EEG and Event Related Potentials in Psychiatry

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Presentation Outline

- Classification of bioelectric signals
- Spontaneous/resting EEG (Intro)
- Event Related Potentials (ERP, Intro)
  - improving signal-to-noise ratio (artifact rejection)
  - improving signal-to-noise (averaging)
- 3-dimensional EEG/ERP tomography
- Illustration of types of ERP, with examples of psychiatric applications

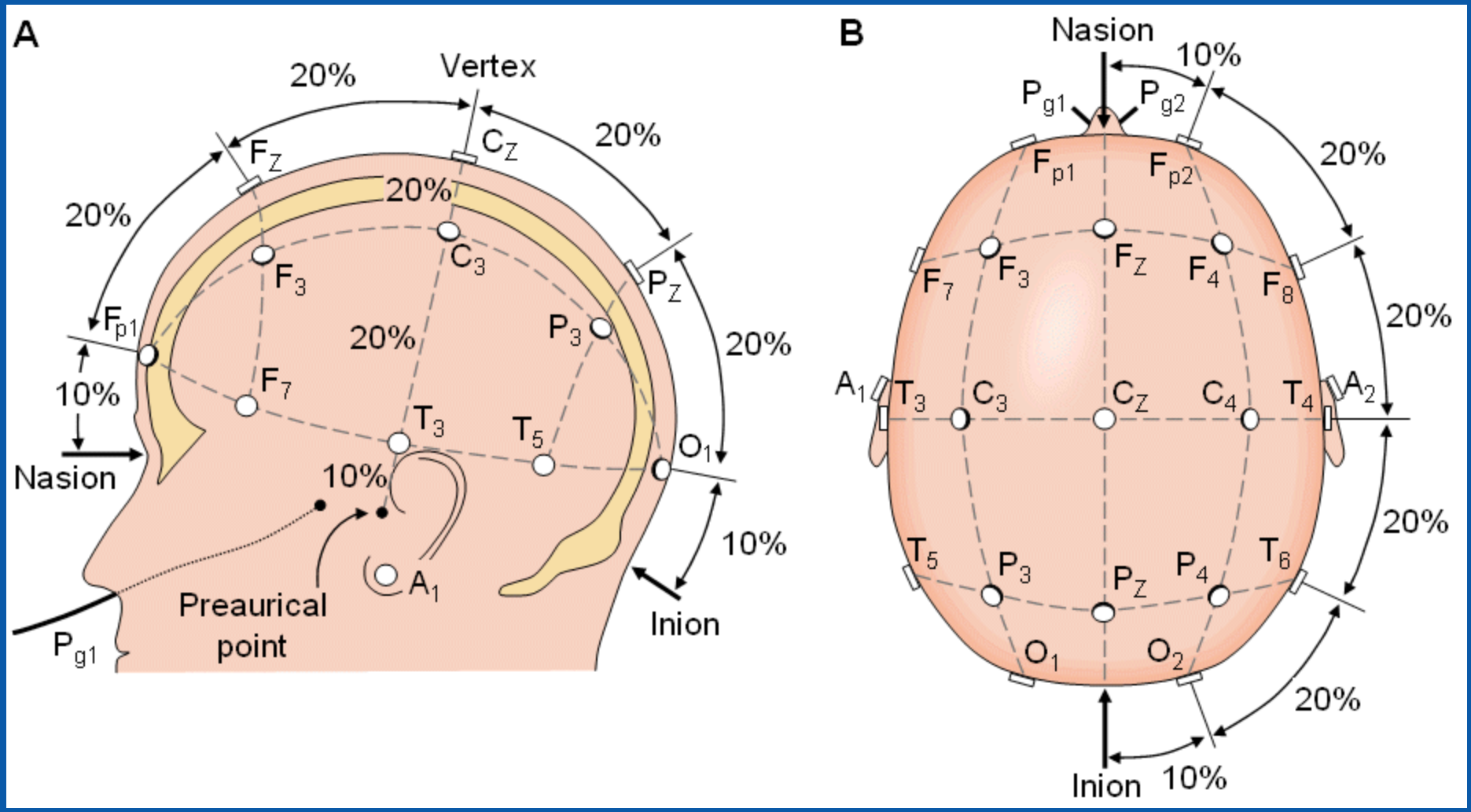
Just a few facts about EEG „signals”

Amplitude/voltage: typically, in the range of MicroVolts (uV): <1 – 100 uV

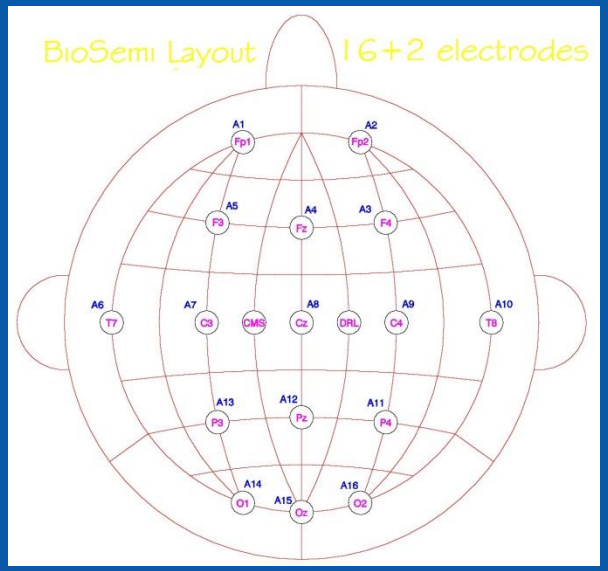
Frequency: typically, in the range of 0.01 – 100 Hz

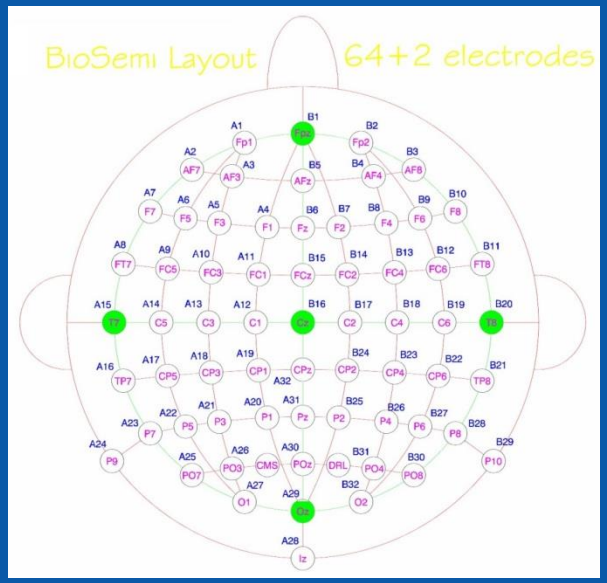
Wave/form: depends on brain area, physiological/ psychological state, clinical condition

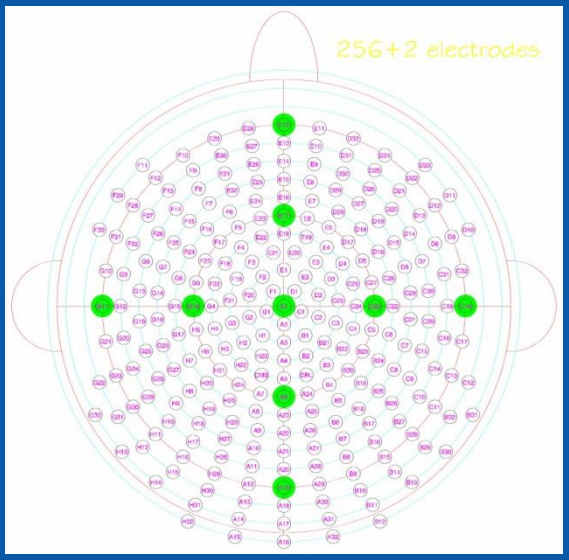
EEG: The 10-20 System of Electrodes



Electrode Arrays (from 16 to 256 sensors)







16 sensors

64 sensors

256 sensors

Bioelectric Signals of the Brain
2 major groups

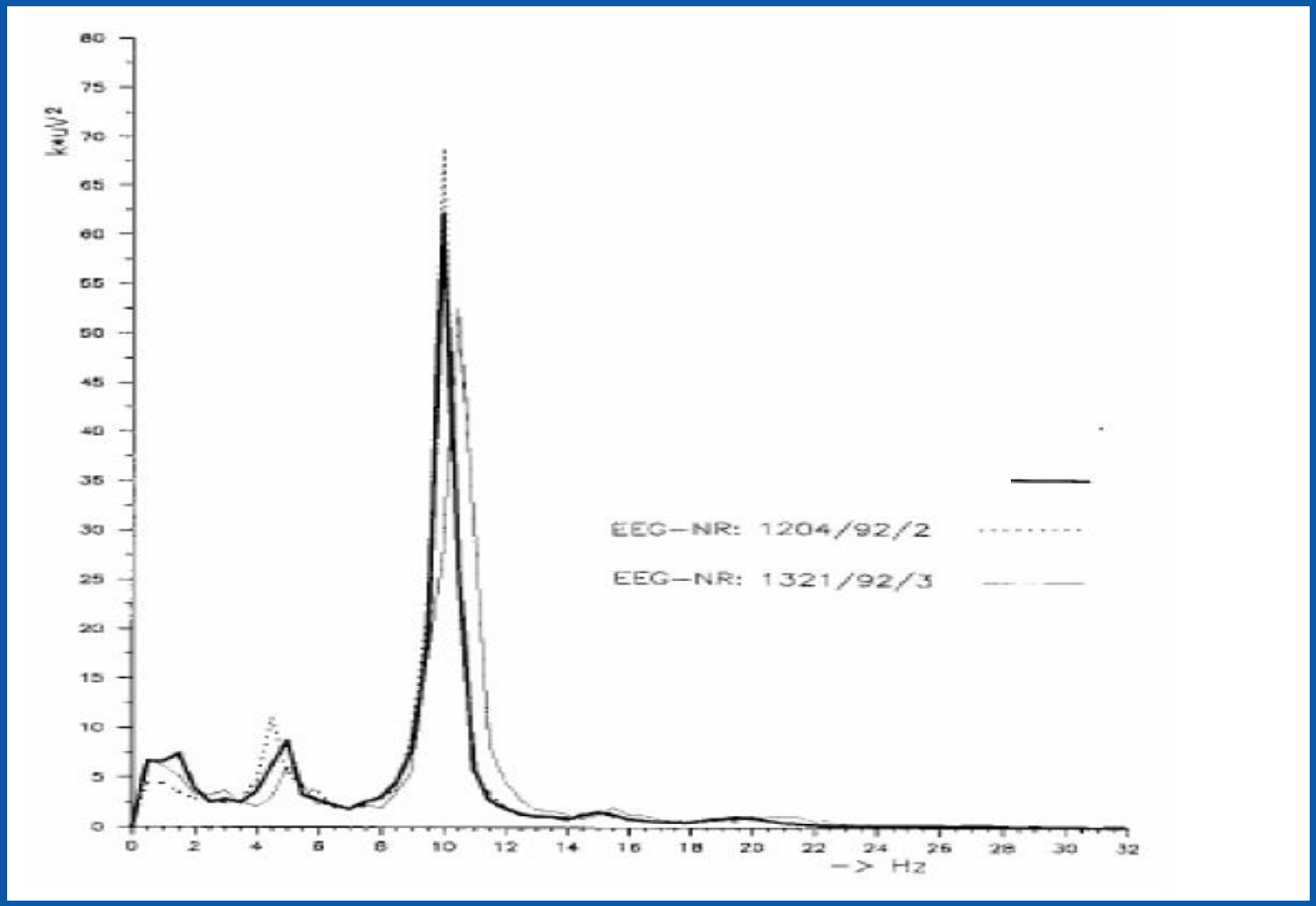
Spontaneous EEG: „spontaneous" electrical activity of the billions of neurons of the brain. It is „always there" in the brain, and in general in the clinical routine it is recorded from the scalp. The best way to picture it as a voltage fluctuation that changes as a function of time.

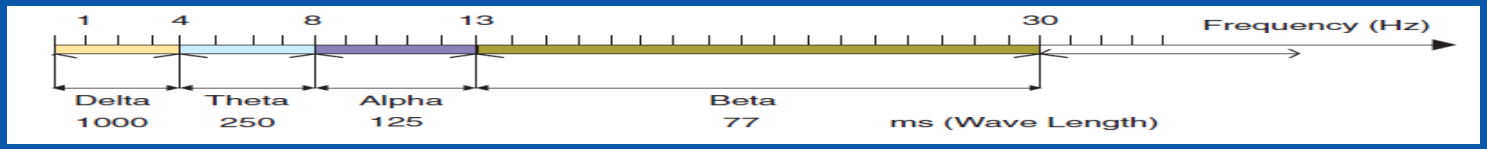
3 important measures can be used for its description:

- its magnitude, i.e., amplitude (in microvolts, uV)
- frequency (Hz, vagy cycles/s),
  i.e., how many times the signal crosses the baseline
- waveform/shape (e.g., „sharp waves")

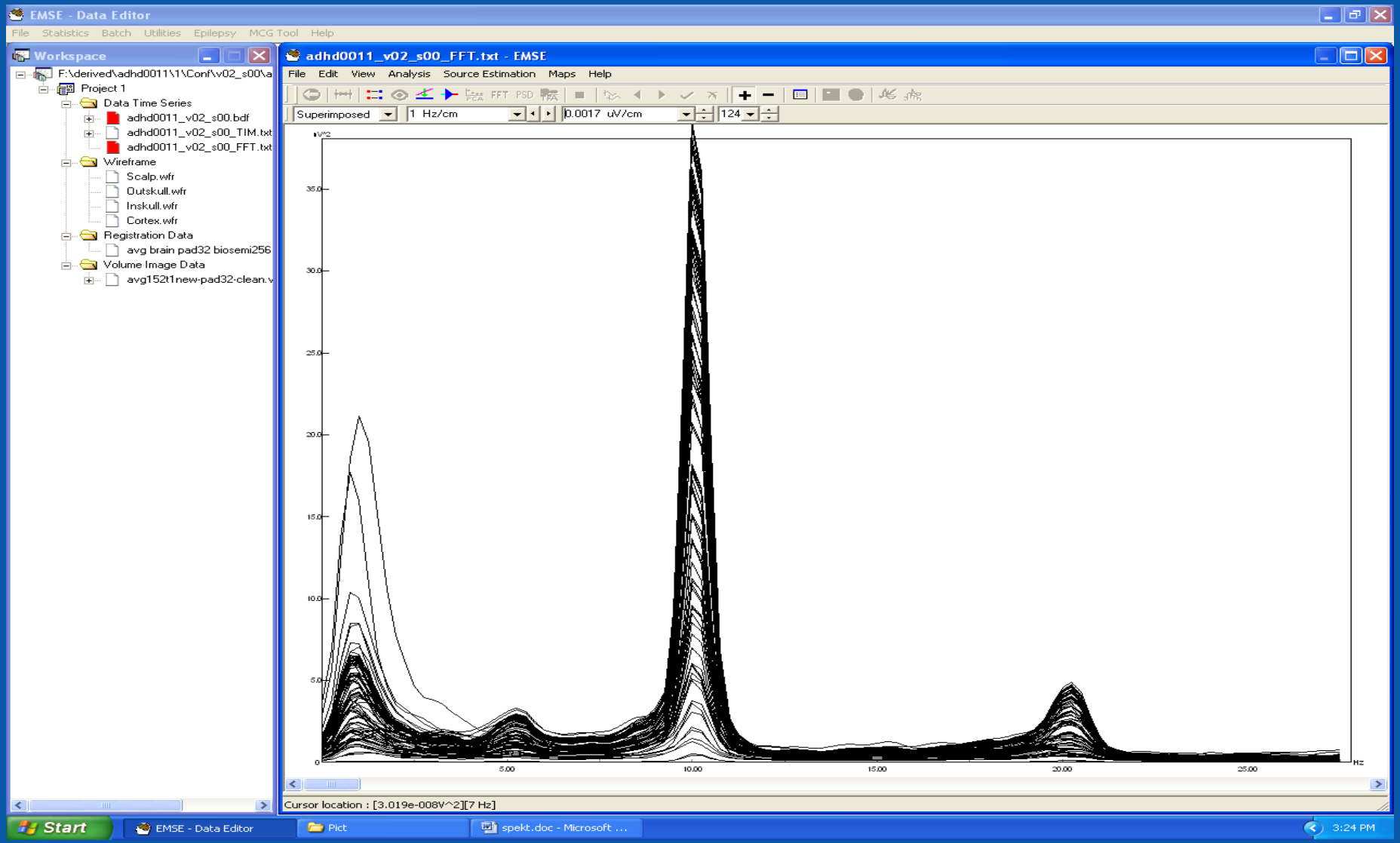
Even Related Potentials: changes in the EEG signals in relation to specific events such as internal or external stimuli, events, or movement

EEG Spectral Composition and Frequency Bands





EEG frequency/power distribution – power spectum over many channels



Event Related Potentials

- If a stimulus is presented to a person – e.g., a flash of light or tone burst – then the spontaneous ongoing EEG activity changes: a series of transient waves occurs. This series of waves is called ERP.

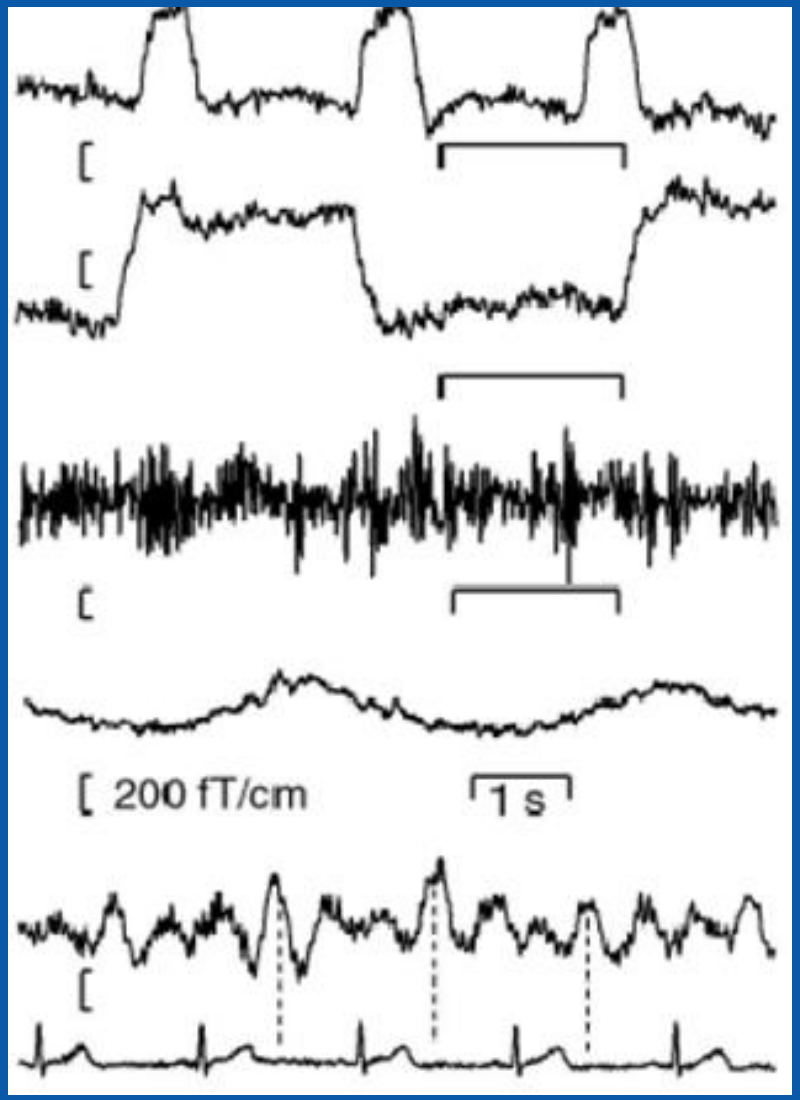
- The number of peaks and troughs in the ERP waveform is a function of the complexity of the stimuli. In case of simple stimuli this means only 3-4 waves. In case of complex psychological stimuli (e.g., name of the person) 5-8 waves are generated.

- One basic problem: the amplitude of the ERP „waves" is much smaller than the backgroung EEG. Therefore, the Signal-to-Noise Ratio (SNR) needs to be improved.

Signal-to-Noise Ratio – where is the noise coming from?

Artifacts

!!!50 Hz/60 HZ!!!



blinking

eye movements

muscles

respiration

ballisto-kardiogram

EKG

EEG!!!

Improving the Signal-to Noise Ratio
Time-locked Averaging

A SUMMATION TECHNIQUE FOR THE DETECTION OF SMALL EVOKED POTENTIALS

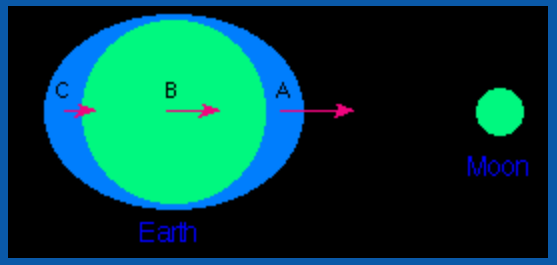
G. D. DAWSON, M.B., M.Sc.
Neurological Research Unit, Medical Research Council, The National Hospital, Queen Square, London

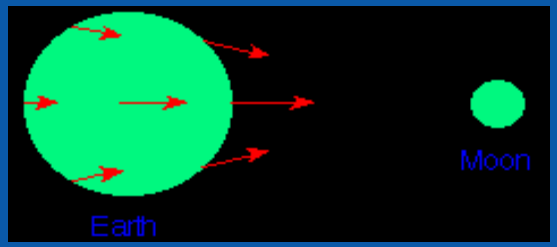
(Received for publication: July 10, 1953)

Averaging has long been applied to the detection of systematic fluctuations amongst larger irregular ones. For example Laplace, in the eighteenth century, predicted that by averaging enough data it should be possible to demonstrate a lunar tide in the atmospheric pressure. The achievement of this in the tropics by Lefroy is described by Sabine (1847) but even the averaging of 180,000 hourly observations by Airy (1878) failed to detect the tide in higher latitudes where the

Oceans: low & high tides

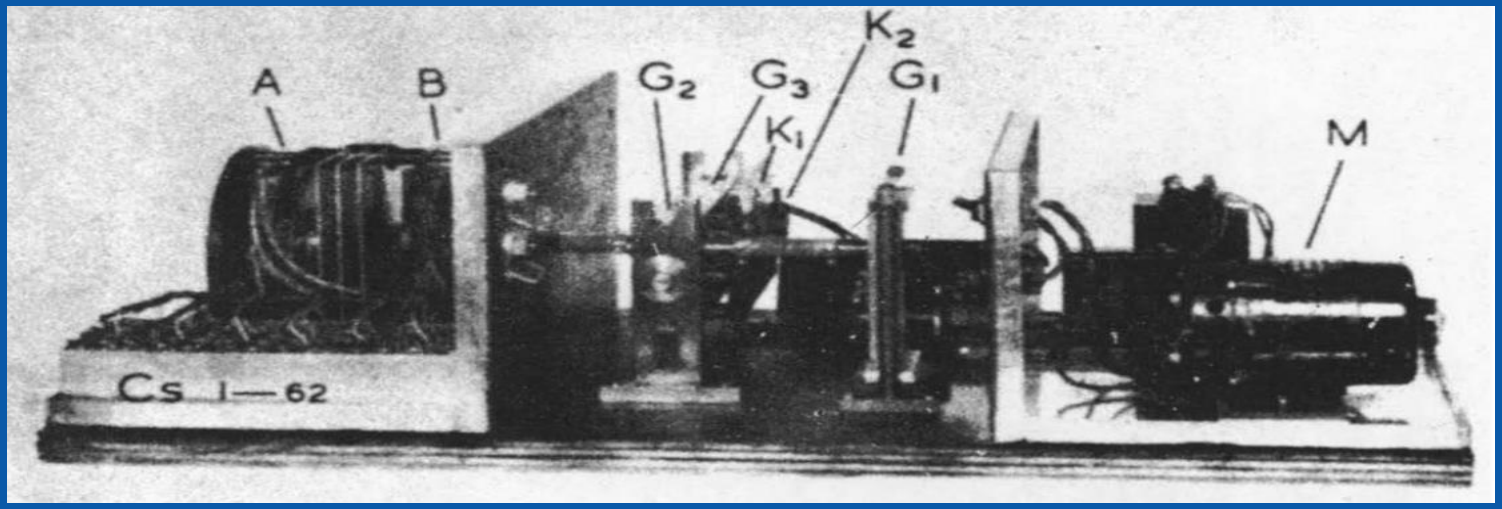
Earth Moon

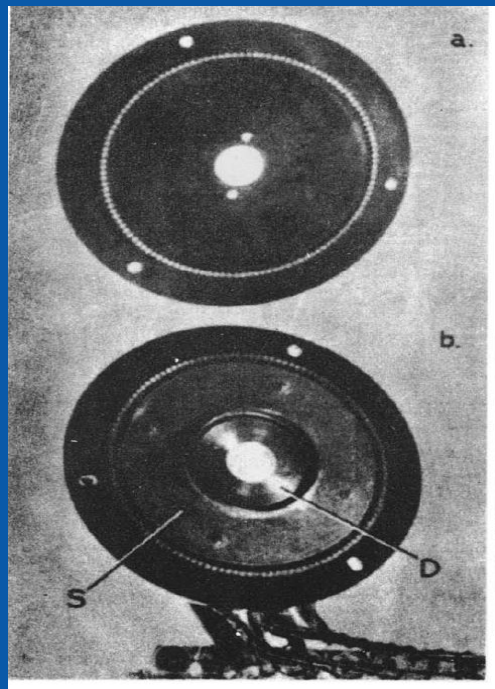


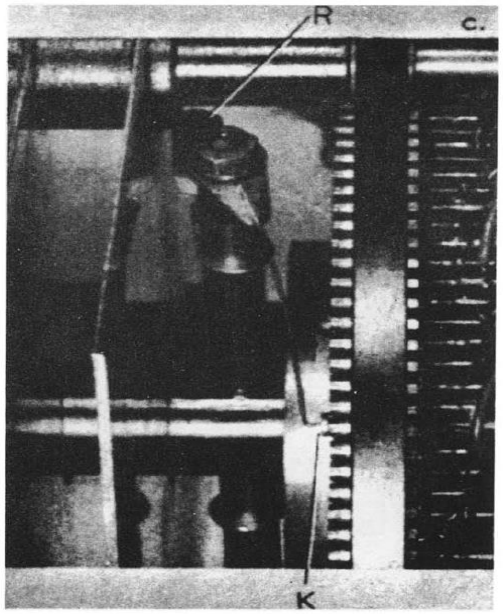


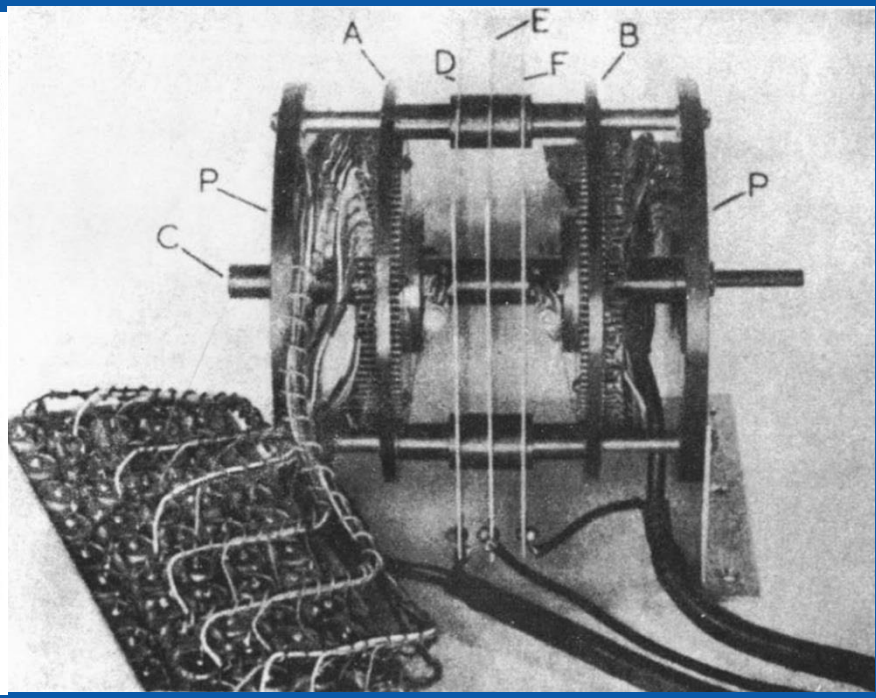
Laplace's prediction: low & high tides are present in the atmosphere – averaging can make them detectable

Dawson's signal-averager









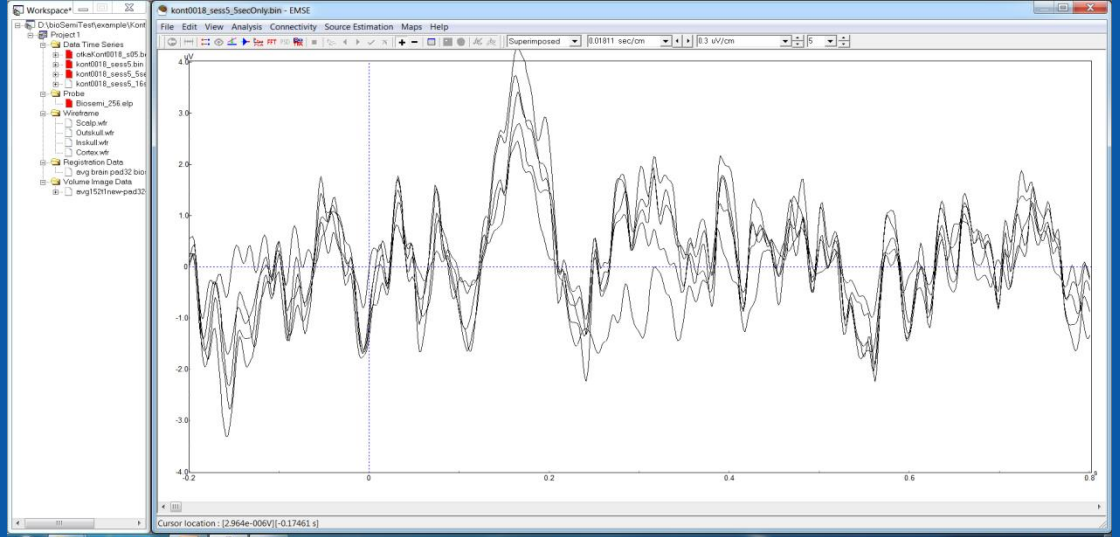
Signal-to-Noise Ratio
How does it improve with the number of repetitions?

- The noise decreases with the square root of the number repetititons.

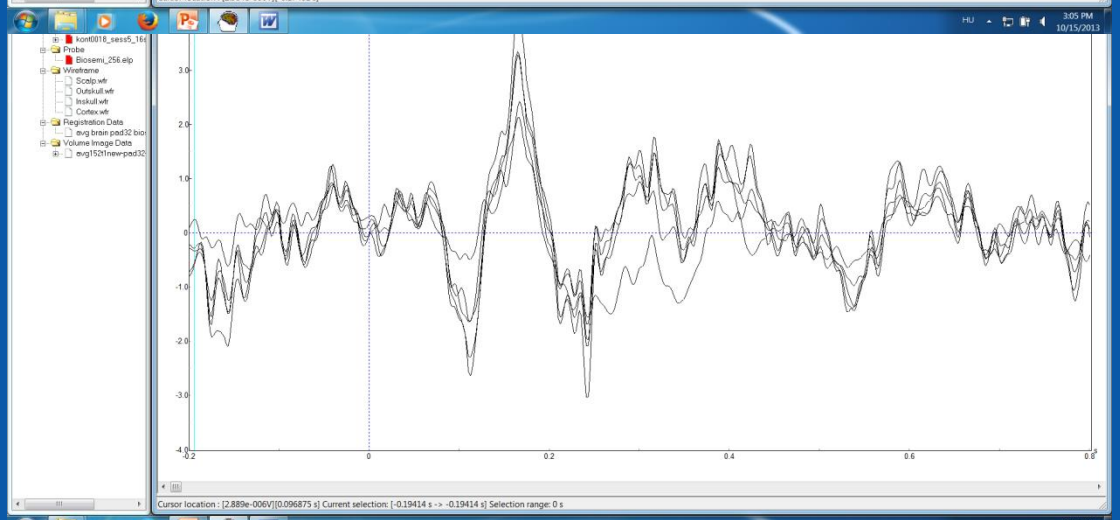
- Example: with 16 stimuli the noise decreases to 1/4th, the signal to noise ratio quadruples, if the signal does not change in the meantime (e.g., habituation).

- Concrete ERP example: the ERP amplitude is 20 uV, background EEG is 50 uV, then with 100 stimuli the EEG is still present at 5 uV (the SNR becomes 4:1, while it showed a 10-fold increase..).

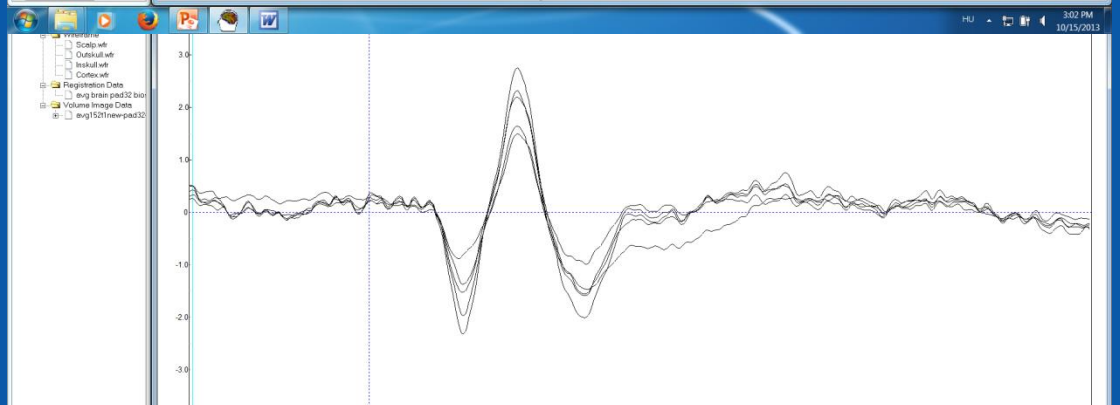
Improvement of Signal-to-Noise Ratio with the Number of Trials



ERP average from 4 single trials

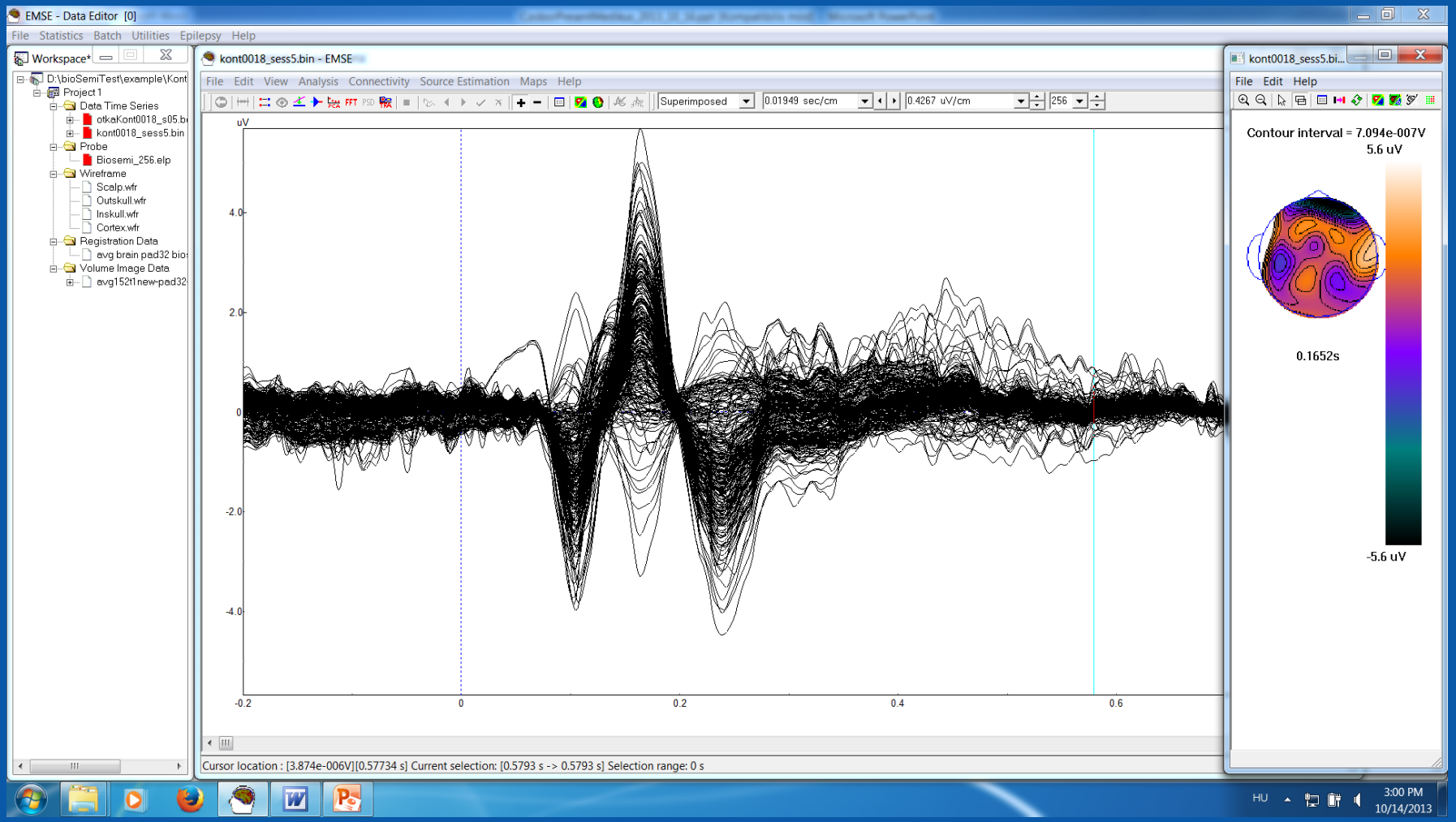


ERP average from16 single trials

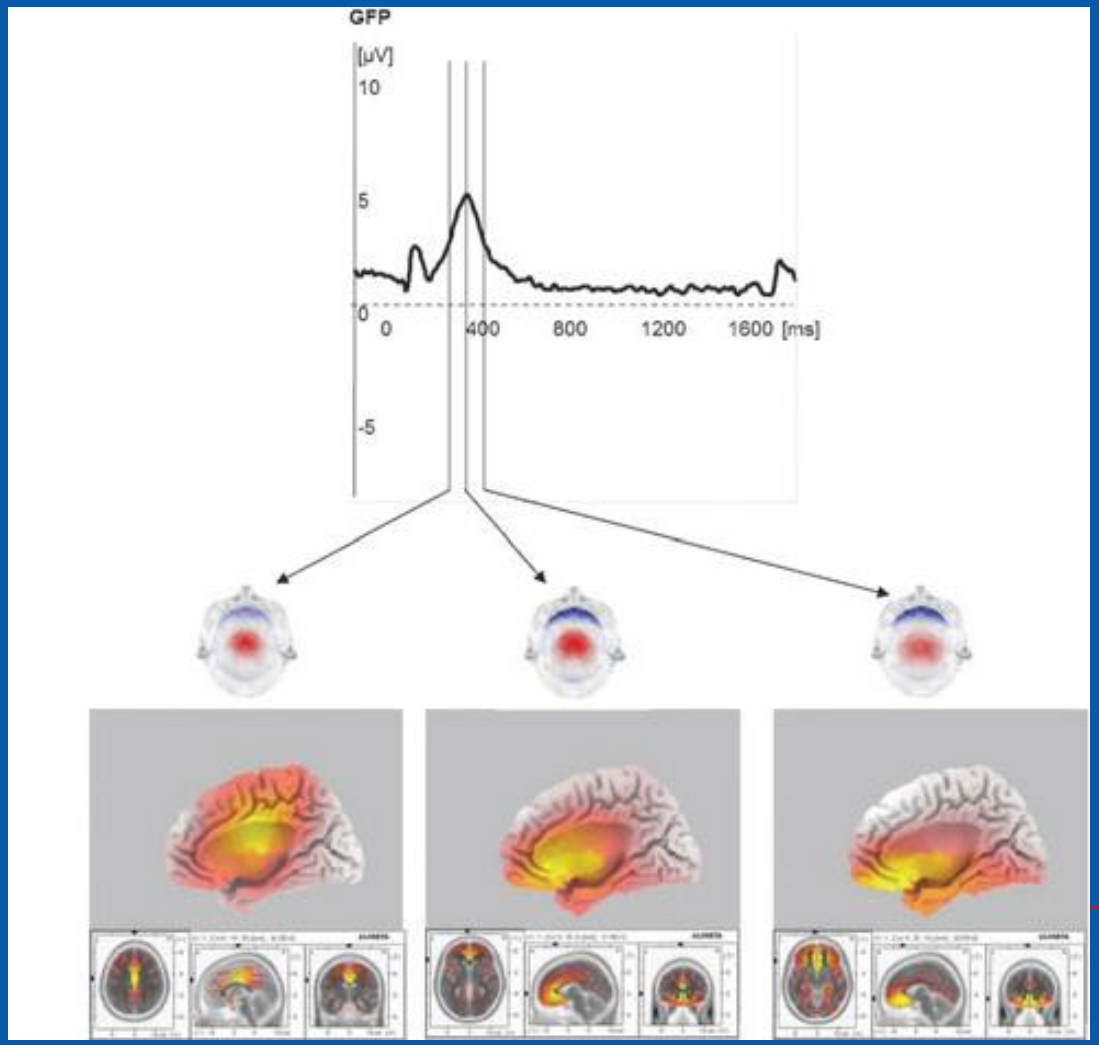


ERP average from 221 single trials

Event Related Potential – Butterfly Plot



How can we investigate the ERPs?



waveform

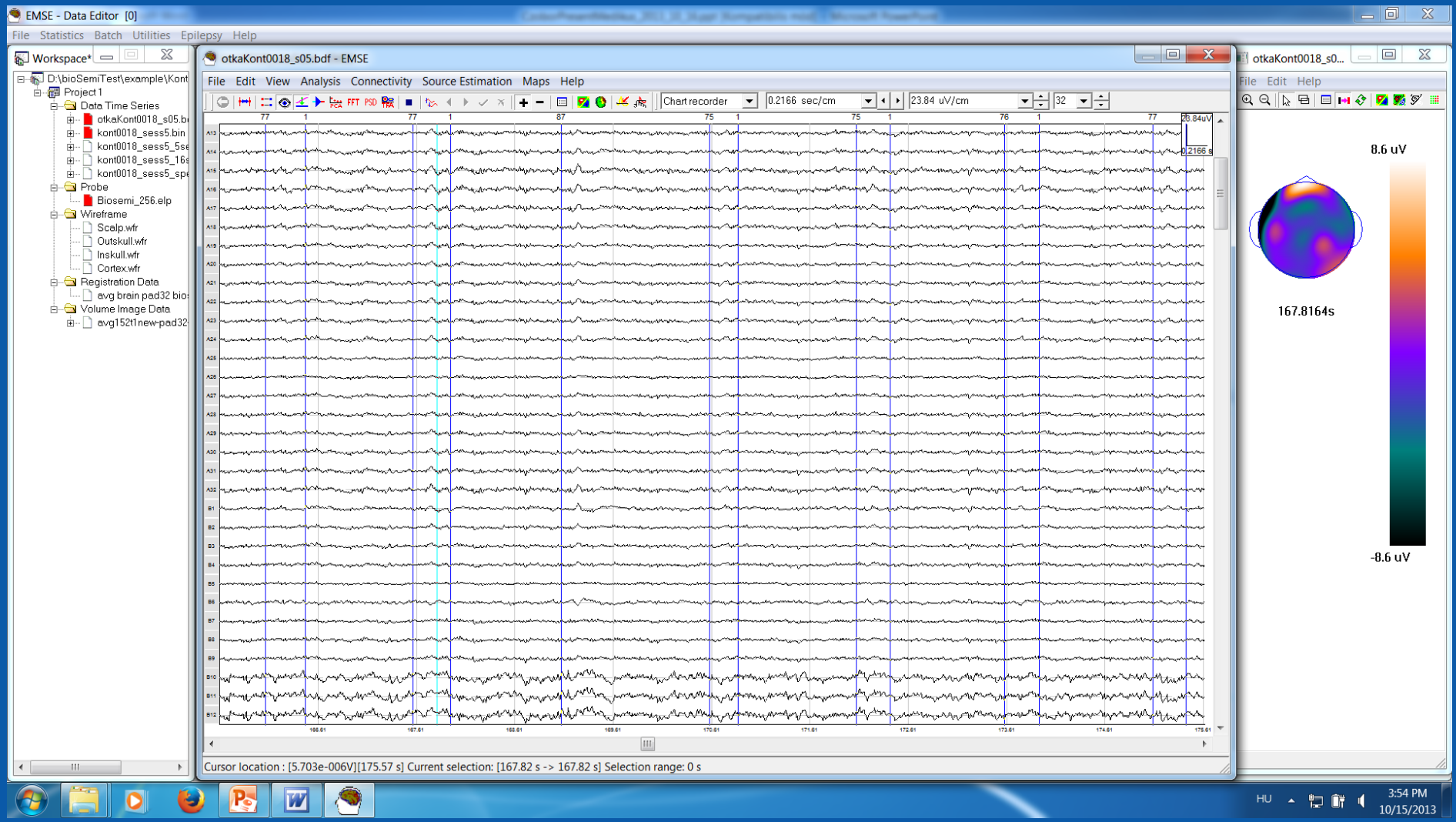
topography

Source-localizations (LORETA)

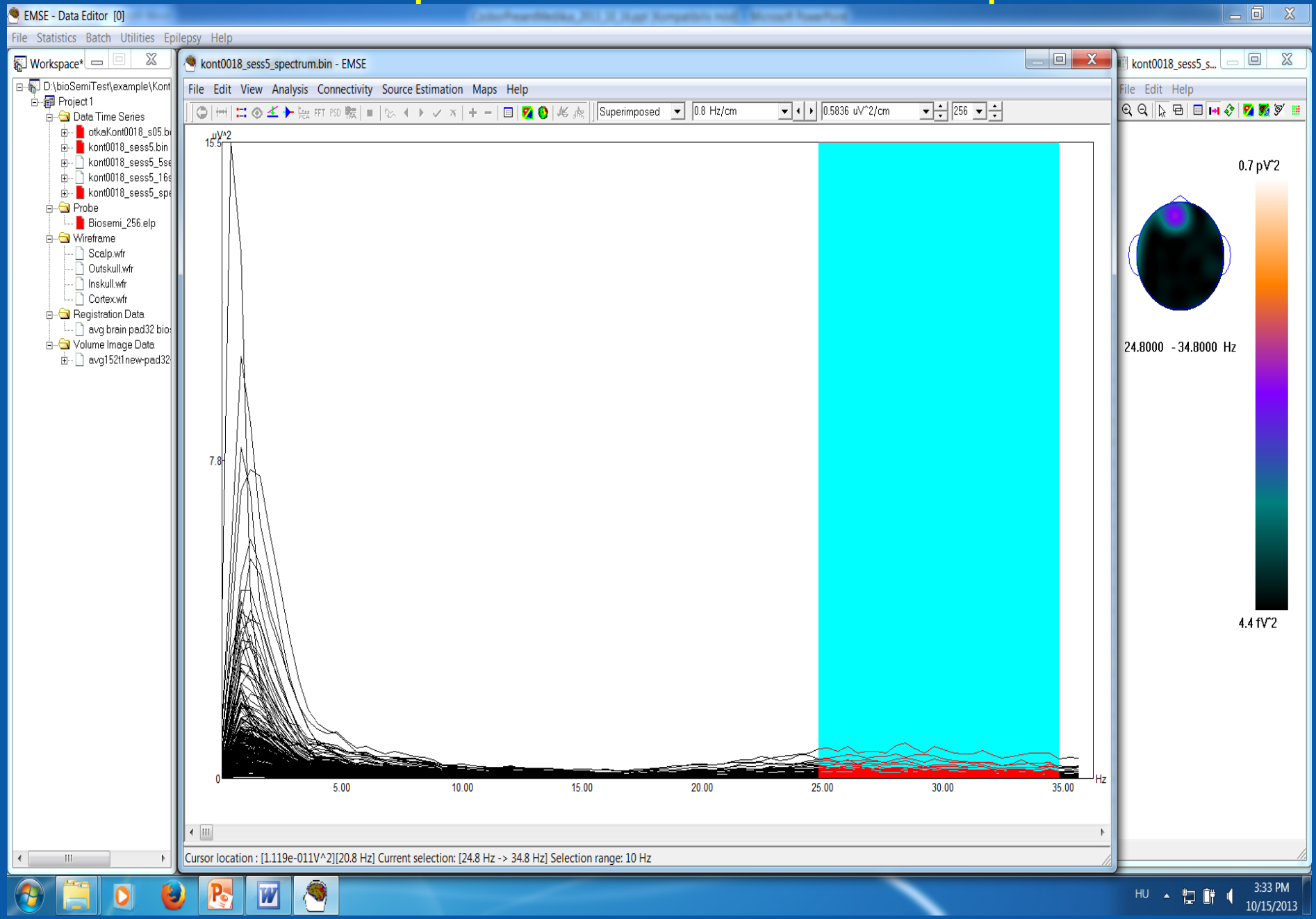
NoGo P300 potentials from CPT OX tasks

T. Banaschewski and T.Brandeis: *Journal of Child Psychology and Psychiatry* 48:5 (2007), pp 415–435

EEG Voltage and Its Map

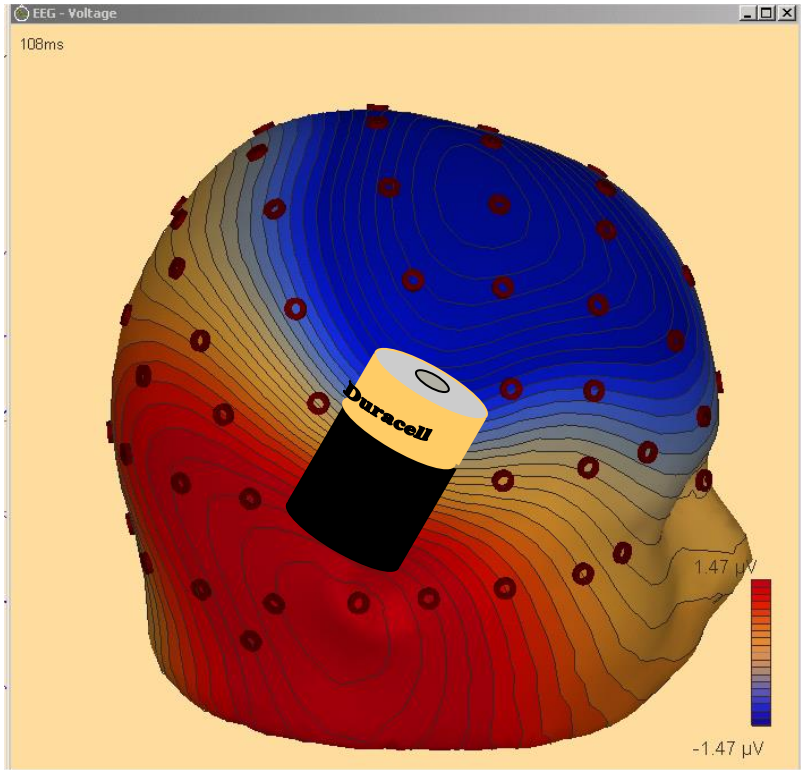


EEG Spectral Power and Its Map

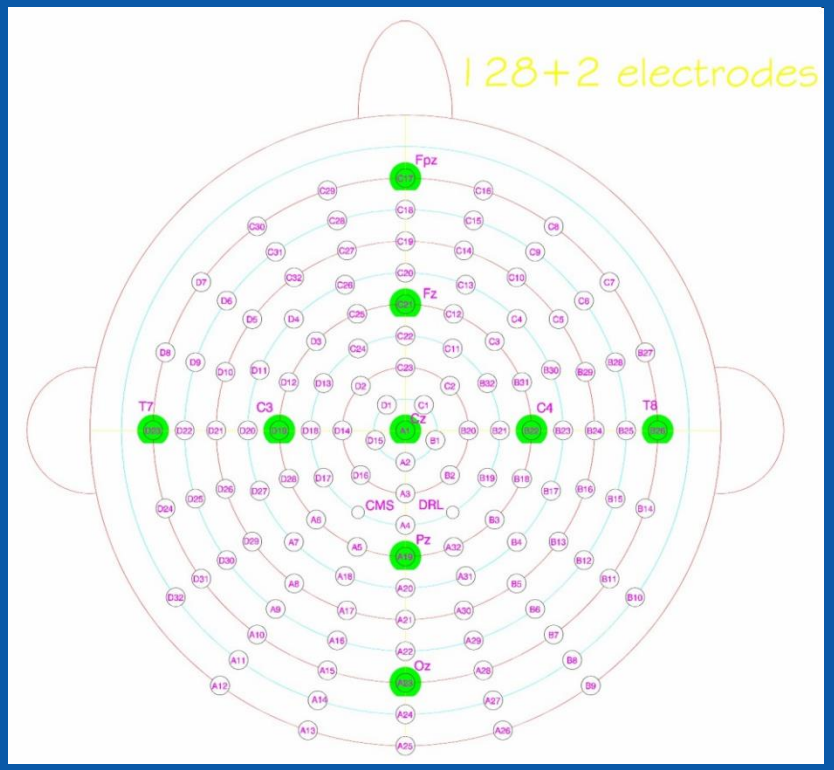


Source localization imaging

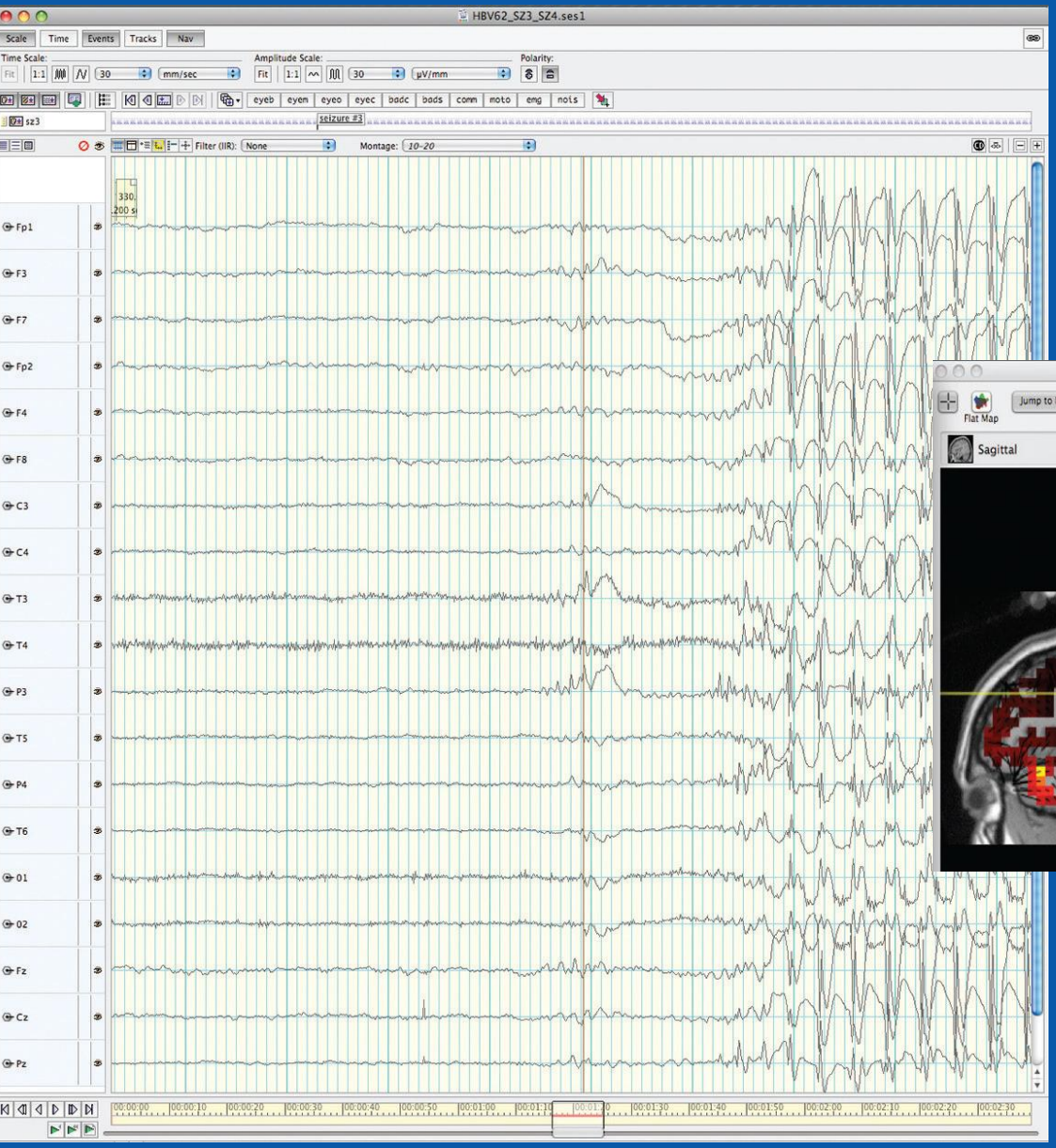
- Question:
  For a given scalp potential distribution where is the generator of the surface-recorded EEG located?

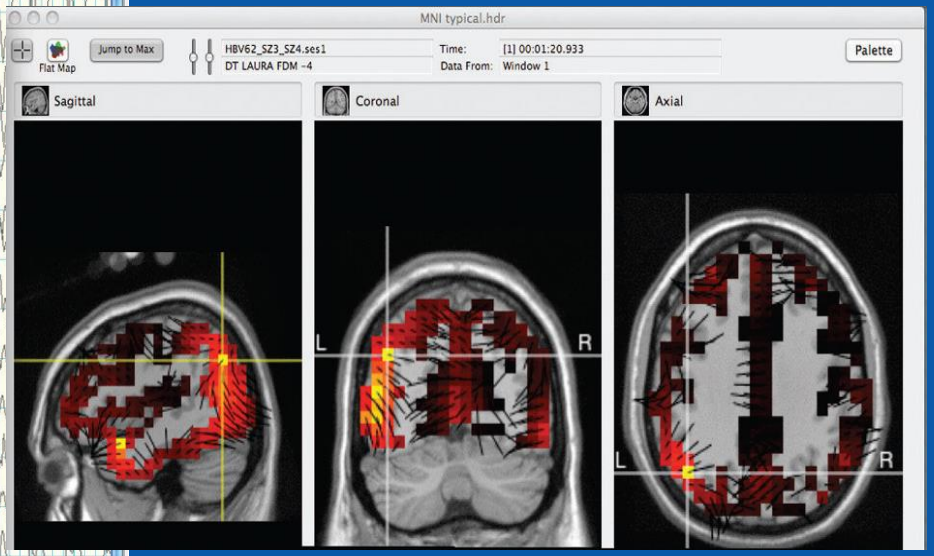


128-electrode „dense” sensor array



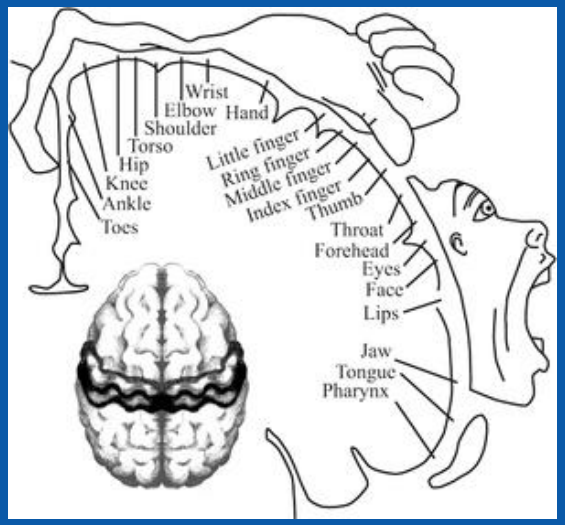
Non-invasive 256 channel dense electrode array vs. intracranial EEG

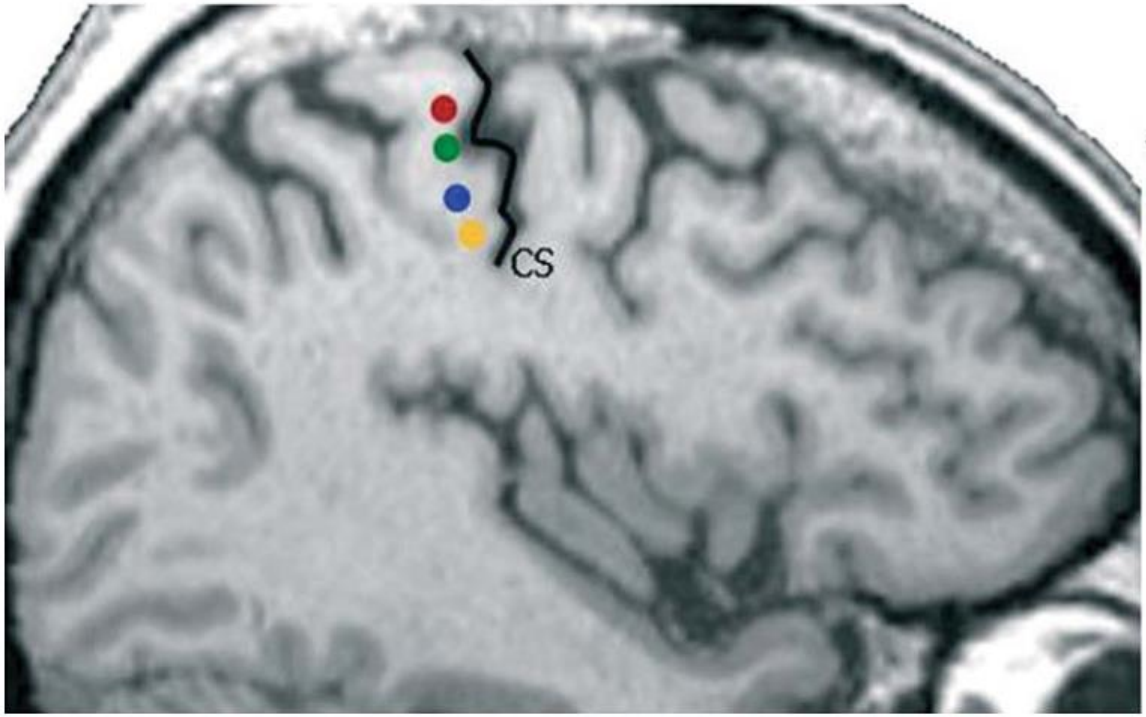




Holmes MD et al.: **Comparing Noninvasive Dense Array and Intracranial Electroencephalography for Localization of seizures. Neurosurgery 66:354-362, 2010**

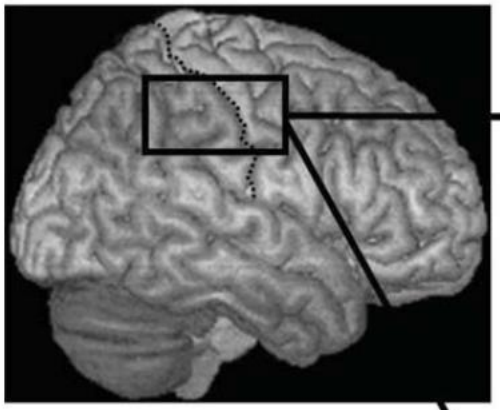
High resolution EEG tomography of the brain representation of the human hand

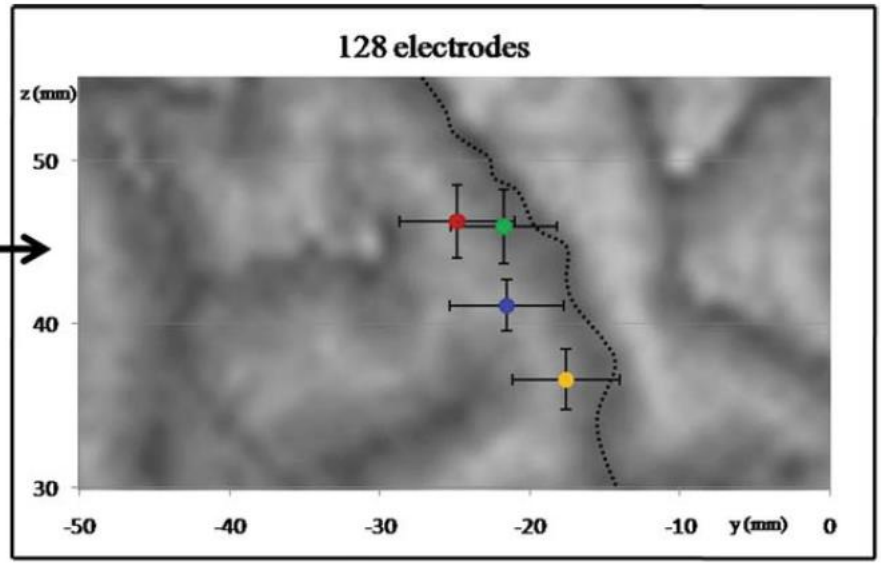


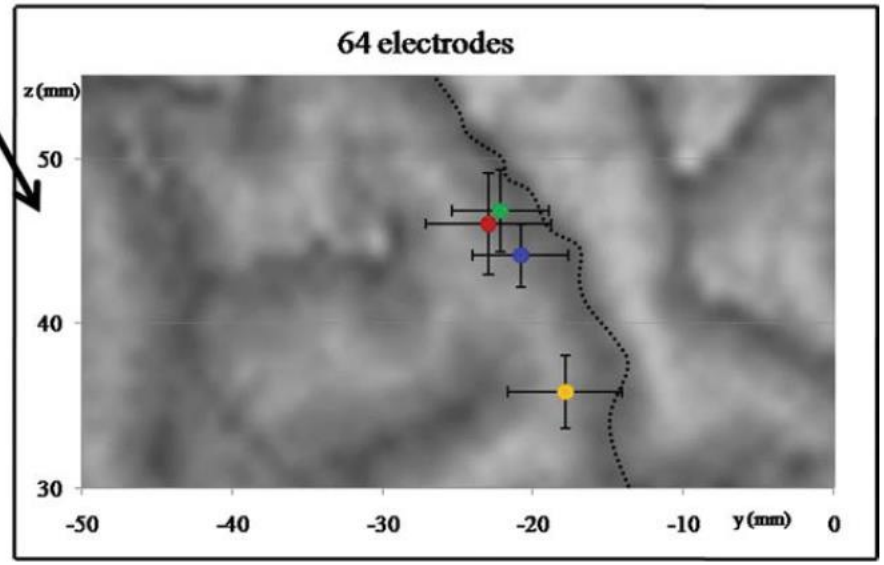


Houzé B. et al: Cortical Representation of the Human Hand Assessed by Two Levels of High-Resolution EEG Recordings Human Brain Mapping 32:1894–1904 (2011)

High resolution EEG tomography of the representation of the human hand in the brain







- 5th digit
- Ulnar nerve
- Radial nerve
- 1st digit

Greater resolution:

128-sensors

Lower resolution:

64-sensors

Houzé B. et al: Cortical Representation of the Human Hand Assessed by Two Levels of High-Resolution EEG Recordings Human Brain Mapping 32:1894–1904 (2011)

Exogenous & endogenous ERP components

- The earliest components from the primary sensory brain areas – they are called „exogeneous" ERPs, since they represent sensory information.

- Often they are called (Stimulus-) Evoked Potentials (EPs). Earlier EP was used as an umbrella term for all time-locked EEG events, but after the description of endogenous and motor potentials, Herbert Vaughn introduced the more general ERP term.

- „Endogenous" ERPs: late components of the ERP, which represent psychological responses to external stimuli.

An Endogenous ERP – the P300

P300: a positive amplitude component which is generated for rare and „meaningful" stimuli (<40% probability)

P300 was described by Sutton et al. in 1965: high and low pitch tones were presented in random order at 8:2 ratio, subjects were told to count the stimuli. The rare tones were followed by P300 (regardless whether the low or high tone served for rare). ODDBALL PARADIGM.

The stimuli were simple „clicks" - the latency of P300 was cca. 250-300 msec. Complex stimuli may result in latencies in the range of 400-800 msec. P300 latency indicates stimulus complexity and processing time.

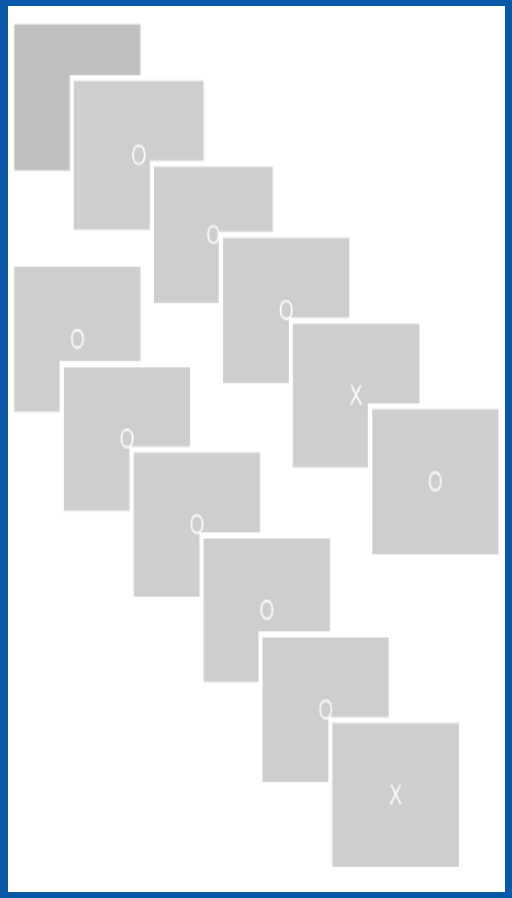
Endogeneous ERPs – P300

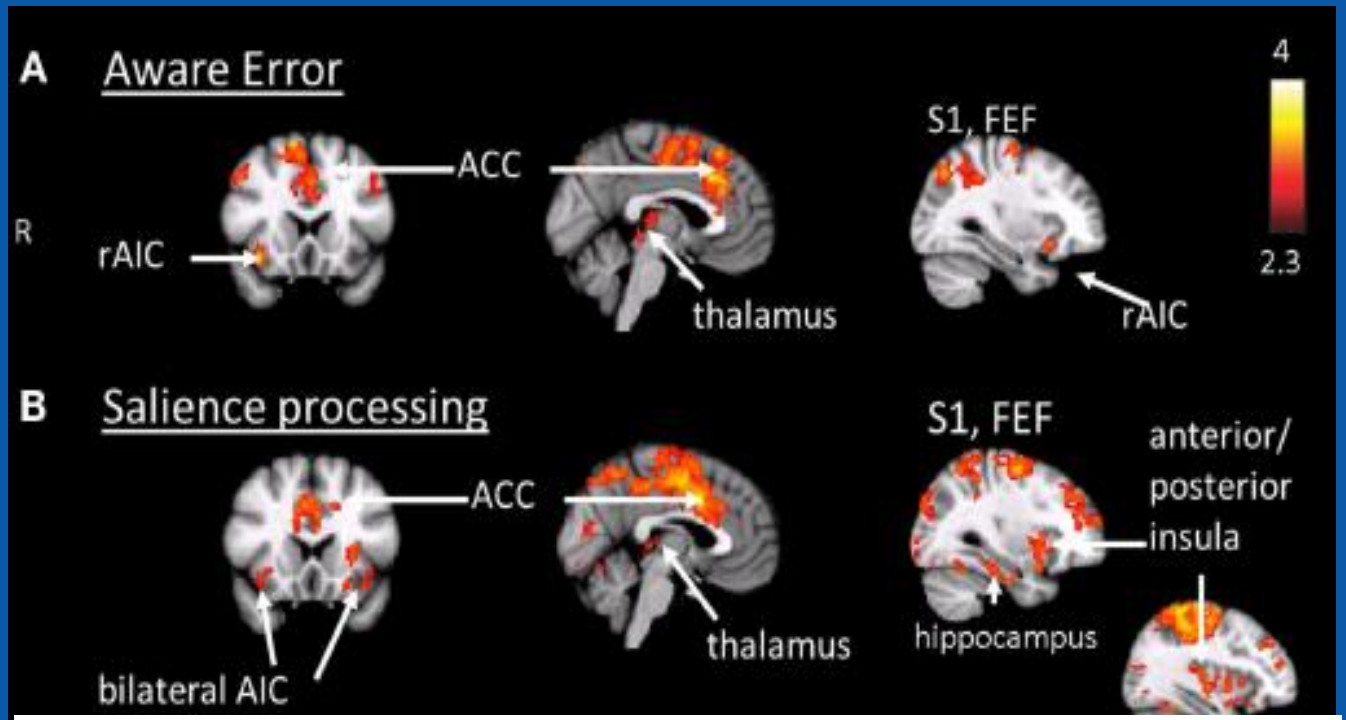
- The scalp distribution of P300 helps its identification: typically it is maximal at the Pz electrode.

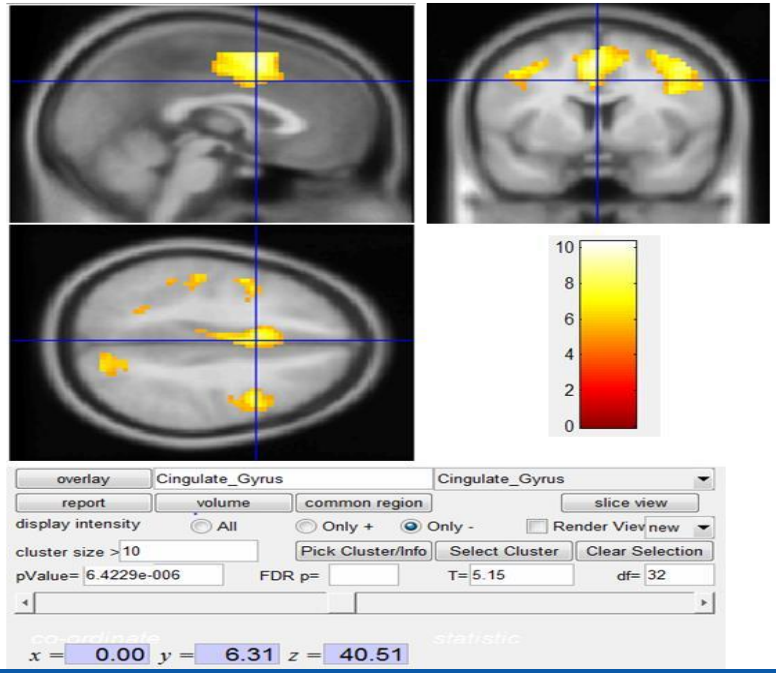
- The amplitude of P300 is proportional with how rare and „meaningful” the stimulus is.

- A stimulus can be made meaningful by linking it to a task (e.g., counting). Other stimuli are meaningful in and of themselves, e.g., infos relating to ourselves, names, birth dates, phone numbers, or details pertaining to a crime..).

Oddball task, error, error awareness



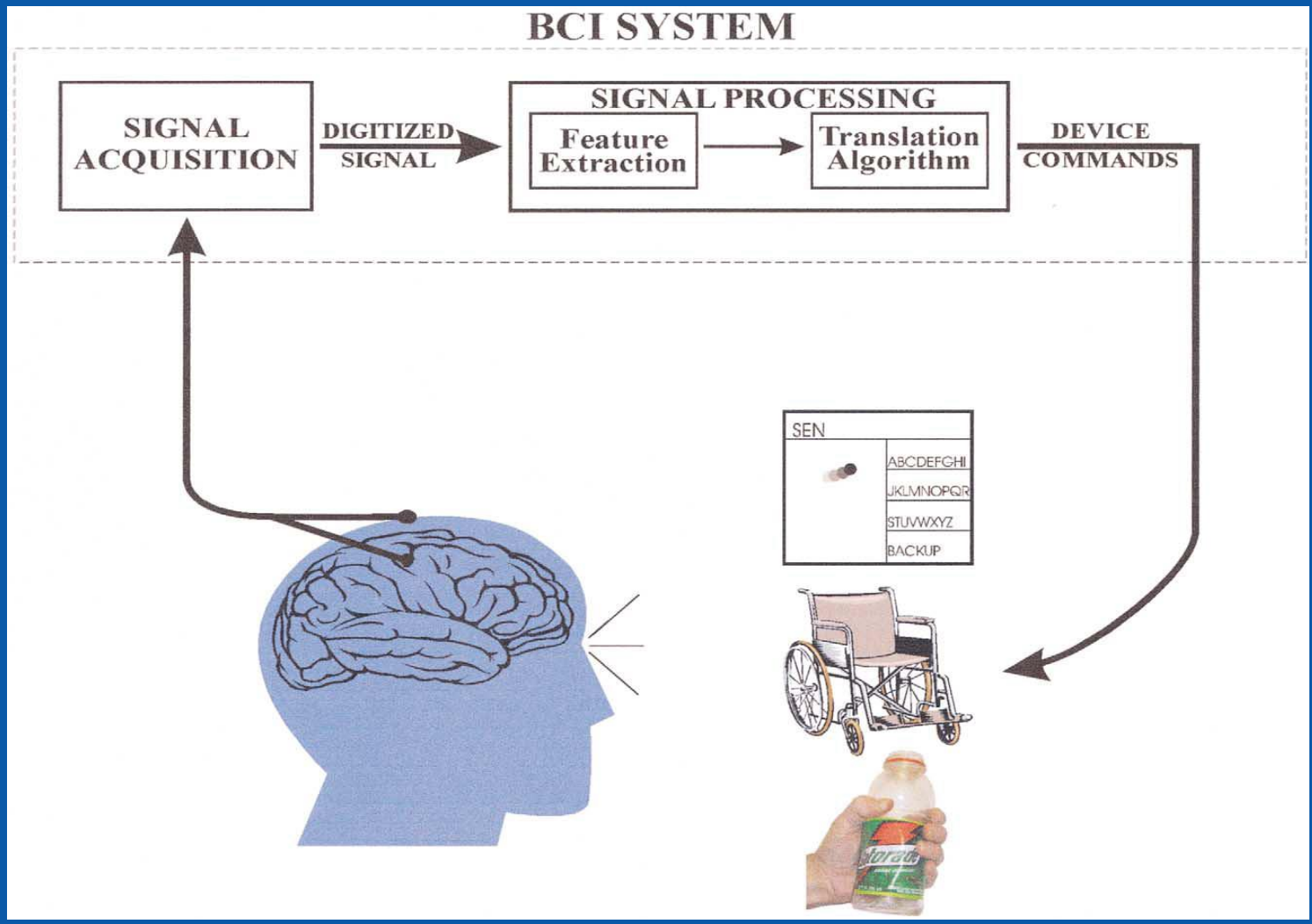




Areas in yellow and brown indicate statistically significant activation corrected for multiple comparisons (FWE rate = 0.05, nominal level of significance in terms of p-value = 0.000006423). The horizontal bar indicates the T-value scale for the BOLD activation (threshold T-value=5.15). Activation at the cross-hair indicates the BOLD signal at the Cingulate Gyrus. Spatial coordinates at the bottom of the figure are shown according to the Montreal Neurological Institute's system.

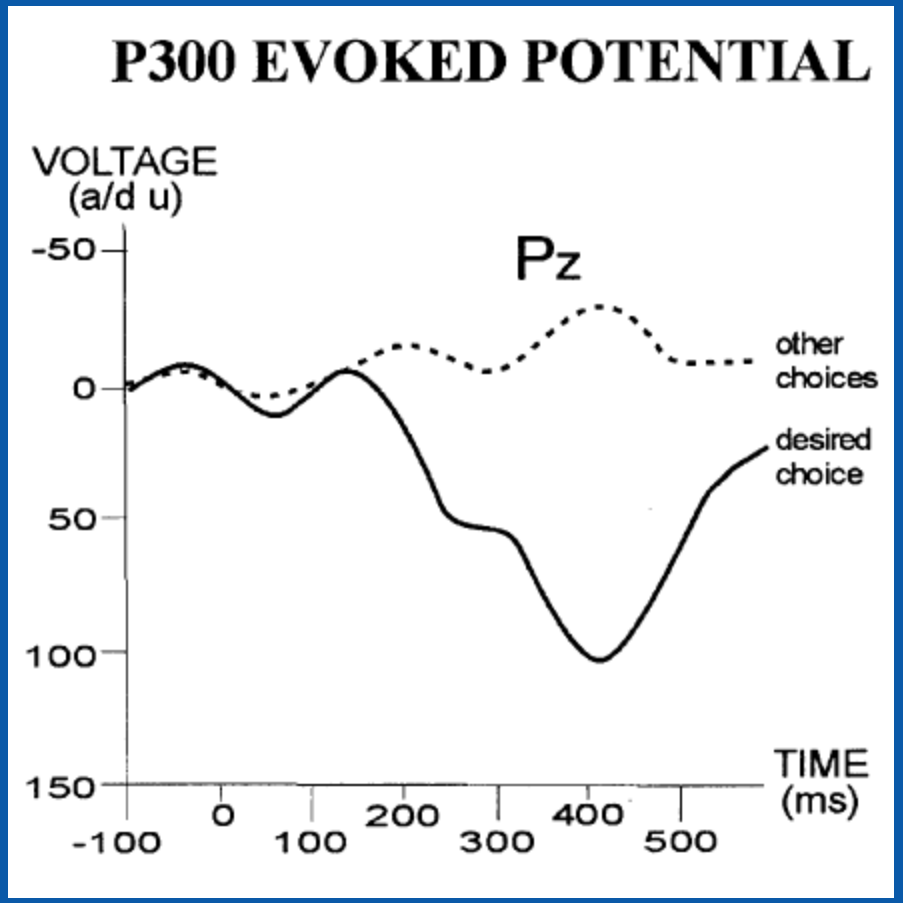
Harsay HA et. al: Errror awareness and salience processing in the oddball task:shared neural mechanisms. Frontiers in Human Neuroscience. 27 August 2012.

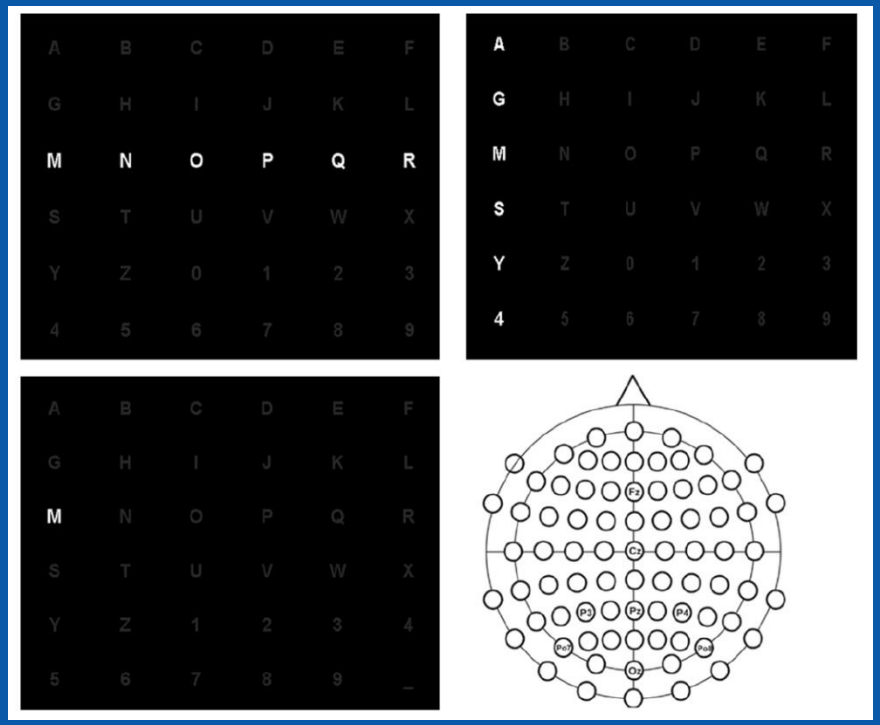
P300 – the central player of the Brain Computer Interface (BCI) systems



Volpaw J.R. et al.: Clinical Neurophysiology 113 (2002) 767–791

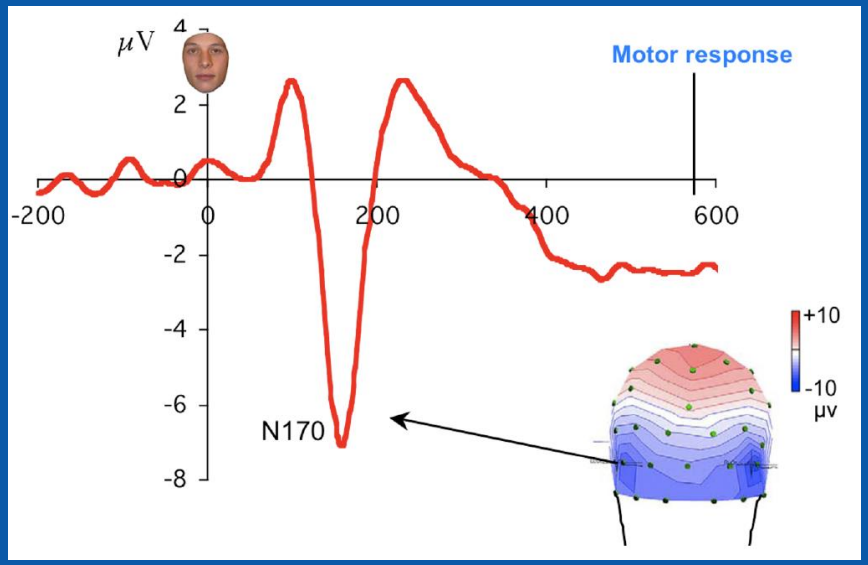
P300 –the central player of the Brain Computer Interface (BCI) systems– typewriter

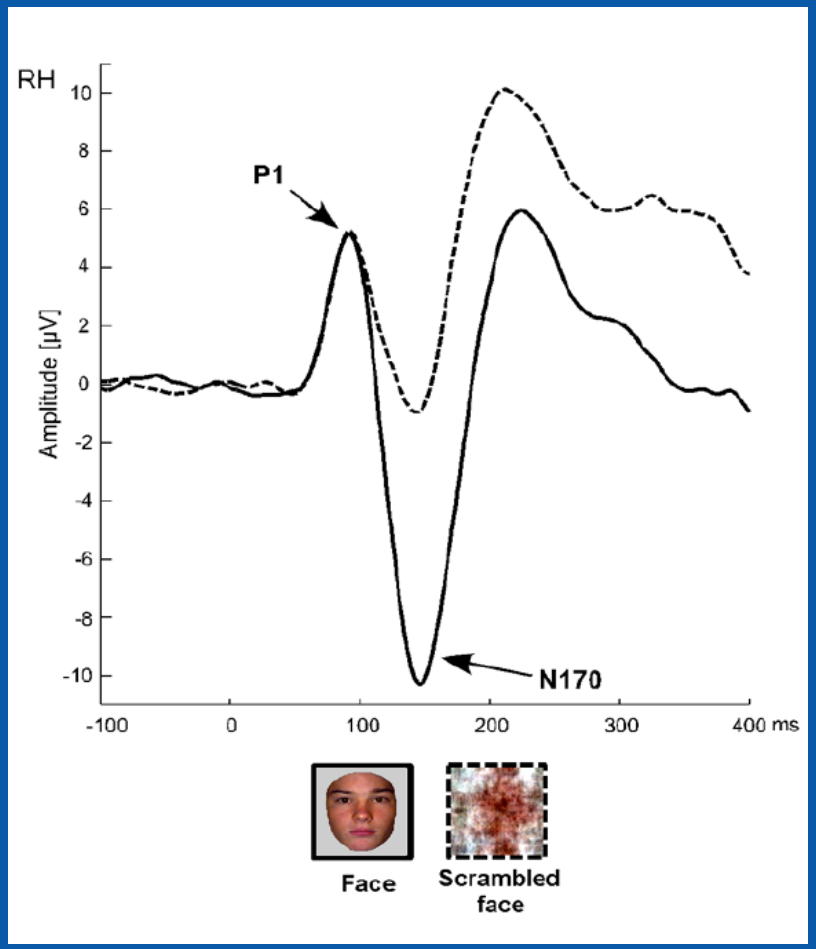




Guger C. et al.: Neuroscience Letters 462 (2009) 94–98

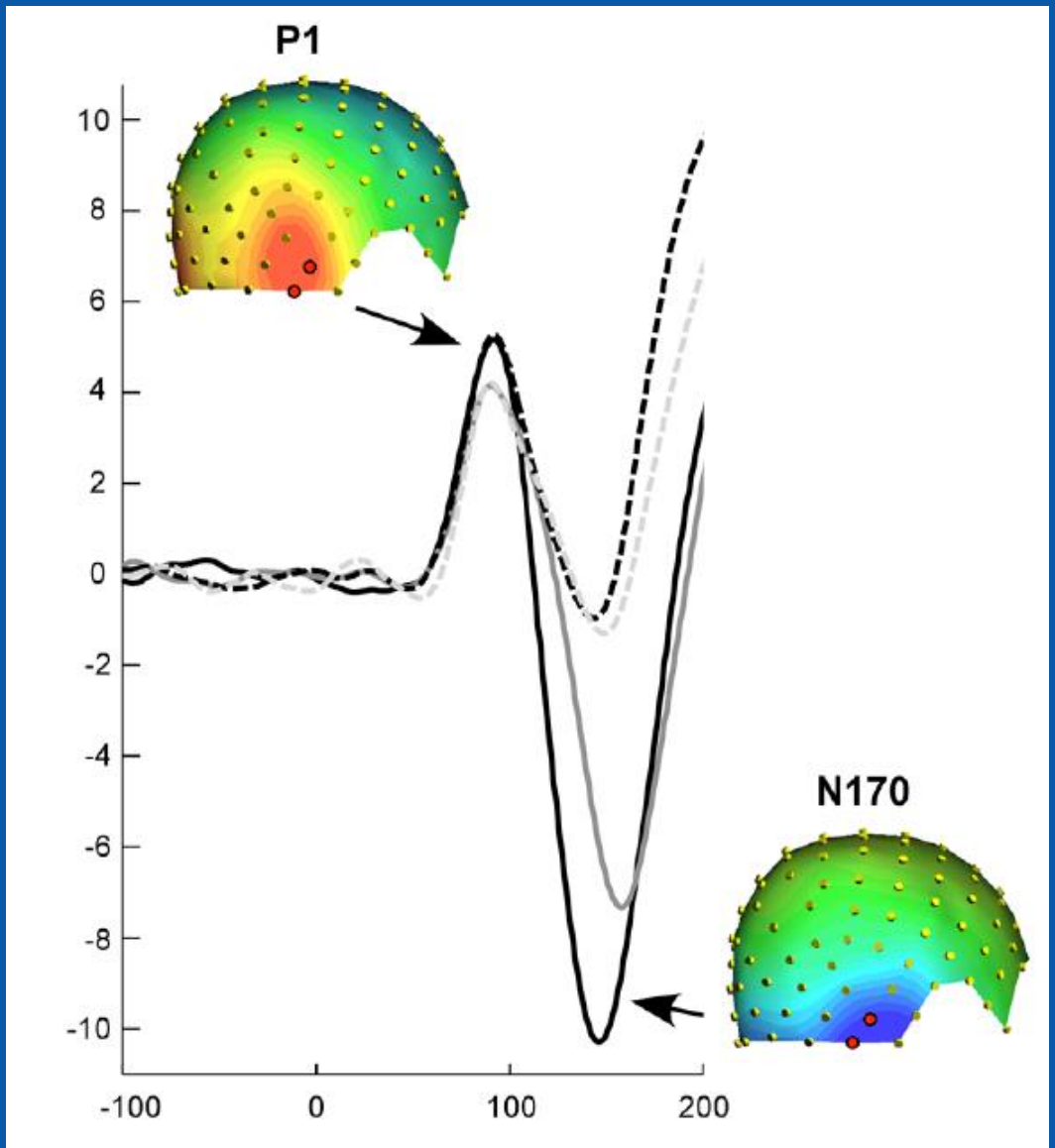
Face recognition specific N170 component

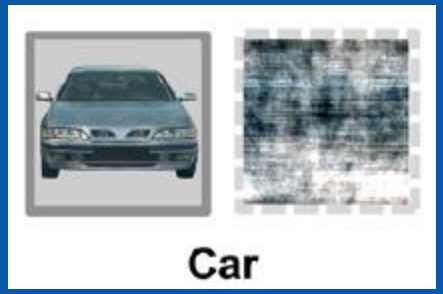


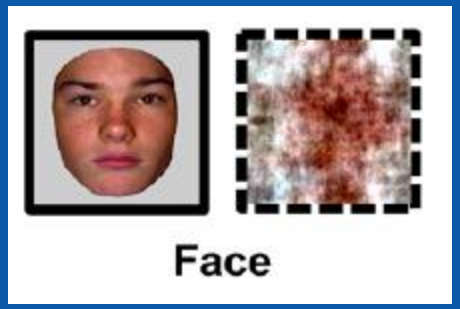


Rossion, B. & Jacques, C. (2011). **The N170 : understanding the time-course of face perception in the human brain**. To appear in *The Oxford Handbook of ERP Components (2011)*, Edited by S. Luck and E. Kappenman. Oxford University Press.

Face recognition specific N170 component







Rossion, B. & Jacques, C. (2011). **The N170 : understanding the time-course of face perception in the human brain**. To appear in *The Oxford Handbook of ERP Components (2011)*, Edited by S. Luck and E. Kappenman. Oxford University Press.

Other cognitive ERP component: N400

N400: ERP response to semantic inconguence.

The 3 stimulus words below (parts of a sentence) are presented one-by-one at 1 sec intervals.

Today

I ate

my breakfast.

The above stimuli do NOT elicit an N400 since words are congruent and not don not have surprise value.

The next 3 words, however, do elicit:

Today

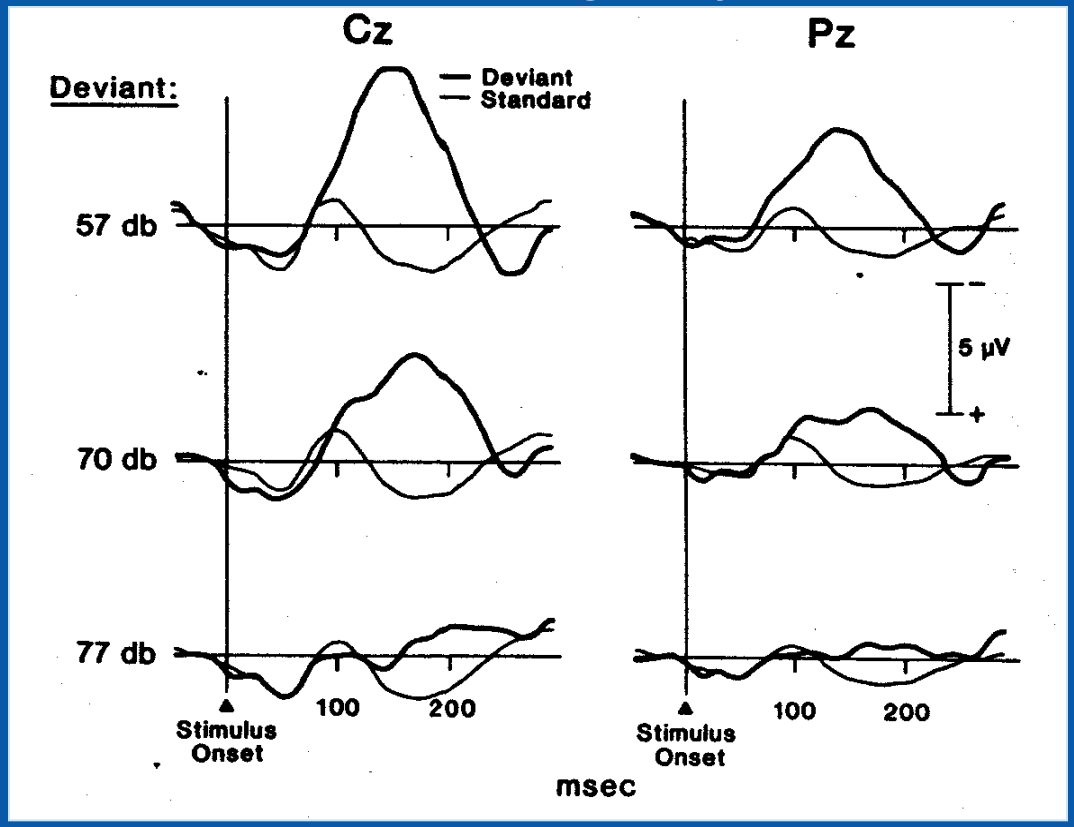
I ate

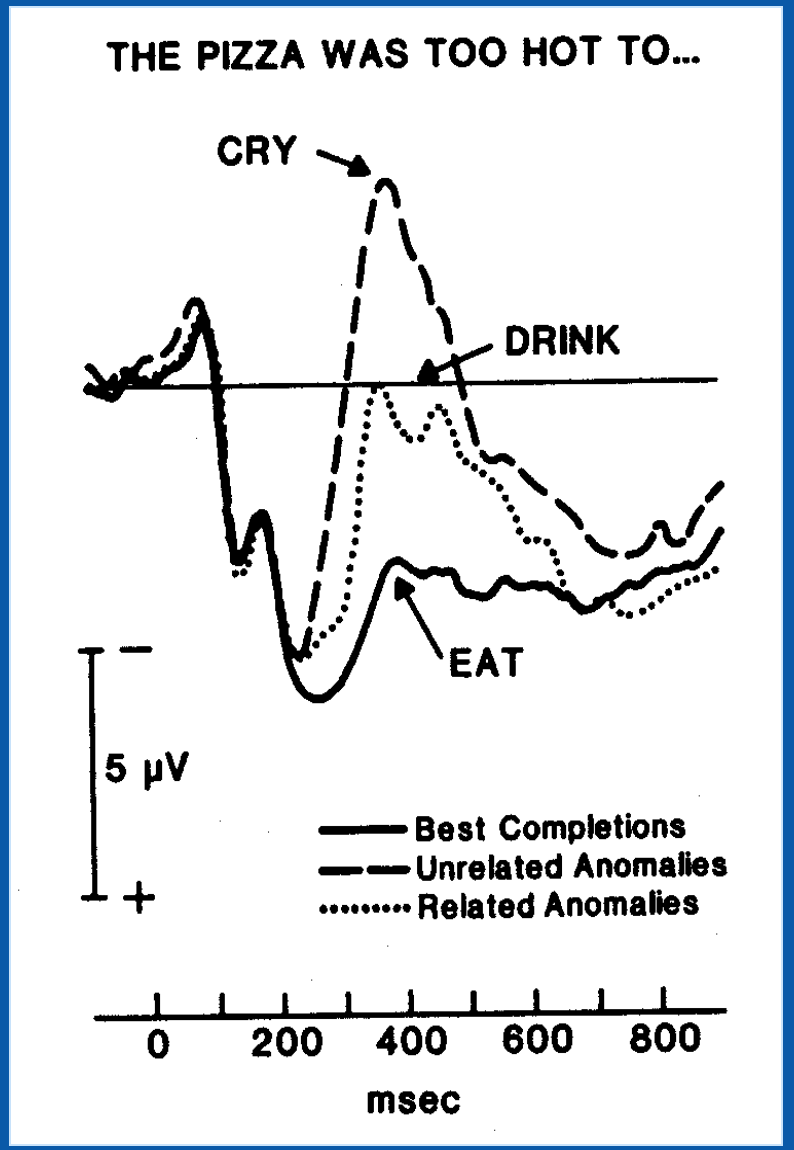
my shoes.

N400

N400, semantic incongruence

MMN = MisMatch Negativity





Baars B. J. et al.: Cognition, Brain and Consciousnesss, 2007, Elsevier

Language-specific ERP components

N400: marker of semantic incongruence **P600**: marker of syntactic incongr.

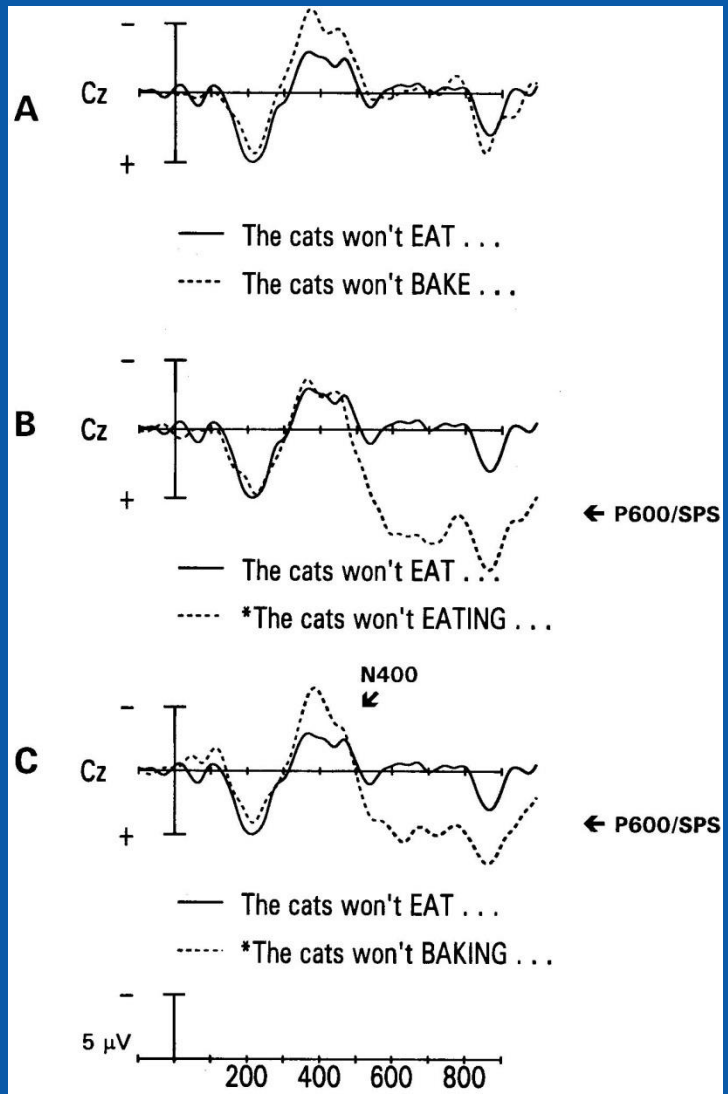
Sentence examples:

Correct (Baseline): The cats won't eat the food Mary gives them.

A/ Semantic mismatch: The cats won't bake the food Mary gives them.

B/ Syntactic mismatch: The cats won't eating the food Mary gives them.

C/ Semantic and syntactic mismatch: The cats won't baking the food Mary gives them.



Baars B. J. et al.: Cognition, Brain and Consciousnesss, 2007, Elsevier

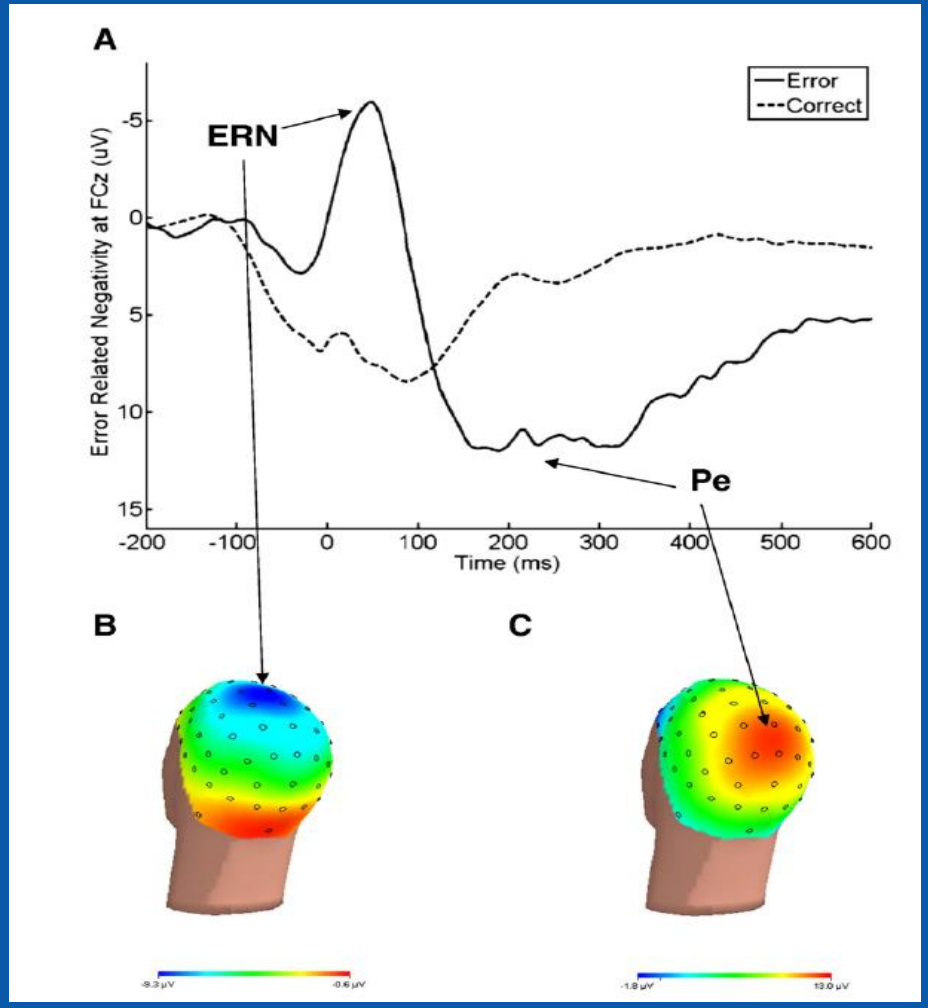
Motor ERP components:

They appear in those motor areas that initiate and execute movements. They reflect the sychronized and summed synaptic activity of pyramidal neurons.

Error-related negativity and positivity

ERN/ERP (error-related negativity/positivity). They are generated when we make a mistake, and we have not (necessarily) realized it.

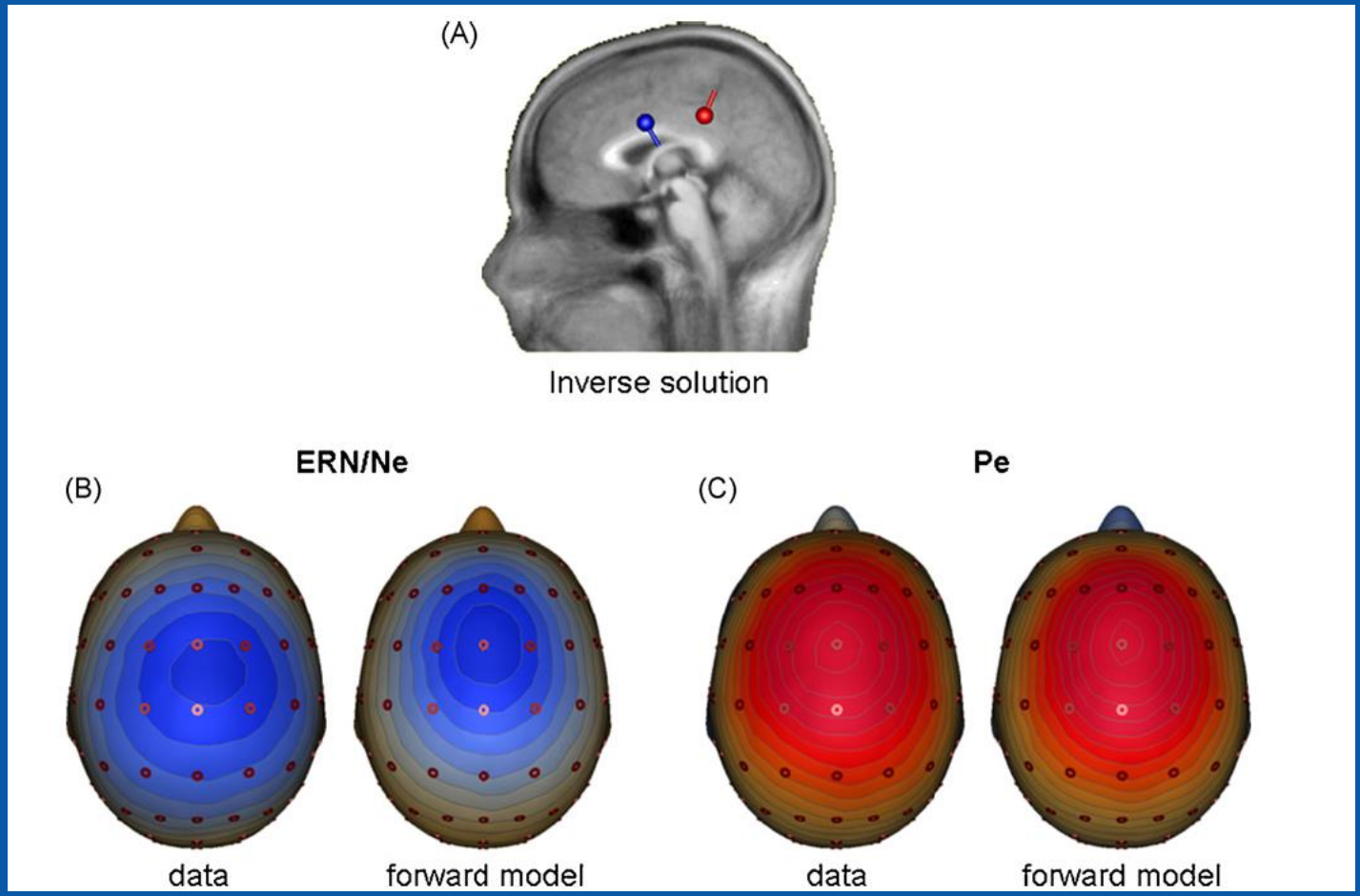
Here the averaging is locked to response, and NOT to the stimuli



Source: DM. Olvet G Hajcak (2008) The error-related negativity (ERN) and psychopathology: Toward an endophenotype. Clinical Psychology Review 28 (2008) 1343–1354

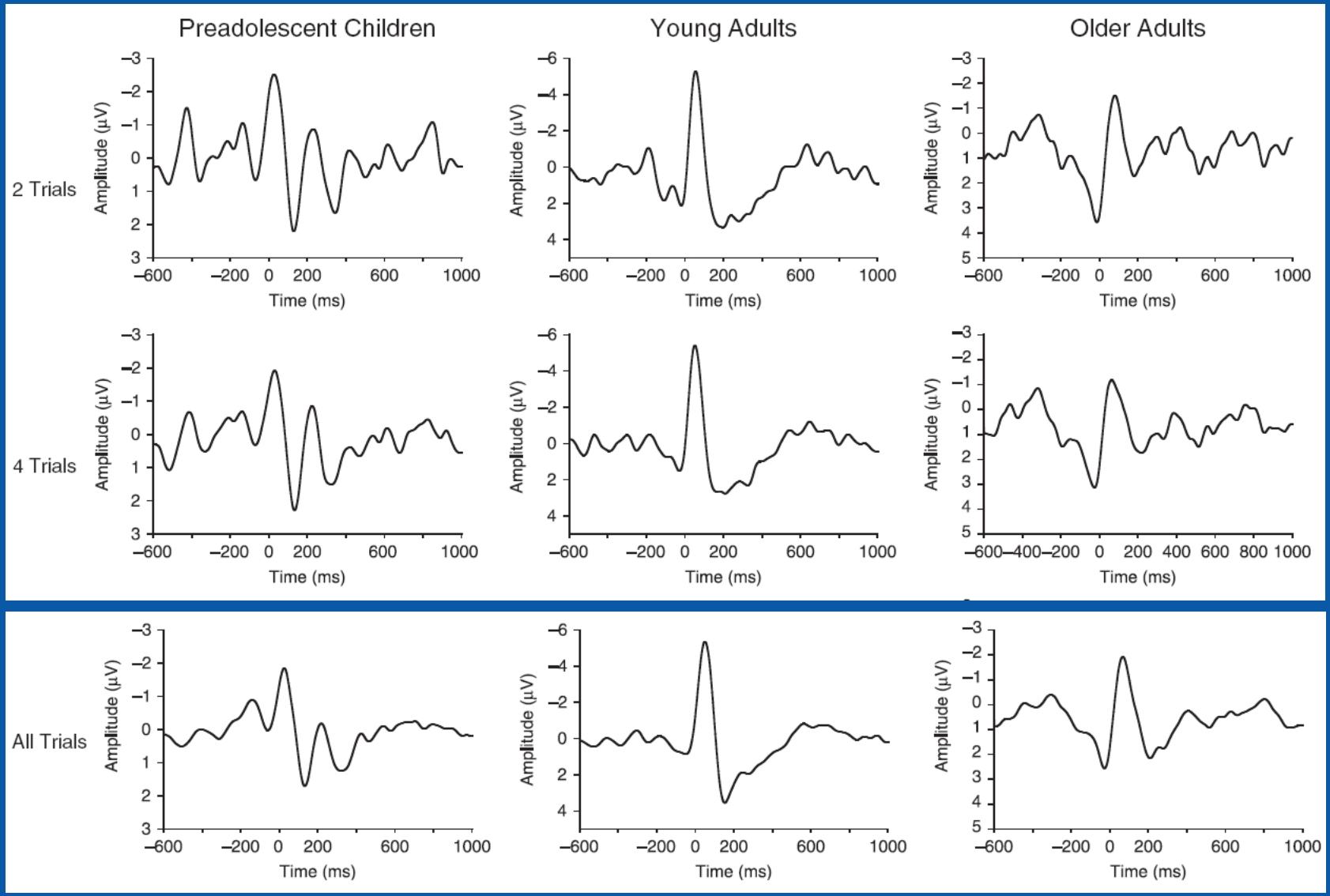
Brain sources of error-negativity and positivity

ERN/ERP (error-related negativity/positivity). They are generated when we make a mistake, and we have not (necessarily) realized it.



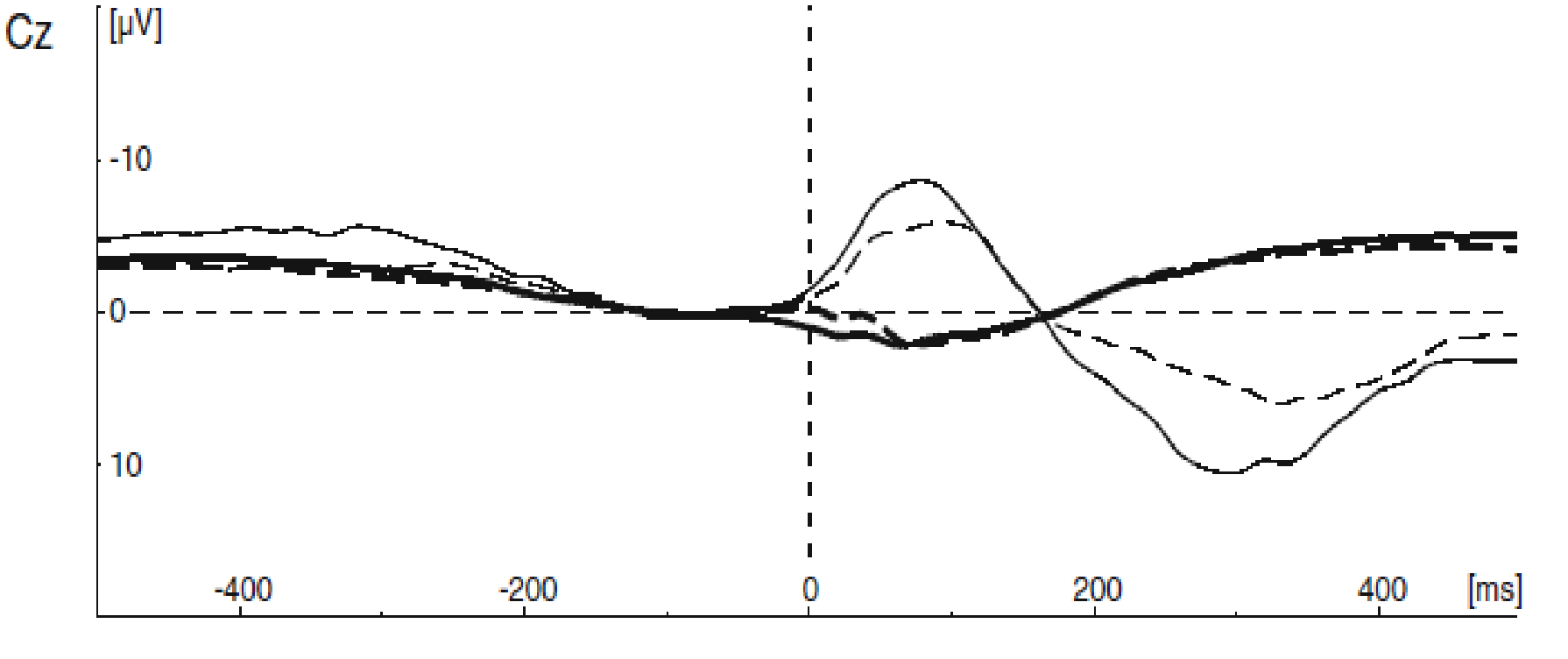
R. Vocat et al. / Neuropsychologia 46 (2008) 2545–2555

ERN: How many stimulus repetitions?



Pontifex M.B. e al.: *Psychophysiology, 47 (2010), 767–773.*

Error processing (potentials)



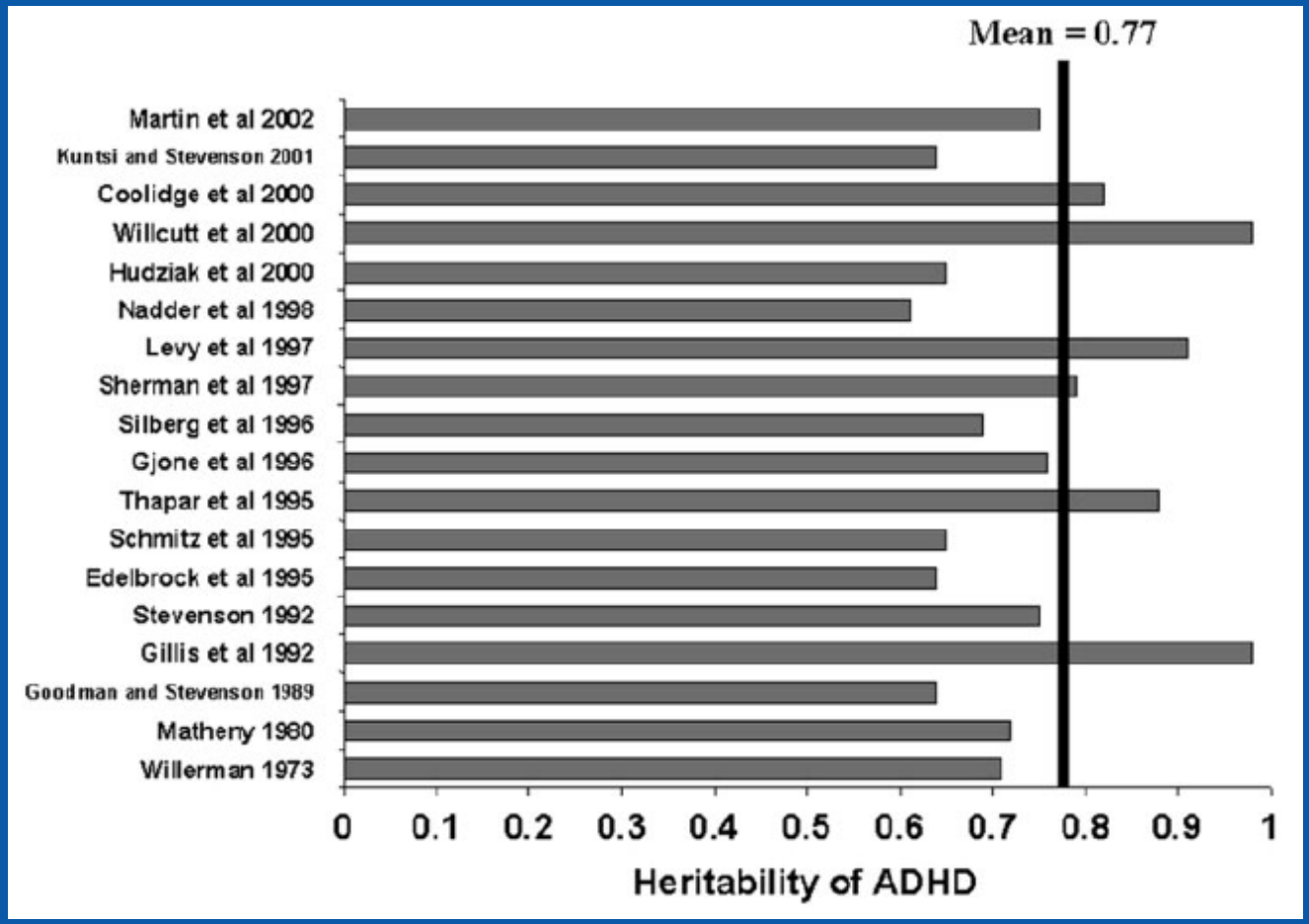
Dotted line: ADHD
Solid line: Healthy Controls

Error negativity

Error positivity

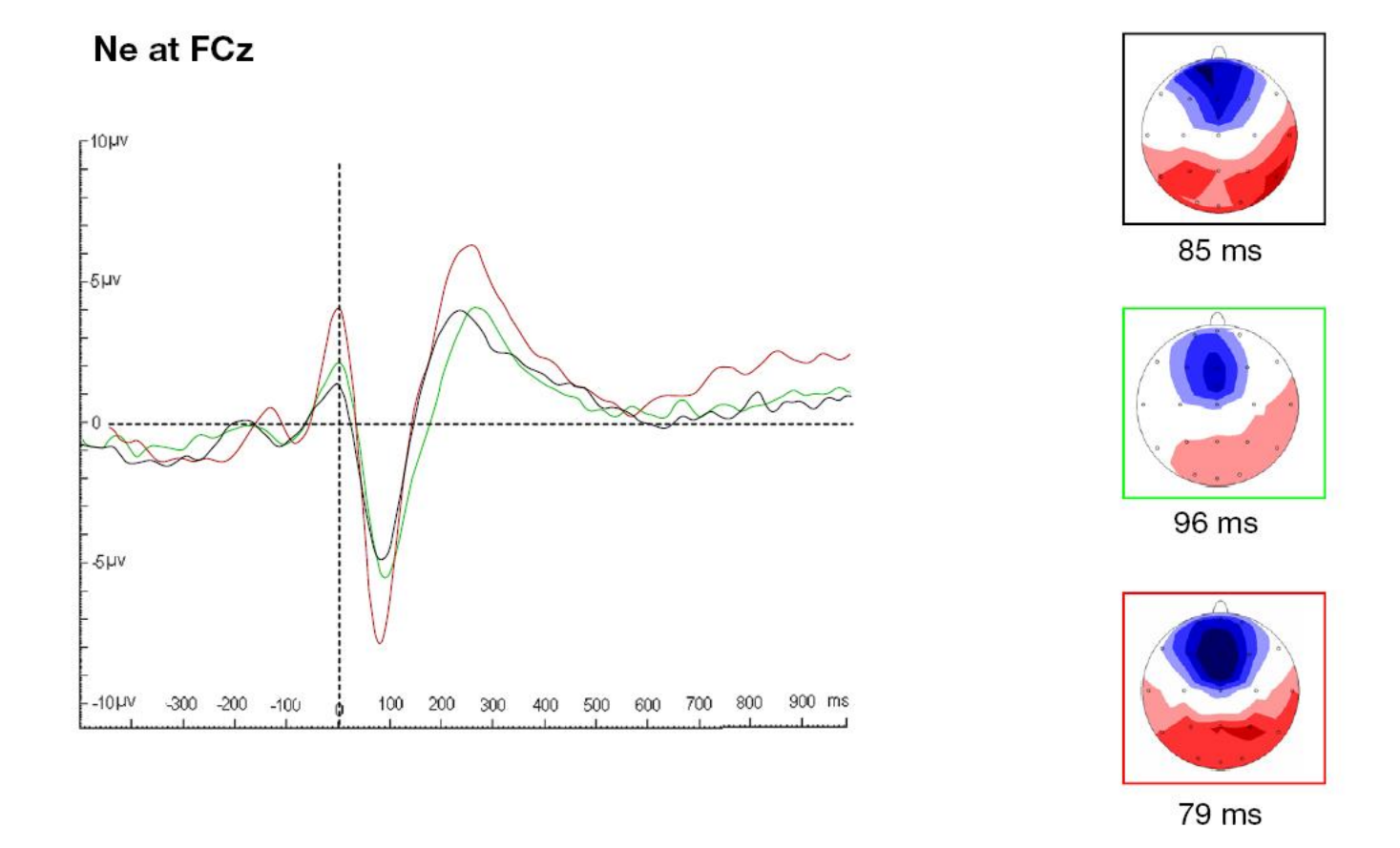
J. R. Wiersema Æ J. J. van der Meere, H. Roeyers: ERP correlates of error monitoring in adult ADHD. J Neural Transm (2009) 116:371–379.

Heritability of ADHD



Heritability of attention-deficit/hyperactivity disorder. Adapted from Faraone et al.

Error-related potential in a conflict task (arrow flanker task) in adult ADHD patients, parents and controls

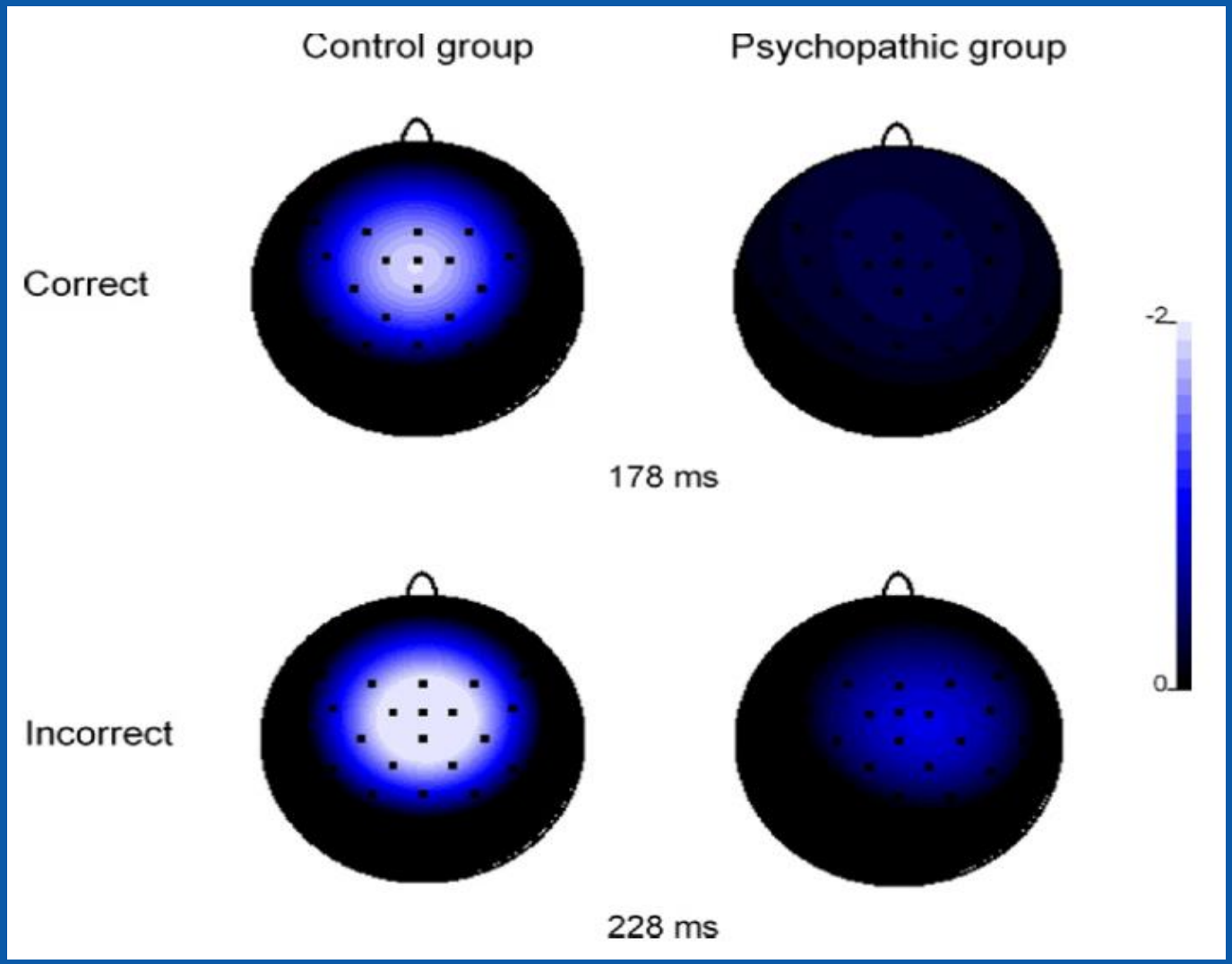


Response-locked ERN averaging at FCz electrode at latency for maximal amplitude for control subjects (red=controls, green=parents, black=ADHD)

Tye C. et al.: Expert reviews in molecular medicine. 2012. In press

Psychopathy: monitoring errors of self and others

Pe topographies, reduced ampl. when observing others' actions



Erikson arrow flanker task

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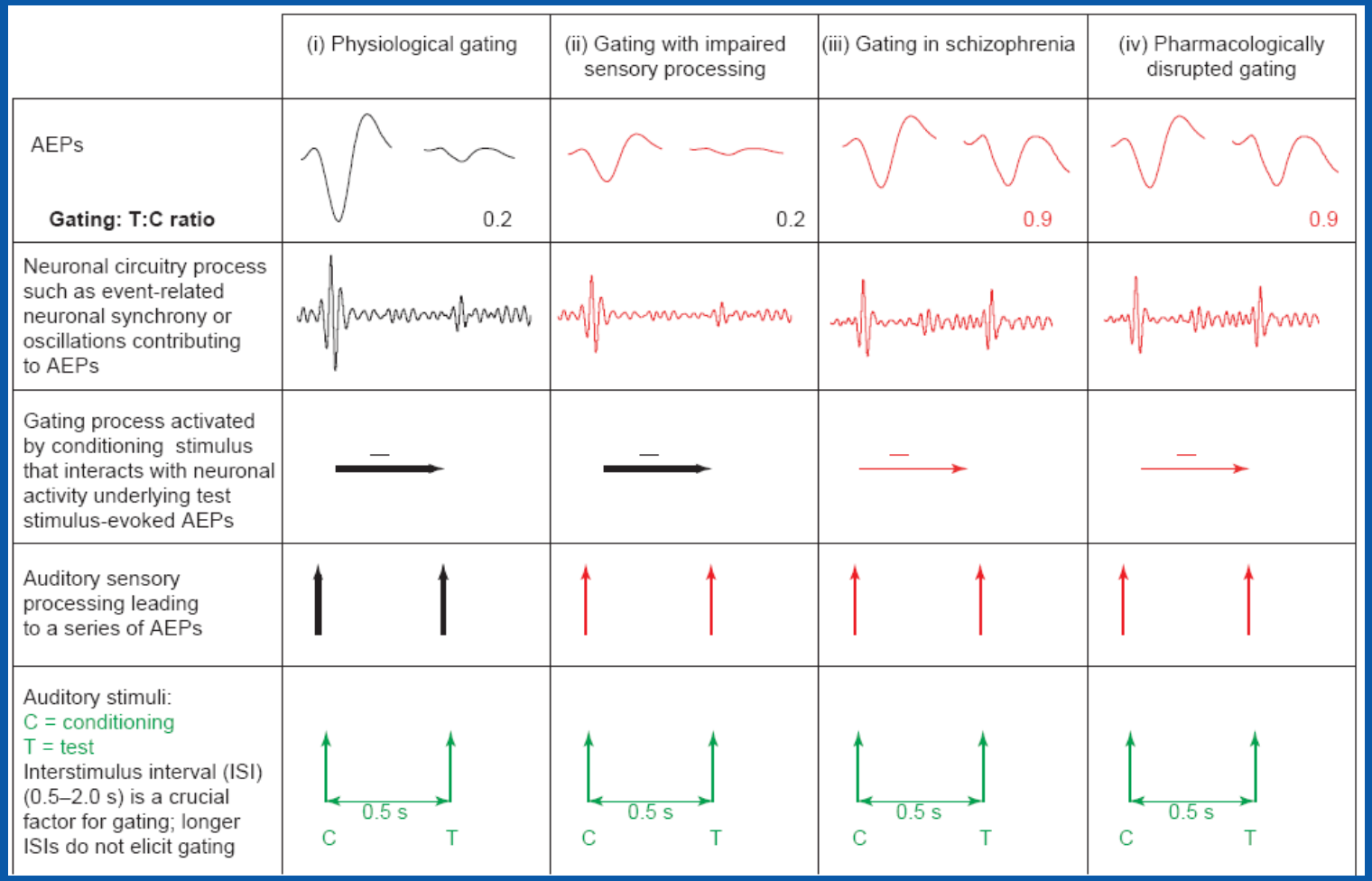
Self error: no diff.

Others' action: major reduction in Pe

Brazil I. A.. et al.: BIOL PSYCHIATRY 2011;69:693–699

Imapairment of sensorimotor gating in patients with schizophrenia

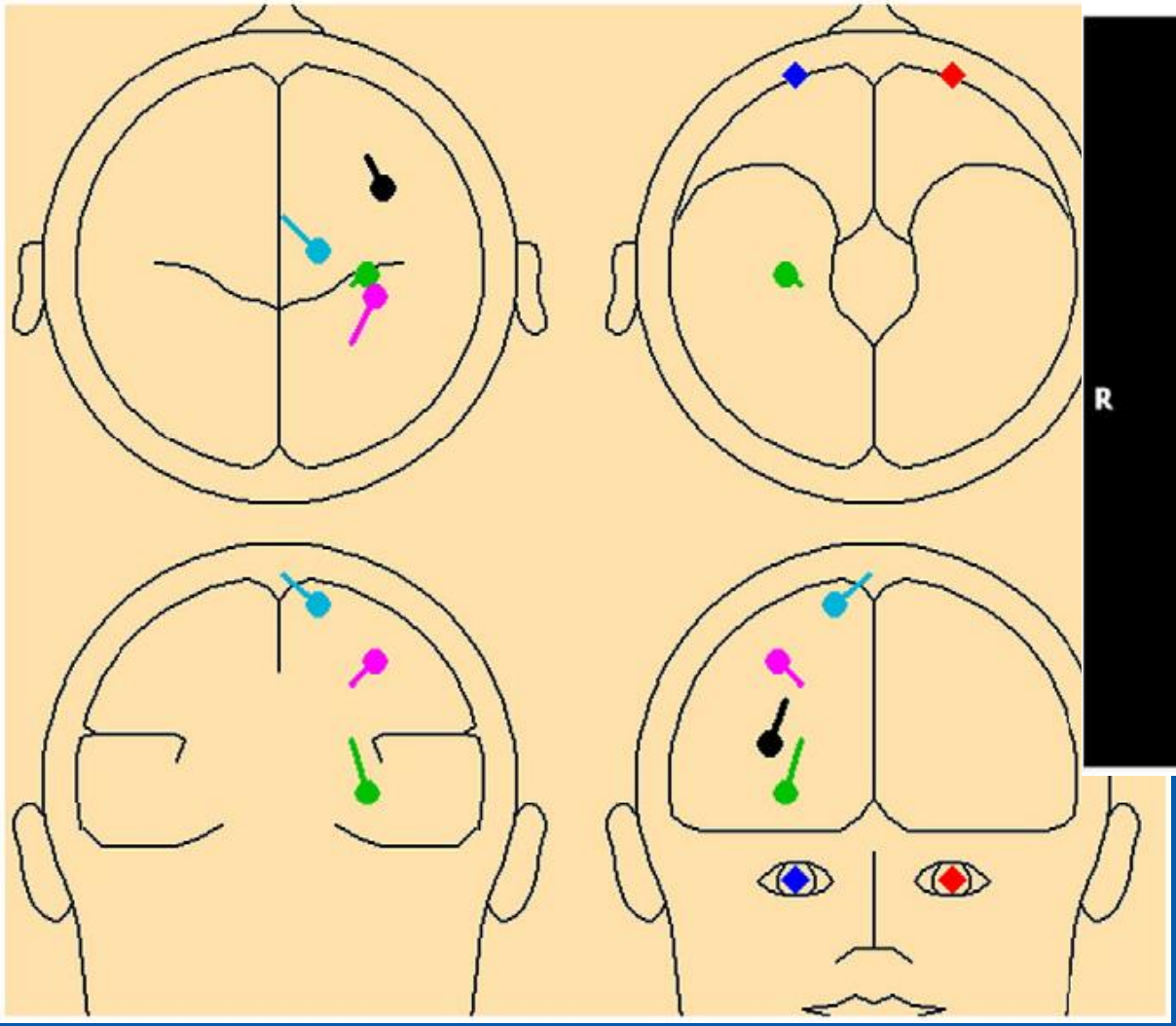


direct & indirect dopamine receptor agonists (amphetamine, apomorphine and cocaine) and NMDA receptor antagonists (PCP, ketamine)

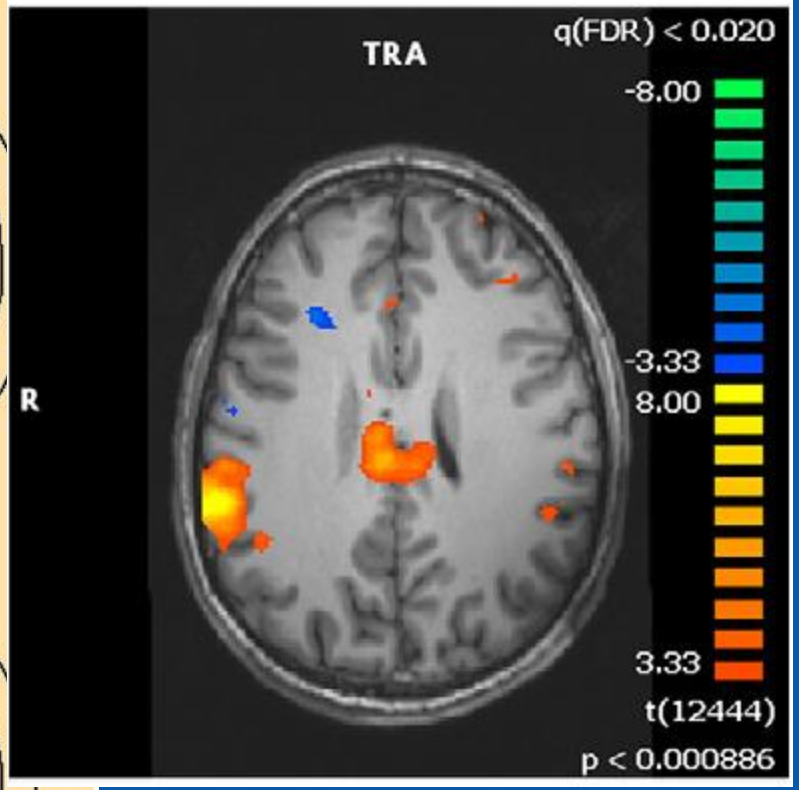
novel, potentially antipsychotic compounds can be tested in different gating deficit models

M. Hajós: Targeting information processing deficit in schizophrenia. Trends in Pharmacological Sciences. Vol 27. No. 7, July 26, 2006

Sensorimotor Gating (P50)



Medial frontal gyrus (blue), the insula (black), the hippocampus (green), and the postcentral gyrus (SI) (pink).



Medial frontal gyrus, insula, hippocampus, cingulate gyrus.

Source localization of sensory gating: A combined EEG and fMRI study in healthy volunteers. NeuroImage 54 (2011) 2711–2718

ERPs as Biomarkers

See Luck et al. (2011, Biological Psychiatry)

- ERPs are tightly tied to neurotransmission
  - MMN may reflect current flow through NMDA receptors
  - A change in ERPs reflects a change in PSPs (not mediated through hemodynamic response)
- Rodent/primate models available for some components
  - Potentially useful as an assay in drug discovery
- Easily tolerated by patients
- Some paradigms have excellent stability, reliability
- Relatively inexpensive, feasible for large-N studies
- May be able to predict which patients will respond to a given treatment
- Potential roadblocks
  - Individual differences, lack of quality assurance standards

Comparison of Techniques

	Microelectrode Measures	Hemodynamic Measures	Electromagnetic Measures
Invasiveness	Poor	Good (PET) Excellent (fMRI)	Excellent
Spatial Resolution	Excellent	Good	Undefined/Poor (ERPs) Undefined/Better (ERMFs)
Temporal Resolution	Excellent	Poor	Excellent
Cost	Fairly Expensive	Expensive (PET) Expensive (fMRI)	Inexpensive (ERPs) Expensive (ERMFs)