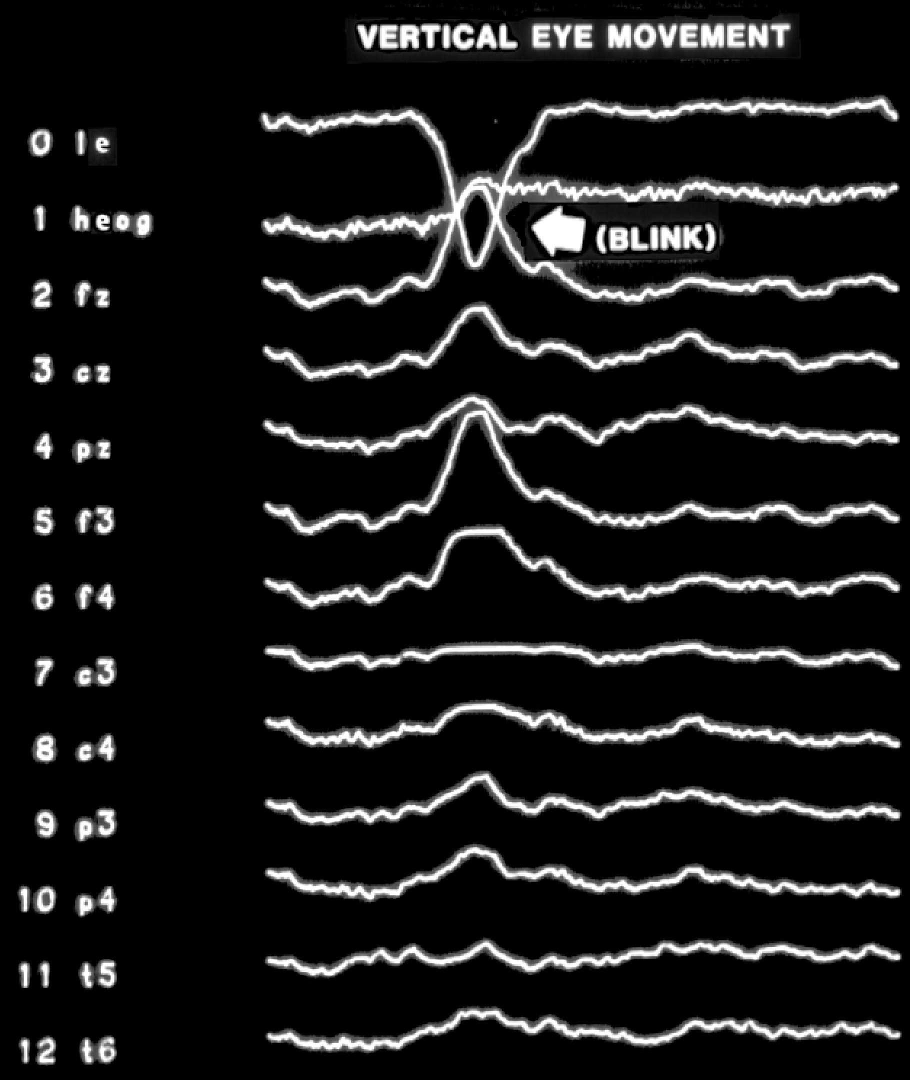
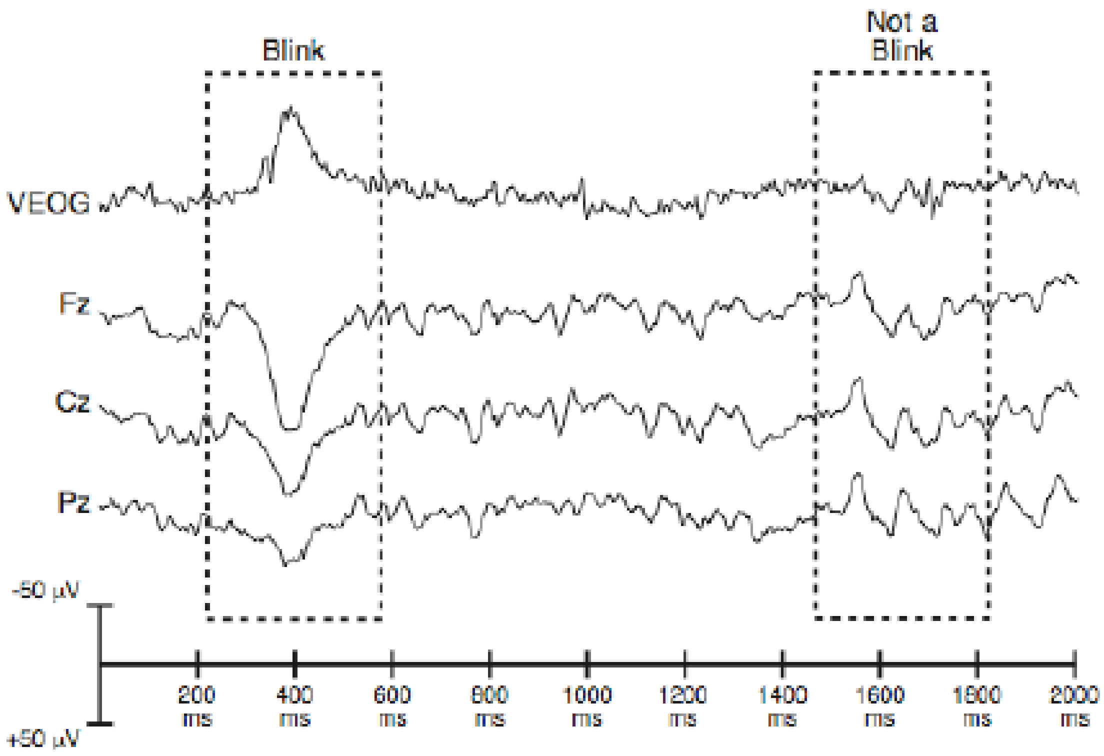
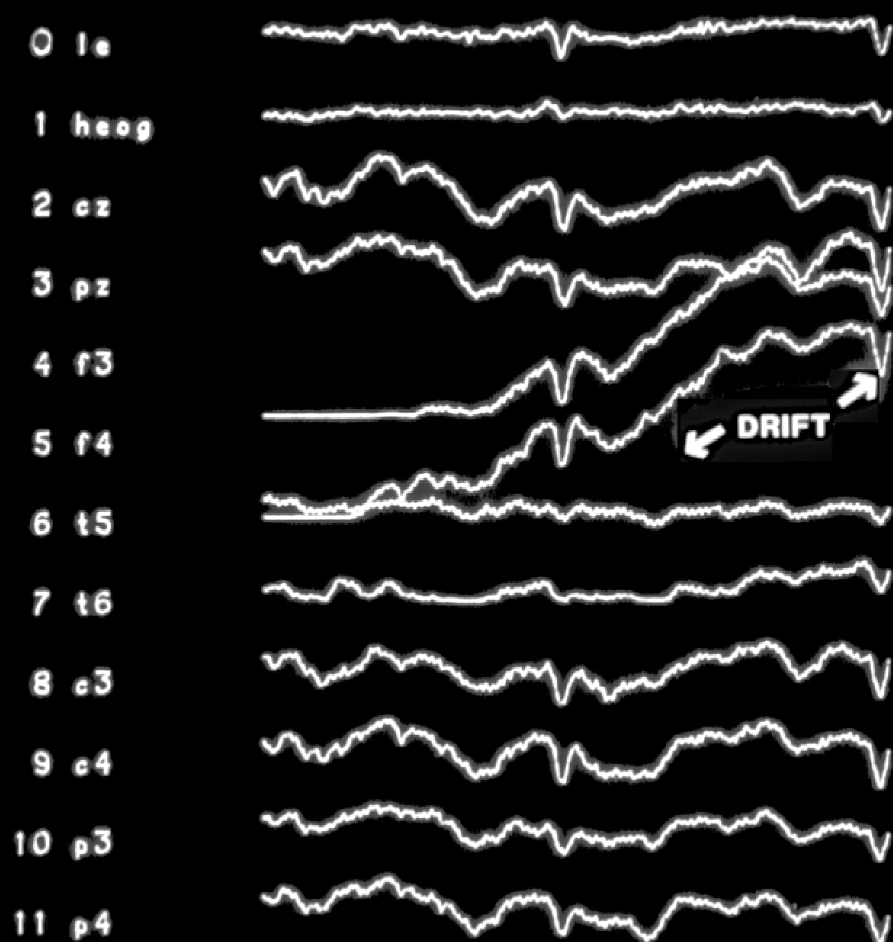
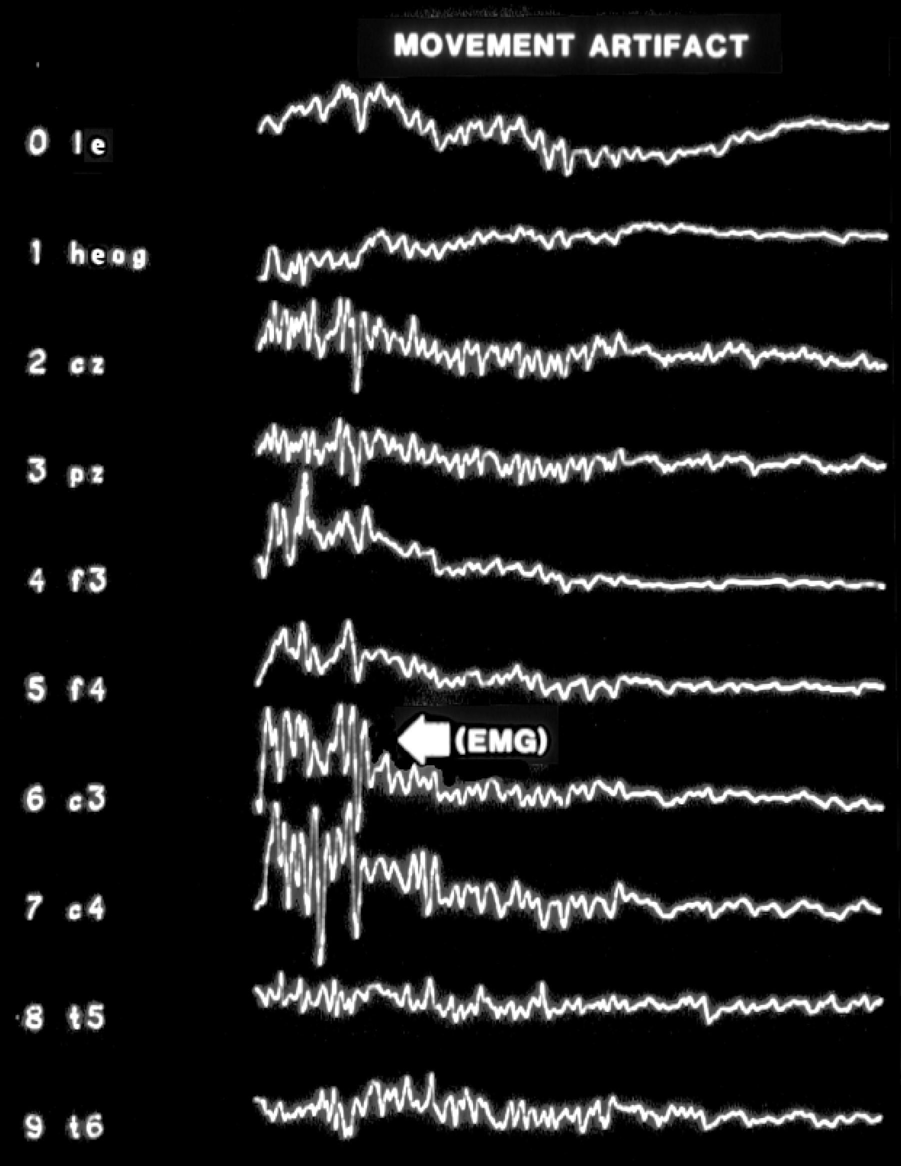
ARTIFACTS


VERTICAL EYE MOVEMENT
0 le
1 heog
2 fz
3 cz
4 pz
5 f3
6 f4
7 c3
8 c4
9 p3
10 p4
11 t5
12 t6
(BLINK)

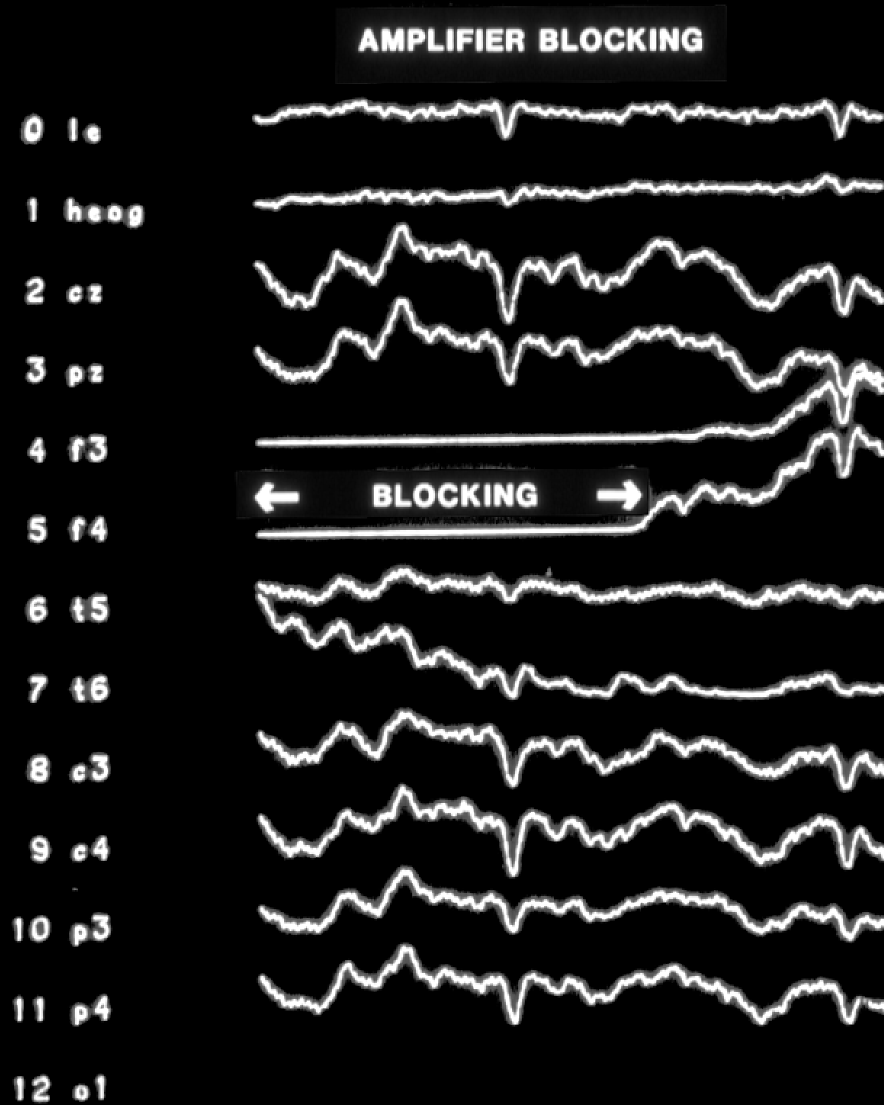

Blink
Not a Blink
VEOG
Fz
Cz
Pz
-50 µV
+50 µV
200 ms
400 ms
600 ms
800 ms
1000 ms
1200 ms
1400 ms
1600 ms
1800 ms
2000 ms

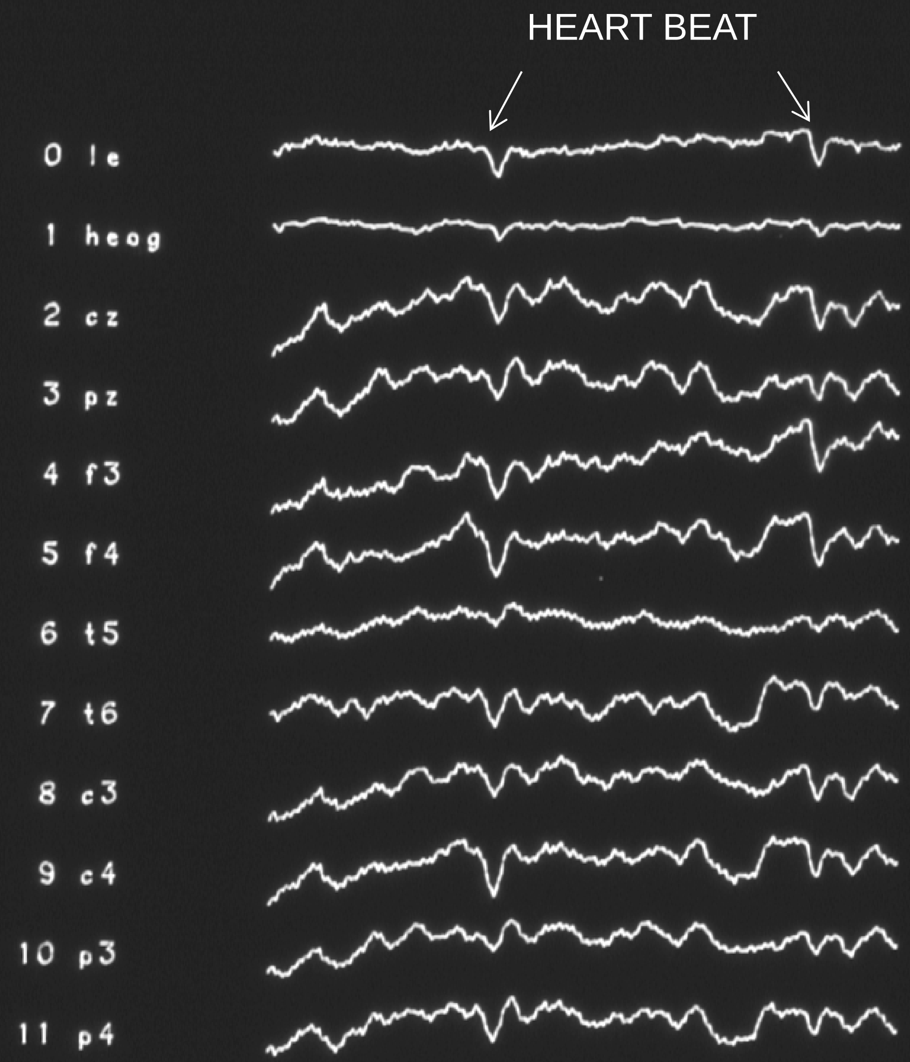


0 le
1 heog
2 cz
3 pz
4 f3
5 f4
6 t5
7 t6
8 c3
9 c4
10 p3
11 p4
DRIFT

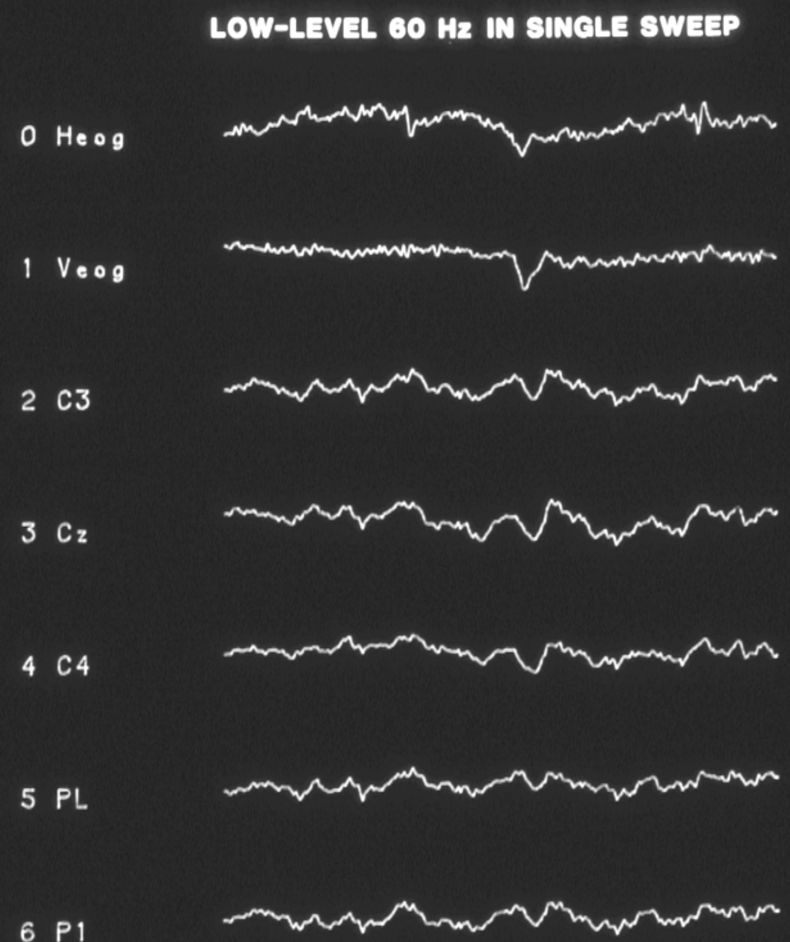


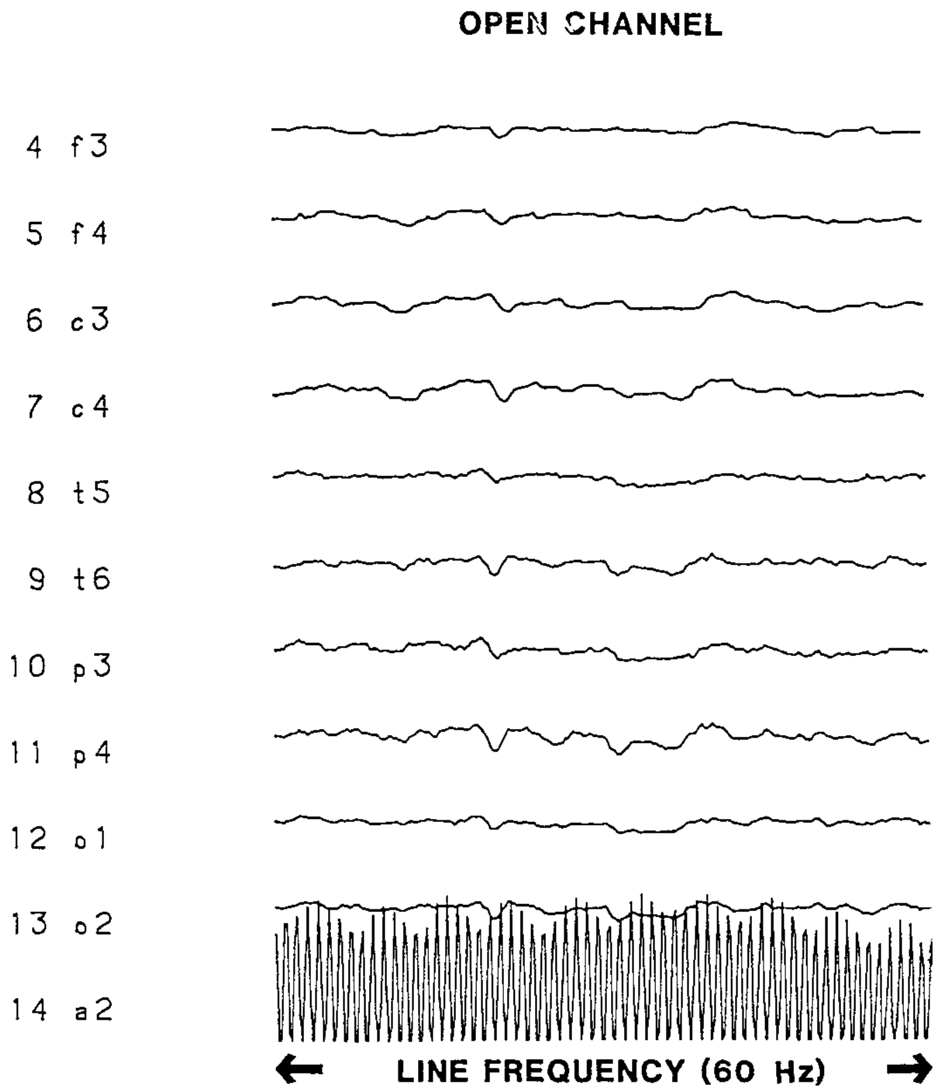
MOVEMENT ARTIFACT
0 le
1 heog
2 cz
3 pz
4 f3
5 f4
6 c3
7 c4
8 t5
9 t6
(EMG)


AMPLIFIER BLOCKING
0 le
1 heog
2 cz
3 pz
4 f3
BLOCKING
5 f4
6 t5
7 t6
8 c3
9 c4
10 p3
11 p4
12 o1

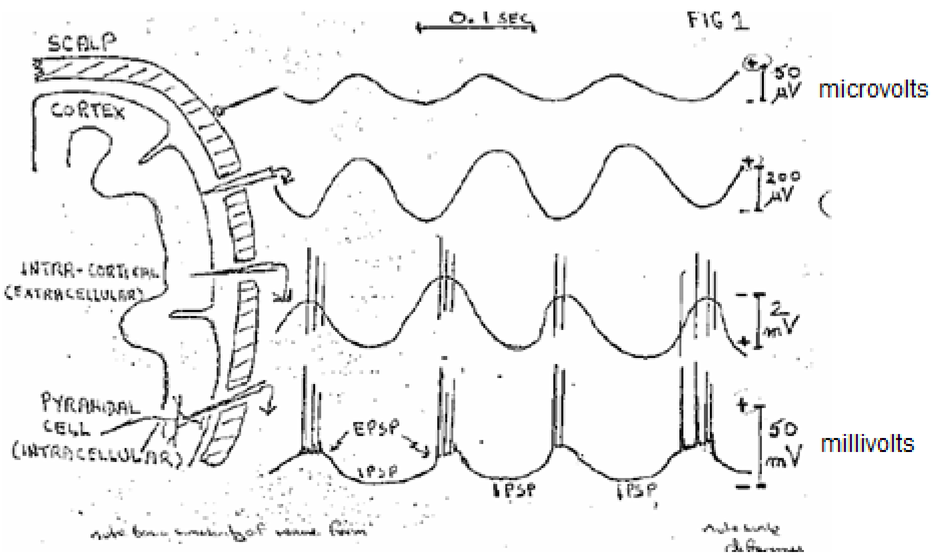

HEART BEAT
0 le
1 heog
2 cz
3 pz
4 f3
5 f4
6 t5
7 t6
8 c3
9 c4
10 p3
11 p4

Electrical noise
AC line current (60 Hz)
video monitors (50-120 Hz, refresh rate)




OPEN CHANNEL
4 f3
5 f4
6 c3
7 c4
8 t5
9 t6
10 p3
11 p4
12 o1
13 o2
14 a2
LINE FREQUENCY (60 Hz)

THE POTENTIAL AT THE SCALP IS QUITE SMALL!



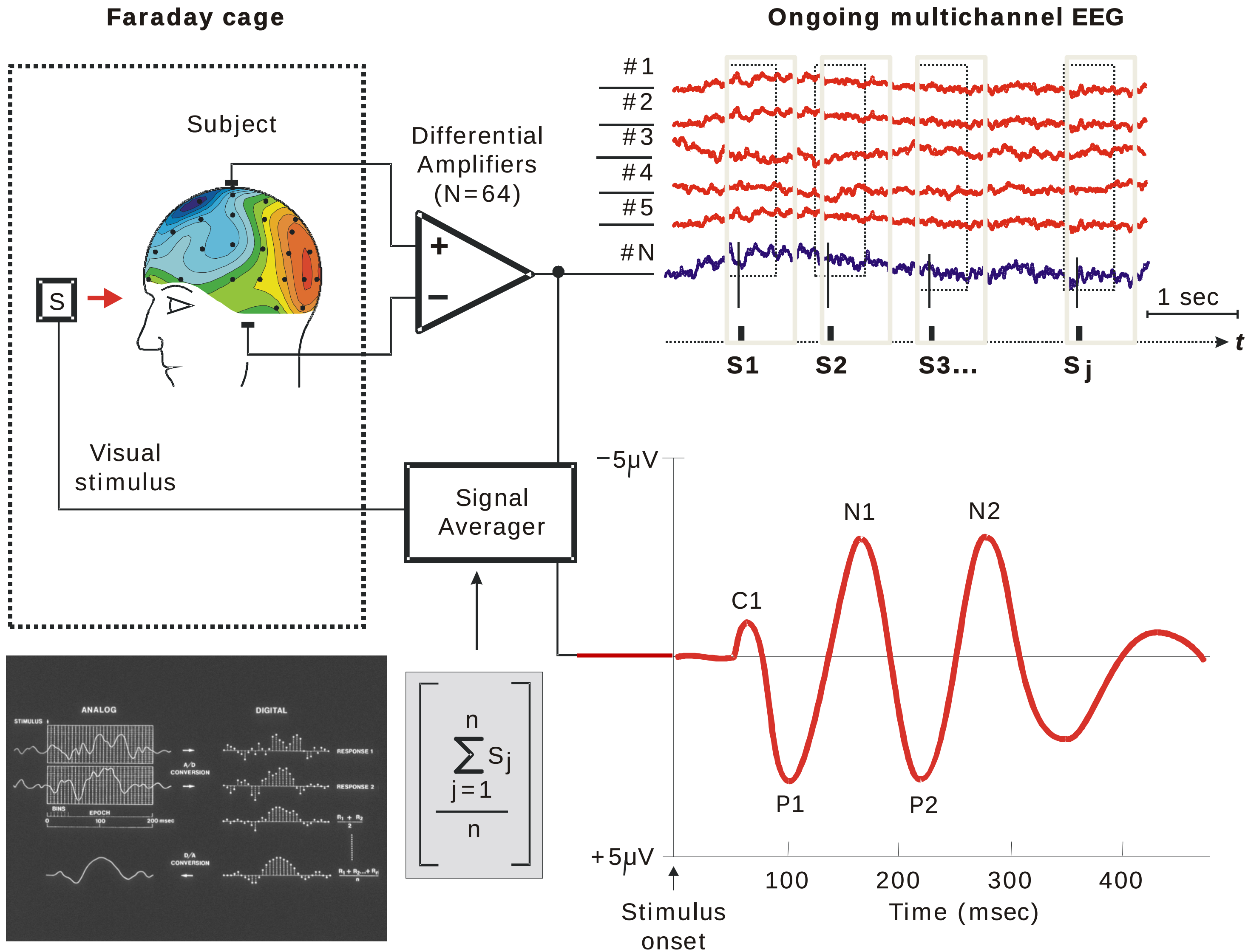
Need to average because EEG (50-100 uV) is larger than EP/ERP (1-20 uV)

ERPs can be isolated various signal averaging given certain assumptions.

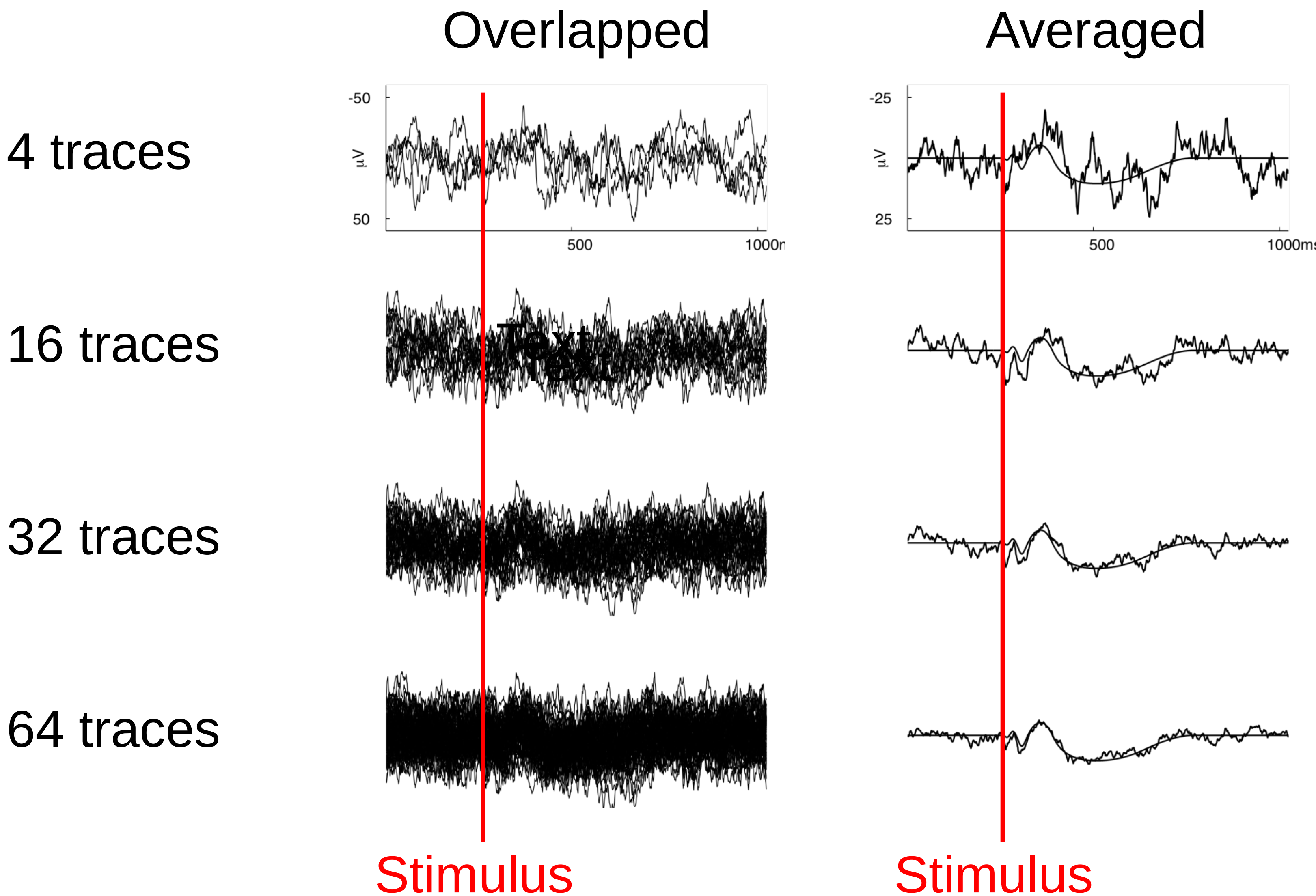
Effect of averaging on noise is NOT a direct, linear function of the number of trials; the noise decreases as a function of the square root of the number of trials in the average. The signal to noise ratio increases as a function of the square root of the number of trials.

e.g., if signal = 20 uV, noise = 50 uV, signal to noise ratio 20:50 = .4 If # trials = 2, then signal to noise ratio increases by sqrt (2)
If # trials = 4, then signal to noise ratio increases by sqrt (4), etc.

EVENT-RELATED BRAIN POTENTIALS (ERPs)



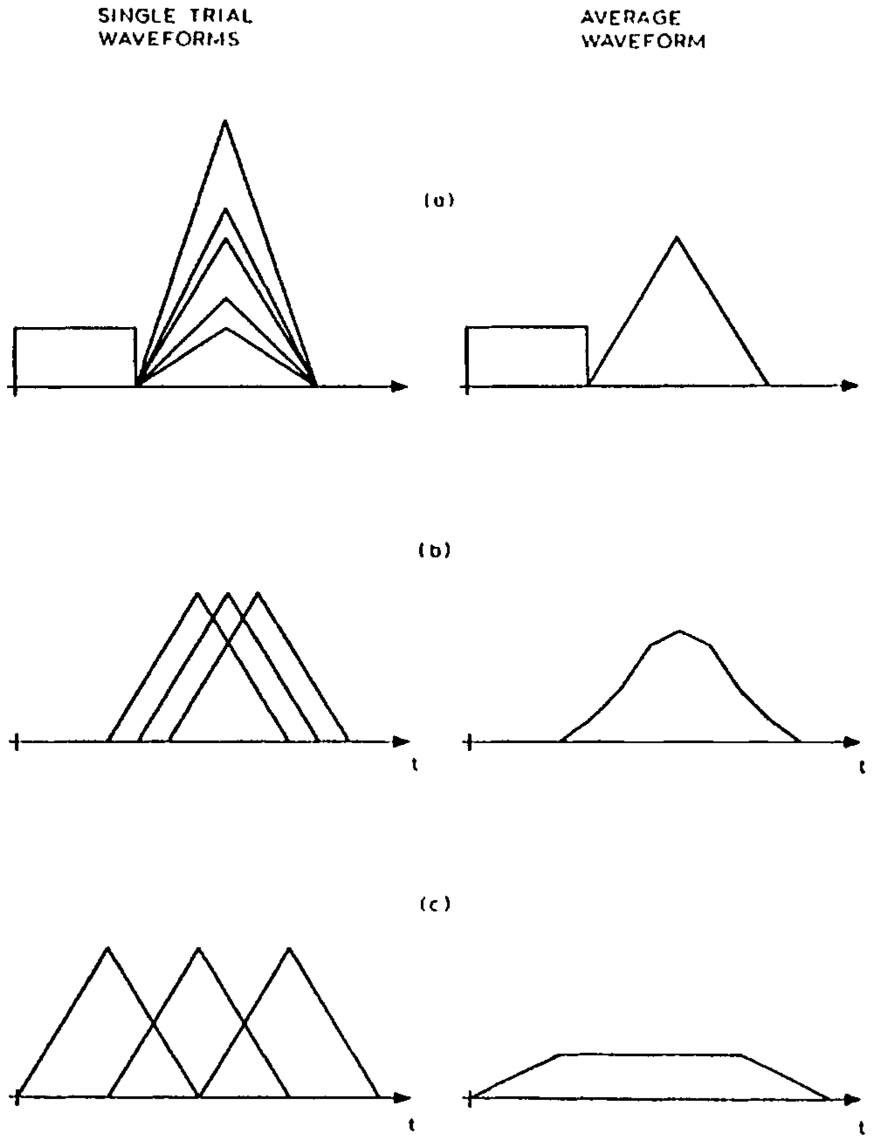
Finding ERP needles in the haystack



Almost always looking at **averages,** which assumes

- signal invariant
- noise random across trials
- signal independent of noise
- statistical properties of noise same across trials

Violating "same ERP" assumption

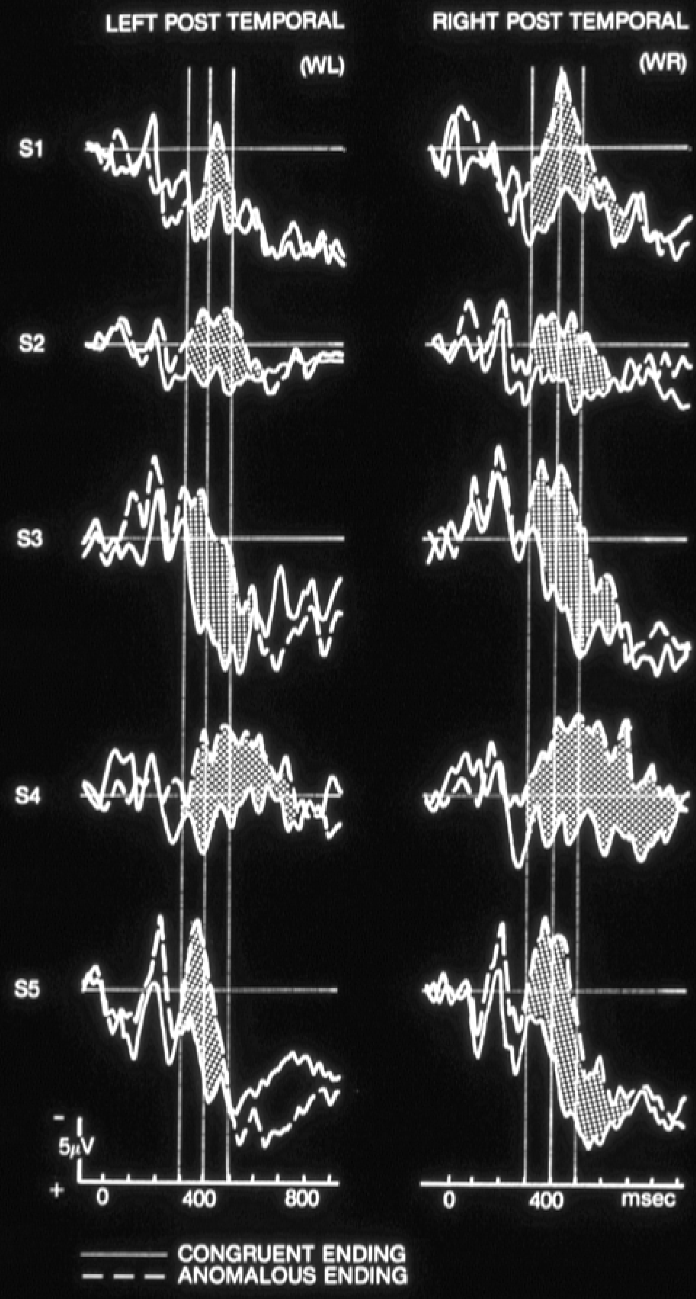


Variance in signal amplitude

Variance in signal latency

Variance in signal latency

Fig. 3. Hypothetical examples of the effects of amplitude modulation and latency variation upon single trial ERPs (left column) and average ERPs (right column). Row A illustrates the effect of amplitude modulation upon the late component of an ERP consisting of two components. Row B illustrates the effect of a relatively narrow range of latency variation (latency range equals 1/3 the duration of the wave). Row C illustrates the effect of a relatively wide range of latency variation (latency range equals the duration of the wave).


LEFT POST TEMPORAL
(WL)
RIGHT POST TEMPORAL
(WR)
S1
S2
S3
S4
S5
-
5μV
+
0
400
800
0
400
msec
CONGRUENT ENDING
ANOMALOUS ENDING

Grand average ERP = average of subject average ERP

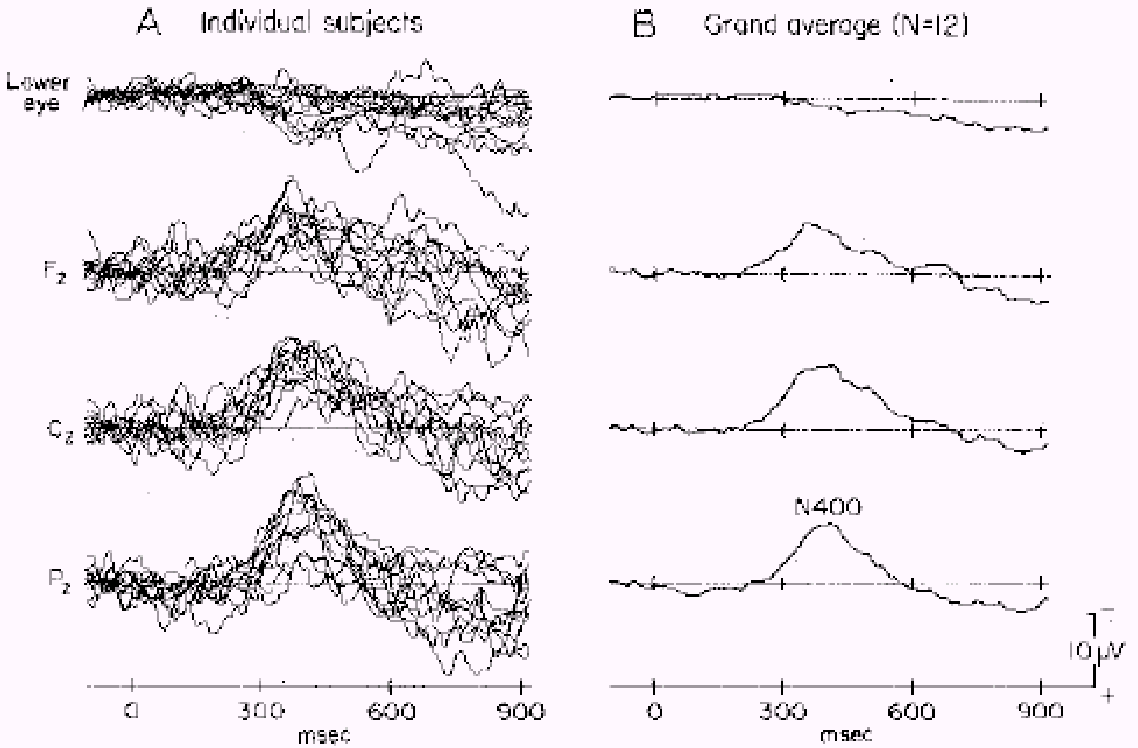
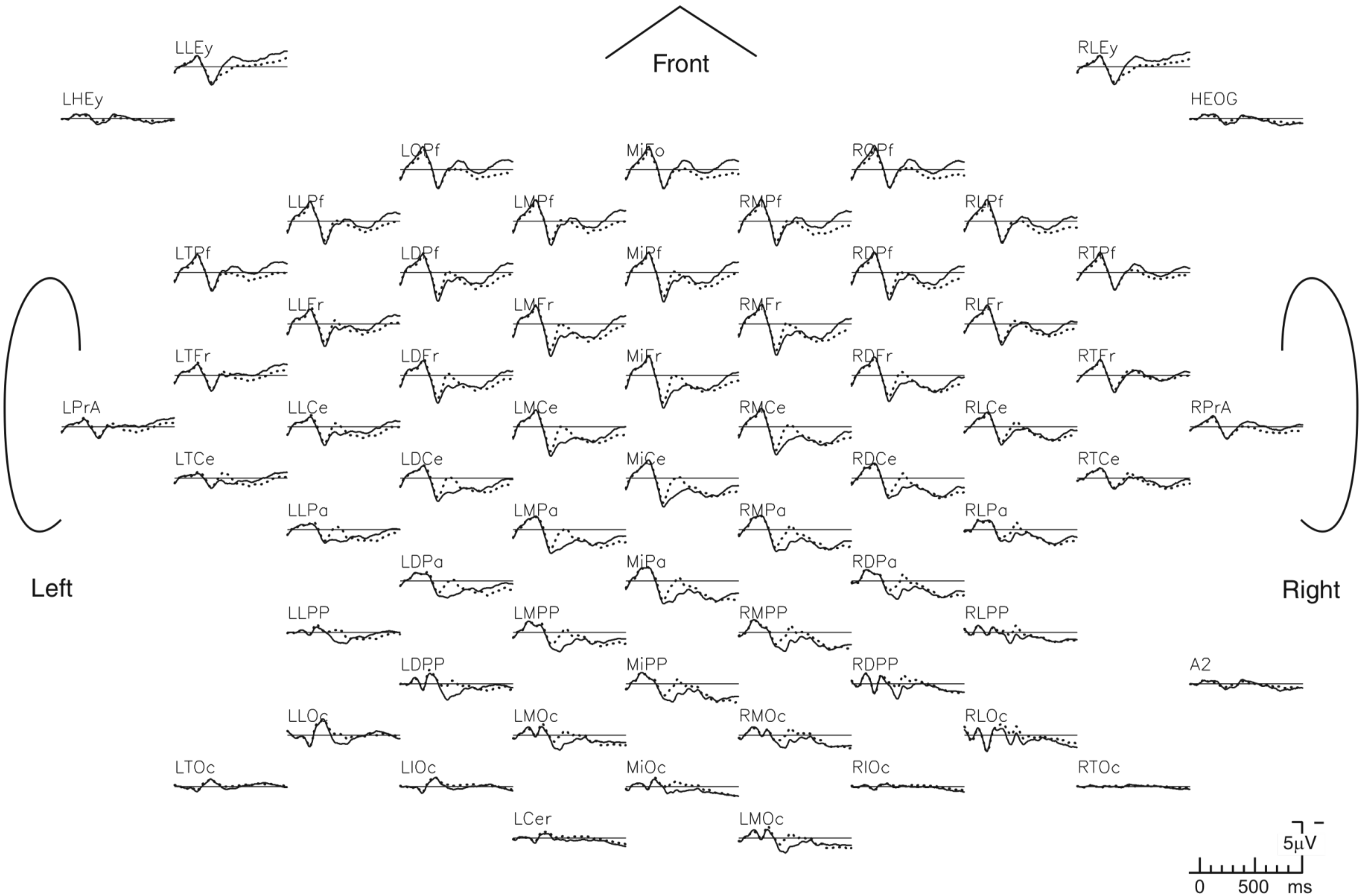


Fig. 2. Difference waves from experiment 2 (strong semantic incongruity). These difference waveforms were obtained by subtracting the averaged ERP's to the semantically congruous words from the ERP's to the semantically incongruous seventh words. Each superimposed tracing (A) represents the difference wave from one subject. The ERP's in (B) are the corresponding grand average waveforms over all 12 subjects.

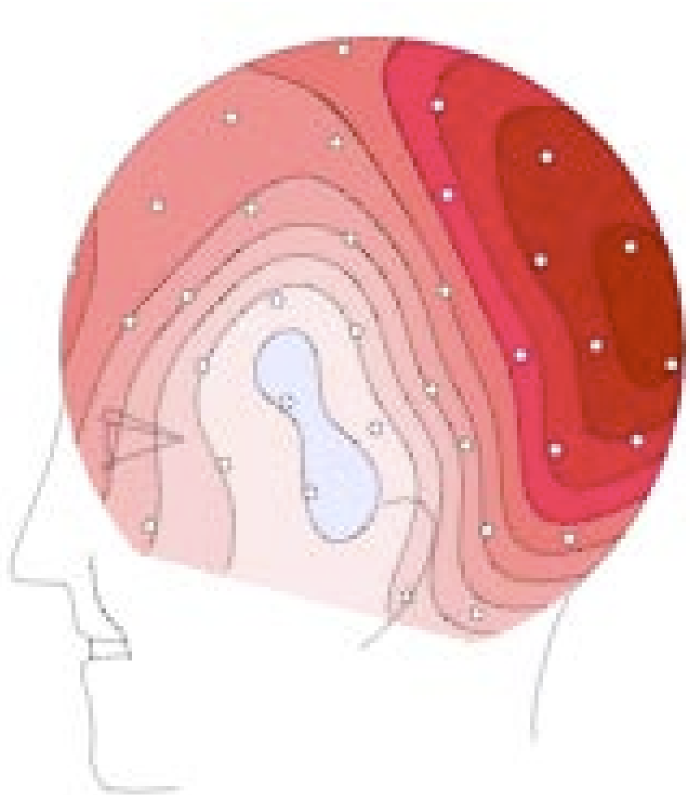
Grand average waveforms



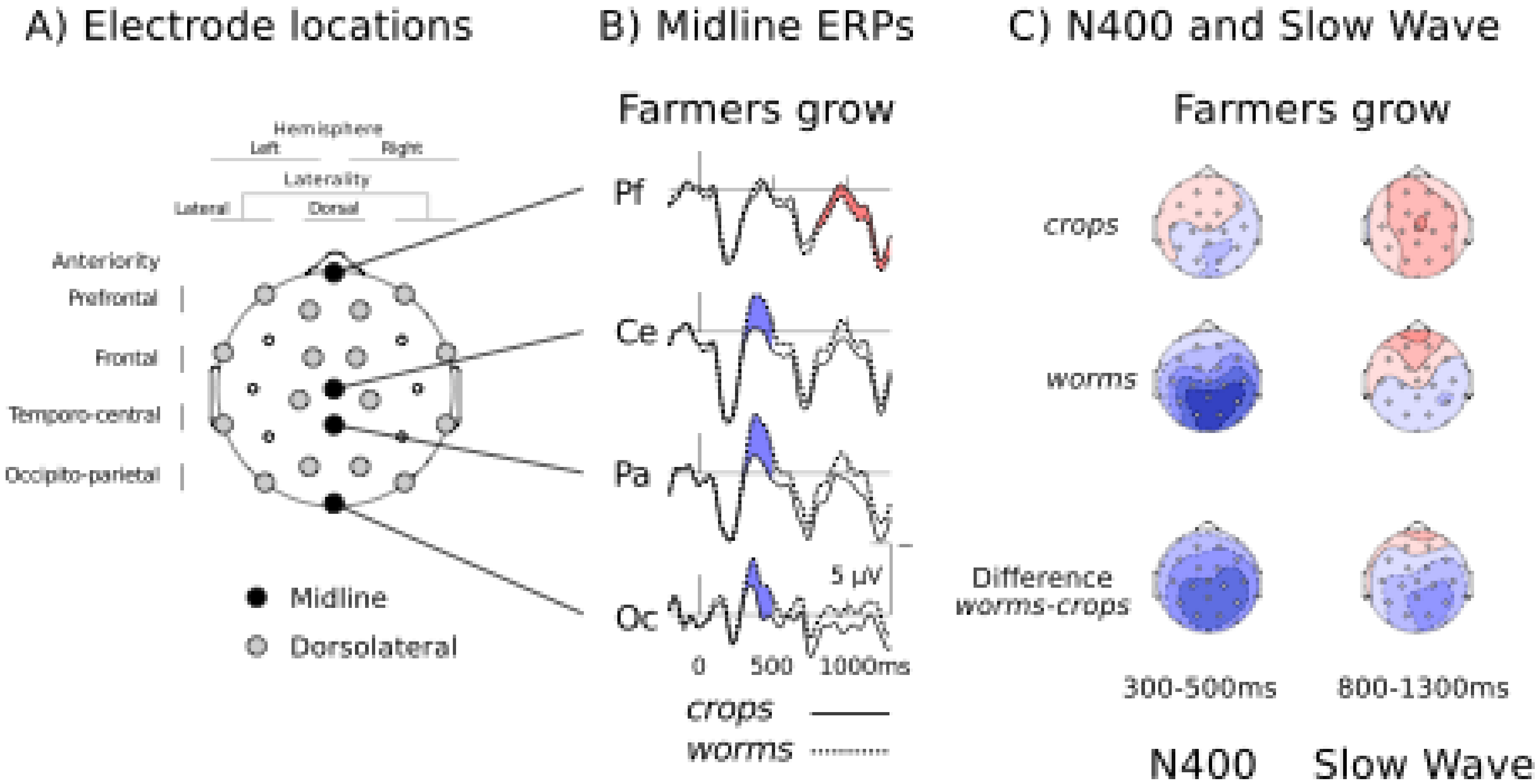
——— *congruous completions* ········ *incongruous completions*

Grand average distribution of scalp potentials

Note 1: values in between the electrodes are interpolated



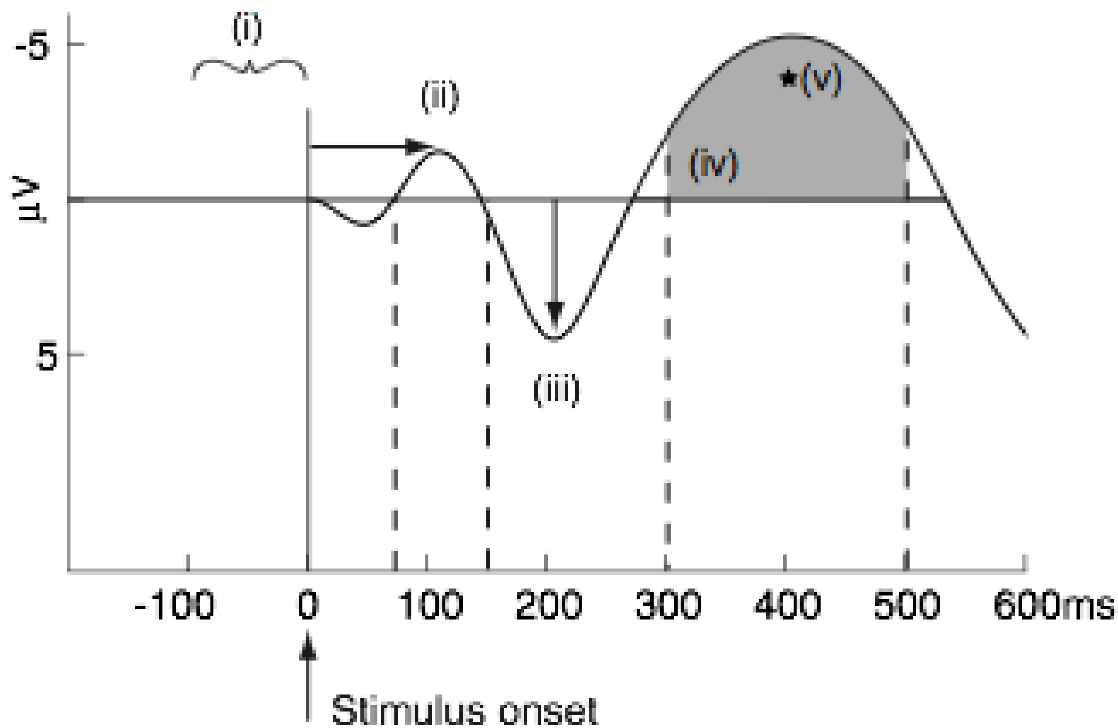
Note 2: *interpolated* sounds better than “guessed” but they mean the same



A) Electrode locations
B) Midline ERPs
C) N400 and Slow Wave
Hemisphere
Left
Right
Laterality
Lateral
Dorsal
Anteriority
Prefrontal
Frontal
Temporo-central
Occipito-parietal
Midline
Dorsolateral
Farmers grow
Pf
Ce
Pa
Oc
5 µV
0
500
1000ms
crops
worms
Farmers grow
crops
worms
Difference
worms-crops
300-500ms
800-1300ms
N400
Slow Wave

Selected ERP data reduction measures

(i) 100ms prestimulus baseline
(ii) peak latency 75-150ms = 110ms
(iii) peak amplitude 150 - 300ms = 4.50μV
(iv) area 300 - 500ms = - 848 μVms
(v) mean amplitude 300 - 500ms = area/interval = -4.24μV



Event-Related Brain Potentials (ERP)

An event-related potential is brain electrical activity which associated with a defined event.

Events that have been shown to be associated with measurable brain activity include external **sensory** events, self-paced **motor** events, and internal **mental** events.

The most straightforward way to demonstrate association of brain activity with an external event is by **time-locked averaging**.

Exogenous and Endogenous EPs and ERPs

- **Exogenous evoked potentials** are potentials whose characteristics (latency, amplitude, scalp distribution) depend on the sensory modality employed, and that are relatively **independent of mental set.**

- **Endogenous event-related potentials** are potentials whose characteristics are relatively independent of the sensory modality employed, but depend on mental set.

Why use electrophysiological measures to study cognition? Because, ERPs

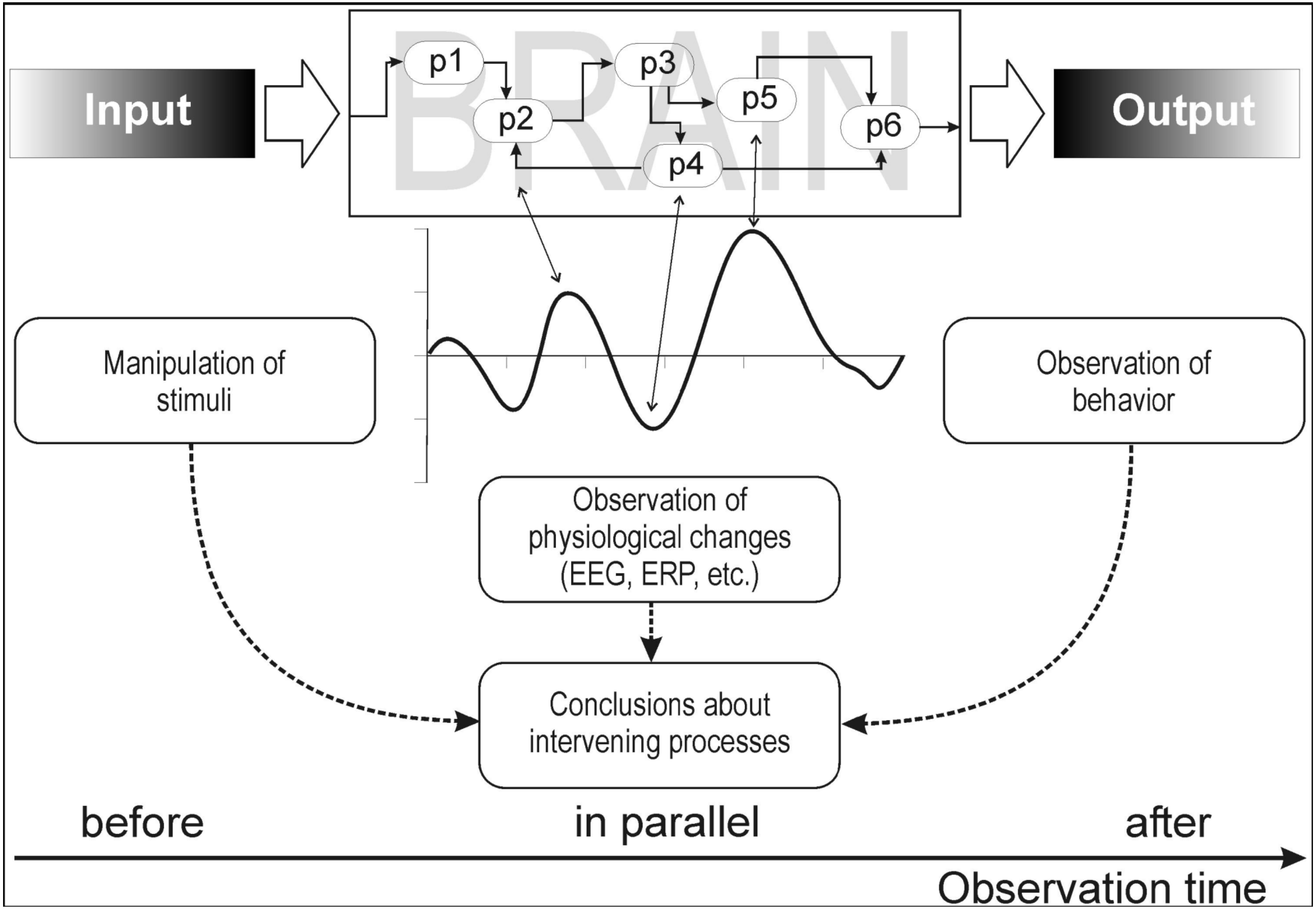
1) A relatively non-invasive brain measure
2) Don't require a behavioral response
3) Provide continuous, instantaneous data, with ms resolution
4) Multidimensional measure – amplitude, polarity, topography
5) Offer a link to neurobiology, as well as psychological constructs, and phenomena

The key to good ERP research is to ask questions where the kinds of answers that ERPs give is informative.

EEG data. Schematically the data in an ERP experiment can be classified hierarchically as follows:

Each experiment	=	a set of subject groups
Each subject group	=	a set of subjects
Each subject	=	a set of within subject experimental conditions and levels
Each within subject condition and level	=	a set of trials
Each trial	=	a set of electrode positions (EEG channels)
Each channel	=	a set of data samples recorded at regular intervals
Each sample	=	the digitized version of an analog scale potential value

Conceptually then, the data from a typical cognitive electrophysiology experiment consist of a six-dimensional array of digital EEG samples, with the dimensions of the array as follows: Groups (for between subject variables) × Subjects × Condition (for within subject variables) × trial × channel × timepoint. The following will outline some common procedures for visualizing and quantitatively analyzing these large data sets. Of primary interest in cognitive experiments are comparisons between groups and between within subject conditions.



Input
BRAIN
p1
p2
p3
p4
p5
p6
Output
Manipulation of stimuli
Observation of behavior
Observation of physiological changes (EEG, ERP, etc.)
Conclusions about intervening processes
before
in parallel
after
Observation time

INFERENCES from ERP COMPARISONS

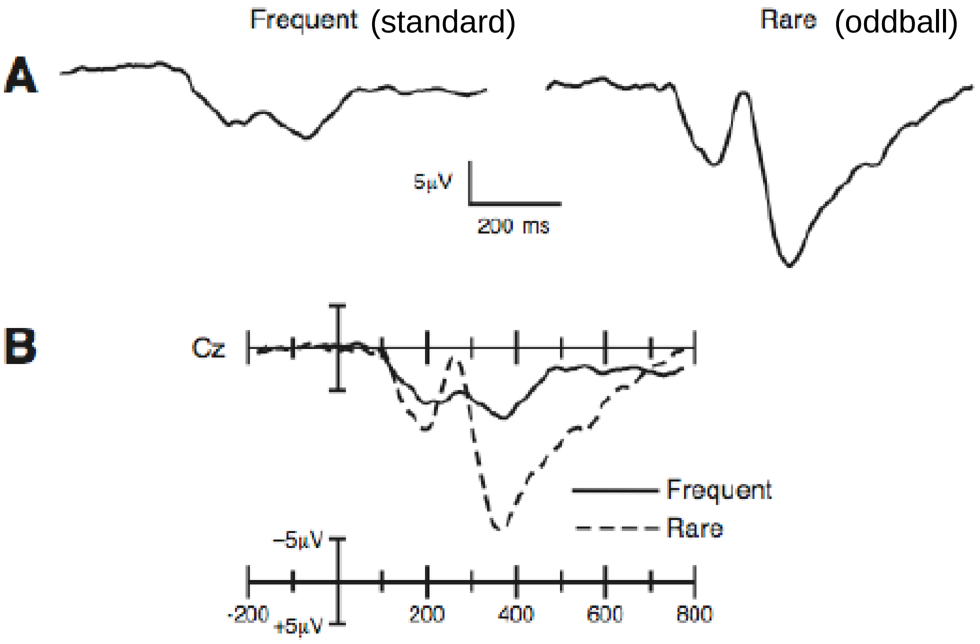
Always comparing 2 (or more)

voltage x time x location functions

-- voltage waveforms in time across different scalp locations

Most ERP studies refer to effects – e.g., N400 effect, P300 effect, etc.; this refers to comparisons, differences, not component in one condition

ODDBALL PARADIGM



Conventional ERP parameters (dependent variable) from which inferences are drawn

Amplitude

Latency

Topography of relative amplitudes across scalp

No difference - Null Results

i.e., no main effect or reliable condition x electrode interaction

Failure to find an effect could arise for various reasons

- Perhaps, there is **no** difference between the conditions
- Design is not (statistically) powerful enough to reveal the difference between the conditions (S/N ok?)
- ERP quantification methods are suboptimal (inadequate temporal & spatial sampling)
- Even if S/N and measurement are good, inference is limited as ERPs only represent a subset of brain activity (closed fields)

Requirements for seeing ERP activity at scalp

- Sufficient numbers (many) neurons with proper orientation
- Firing synchronously
- With electric fields that sum rather than cancel (i.e., open field configuration neurons with dendritic trees all oriented on one side and axons on the other)

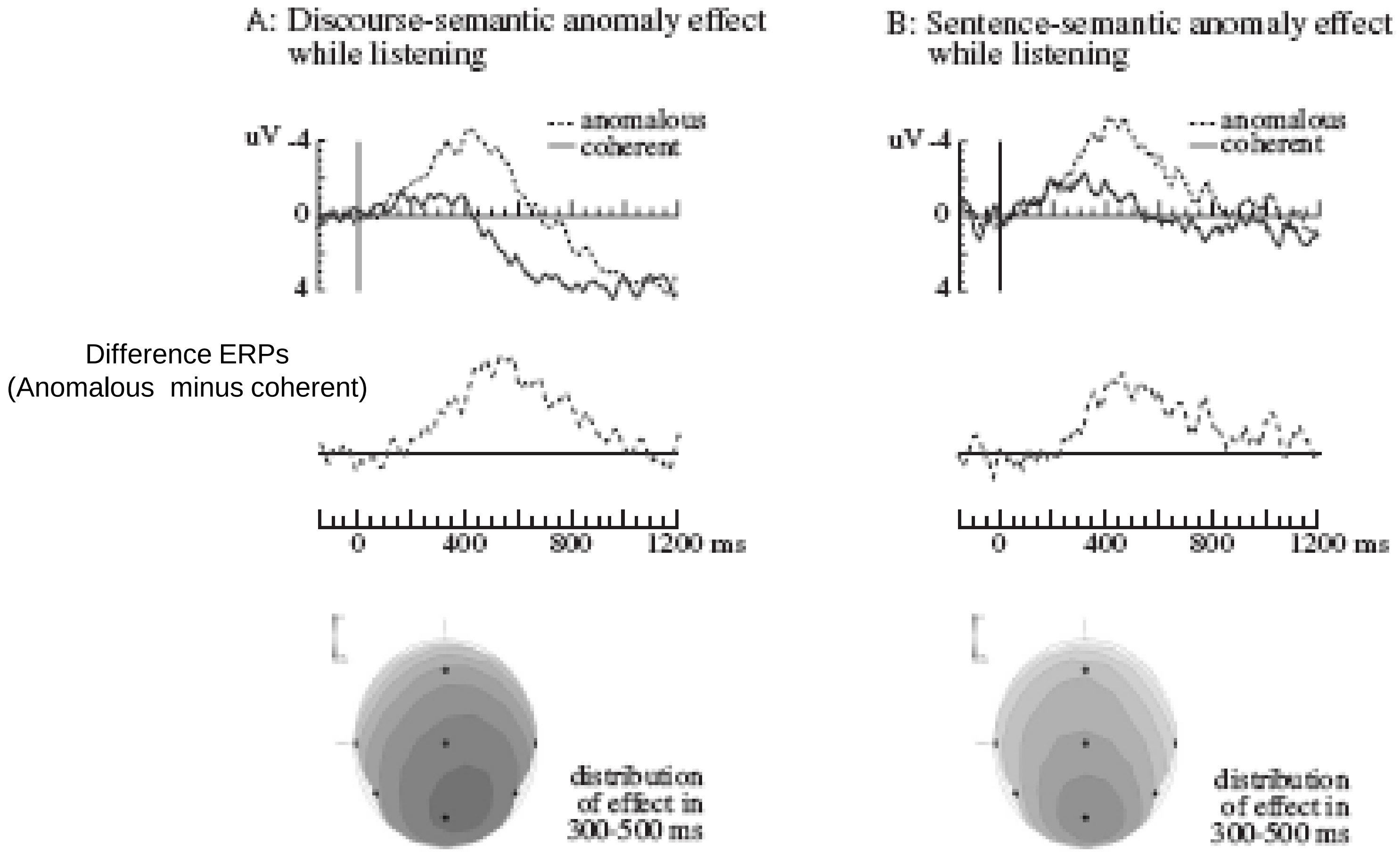


Figure 13.4 Discourse- and sentence-dependent semantic anomaly effects in spoken language comprehension. Top: Grand-average waveforms at Pz for anomalous and coherent words respectively. Middle: Corresponding anomalous–coherent difference waves. Bottom: spline-interpolated scalp distribution of the anomaly effect, based on mean difference-wave amplitude in the 300–500 ms latency range at each of 13 electrodes (6 of which are below the "equator" and therefore not visible; data from "When and how do listeners relate a sentence to the wider discourse? Evidence from the N400 effect," by J. J. A. Van Berkum, P. Zwitserlood, C. M. Brown, and P. Hagoort, 2003b, *Cognitive Brain Research*, 17, 701–718).

Table I. Example stimuli in each of the four experimental conditions (from [17]).

Condition	Example
A. GRAM-AN	| Peter | fragt sich, | welchen Arzt | *der Jäger* | gelobt | hat. | Peter asks himself, [which doctor]$_{OBJ}$ [the hunter]$_{SUBJ}$ praised has
B. GRAM-IN	| Peter | fragt sich, | welchen Arzt | *der Zweig* | gestreift | hat. | Peter asks himself, [which doctor]$_{OBJ}$ [the twig]$_{SUBJ}$ brushed has
C. UNGRAM-AN	| Peter | fragt sich, | welcher Arzt | *der Jäger* | gelobt | hat. | Peter asks himself, [which doctor]$_{SUBJ}$ [the hunter]$_{SUBJ}$ praised has
D. UNGRAM-IN	| Peter | fragt sich, | welcher Arzt | *der Zweig* | gestreift | hat. | Peter asks himself, [which doctor]$_{SUBJ}$ [the twig]$_{SUBJ}$ brushed has

Abbreviations: GRAM ('grammatical'), UNGRAM ('ungrammatical'), AN ('second argument is animate'), and IN ('second argument is inanimate'). All measures reported are relative to the second argument (in italics). Segmentation for stimulus presentation is indicated with vertical bars.

No diff in N400 for ungram conditions; animacy does not affect N400, but it may still have an effect

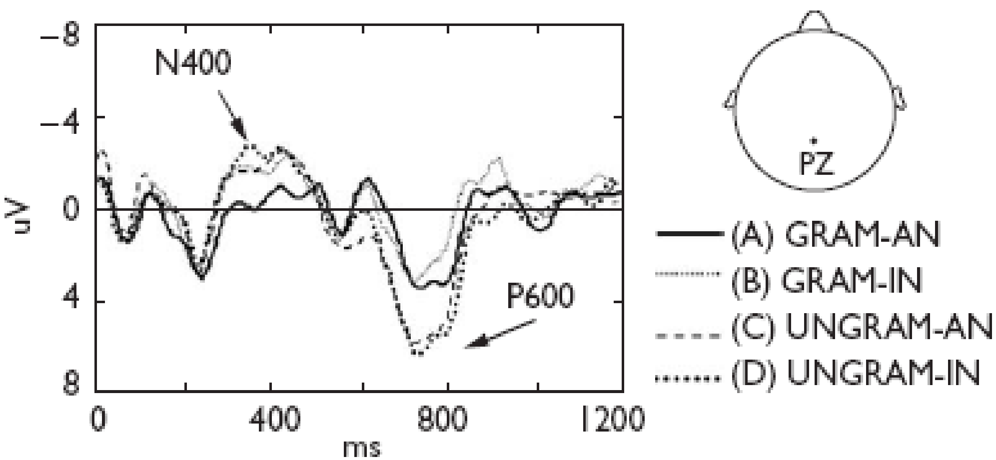


Fig. I. Grand average ERPs (n=16) at electrode PZ for the critical second argument (onset at vertical bar) of the four conditions described in Table I. Negativity is plotted upwards.

Roehm et al.

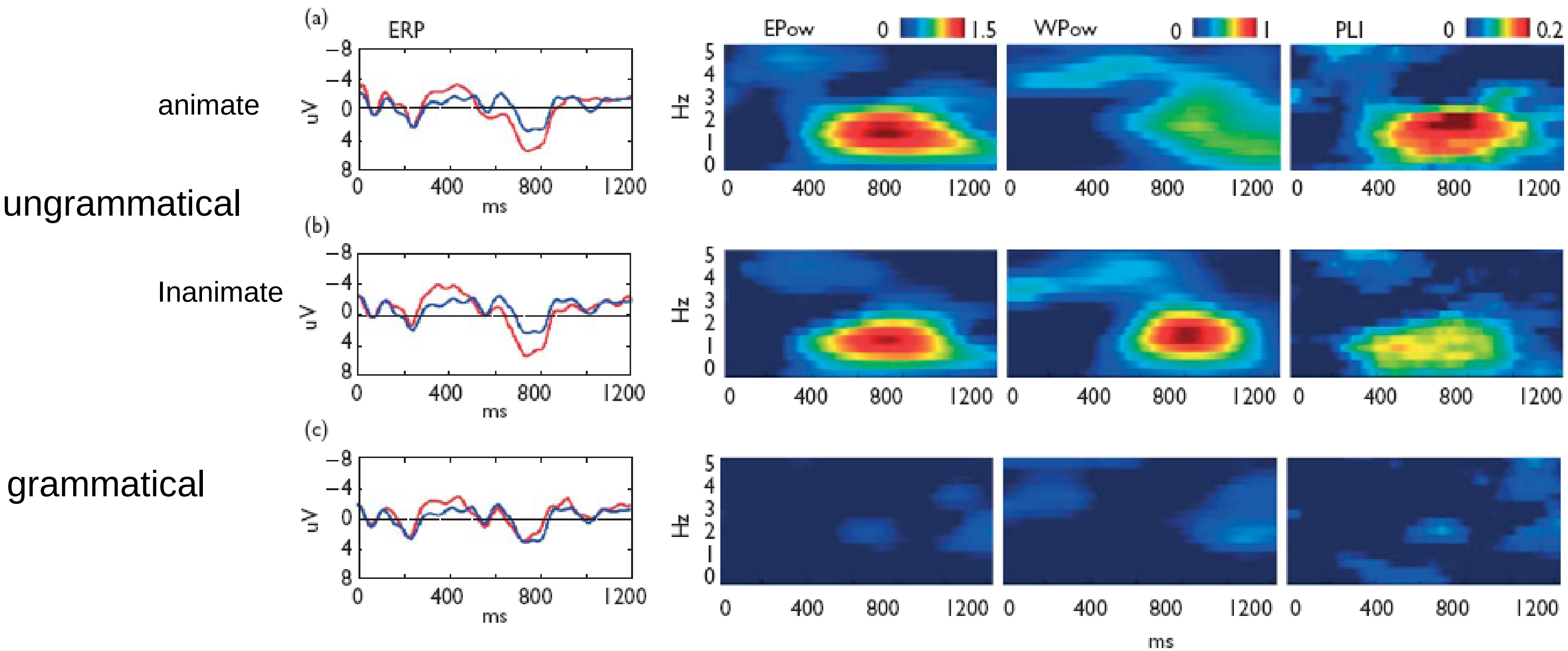


Fig. 3. Grand average ERPs and Gabor wavelet-based time/frequency plots in the delta band (1–3 Hz) for the ungrammatical animate (C; **a**), ungrammatical inanimate (D; **b**), and grammatical inanimate conditions (B; **c**) in comparison to the control condition (A) at electrode PZ (n=16). ERPs are shown in the far left panel, whereas the remaining three panels depict wavelet coefficient differences in evoked power (EPow; second panel from left) and whole power (WPow; second panel from right) and phase-locking index differences (PLI; far right panel). The colour scale depicts the magnitude of the wavelet coefficient differences for EPow and WPow and the PLI value difference for PLI.

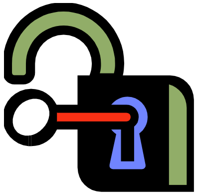
Roehm et al.

Let’s assume a real difference (& not due to artifacts)…

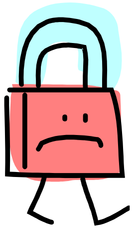
Main effect of condition; condition x electrode interaction

In some cases, that alone may be enough – that there is a difference, but we can conclude more, even if we know nothing about components or their functional significance or generators

Open vs. Closed Class Words



- **Open Class**
  - Set that is continually changing as words come into and go out of fashion
- Content Words
  - Meaning bearing elements
  - Important for semantic function
- Nouns
- Verbs
- Adjectives
- (most) Adverbs
  - Formed by adding –ly to an adjective



- **Closed Class**
  - Set of these words changes very slowly
  - Remains relatively constant over time
- Function Words
  - Very abstract meaning, if any
  - Important for grammatical function
- Prepositions
- Determiners
- Conjunctions
- Pronouns
- (some) Adverbs
  - “where” “when”

Coulson, 2006

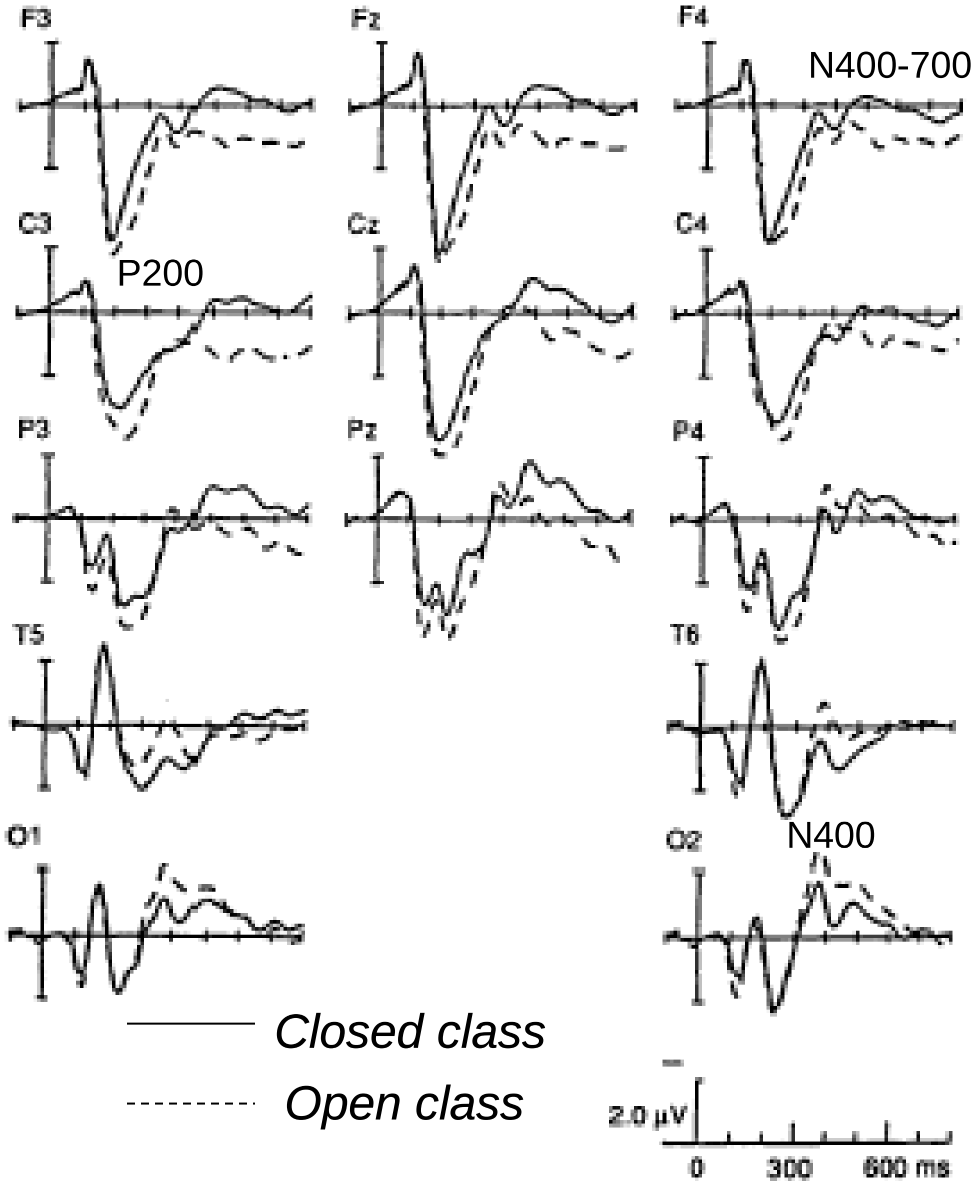
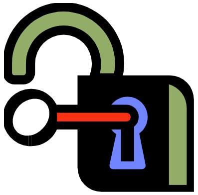
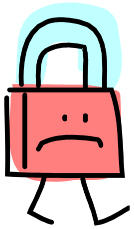


FIG. 9 ERPs elicited by open (*dashed lines*) and closed (*solid lines*) class words in sentences, excluding the initial and final words. F, frontal; C, central; P, parietal; T, temporal; O, occipital. Odd numbers denote sites over the left hemisphere; even numbers, sites over the right hemisphere. Data from Van Petten and Kutas (1990).

Open vs. Closed Class Words





- **Open Class**
- Large <u>set</u> of words (10s to 100s of 1000s)
- Varying <u>length</u>
- Varying <u>frequency</u>

- **Closed Class**
- Relatively small set of words (few hundred)
- Typically short (1-5 letters)
- Often repeated
  - Typically high frequency words

When??? …TIMING

Time of divergence is upper limit on the time by which the brain has appreciated ***difference between two conditions*** (there might always be earlier ones (different by at least…x ms) !

-- peak/mean latency, or condition x time interaction

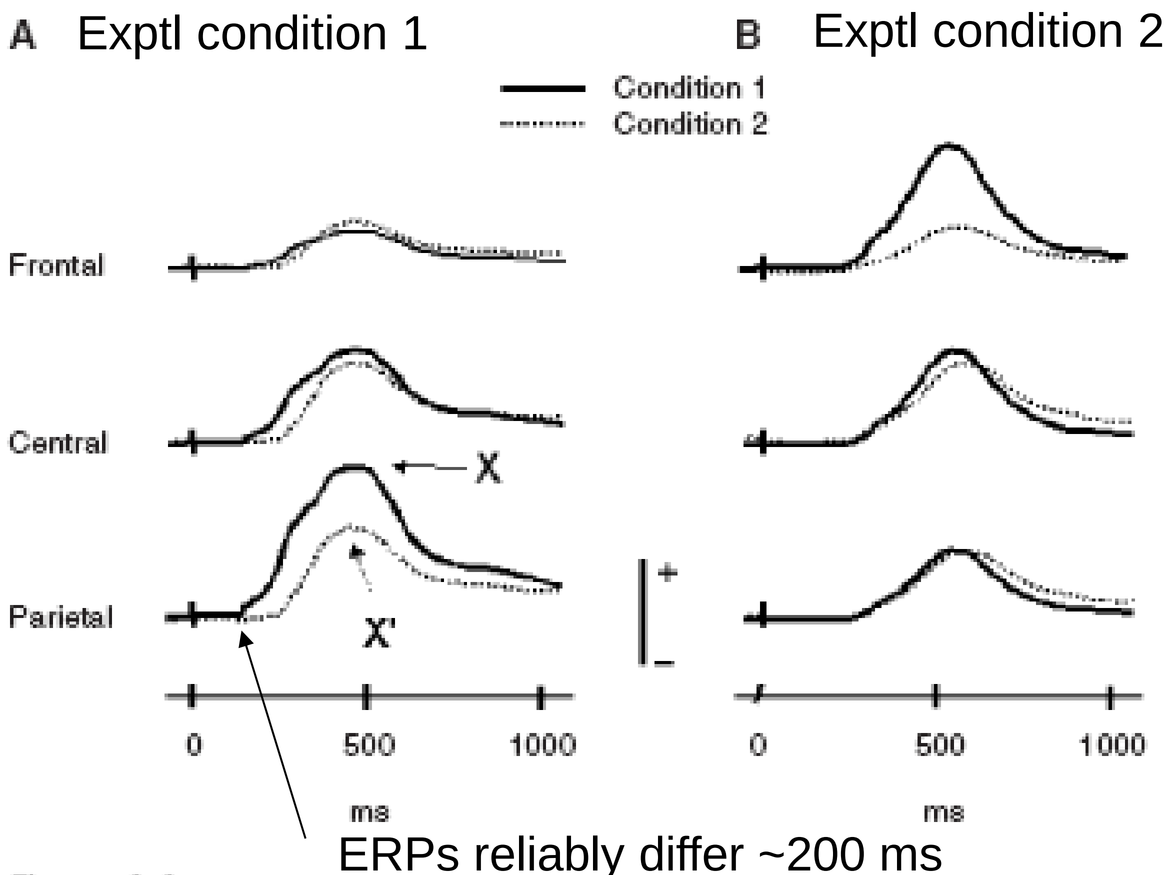


Figure 1.1

Hypothetical ERP waveforms elicited at three electrode sites in two experimental conditions in two experimental situations (*A* and *B*). The differences between the waveforms allow a number of functional interpretations. See text for details.

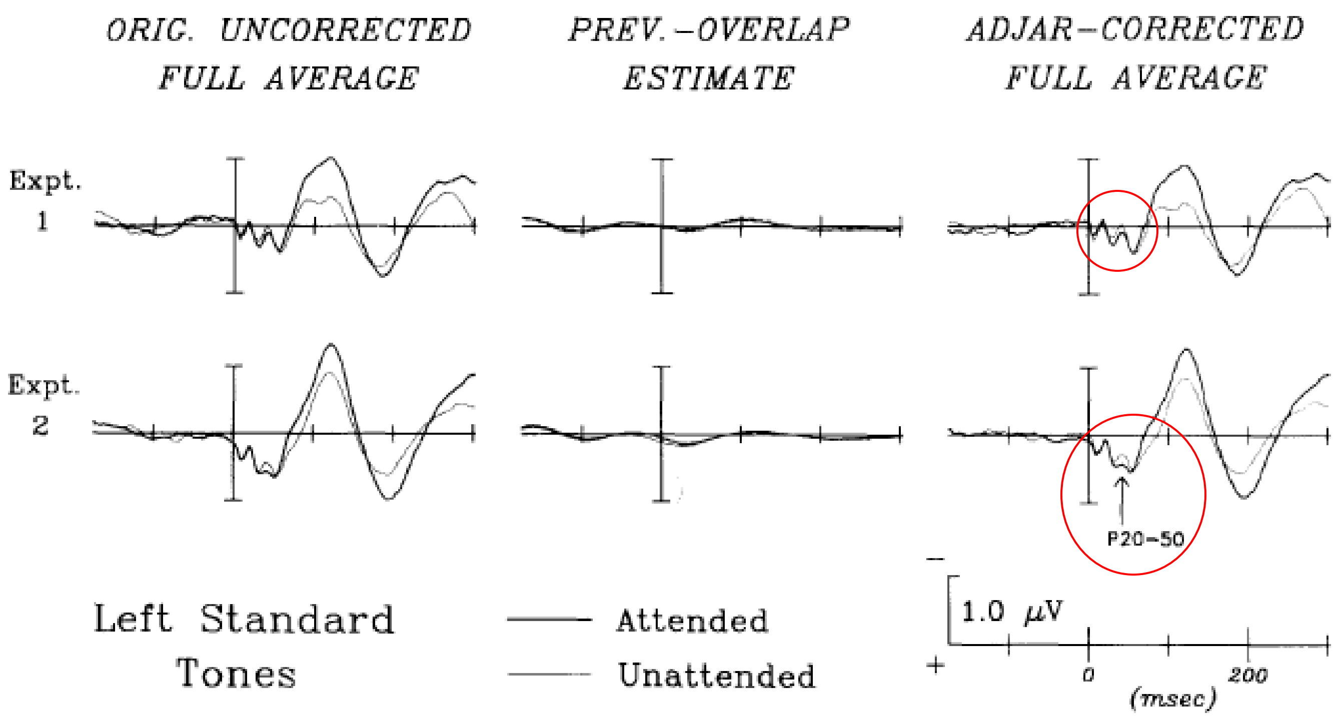


Fig. 1. Uncorrected and corrected full average ERPs elicited by the left-ear standard tones at the C3 site, along with the corresponding summated overlap from previous responses that was estimated and removed. All wave forms are grand averages across subjects (N = 10 in experiment 1, N = 16 in experiment 2). Note that the distortion from overlapping previous ERPs was fairly small in these full averages and did not differ for attended versus unattended ERPs.

Woldorff & Hillyard, 1991

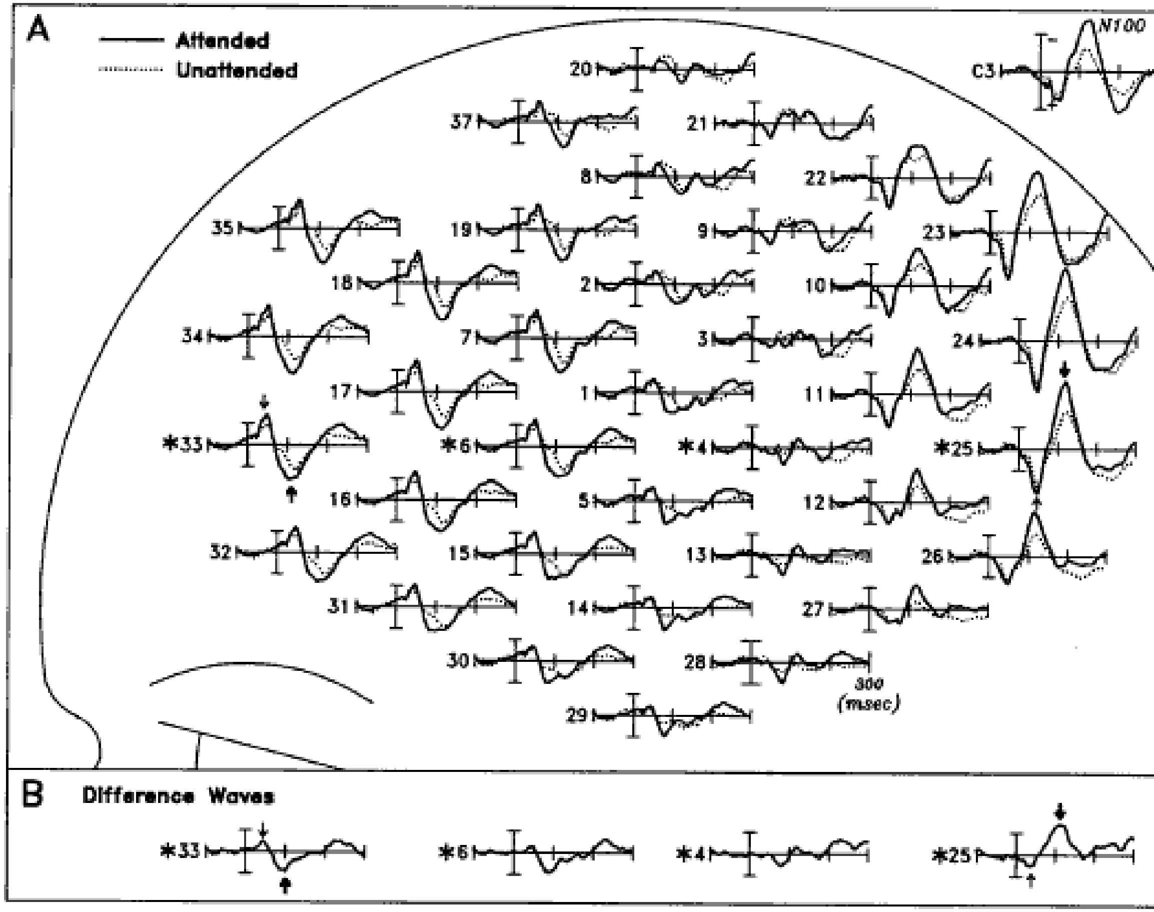
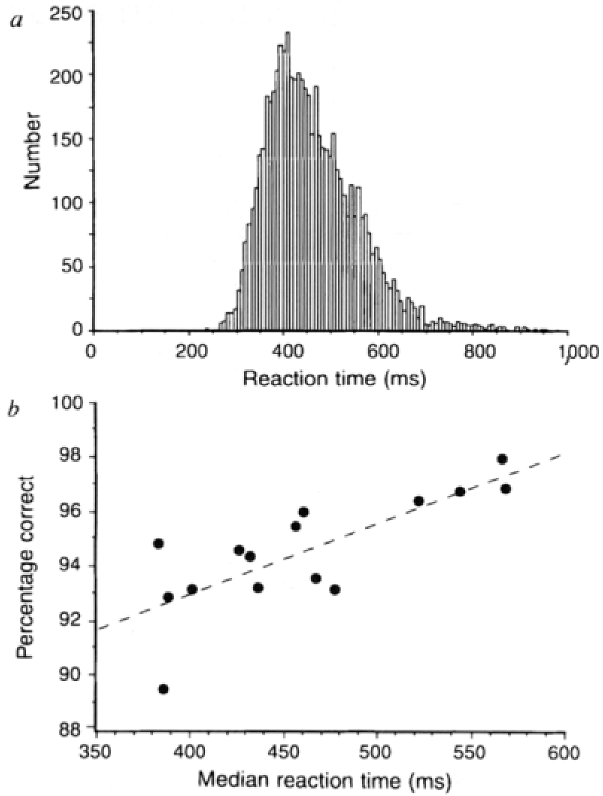


FIG. 1. (*A*) Grand-average waveforms (i.e., averaged across all seven subjects) of the event-related magnetic activity elicited by right-ear standard tones when they were attended versus when they were unattended, displayed at approximate locations of the magnetic sensors over the left hemisphere. At the upper right are the simultaneously recorded ERPs from the C3 site. Positive (upward) values for the magnetic activity indicate that the fields are directed out of the head, and negative values indicate inward-directed fields [calibration bars = ±20 femtotesla (fT)]. ERP scalp negativity is plotted upward [calibration bars = ±1 microvolt (μV)]. Large arrows mark the polarity-inverting M100 at sites 25 and 33; small arrows denote the polarity-inverting M50. (*B*) Grand-average attentional-difference waveforms (attended minus unattended ERFs) derived from the data in *A* for four sites (denoted with asterisks in *A*) in the anterior-to-posterior line across the array. Large and small arrows mark the polarity-inverting attention effects for M100 and M50, respectively.

How quickly does the visual system differentiate between different categories of objects?



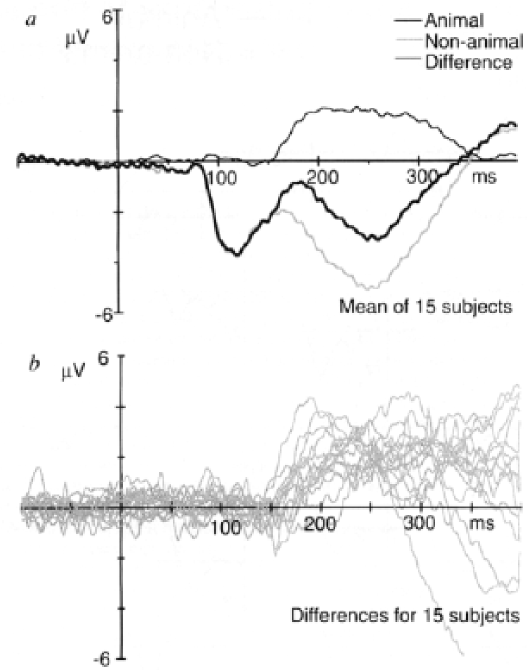


FIG. 3 Event-related potentials for 15 subjects. a, As Fig. 2c, but averaged over all 15 subjects. b, Average difference curves for the seven frontal electrodes plotted separately for each of the 15 subjects. Note that all subjects show a similar difference function, more negative on 'no-go' trials, and that the onset of the differential response is relatively constant across

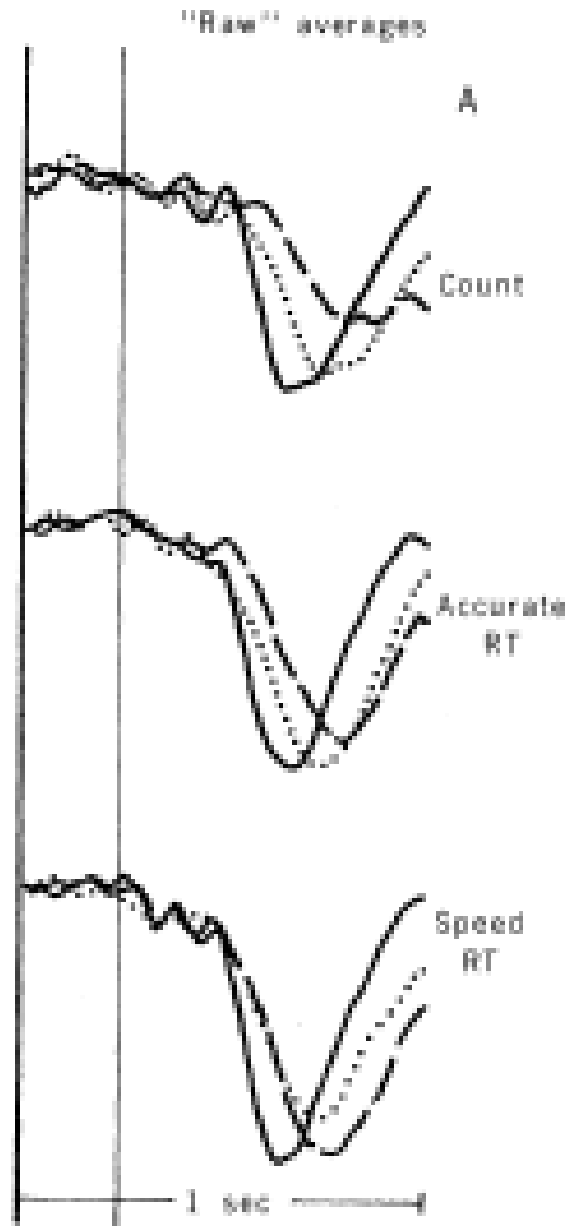
Thorpe et al. 1996

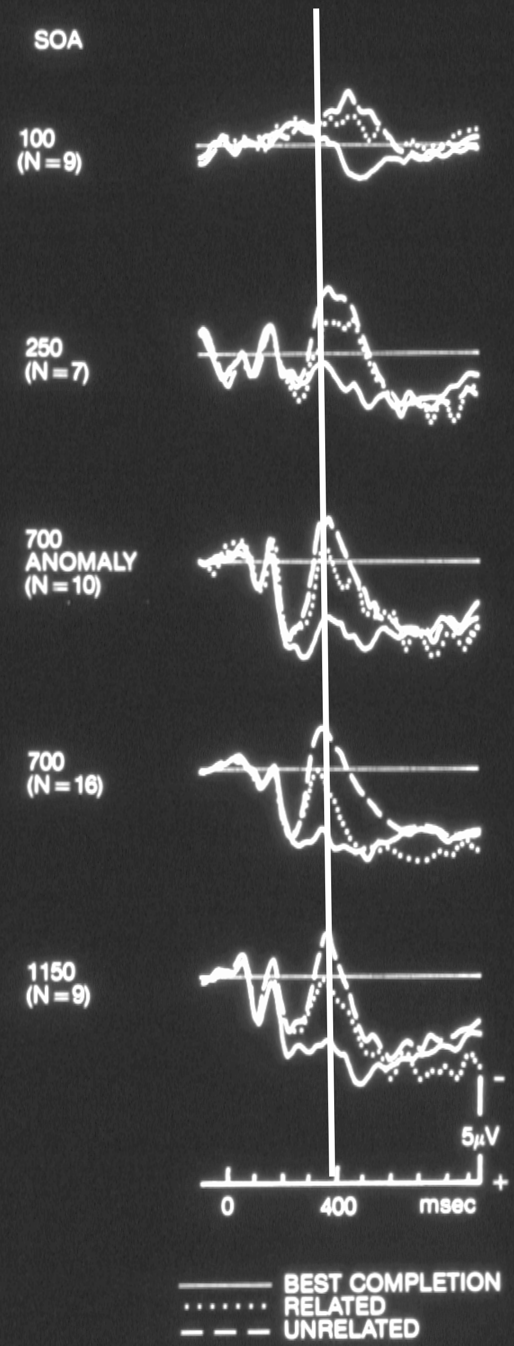
When??? ...TIMING

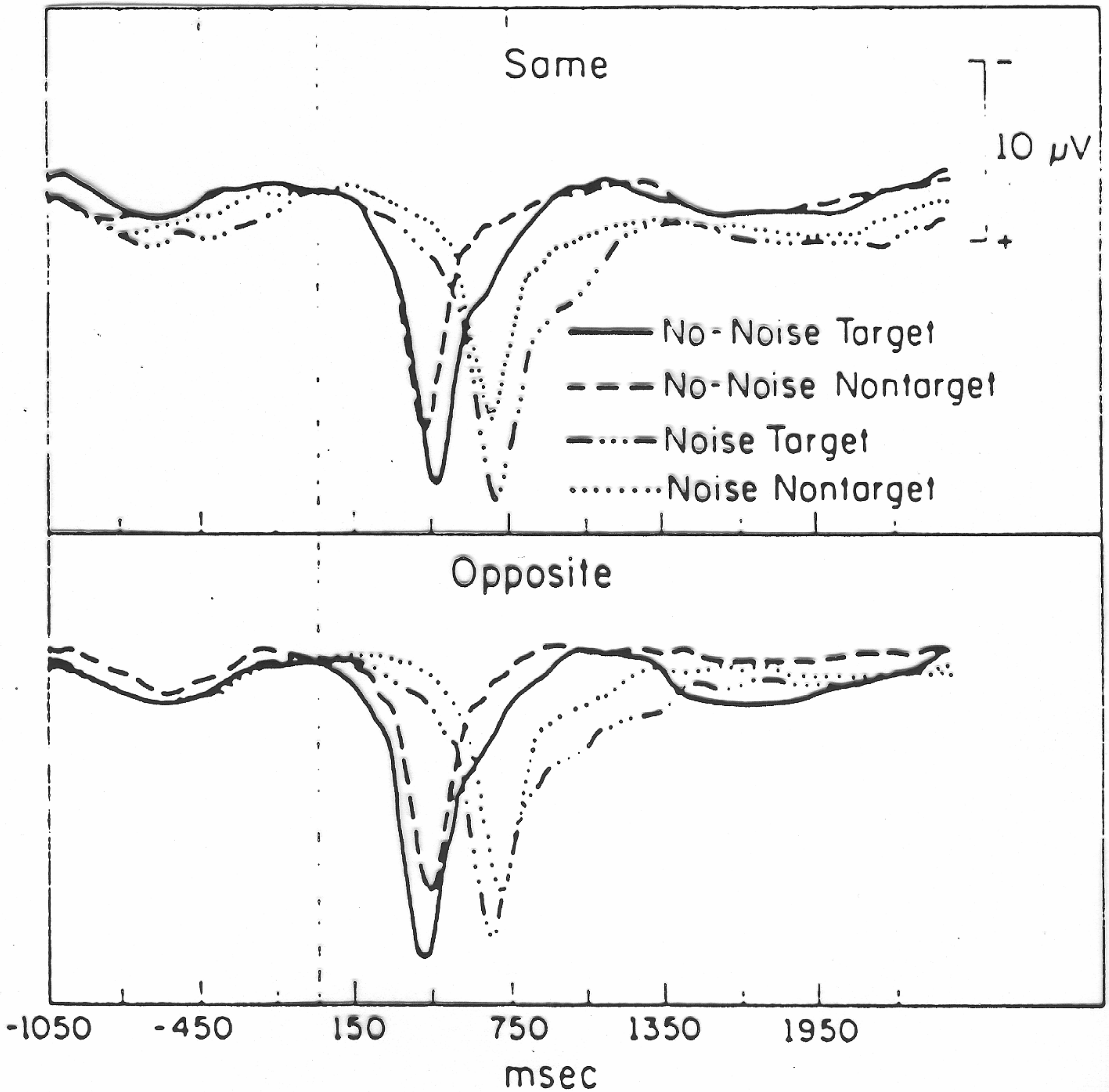
Time of divergence is upper limit on the time by which the brain has appreciated ***difference between two conditions*** (there might always be earlier ones (different by at least…x ms) !

When components are known (identified, measured, analyzed) and ERPs only vary in latency of that particular component it is generally concluded that same neural process (and the same psychological process that it reflects) is present but with different time course.

Traditionally, quantitative effect, though could have qualitative consequences


"Raw" averages
A
Count
Accurate
RT
Speed
RT
1 sec


SOA
100
(N=9)
250
(N=7)
700
ANOMALY
(N=10)
700
(N=16)
1150
(N=9)
-
5μV
+
0
400
msec
BEST COMPLETION
RELATED
UNRELATED


Same
10 μV
No-Noise Target
No-Noise Nontarget
Noise Target
Noise Nontarget
Opposite
-1050
-450
150
750
1350
1950
msec

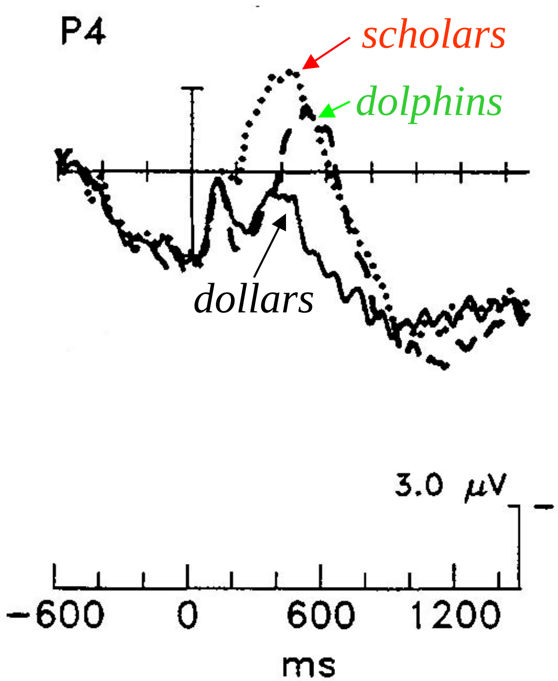
NO NOISE

```
######    ######
#RIGHT    ######
######    ##LEFT
######    ######
  (a)       (b)
```

NOISE

```
NRIGHT    KWSMNT
BMJUKM    UYRMUD
EQEIKM    VTFMZS
KEHEHG    ILEFTA
  (c)       (d)
```

It was a pleasant surprise to find that the car repair bill was only seventeen



Cohort congruous (dollars)

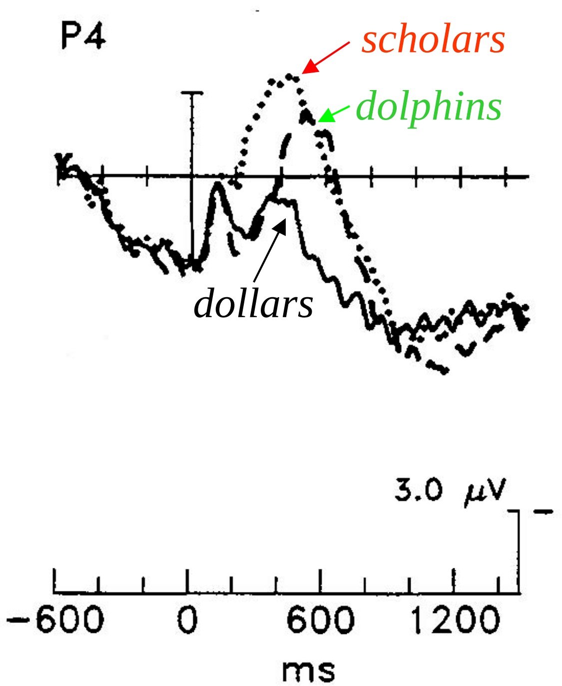
Cohort incongruous (dolphins)

Rhyme (scholars)

Van Petten et al. 1999

Semantic integration or t least context effect can begin before word identification.

It was a pleasant surprise to find that the car repair bill was only seventeen



——— *Cohort congruous (dollars)*

– – – *Cohort incongruous (dolphins)*

········ *Rhyme (scholars)*

Van Petten et al. 1999

Amplitude difference

main effect of condition, peak or mean amplitude measure

- ERPs differ only in amplitude of peak/component

  -- must rule out single trial variability

- Real amplitude difference

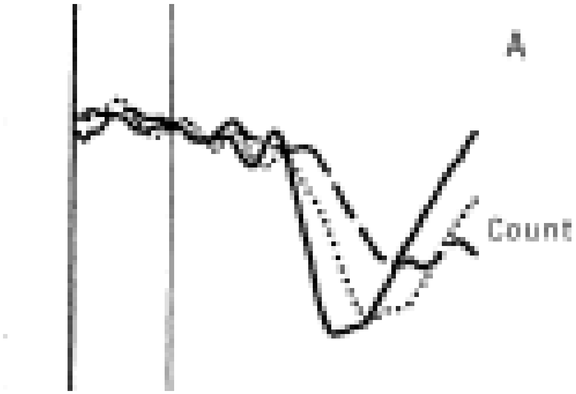
  - same neural process, but more or less activation or engagement (strength, degree)

    -- smaller PSPs in same neurons

    -- smaller number of neurons

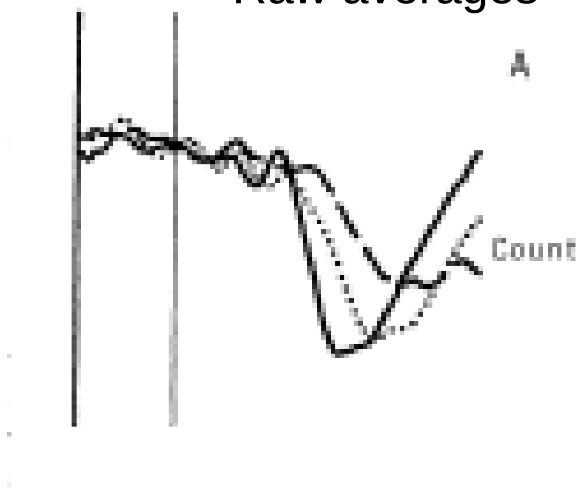
    -- less temporal synchrony

Raw averages

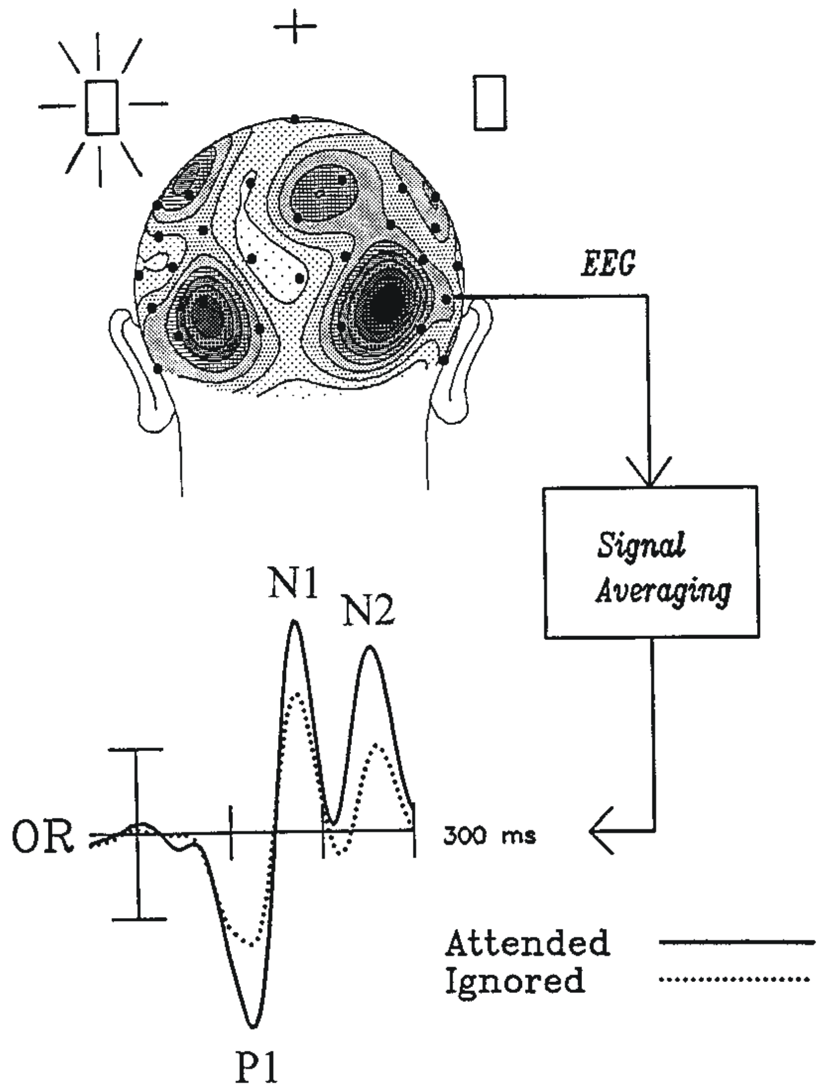


AMPLITUDE DIFFERENCE

Raw averages Latency Adjusted



Spatial Attention Modulates Early ERP Components



Mangun, Hillyard & Luck Attention & Performance 1990

Difference in Scalp Distribution

Condition x electrode interaction

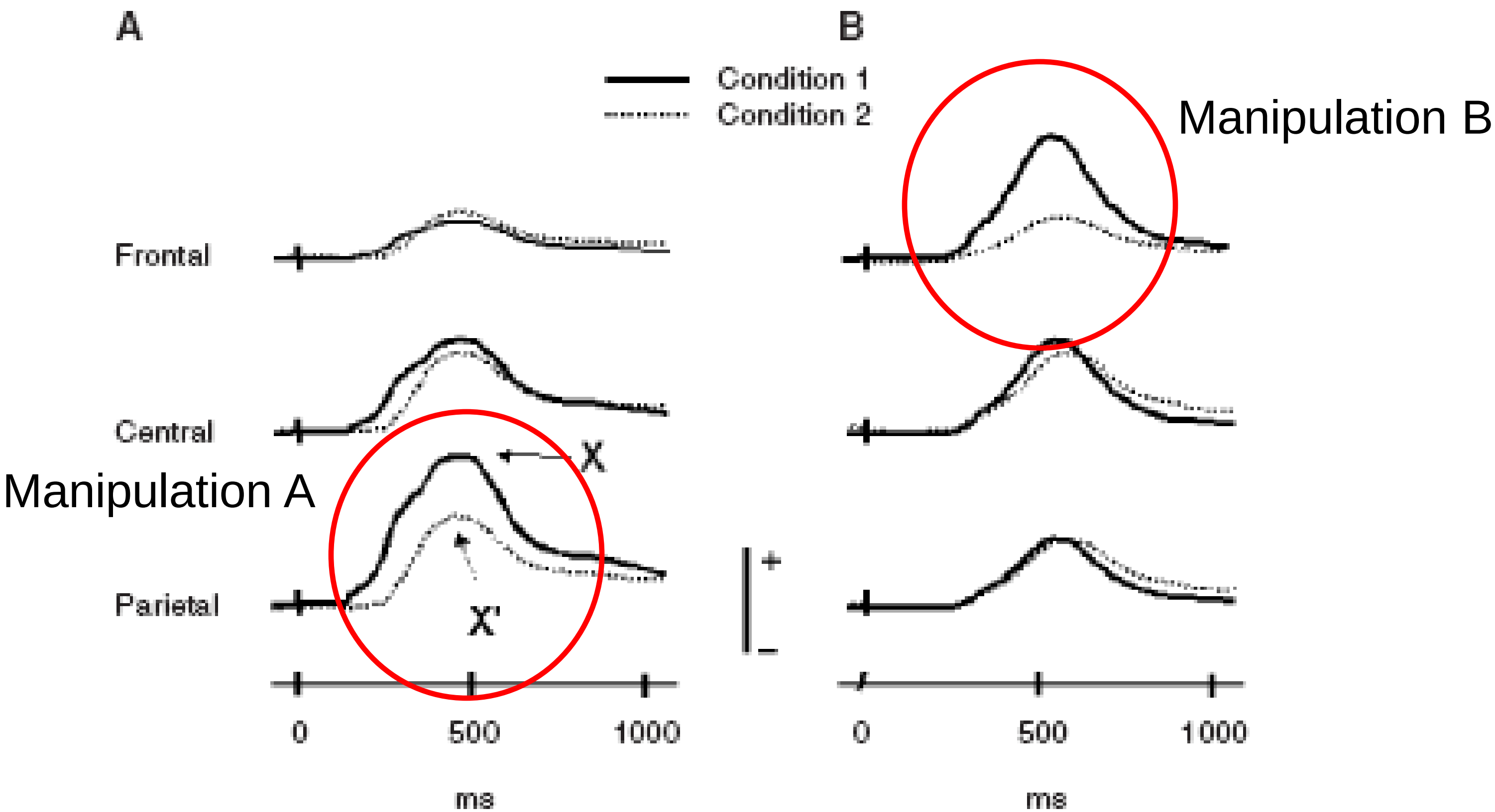


Figure 1.1
Hypothetical ERP waveforms elicited at three electrode sites in two experimental conditions in two experimental situations (*A* and *B*). The differences between the waveforms allow a number of functional interpretations. See text for details.

Figure 1. One of the sentences used in the experiment. This is the actual font employed (Chicago). The relative size of the words and the picture is very close to reality.

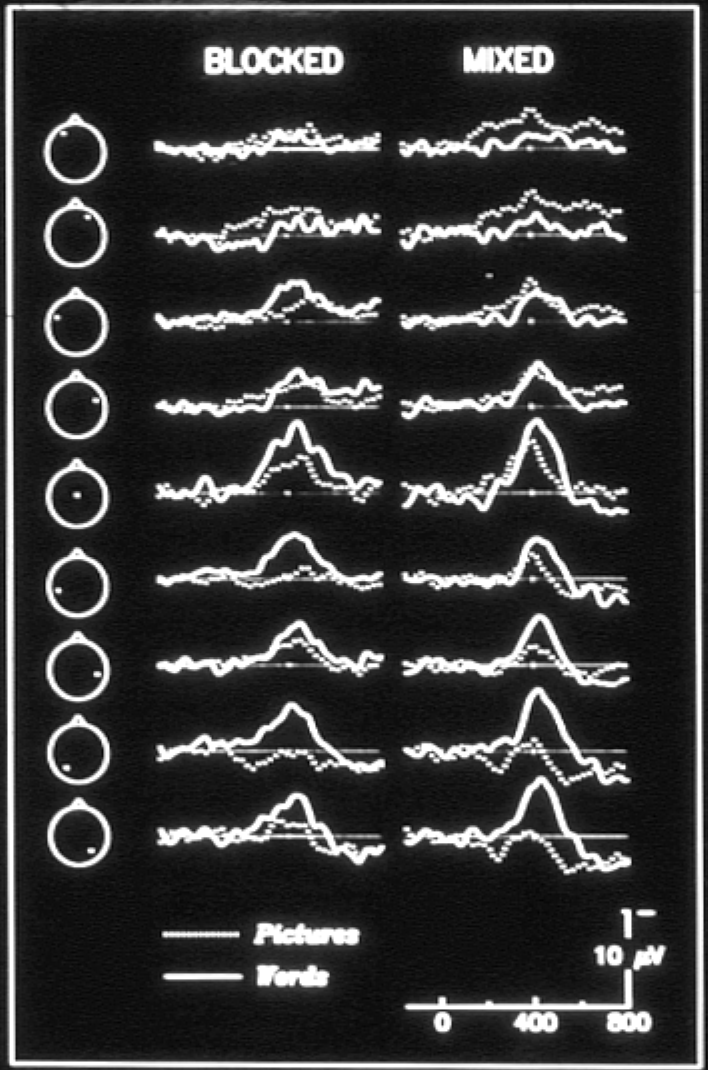


Figure 4. Difference ERP waveforms (incongruous minus congruous) obtained in the blocked (left) and mixed (right) conditions for words (solid line) and pictures (dotted lines). Only nine representative electrodes are shown for clarity.

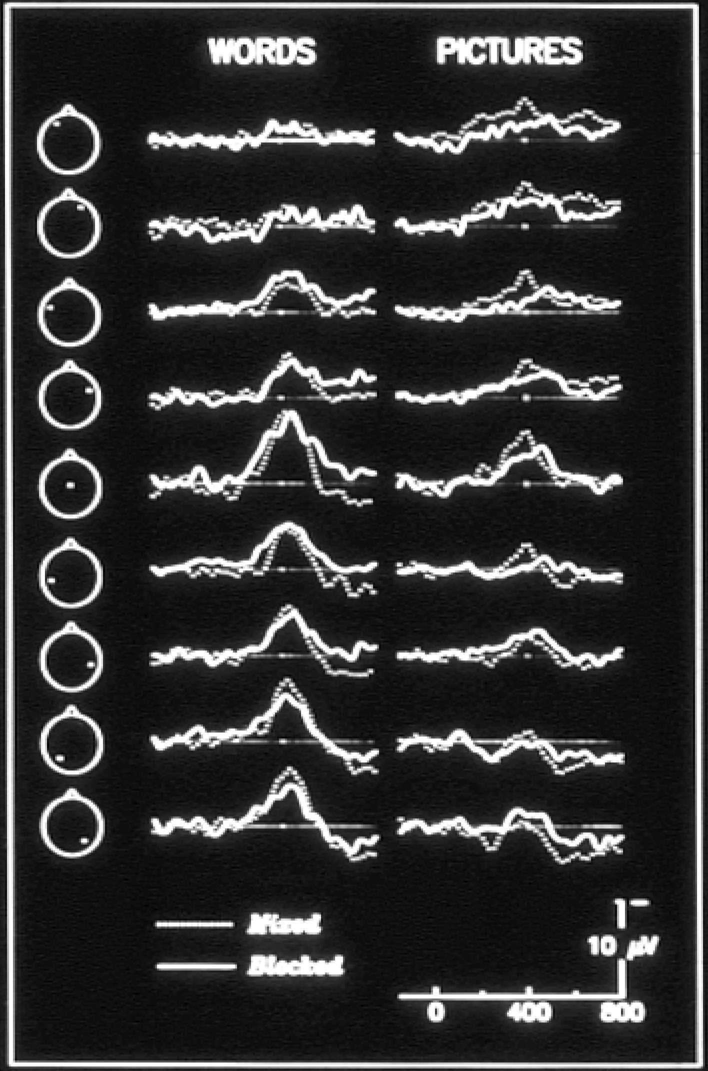


Figure 5. Difference ERP waveforms (incongruous minus congruous) obtained for words (left) and pictures (right) in the blocked (solid line) and mixed (dotted line) conditions.

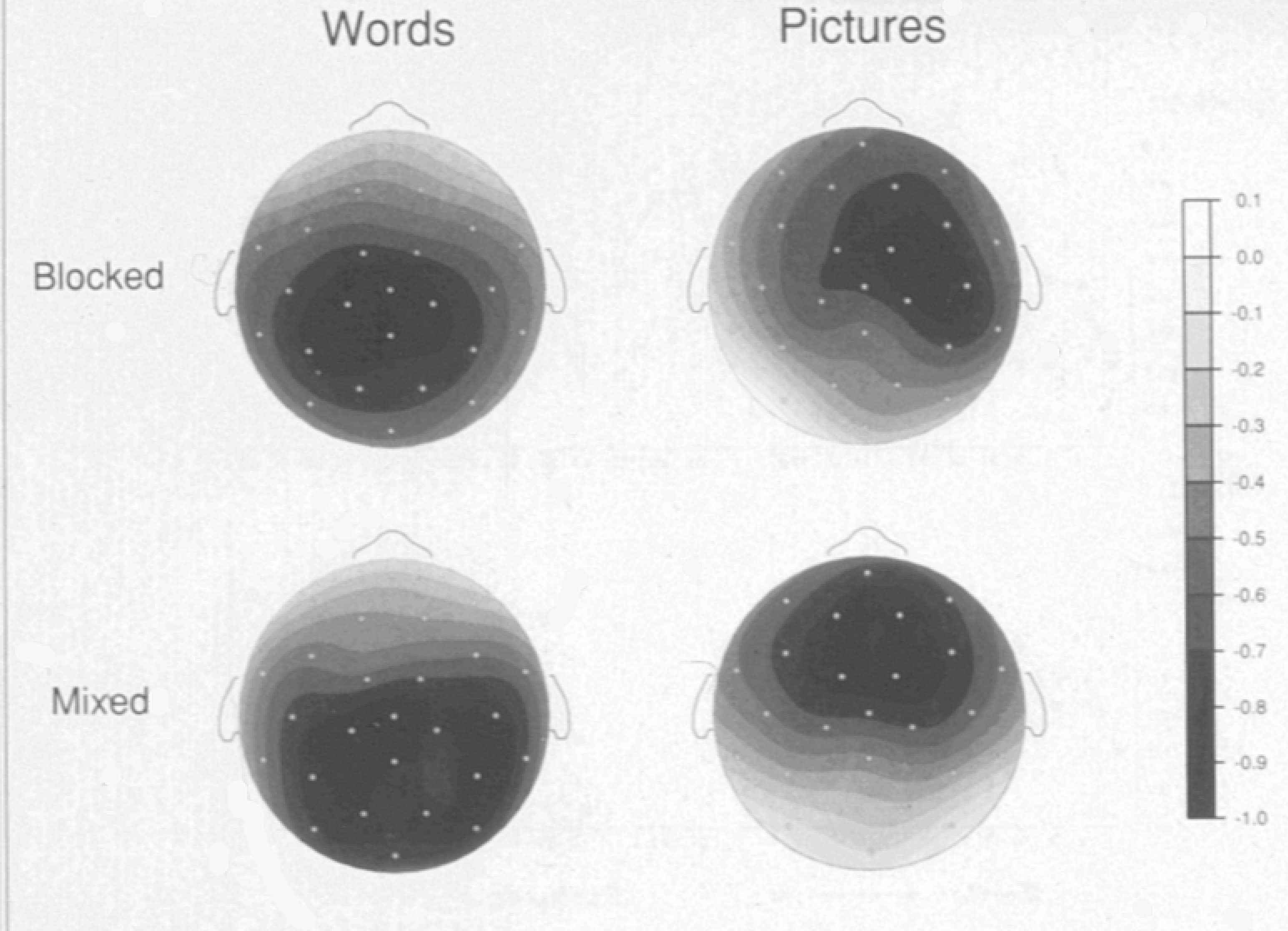


Figure 7. Isopotential gray-scale maps of the normalized distribution of the N400 effect (mean amplitude of the difference waves between 325 and 475 msec) in the blocked (top) and mixed (bottom) conditions for words (left) and pictures (right). The original scattered data (26 scalp sites) were interpolated with a spherical spline algorithm (Hassainia et al., 1994).

Ganis, Kutas,& Sereno

Scalp Distribution

Statistically reliable between-condition differences in the distribution of scalp potentials show without question that corresponding neural generators do differ *somehow* with respect to their location, polarity or intensity -- i.e., in some combination of location, polarity, and relative or overall strength.

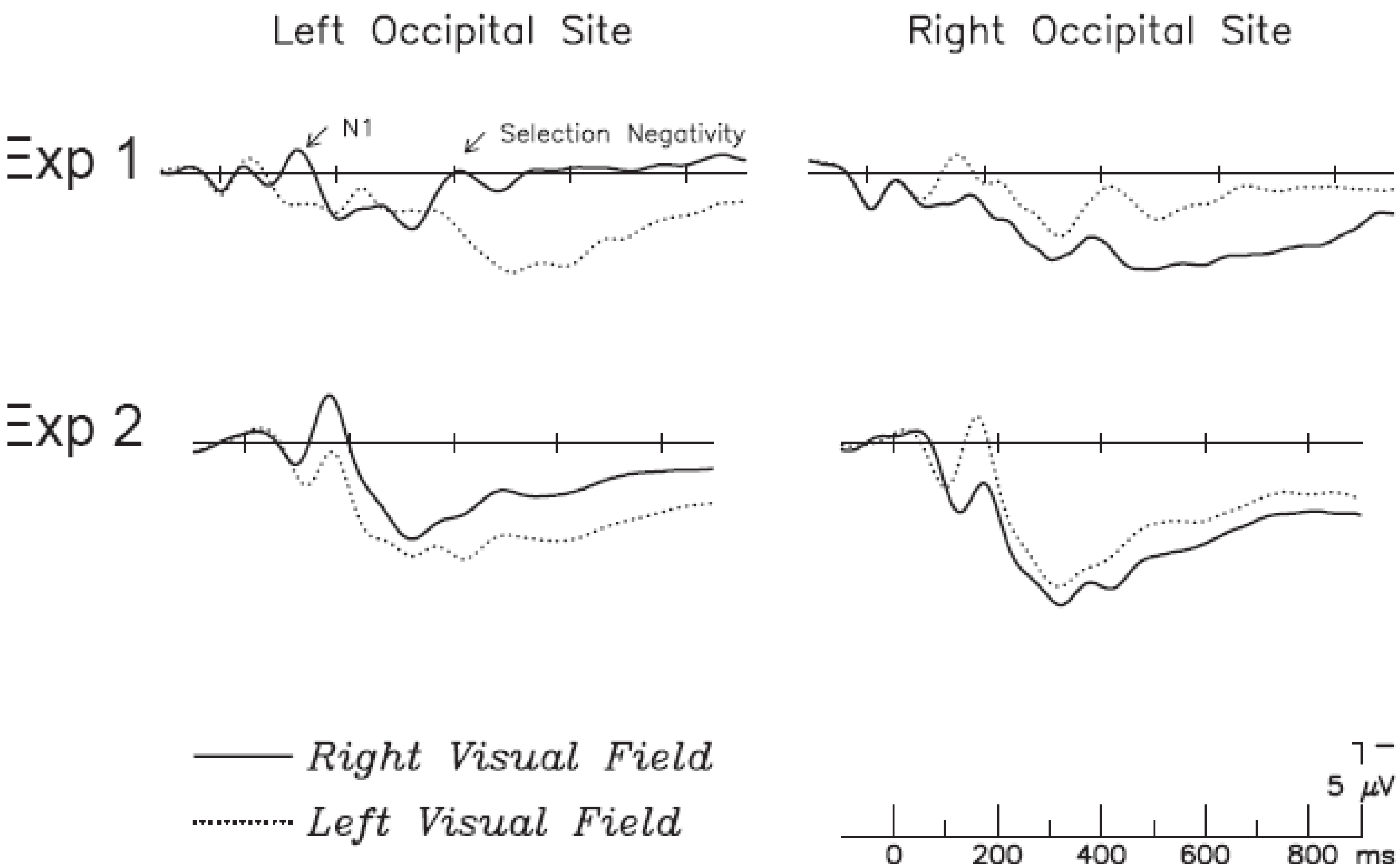
We’d like to go from scalp distribution differences to differences in neural generators. But we can’t!!!

Inverse Problem: An infinite number of generator configurations can lead to the same distribution of potentials at the scalp … so we can’t find generators from scalp data alone.

SCALP DISTRIBUTION
(condition x electrode interaction)

Usually taken as qualitative difference, but we can’t really be sure, and we have to be careful

Visual Sensory Evoked Potentials with Half field presentation



We can make some inferences when we know nothing about componentry, but in fact we do know something about components and their functional significance.

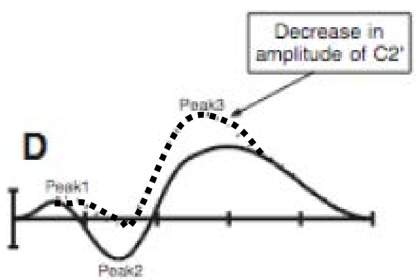
Exogenous (sensory)/evoked components
 - more dependent on external factors
 - evoked, obligatory, sensory
 - <150 ms (BER, P1, N1, P2)
Endogenous (cognitive) components
 - more dependent on internal factors
 - >200 ms (N2, P3, N4, etc.)

THERE'S NOTHING SPECIAL ABOUT PEAKS

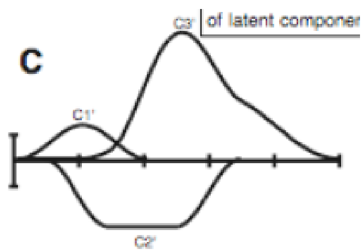
We measure peaks and troughs and effects for convenience. However, there is nothing that guarantees that a peak or trough is a component, and there is nothing special about the point at which voltage reaches a local maximum or minimum.

A PEAK IS NOT A COMPONENT

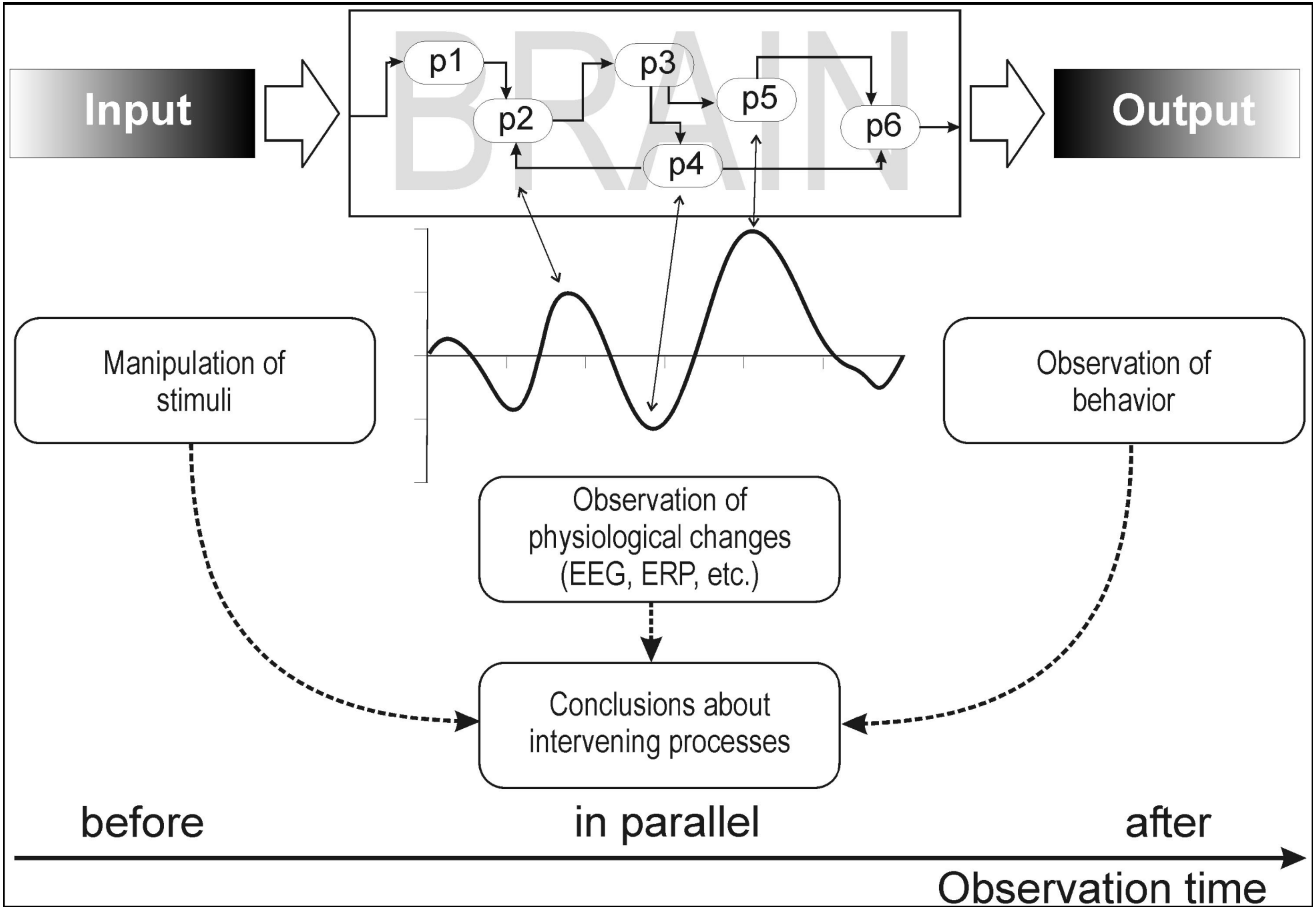
As already stated, one ERP alone cannot reveal its functional significance. Neither the peak latency nor the time course of an underlying ERP component are evident from a single ERP waveform and even differences alone cannot reveal the underlying (latent) componentry.



THE ERP RECORDED



LATENT COMPONENTS



Input
BRAIN
p1
p2
p3
p4
p5
p6
Output
Manipulation of stimuli
Observation of behavior
Observation of physiological changes (EEG, ERP, etc.)
Conclusions about intervening processes
before
in parallel
after
Observation time

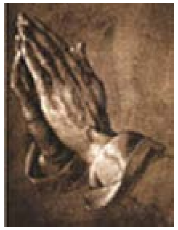
DETERMING FUNCTIONAL SIGNIFICANCE

1. SPECIFY ANTECEDENT CONDITIONS – what independent variable do/don't influence amplitude or latency of "component" or "effect"

2. IDENTIFY CONSEQUENCES OF COMPONENT VARIATION – what aspects of behavior are related to component

We need a linking hypothesis that links/correlates particular physical/mental process or state to a particular type of change in measure. But, at best, what we have is a correlate of the processing. To assume process is causally responsible for activity, we need to show that the activity is ***necessary and sufficient*** for the process.

Luck's Strategies for Avoiding Ambiguities in Interpreting ERP Components



1. Focus on a specific component

2. Use well-studied experimental manipulations

3. Focus on large components

4. Isolate components with difference waves

5. Focus on components that are easily isolated

6. Use experimental designs which are not dependent on what component is.

How quickly does the visual system differentiate between different categories of objects?

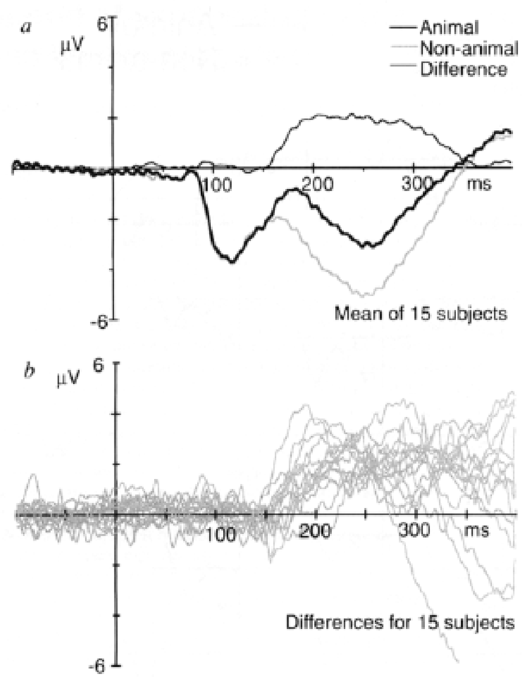


FIG. 3 Event-related potentials for 15 subjects. *a*, As Fig. 2*c*, but averaged over all 15 subjects. *b*, Average difference curves for the seven frontal electrodes plotted separately for each of the 15 subjects. Note that all subjects show a similar difference function, more negative on 'no-go' trials, and that the onset of the differential response is relatively constant across

Thorpe et al. 1996

Experiment 1

Experiments 2,4

Experiment 3

Johnson & Olshausen, 2003

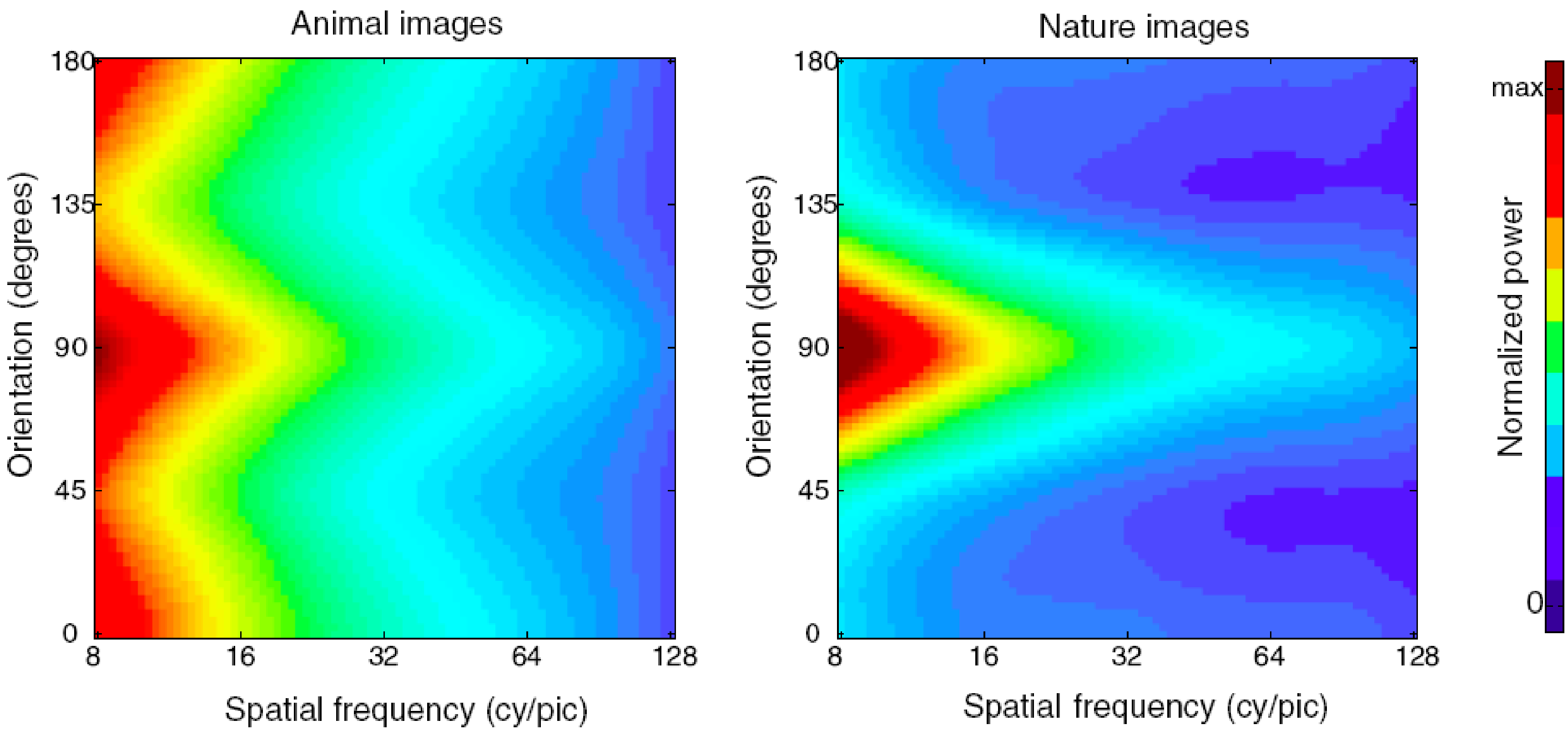


Figure 3. Power spectrum of animal and nature images. Each plot shows the average power spectrum (in log-polar coordinates) for 100 randomly selected images from each class (see methods). The animal images have a more even distribution of power among different orientations. The strong anisotropy in the nature images is most likely due to the presence of the horizon, which produces strong power at 90 degrees orientation in the spatial-frequency domain. Both plots are normalized to the same scale.

Johnson & Olshausen, 2003

Make sure that given experimental effect has a single possible cause.

When physical stimuli across conditions differ, consider the possibility that they can account for some if not all the condition differences observed.

Be extra cautious when comparing conditions with different numbers of trials.

Be cautious when the presence or timing of motor responses differs between conditions.

Whenever possible, experimental conditions should be varied within trial blocks rather than between trial blocks.