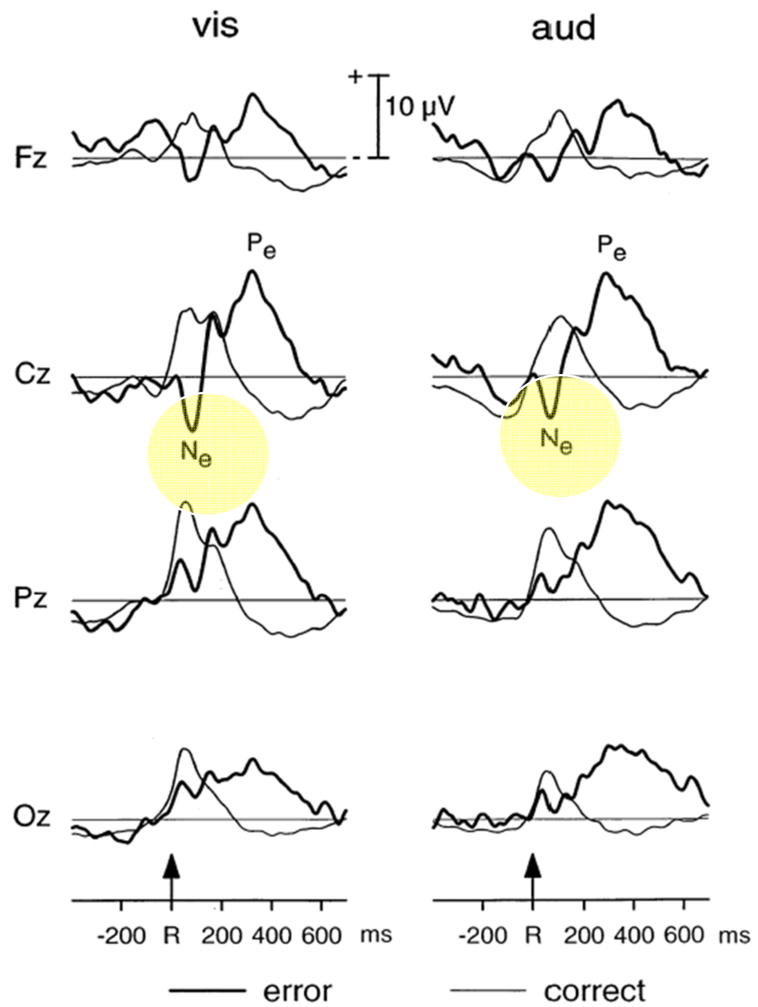
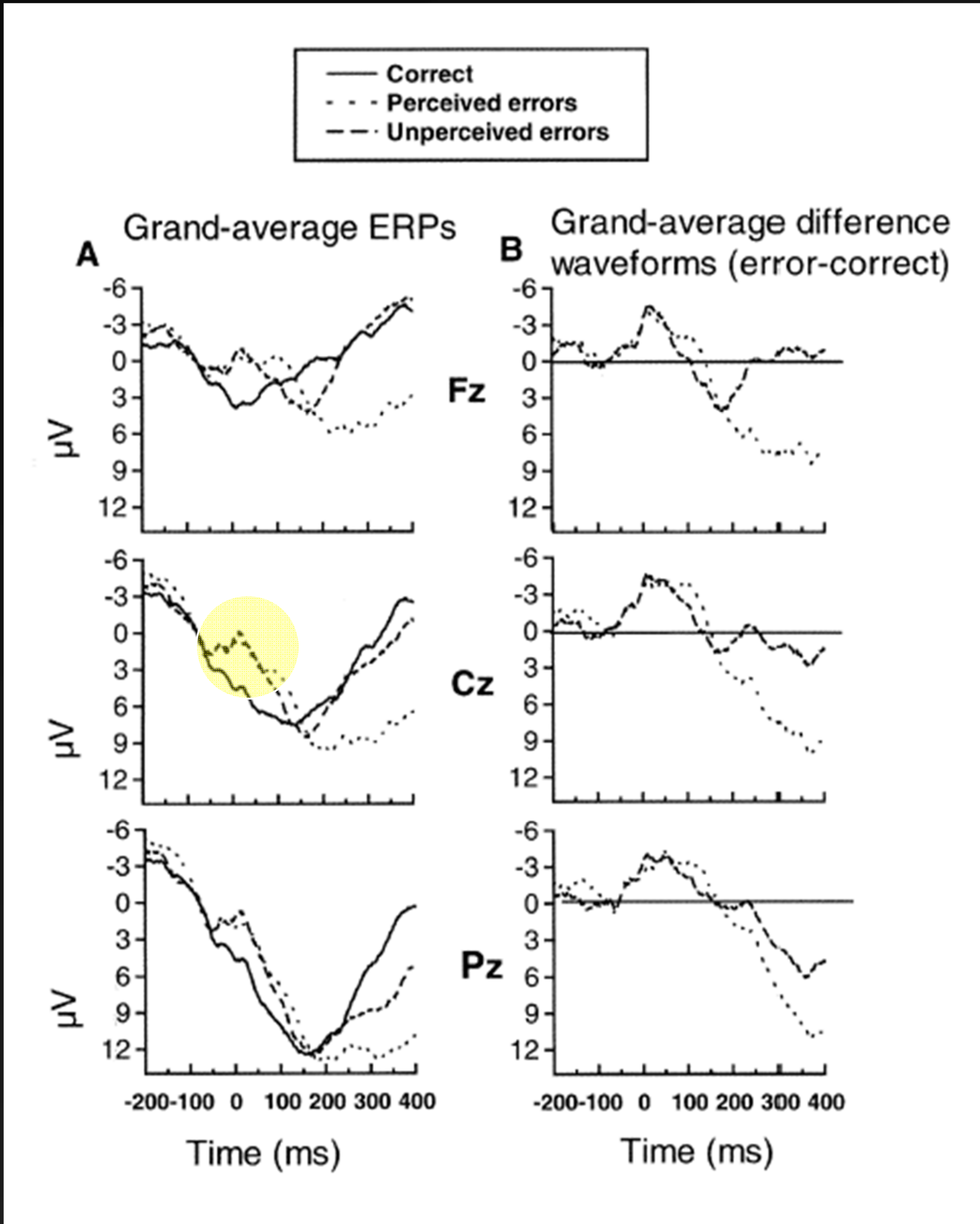


Fig. 1. Grand averages (Experiment 4; $n = 12$) of the RTA for errors (heavy lines) and correct trials (light lines) after visual (vis) and auditory letter stimuli (aud) in a 2-CR task. The error negativity ('Ne') is seen as a sharp negative deflection with central maximum peaking at about 80 ms after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

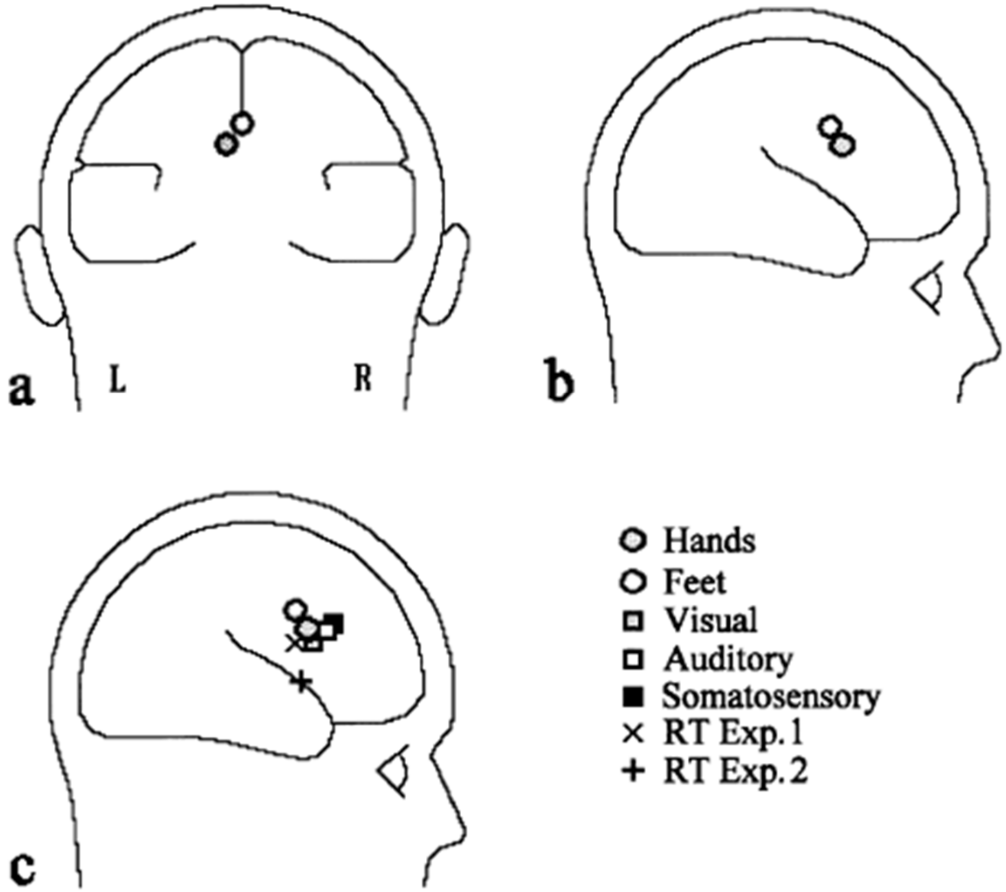


Fig. 2. Source localization of the error-related negativity. Circles represent locations of sources determined for hand and foot responses: (a) coronal view; (b) sagittal view; (c) for comparison, source locations of the ERN determined in previous studies are depicted along with the locations of the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

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… press only for X following X

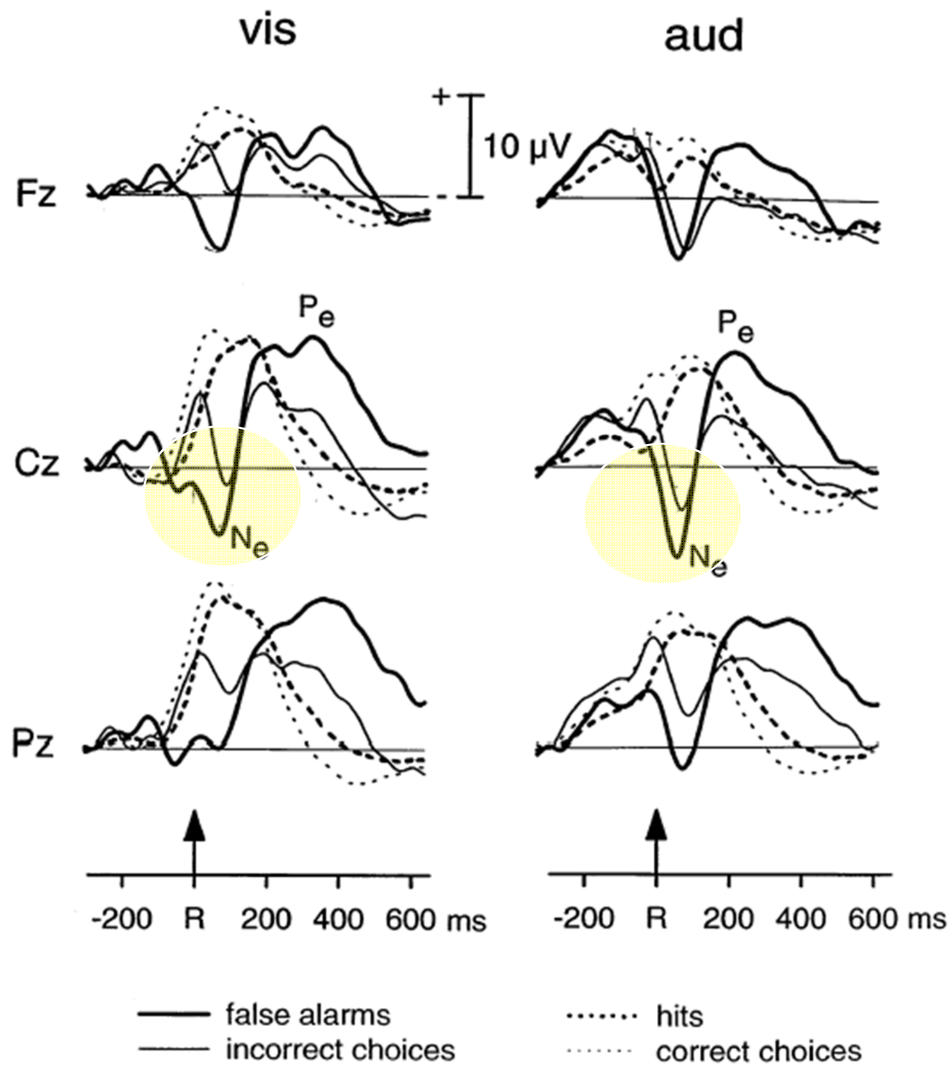


Fig. 5. Grand averages (Experiment 2; $n = 10$) of the RTA for false alarms and hits in Go/Nogo tasks (heavy lines), and choice errors and correct choice trials in two-way choice tasks (thin lines). Errors continuous lines, correct responses broken lines. The Ne is delayed relative to the incorrect key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

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

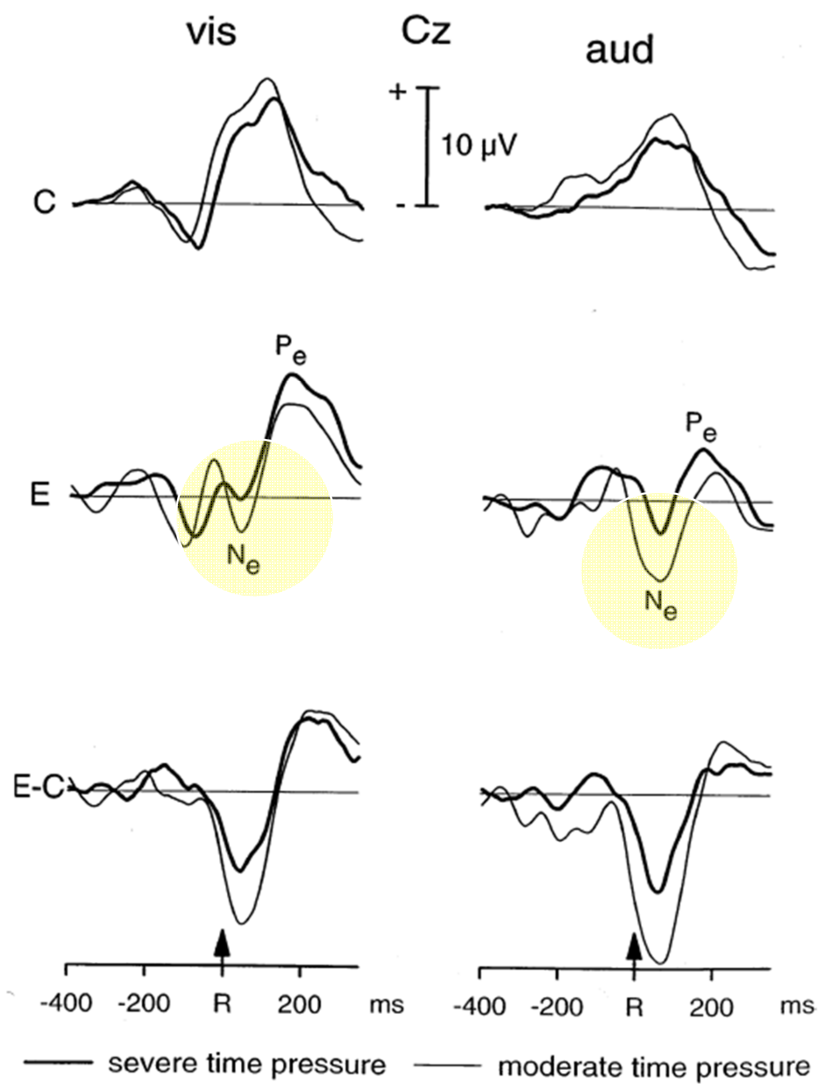


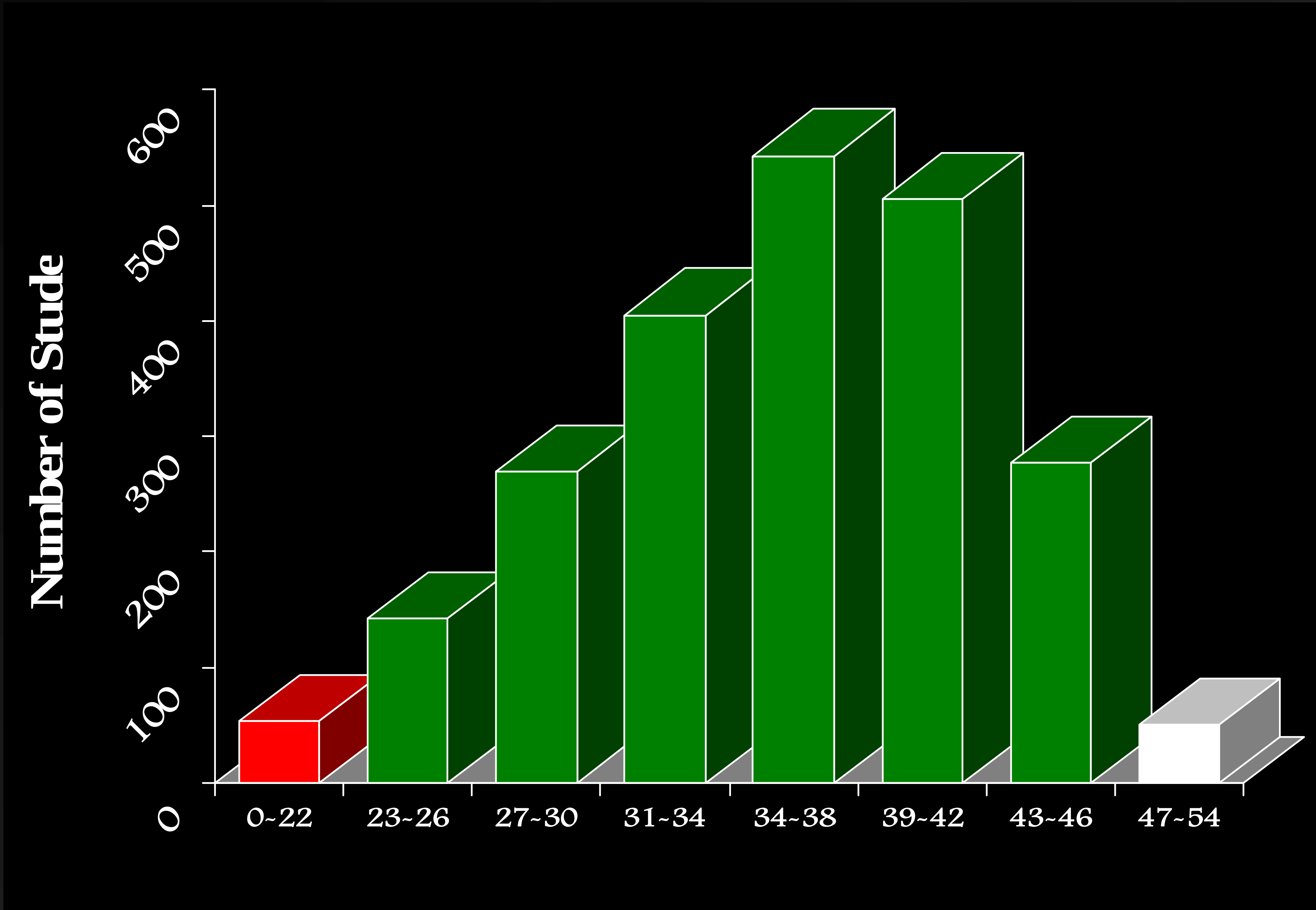
Fig. 4. Grand averages (Experiment 1; $n = 9$) of the RTA for correct responses (C), errors (E), and difference waveshapes (error minus correct; E – C) in a 2-CR task under moderate (light lines) and severe time pressure (heavy lines). The error rates were 15% (moderate) and 30% (severe); the number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



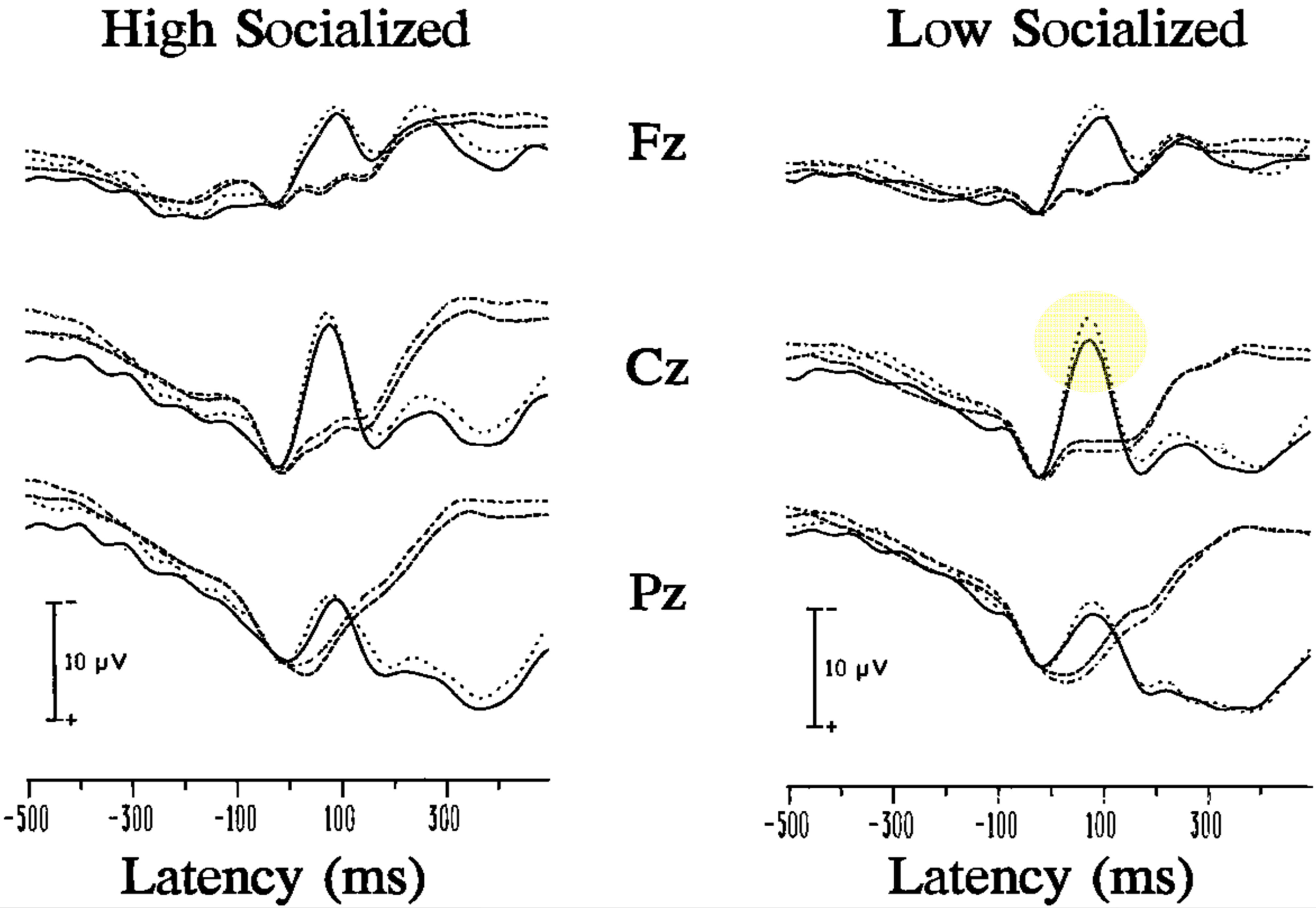
Thirty participants selected: 15 high SO

15 low SO

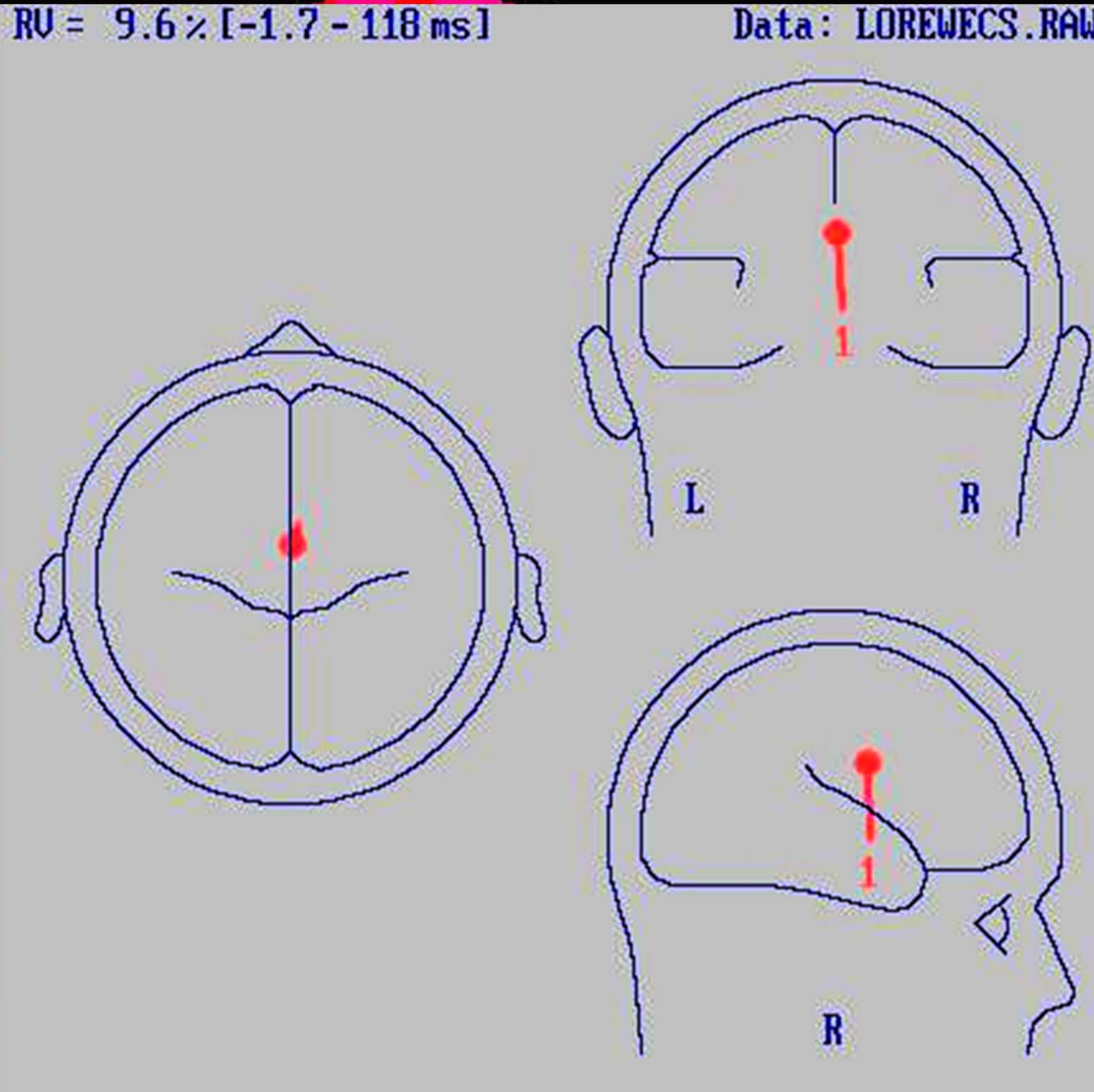
Dikman & Allen, 2000, *Psychophysiology*

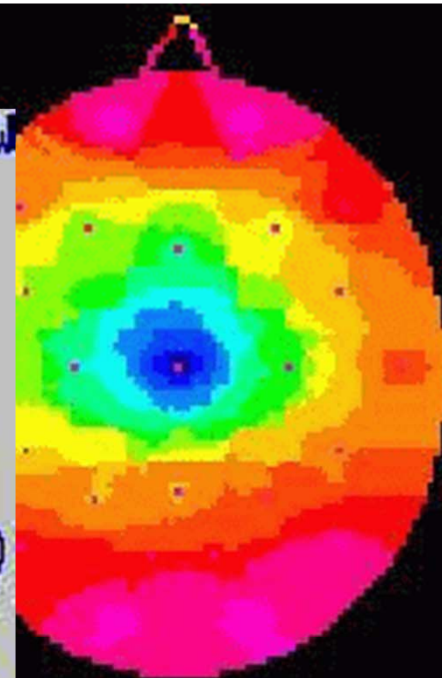
Procedure

- 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

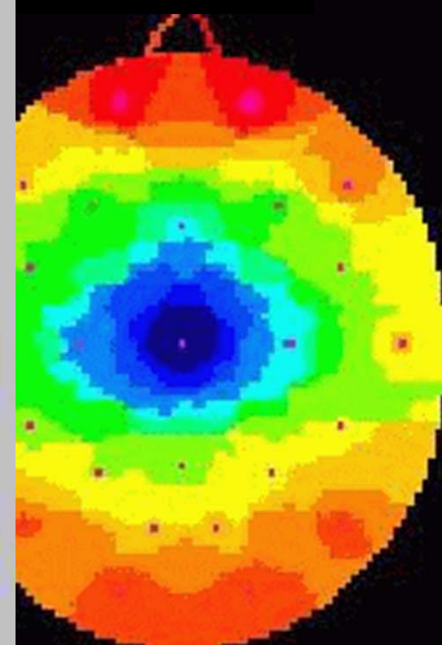


Dikman & Allen, 2000, *Psychophysiology*





Rew



Results re matched trials

ERN in OCD

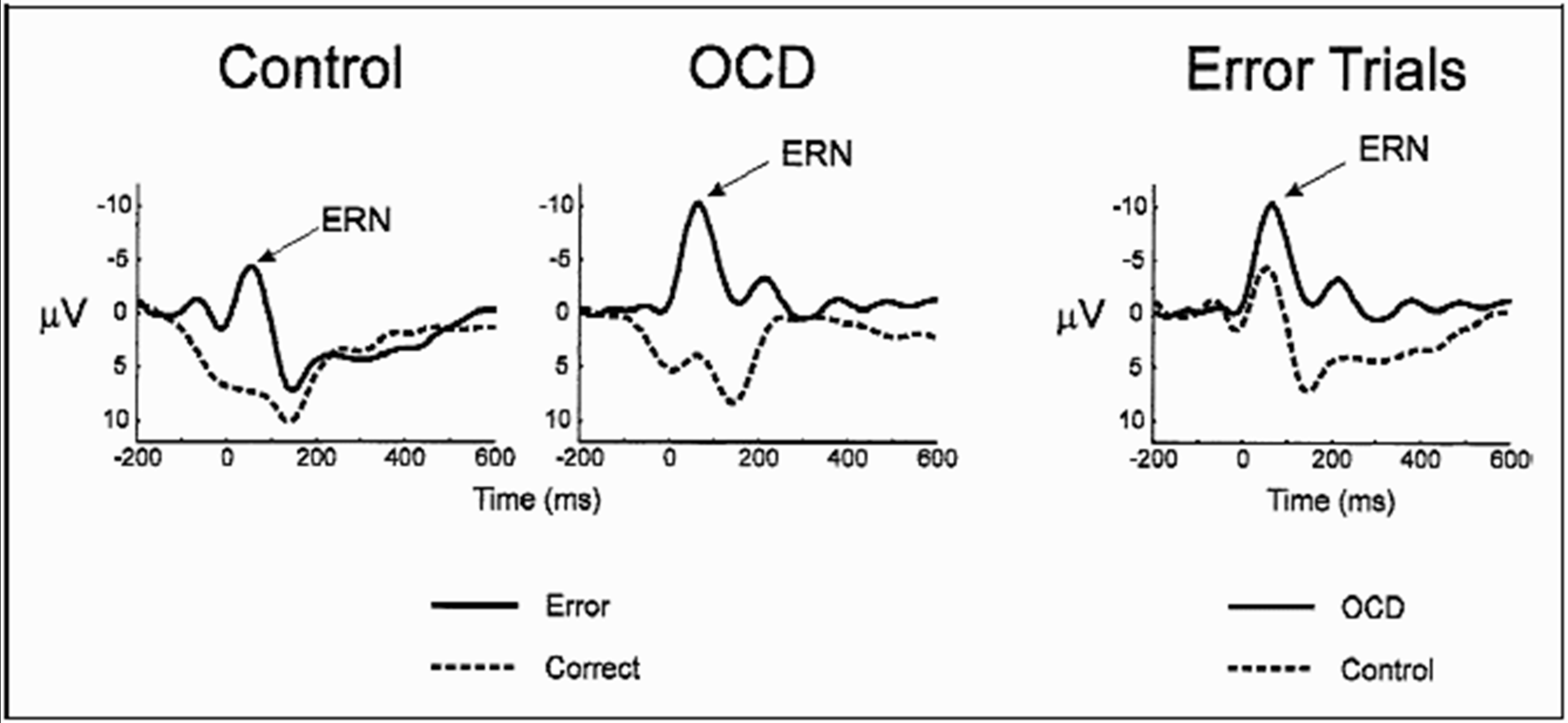


Fig. 1. Response-locked event-related potential waveforms at the Cz electrode location. The left panel compares correct-trial and error-trial waveforms for control participants and for individuals with obsessive-compulsive disorder (OCD). The right panel compares error-trial waveforms for the two groups.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

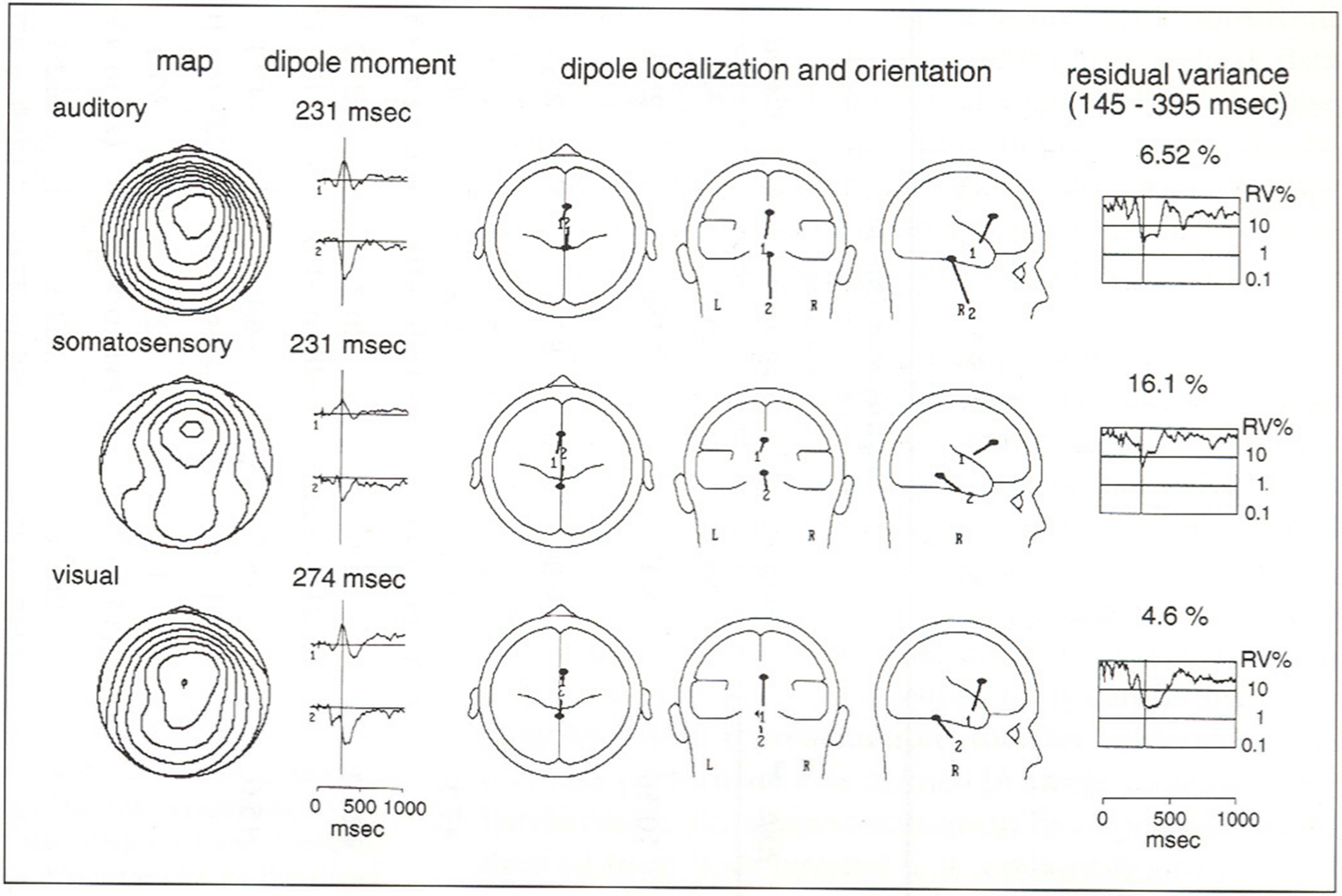
Theoretical Squabble #3: Error Detection Vs. Conflict

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

Errors and Feedback

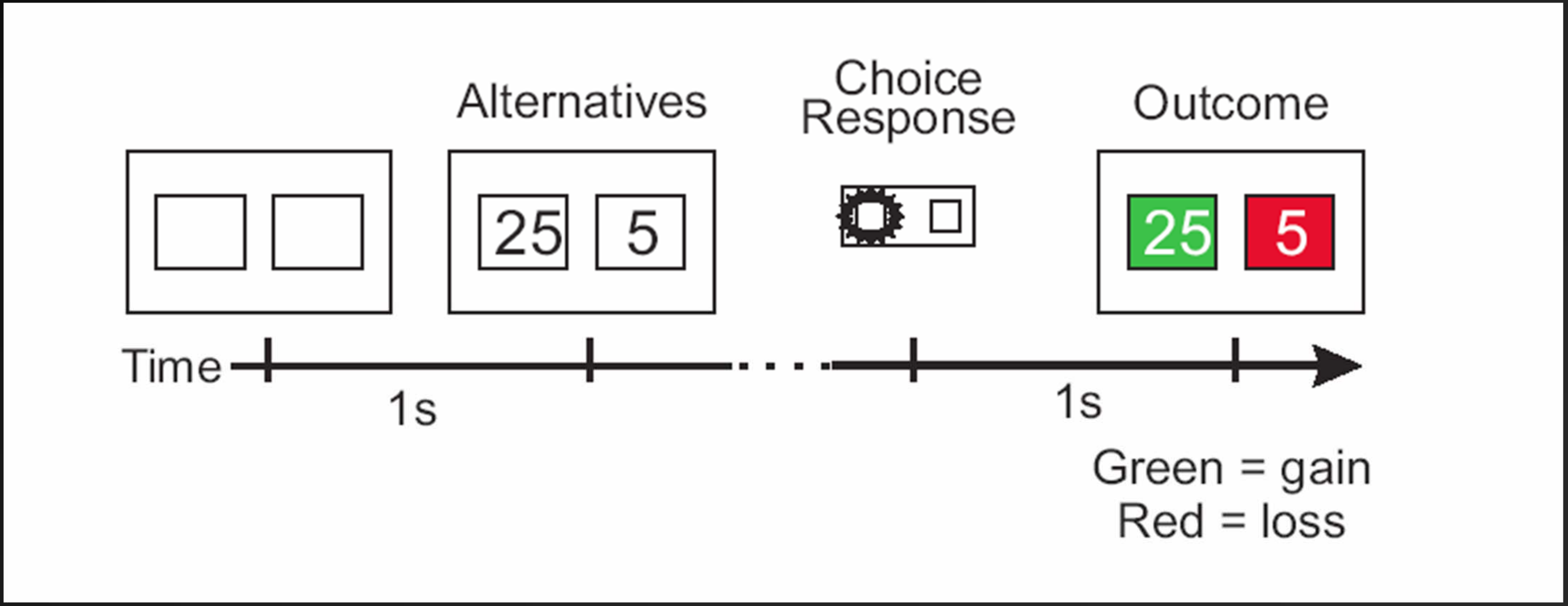
- Endogenous Error Detection
- Exogenous Error Feedback
- Common Mechanism?

The Feedback Medial Frontal Negativity



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

The Gambling Task



Gehring and Willoughby, 2002 *Science*

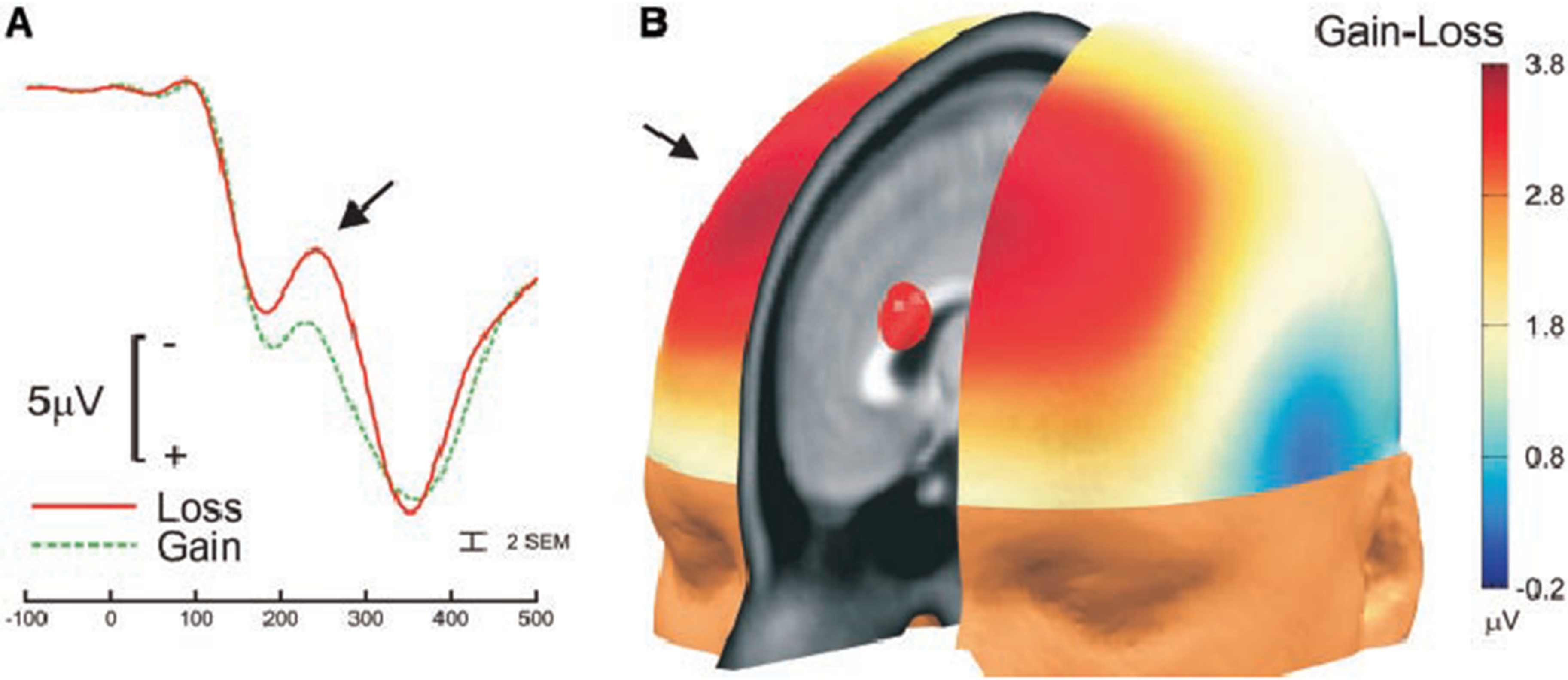
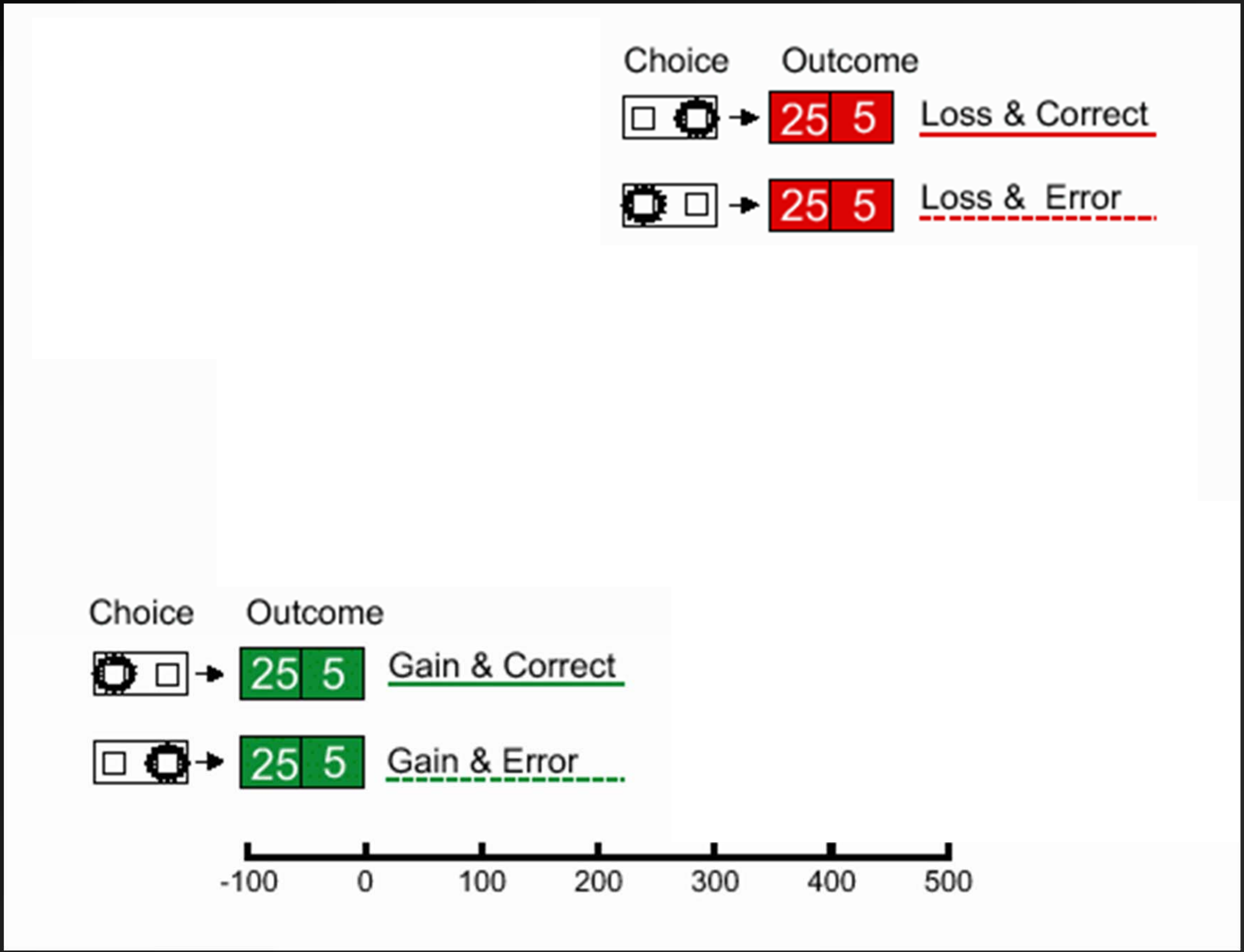


Fig. 2. ERP waveforms, scalp topography, and likely neural generator of the MFN. (**A**) The waveforms are shown at the Fz (frontal) electrode site. The solid red line corresponds to the average ERP waveform for all trials in which the participant lost money. The dashed green line corresponds to those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

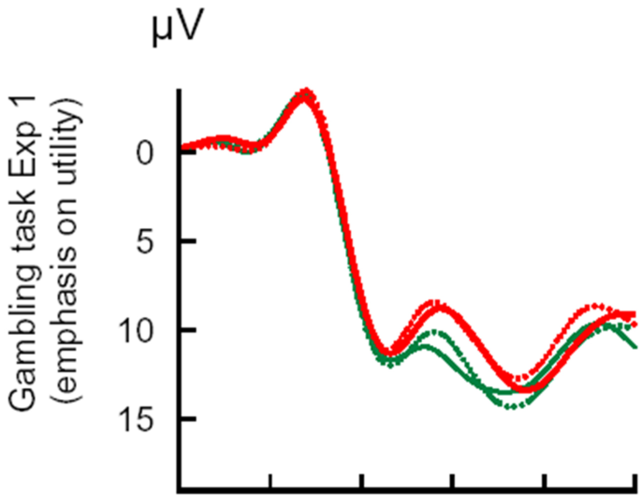
Gehring and Willoughby, 2002 *Science*

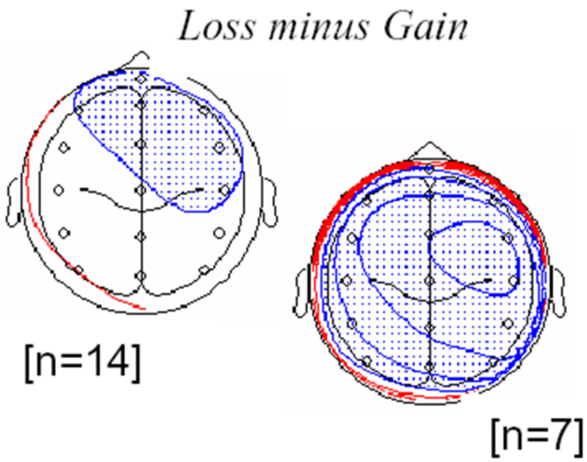
Error, or motivation?



Gehring and Willoughby, 2002 *Science*

Effect may depend on *relevant* dimension of feedback





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