The Electrical Manifestation of Mind and Brain

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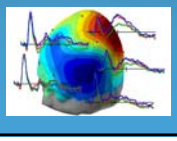
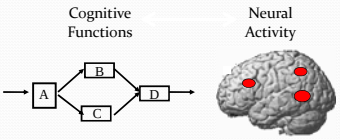
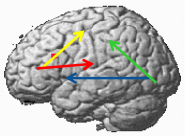


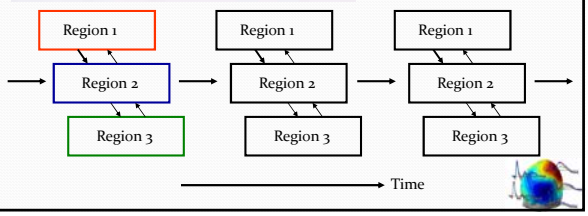
What's the role of Cognitive Neuroscience then?

- To understand the identity and organization of information-processing operations underlying cognitive functions, as well as how these operations are implemented by the nervous system.
- Assumption: We're materialists rather than dualist.



Mapping Neural Activities with Cognitive Functions

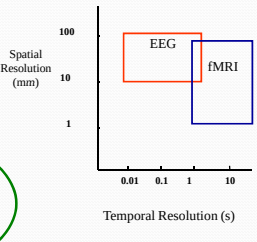




Two Non-Invasive Ways to Measure Brain Activities

Haemodynamic (brain blood supply)
e.g., PET, MRI

Electrophysiological (electromagnetic fields)
e.g., EEG/MEG



Spatial and temporal resolution

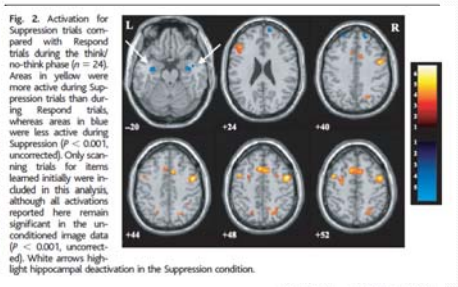
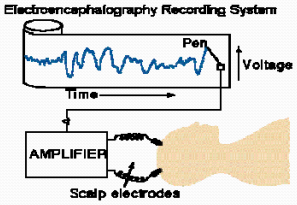


Fig. 2. Activation for Suppression trials compared with Respond trials during the think/no-think phase ($n = 24$). Areas in yellow were more active during Suppression trials than during Respond trials, whereas areas in blue were less active during Suppression ($P < 0.001$, uncorrected). Only scanning trials for items learned initially were included in this analysis, although all activations reported here remain significant in the unconditioned image data ($P < 0.001$, uncorrected). White arrows highlight hippocampal deactivation in the Suppression condition.

Anderson, et al., 2004

Electroencephalography (EEG)

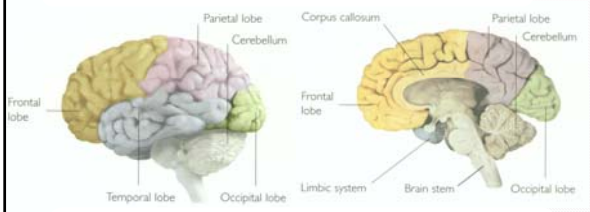
- ElectroEncephaloGraphy: a recording (graphy) of electrical signal (electro) from the brain (encephalo).



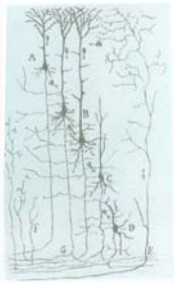
The History of EEG Recording

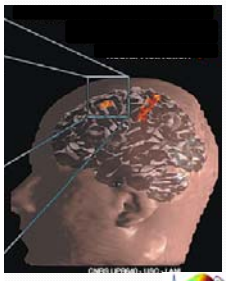
- Richard Caton: the first person to record electrical signal from animal (rabbits and monkeys) brain (1875).
- Hans Berger: the first person to record EEG from human brain (1929). His finding was confirmed by Adrian in Cambridge (Adrian & Matthews, 1934).
- Berger was also the first one to propose the term "electroencephalogram" instead of "electrocerebrogram".

The most mysterious organ: Brain

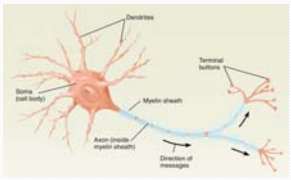


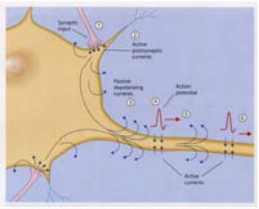
Neuron: Building Bricks of Cortex



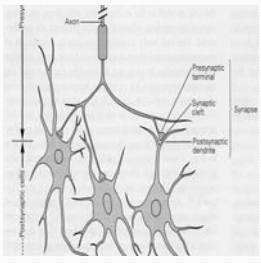


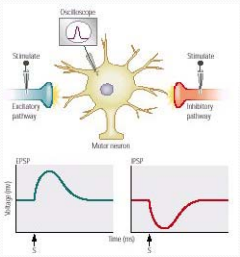
Electrogenesis



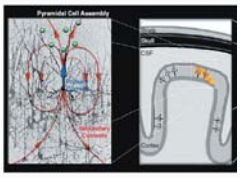


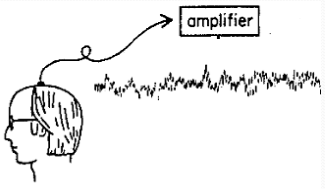
Excitatory/Inhibitory Post-Synaptic Potentials (EPSP/IPSP)



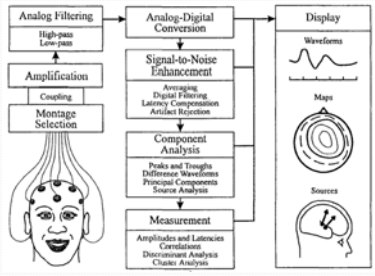


Summation of EPSP/IPSP

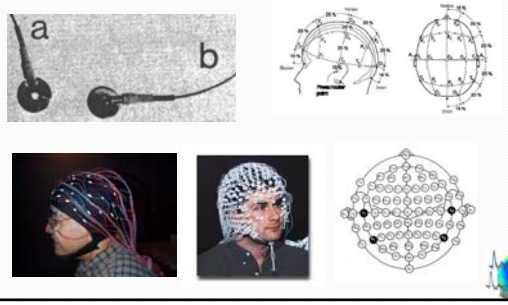




EEG/ERP Recording/Processing



Electrode Cap/Net



10-20 system

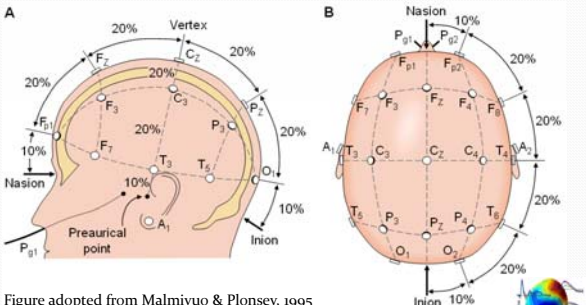


Figure adopted from Malmivuo & Plonsey, 1995

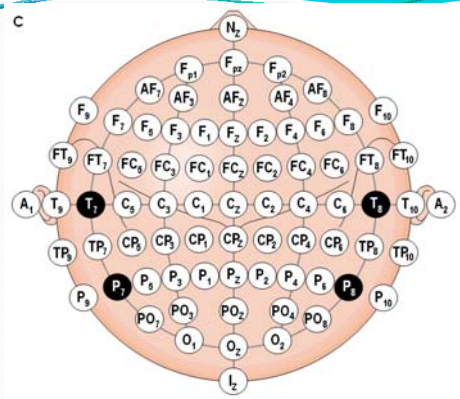


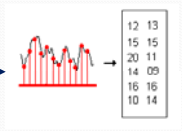
Figure adopted from Malmivuo & Plonsey, 1995

Capping

- Place the cap
- Clean/Scrub skin and Attach non-scalp electrodes (mastoids, EOG)
- (Scrub scalp)
- Insert Gel to Electrode
- Impedance Check (<5KOhm)

Amplifier & A/D Conversion

Analog-to-Digital conversion



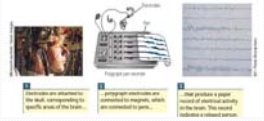
Parameter setting:

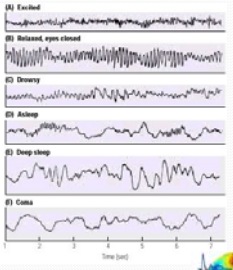
AC vs. DC Recording (low frequency components needed?)

Sampling Rate (Nyquist's theorem)

Filter (high-pass, low-pass filtering)

EEG in Different Frequency Bands



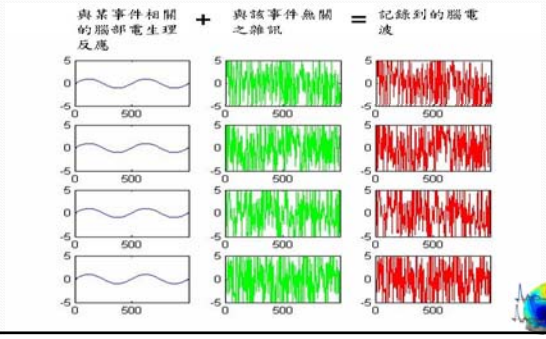


Delta wave : 0-4 Hz
Theta wave: 4-7 Hz
Alpha wave: 8-12 Hz.
Beta wave : 13-40 Hz
Gamma Wave : around 40 Hz

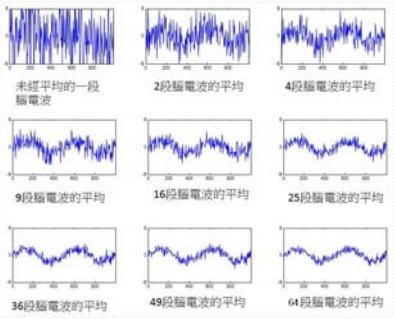
EEG vs. Event-Related Potentials (ERPs)

- EEG represents the sum of numerous neural activities and is difficult to be isolated into individual cognitive-neural process.
- Electrical activities associated with specific cognitive processes are embedded in EEG and may be extracted by enhancing the signal/noise ratio.
- ERPs are extracted from epochs of EEG associated with stimuli of the same category, and reflect the neural processing of experimental stimuli.

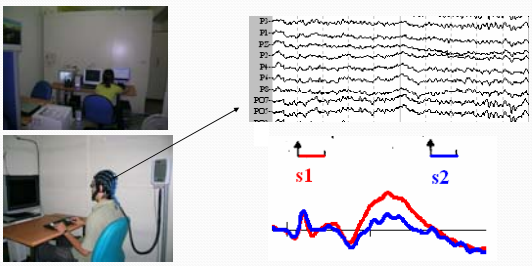
EEG and ERP



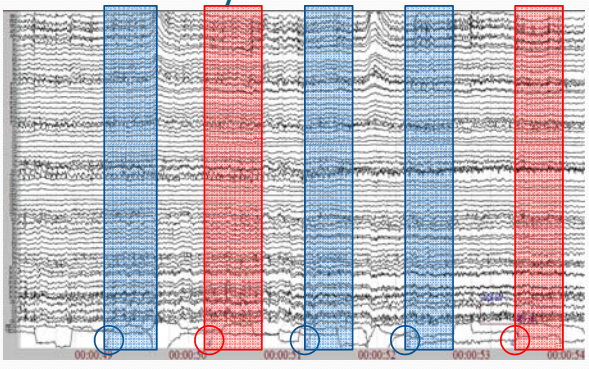
EEG and ERP



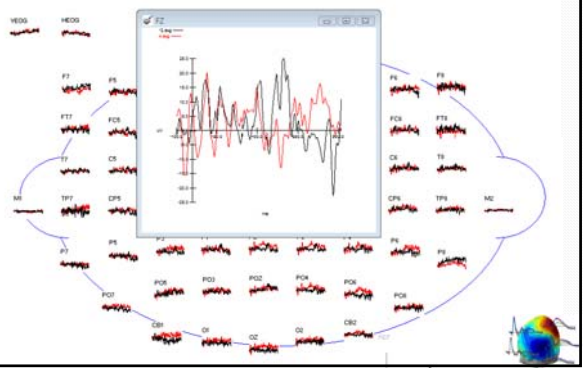
Extracting ERPs from EEG: Epoching and Averaging



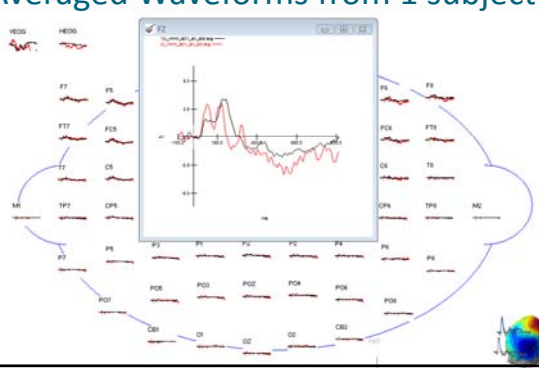
Continuously Recorded EEG



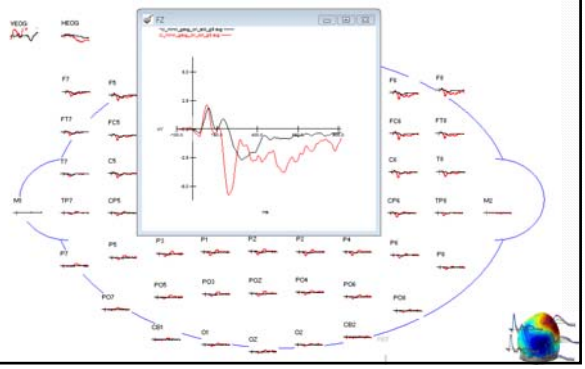
EEG Epochs time-locked to events



Averaged Waveforms from 1 subject



Averaged Waveforms from 9 subjects



The waves, are actually a lot of numbers…

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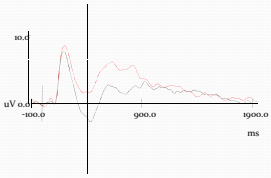
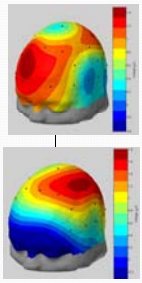
[Electrode Labels]
[      FP1]  [      FPZ]  [      FP2]  [      AF3]  [      AF4]  [       F7]  [       F5]
[Electrode XUnits]
[ Default]   [ Default]   [ Default]   [ Default]   [ Default]   [ Default]   [ Default]
[Electrode YUnits]
[ Default]   [ Default]   [ Default]   [ Default]   [ Default]   [ Default]   [ Default]
[Average Data]
    0.0384       0.2609       0.3703       0.1582       0.2065       0.3305       0.4546
    0.0384       0.2609       0.3703       0.1582       0.2065       0.3305       0.4546
    0.0450       0.2568       0.3036       0.1450       0.1766       0.3212       0.4244
    0.0659       0.2395       0.1397       0.1150       0.1212       0.3208       0.3739
    0.0997       0.2182       0.0582       0.0880       0.1398       0.3556       0.3661
    0.1244       0.2130       0.1589       0.0374       0.2294       0.3323       0.3060
    0.1012       0.1970       0.2595      -0.0628       0.2479       0.1485       0.0721
    0.0347       0.0991       0.1816      -0.1305       0.1544      -0.1356      -0.2314
   -0.0492      -0.1272      -0.0530      -0.1059       0.0176      -0.3836      -0.4619
   -0.1426      -0.3835      -0.2872      -0.0544      -0.1122      -0.4742      -0.5382
   -0.1800      -0.4521      -0.3770      -0.0189      -0.1874      -0.4153      -0.4595
   -0.1287      -0.2966      -0.2933      -0.0026      -0.1793      -0.3363      -0.3276
   -0.1075      -0.1169      -0.1055      -0.0649      -0.1284      -0.2816      -0.2411
   -0.2187      -0.0608       0.0557      -0.2310      -0.0949      -0.2609      -0.2244
   -0.3910      -0.0991       0.0669      -0.3963      -0.0940      -0.2774      -0.2385
   -0.4524      -0.1068      -0.0740      -0.4151      -0.1134      -0.1995      -0.1603
   -0.2845      -0.0053      -0.2406      -0.2315      -0.1508       0.0351       0.0478
    0.0677       0.1291      -0.2688       0.0809      -0.1612       0.2604       0.2555
    0.3695       0.1293      -0.1356       0.3226      -0.1028       0.3036       0.3379
    0.3861      -0.0522      -0.0224       0.3173      -0.0490       0.1434       0.2713
    0.1522      -0.2633      -0.0500       0.1204      -0.0765      -0.1101       0.0996
   -0.0913      -0.3272      -0.1055      -0.0682      -0.1207      -0.3142      -0.1087
   -0.1358      -0.1838      -0.0548      -0.1037      -0.0620      -0.3030      -0.2438
    0.0377       0.0530       0.0397       0.0126       0.0580      -0.0639      -0.2076
    0.2547       0.1937       0.0527       0.1418       0.0776       0.2477       0.0668
    0.3661       0.2243       0.0107       0.1885      -0.0027       0.4343       0.2477
    0.3557       0.2348      -0.0065       0.1877      -0.0721       0.4648       0.3661
```

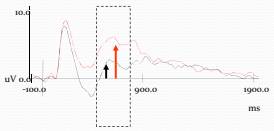
What to Analyze?





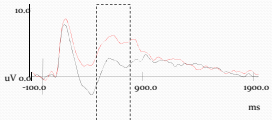
Waveform -- Peak Amplitude

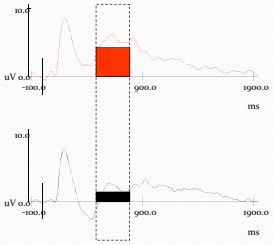
- Define a time window and find the maximum amplitude inside this window.



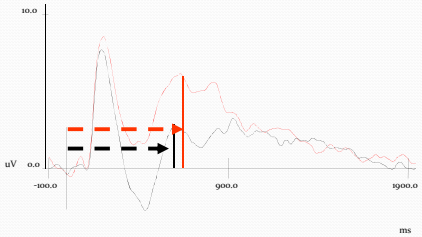
Waveform -- Mean Amplitude

- Calculate the mean amplitude in a defined time-window

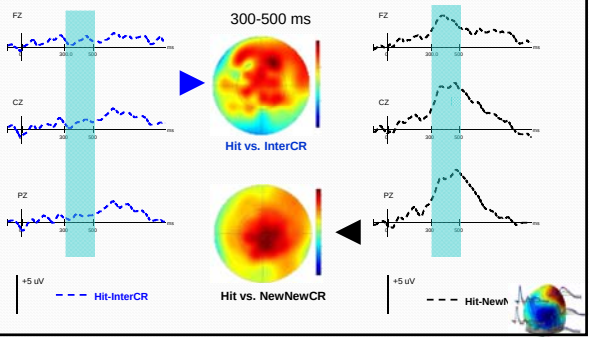




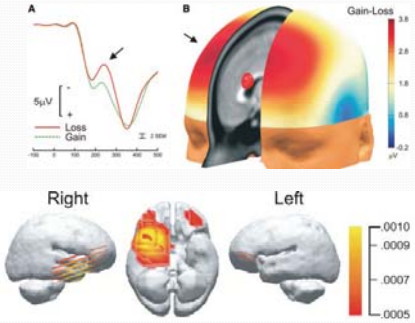
Waveform – Peak Latency



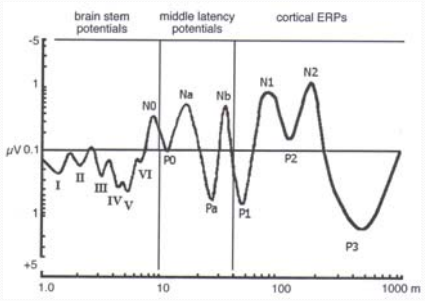
Topographic Distribution



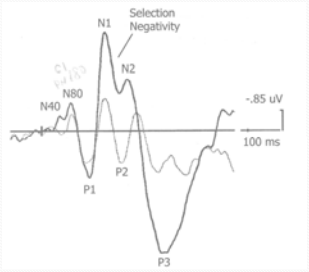
Source Localization



AEP

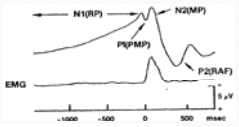


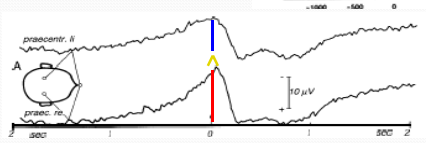
VEP



Lateralized Readiness Potential (LRP)

- A slow, ramp-like negative shift that precedes the actual production of a voluntary hand movement by as much as 1000 milliseconds.

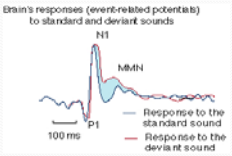


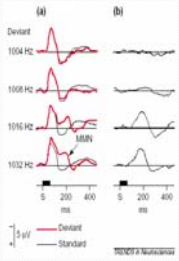


Kornhuber & Deeke, 1965

Mismatch Negativity (MMN)

- a component of the **auditory** ERP, which is elicited task-independently by an infrequent change in a repetitive sound (**oddball task**).





Sams et al., 1983

MMN & Cochlear Implant Simulations of Lexical Tones

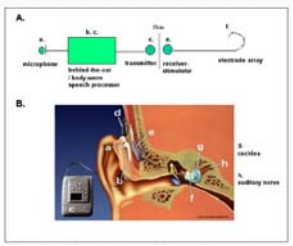
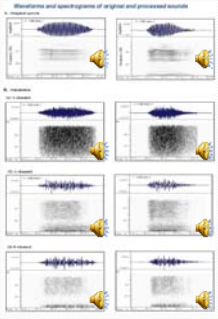
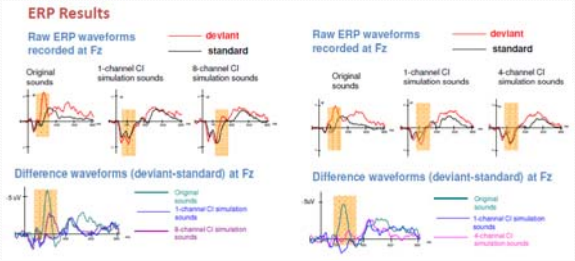


Figure 1. A: Components of the multi-channel cochlear implant system (modified from Leicon, 1998). B: An implant system and its placement in an implant user (from the website of the Bionic Ear Institute; the implant device shown here is the Nucleus device).

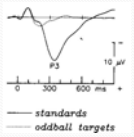


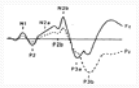
MMN & Cochlear Implant Simulations of Lexical Tones

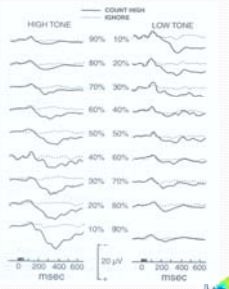


P300, P3a, P3b, Novelty P300

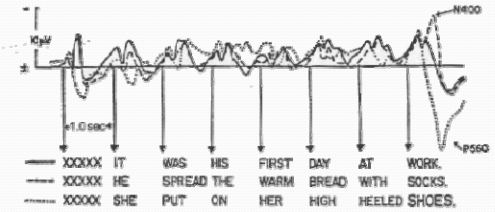
- A positive waveform elicited by low probability deviant stimuli, broadly distributed across the scalp with a posterior maximum and a peak around 300 ms post stimulus.







N400, sensitive to semantics



N400

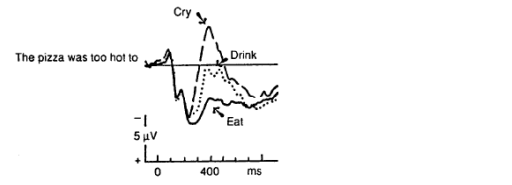
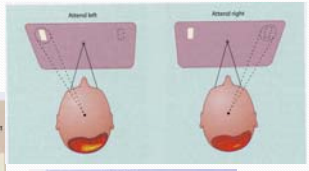


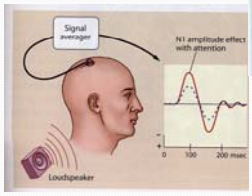
FIG. 4 ERPs elicited by sentence-final words at a midline central site, showing the positivity *(solid line)* for a predictable word. N400 elicited by an incongruous word *(dashed line)*. When the final word is semantically incongruent but related to the expected final word *(dotted line)*, it elicits a smaller N400 than an unrelated incongruity. Sample endings are for illustrative purposes only, since the same sentence frames were never repeated in this experiment. Figure from Kutas et al. (1984). Copyright Raven Press. Reprinted with permission.

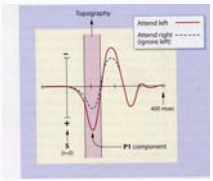
Attention

Visual

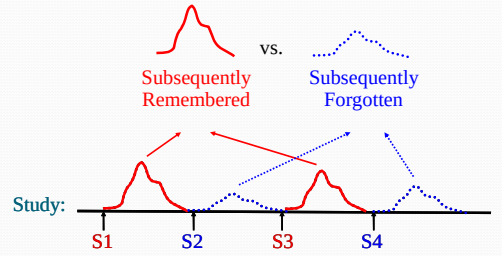


Auditory



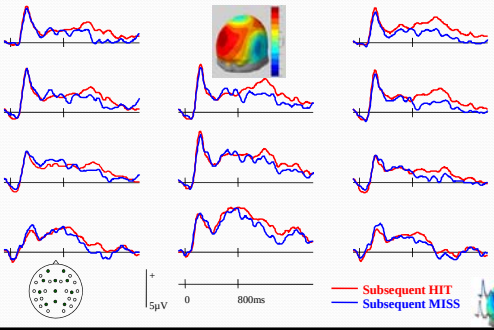


Memory Encoding

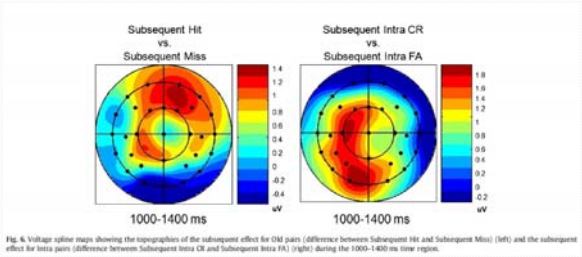


Test: Remembered: S1, S3 Forgotten: S2, S4

Subsequent Memory Effect



Gist vs. Verbatim encoding

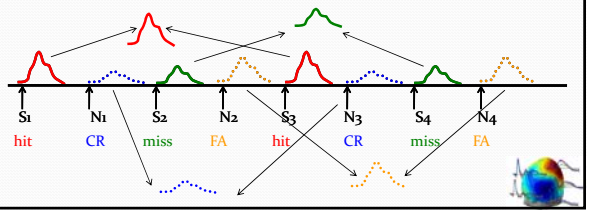


Cheng & Rugg, 2010

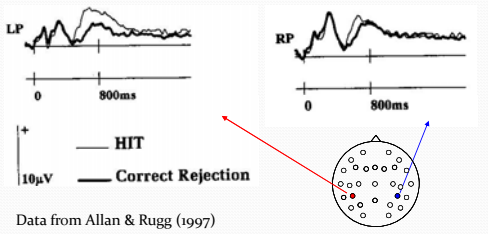
Memory Retrieval

ENCODING → STORAGE → RETRIEVAL

- Study Phase: S1, S2, S3, S4, S5....
- Test Phase: S1, N1,S2,N2,S3, N3,S4,N4...



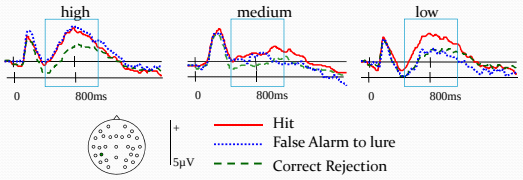
ERP Memory Effect



Data from Allan & Rugg (1997)

Left Parietal ERP Old/New Effect

False Recollection is Modulated by the Strength of the Gist



Cheng & Rugg, 2004

How to read ERP papers? (I)

- ERPs must be recorded from tasks that are designed to investigate a specific research problem.
- There is no way an ERP study can report electrophysiological data without a behavioral task.
- So reading an ERP paper should start with finding out the specific research hypothesis, the experimental task, and the manipulated variables of the experiment.
- Most importantly, find out how the manipulated variables are thought to affect the underlying processes and hence the ERPs.

How to read ERP papers? (II)

- ERPs are averaged epochs of EEG time-locked to specific events.
- Find out the events that the ERPs are time-locked to in the study.
- It could be the stimuli presented by the experimenter (stimulus-locked) or the response made by the participant (response-locked).
- Some times, both stimulus-locked and response-locked ERPs are analyzed in a study.
- Most importantly, find out the predictions of the experimenter (or yours).

How to read ERP papers (III)

- An ERP paper must comprise ERP recording and analysis sections that report how the data are recorded and analyzed.
- Key information: sampling rate, AC or DC recording, low-pass filter, epoched time window, and the montage that are used.

Psychophysiology, 37 (2000), 127–152. Cambridge University Press. Printed in the USA.

COMMITTEE REPORT

Guidelines for using human event-related potentials to study cognition: Recording standards and publication criteria

T.W. PICTON,[a] S. BENTIN,[b] P. BERG,[c] E. DONCHIN,[d] S.A. HILLYARD,[e] R. JOHNSON, JR.,[f] G.A. MILLER,[g] W. RITTER,[h] D.S. RUCHKIN,[i] M.D. RUGG,[j] AND M.J. TAYLOR[k]

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[d]Department of Psychology, University of Illinois, Champaign, USA
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[f]Department of Psychology, Queens College, CUNY, Flushing, New York, USA
[g]Departments of Psychology and Psychiatry, University of Illinois, Champaign, Illinois, USA
[h]Department of Neuroscience, Albert Einstein College of Medicine, Bronx, New York, USA
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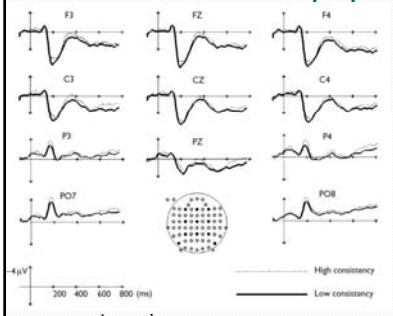
[j]Institute of Cognitive Neuroscience, University of London, England
[k]Centre de Recherche Cerveau et Cognition, Université Paul Sabatier, Toulouse, France

Now we can start looking at the waveforms in the papers. But how?

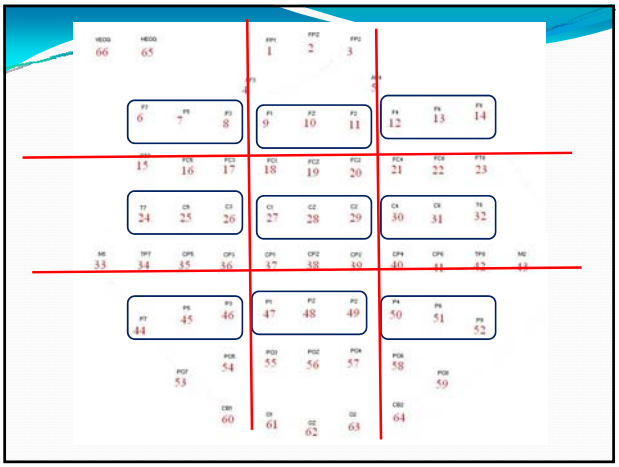


Lee et al., 2007

1. Electrode locations
2. Experimental conditions
3. Time scale (x axis)
4. Amplitude (y axis)
5. Negative down or negative up?
6. Raw waveform or difference waveform?

How are the ERP waveforms analyzed?

- The waveforms are just visual illustrations. There must be statistical analysis on the ERP features from which research hypotheses are tested.
- Find out what waveform features are employed as the dependent variable(s)?
- Mean amplitude, peak amplitude, or peak latency?
- What are the time windows that have been analyzed?
- What are the recording sties that have been analyzed?

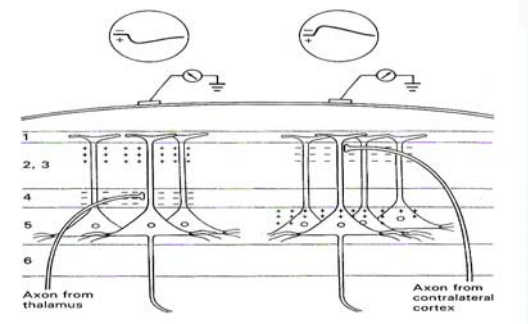


How are the ERP results explained?

- Behavioral data must be considered.
- Are the reported ERP effects one of the components that have been well investigated in previous literature, such as P300, N400?

Note that…

- As in behavioral data, null results in ERPs provide little information, unless there is a very strong theoretical prediction.
- Polarities of the ERPs (i.e., positive or negative going) do not correspond to facilitation or inhibition of a particular cognitive process.
- In fact, the polarities of ERPs even do not reflect excitatory or inhibitory neuronal activities.



Nunez, 2006

A single electrode provides estimates of synaptic action averaged over tissue masses containing between roughly 100 million and 1 billion neurons.

- Scalp fields does not equal to intracerebral sources.
- An ERP effect observed in a specific recording site does not necessarily originate from the cerebral region below or nearby.
- In fact, an ERP effect could have multiple neuronal origins.
- Peaks in waveforms do not necessarily reflect specific neuronal events.

NEUROLOGY

Patients with MCI and N400 or P600 abnormalities are at very high risk for conversion to dementia

J. M. Olichney, J. R. Taylor, J. Gatherwright, D. P. Salmon, A. J. Bressler, M. Kutas and V. J. Iragui-Madoz

Neurology 2008;70;1763-1770; originally published online Dec 12, 2007;
DOI: 10.1212/01.wnl.0000281689.28759.ab

AMERICAN ACADEMY OF NEUROLOGY

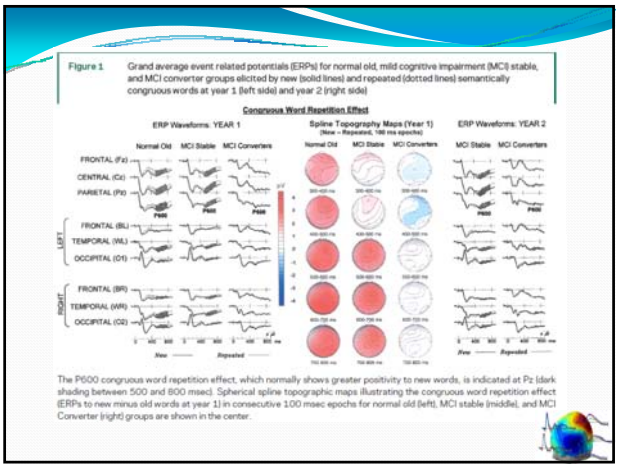


Figure 1 Grand average event related potentials (ERPs) for normal old, mild cognitive impairment (MCI) stable, and MCI converter groups elicited by new (solid lines) and repeated (dotted lines) semantically congruous words at year 1 (left side) and year 2 (right side)

Congruous Word Repetition Effect

ERP Waveforms: YEAR 1 | Spline Topography Maps (Year 1) (New – Repeated, 100 ms epochs) | ERP Waveforms: YEAR 2

Normal Old | MCI Stable | MCI Converters

FRONTAL (Fz)
CENTRAL (Cz)
PARIETAL (Pz)
P600

LEFT
FRONTAL (BL)
TEMPORAL (WL)
OCCIPITAL (O1)

RIGHT
FRONTAL (BR)
TEMPORAL (WR)
OCCIPITAL (O2)

New —— Repeated

The P600 congruous word repetition effect, which normally shows greater positivity to new words, is indicated at Pz (dark shading between 500 and 800 msec). Spherical spline topographic maps illustrating the congruous word repetition effect (ERPs to new minus old words at year 1) in consecutive 100 msec epochs for normal old (left), MCI stable (middle), and MCI Converter (right) groups are shown in the center.

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Home › DMW Daily › February 7, 2008

Nielsen Invests in Brainwave Researcher NeuroFocus

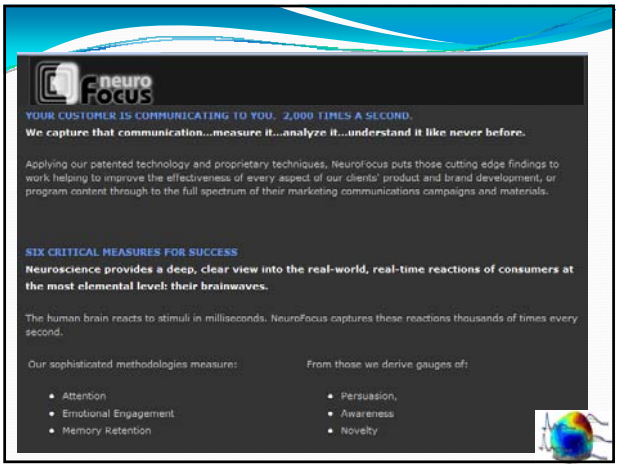
Authored by Mark Hefflinger on February 7, 2008 - 11:28am.

New York - Nielsen, the media ratings and research provider, announced on Thursday that it has made a strategic investment in NeuroFocus, a Berkeley, Calif.-based firm that specializes in applying brainwave research to advertising, programming and messaging.

The two companies will work together to develop new forms of measurement and metrics based on the latest advances in neuroscience, Nielsen said.

NeuroFocus applies brainwave, eye-tracking and "skin conductance" measurements to track the effectiveness of advertising, branding, packaging, pricing and product design.

Terms of the investment in privately held NeuroFocus were not disclosed.



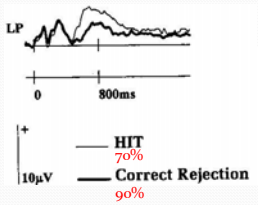
Brain Waves in Marketing?

- Theoretically, should be feasible.
- Practically, better be careful and cautious.

- You need to know what cognitive processes are critical for your purpose.
- You need to identify ERP components that are correlated with the specific cognitive processes.
- All these require good experimental design (and usually many experiments needed) and data analysis.

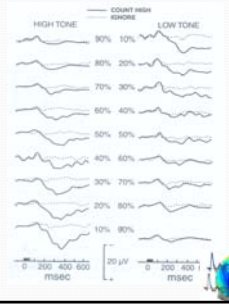
Confoundings in Experiments ?

Memory Effect



Data from Allan & Rugg (1997)

P300



Signal/Noise Ratio