Electrophysiology III

Event-related potentials (ERPs)

Learning objectives:
at the end of this lecture, students will be able to

- explain the principles underlying the measurement of ERPs within EEG recordings
- give examples of typical ERP waveforms and their modulation by sensory and cognitive processing in the brain
- differentiate strengths and weaknesses of ERPs
- compare ERPs with other non-invasive methods of cognitive neuroscience

http://www.psychology.nottingham.ac.uk/staff/mxs/MScCognNeurosciNeuroimaging/

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ERPs: a special case of EEG recordings

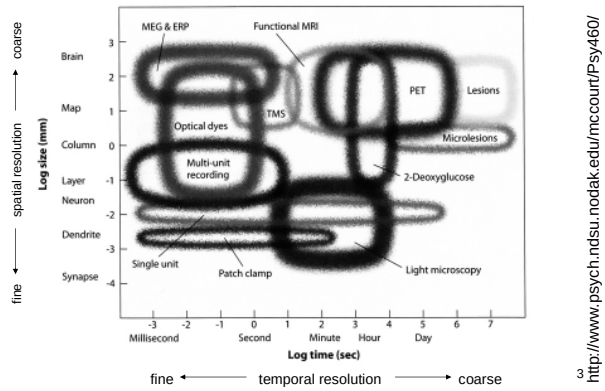
MEG, magnetoencephalography
EEG, electroencephalography
en * kephale * graphein
-graphy is the method
-gram is the result

MEG and EEG record neuronal electrical activity directly
- as opposed to hemodynamic by-effects in functional MRI
- with excellent temporal resolution (milliseconds)
- with good spatial resolution in the case of MEG

MEG measures magnetic field around the head ⟷ different signal, but same biophysical basis ⟷ EEG measures voltage changes on the scalp

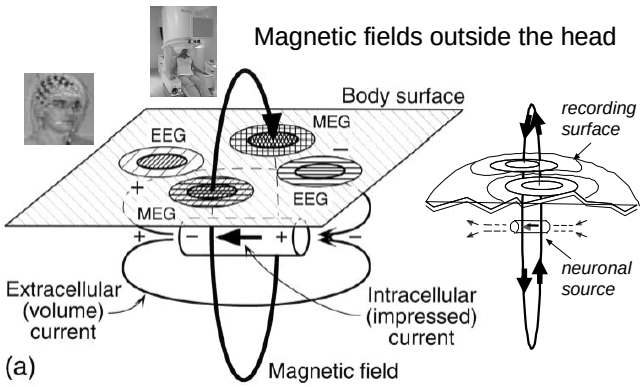
MEG and EEG as methods for cognitive neuroscience
- study the brain basis of sensory and cognitive processes
- in many cases single-subject data can be evaluated in MEG

Brain imaging methods: spatial and temporal resolution



http://www.psych.ndsu.nodak.edu/mccourt/Psy460/

Magnetic fields outside the head

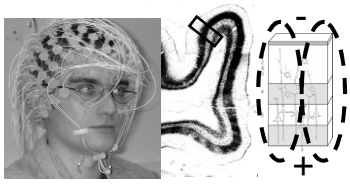


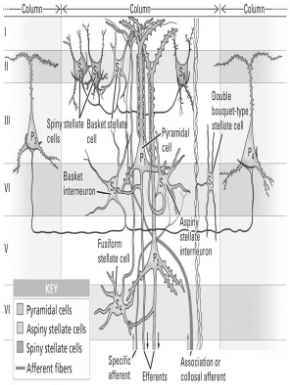
Skull is "transparent" to magnetic fields (i.e. no distortion) whereas electric fields are distorted (important consequences for spatial reolution of EEG vs MEG)

1:5

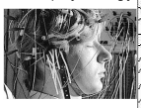
Measuring electrical activity of the brain

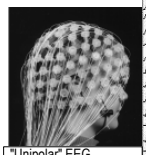
- Under the influence of postsynaptic potentials, cortical neurons create surface-negative electrical dipoles
- Neurons aligned perpendicular to cortical surface, dendrites closer to the surface and axons closer to the white matter
- Synchronous firing of large neuron populations can be recorded non-invasively



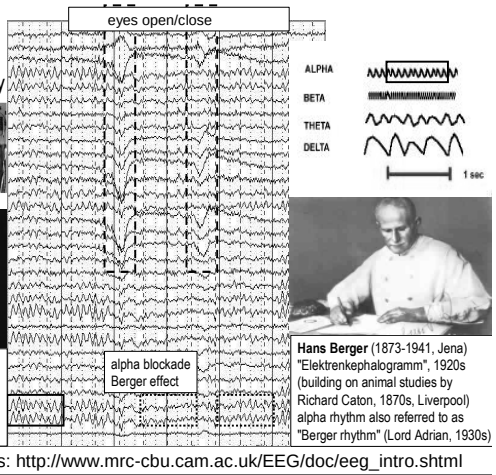


EEG: non-invasive neurophysiology





"Unipolar" EEG measures [voltage difference betw' active electrode on the scalp and reference electr'] X number of electr' sites

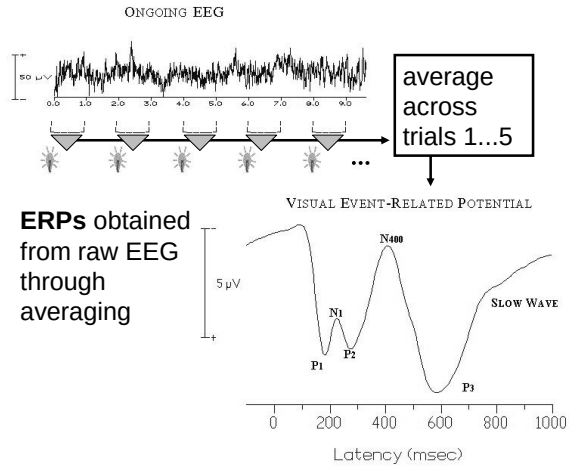


Hans Berger (1873-1941, Jena) "Elektrenkephalogramm", 1920s (building on animal studies by Richard Caton, 1870s, Liverpool) alpha rhythm also referred to as "Berger rhythm" (Lord Adrian, 1930s)

Louis S. http://www.emedicine.com

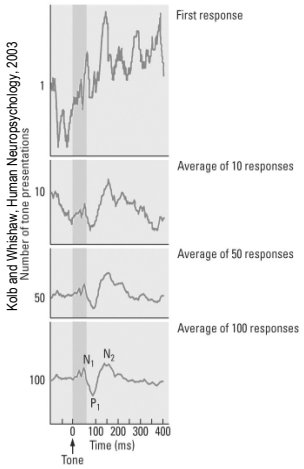
http://www.ruf.rice.edu/~gpotts/EEGlab/ERP.html

More details: http://www.mrc-cbu.cam.ac.uk/EEG/doc/eeg_intro.shtml



http://www.u.arizona.edu/~jallen/

ERPs obtained from raw EEG through averaging



Kolb and Whishaw, Human Neuropsychology, 2003

ERPs as averaged EEG epochs:
* record EEG trials, time-locked to the event of interest
* each trial contains ERP and voltage fluctuations that are not time-locked to the event

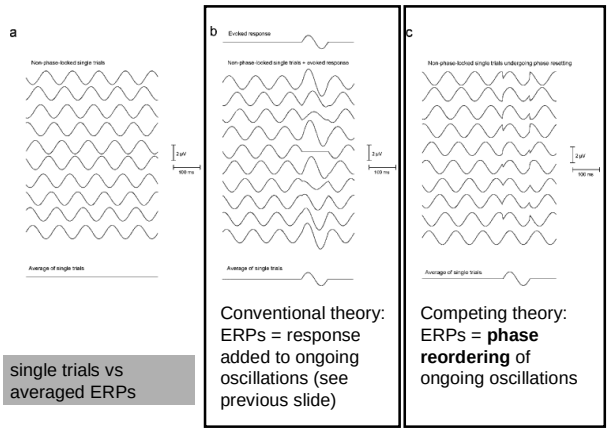
Under the **assumptions (!)**
(1) ERP signal constant over trials
(2) noise random across trials
(3) ERP signal independent of background fluctions

averaging increases the signal-to-noise ratio of the ERP signal

Examples of artifacts (EEG, ERPs):
* movement of the eyeballs
* muscle activity (e.g. clenching teeth)
* electrocardiogram

optimize recording to minimize artifacts, discard artifactuous trials or remove artifacts by signal processing

Fabiani et al., in: Handbook of Psychophysiology, 2000



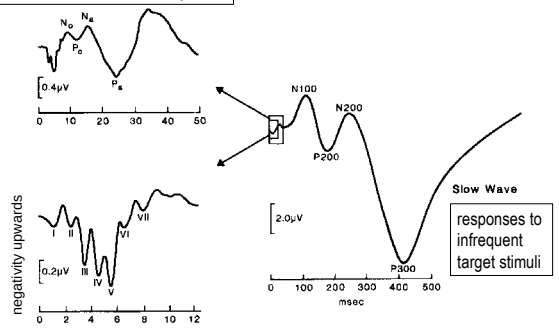
single trials vs averaged ERPs

Conventional theory: ERPs = response added to ongoing oscillations (see previous slide)

Competing theory: ERPs = **phase reordering** of ongoing oscillations

Review: Sauseng, Klimesch, Gruber, Hanslmayr, Freunberger, Doppelmayr, Neuroscience 2007

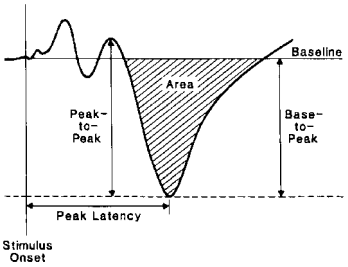
Auditory ERPs (responses on different time scales)

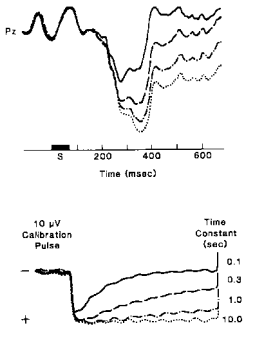


Fabiani et al., in: Handbook of Psychophysiology, 2000

Plots show averaged ERPs, voltage as a function of time
ERPs often plotted with **negativity upwards** (for historical reasons)

ERP waveform (schema of component quantification)

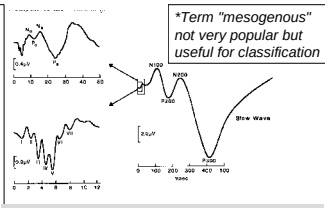




ERP waveform depends on amplifier settings (high-pass)

Fabiani et al., in: Handbook of Psychophysiology, 2000

Exogenous ERPs: automatic responses of the brain, controlled by physical properties of stimulus
Endogenous ERPs: depend on interaction between subject and event (attention, task-relevance, expectation: resp' to omitted stimulus)
Mesogenous ERPs: semi-automatic but modulated by cognitive processes (attention, memory)*



**Term "mesogenous" not very popular but useful for classification*

Generation of ERPs (~EEG):
1. neurons active in synchrony
2. electric fields oriented in such a way that the y cumulate ("open field" in layered cortex vs "closed field" in midbrain)

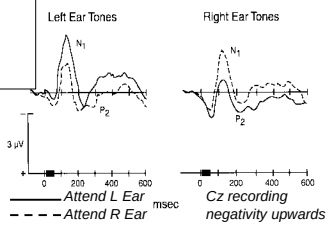
If experimental manipulation has no effect on ERP, one cannot conclude that it does not influence brain processes

Source localization for ERPs?
"determine (one or several) neural generators whose activity results in the scalp-recorded potential"
inverse problem: no unique solution!
(Hermann von Helmholtz 1821-1894)
further complication: **scalp distorts and "smears" electrical fields** (can be overcome by recording *magnetic* instead of *electric* fields as skull is transparent to the former: **MEG**)

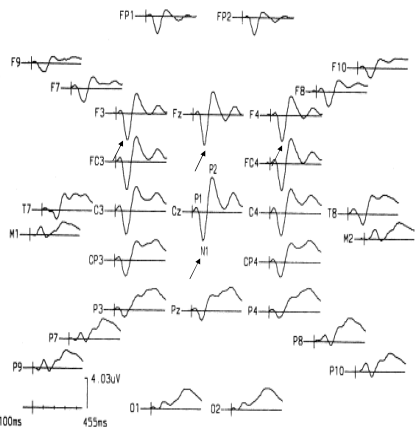
Exogenous ERPs: sensory evoked potentials (up to ~100 ms post stim')
* elicited whenever the respective modality-specific sensory pathway (auditory, visual, somatosensory ...) is intact
* influenced by intensity and frequency of stimuli
* highly important for neurological diagnosis, less so for psychol' research

***"Mesogenous"* ERPs:**
some negative components with 100-200 ms latency underlie cognitive modulation
example: selective attention modulates auditory N100
in other words: effect of selective attention emerges as early as 100 ms after stimulus (or earlier)

* stimuli differ along two dimensions, location (left, right ear) and pitch (low, high tone)
* instruction: "attend to low tones in right ear"
* effect of attention shows up as difference between standard tones in attended ear (right) vs standard tones in unattended ear (left)



Fabiani et al., in: Handbook of Psychophysiology, 2000



"Mesogenous" ERPs:

Topography of N100

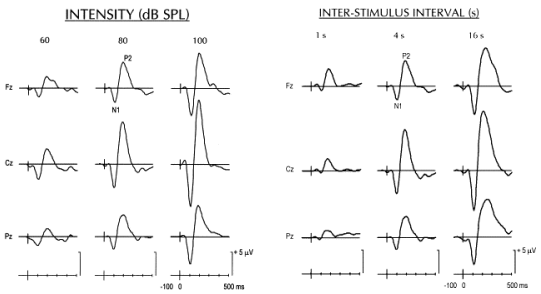
N100 (N1) scalp distribution (**reference:** tip of the nose). Positivity upwards. 80-dB SPL 1000-Hz auditory stimulus, 55 ms duration, binaurally every 1.5 s

Large negative wave apparent at approx 80–100 ms, frontocentral maximum, N1 or N100

Later negativity, peaking at approximately 120–150 ms, apparent over temporal sites

EEG, ERPs measure voltage difference between electrode X and reference electrode, i.e. ***topographic pattern depends on site of reference electrode!***

Positivity upwards. Müller-Grass and Campbell Int J Psychophysiol 2002; 46: 177-195

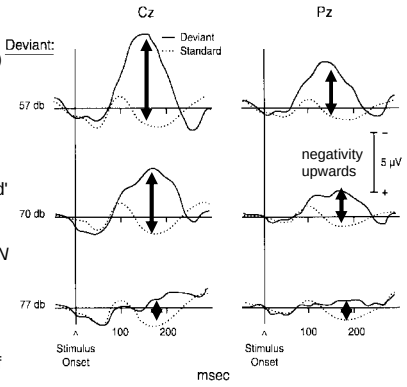


"Mesogenous" ERPs: N1-P2 depends on stimulus intensity (=physical attribute of stimulus). As intensity increases, amplitudes of N1, P2 increase

N1-P2 depends on rate of stimulus presentation. As rate is slowed, amplitudes of N1, P2 increase (and topography changes, different source?)

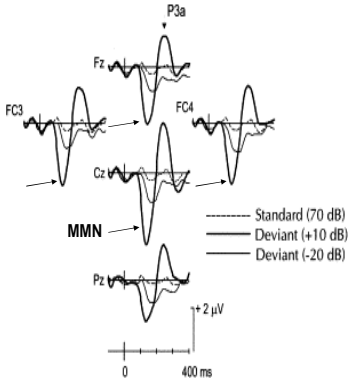
Positivity upwards. Müller-Grass and Campbell Int J Psychophysiol 2002; 46: 177-195

***"Mesogenous"* ERPs:**
mismatch negativity (MMN)
passive auditory oddball paradigm (frequent tones "standard", rare tones are "deviant" in pitch, intensity, duration)
subject not attending to aud' stimuli but reading a book
the more discriminable the stimuli, the shorter the MMN latency and the larger the MMN amplitude
frontal/central maximum
MMN may reflect
* preattentive processing of deviant features
* sensory memory or 'echoic memory' (not recorded after very long interstimulus intervals!)



Standard tone (90%): 80 dB
Deviant tone (10%): 57, 70, or 77 dB

Fabiani et al., in: Handbook of Psychophysiology, 2000

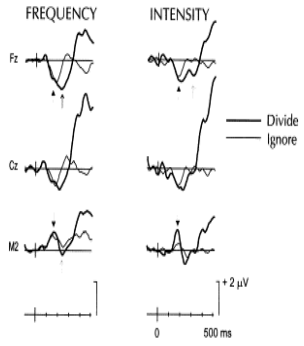


"Mesogenous" ERPs:

MMN to deviant stimuli among frequent 70-dB stimuli

Subjects ignored stimuli while reading a book; intensity increment elicited MMN and P3a (novelty P3 - subjects distracted from reading task?)

Positivity upwards. Müller-Grass and Campbell Int J Psychophysiol 2002; 46: 177-195



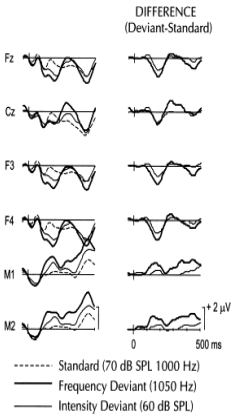
"Mesogenous" ERPs:

MMN modulated by selective attention

Subjects asked to either attend to the visual channel (and ignore the auditory) or to attend to both the auditory and visual channels.

In the auditory channel, a frequency and an intensity deviant were presented. Plots show differences standard - deviant

Positivity upwards. Müller-Grass and Campbell Int J Psychophysiol 2002; 46: 177-195



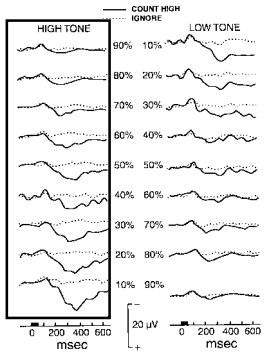
"Mesogenous" ERPs:

Mismatch negativity (MMN)

Standard tone 70-dB 1000-Hz, 90% of trials. Rare tones deviant in either pitch (1050 Hz) or intensity (60 dB). MMN larger for pitch change. A nose reference was used in this recording. The MMN inverts in polarity at the mastoids, consistent with neural sources in and around the auditory cortex.

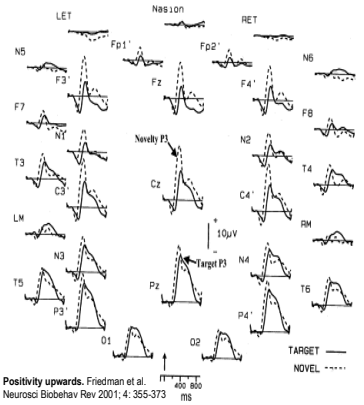
Positivity upwards. Müller-Grass and Campbell Int J Psychophysiol 2002; 46: 177-195

Endogenous ERPs, P300:
(a) response to oddball stimuli, parietal maximum ("classic" P3, P3b)
* marked response to **task-relevant stimuli**
* sensitive to stimulus probability
* may reflect categorization of stimuli (longer P300 latency for stim' that are difficult to categorize)
completion of stim' evaluation?
auditory oddball paradigm may elicit MMN **and** P300
(b) "novelty" P3, P3a, as a response to **unexpected deviant stimuli**, frontal max
orienting to stimuli for which no memory template available?
(c) "omitted stimulus" P3



In this experiment, P300 inversely correlated with probability and absent when rare stimuli are not task-relevant

Fabiani et al., in: Handbook of Psychophysiology, 2000



Positivity upwards. Friedman et al. Neurosci Biobehav Rev 2001; 4: 355-373

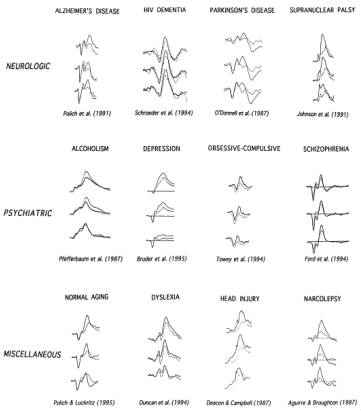
Comprehensive theory of P3 and P3b: Polich J Clin Neurophysiol 2007 – controversial! see Verleger R Clin Neurophysiol 2008

Endogenous ERPs elicited by
* infrequently occurring targets **("classic" P3, target P3, P3b)** and
* equally infrequent novel, environmental sounds **(novelty P3, P3a)**

during an actively attended novelty oddball task

Note different topographic distributions

Surface potential maps

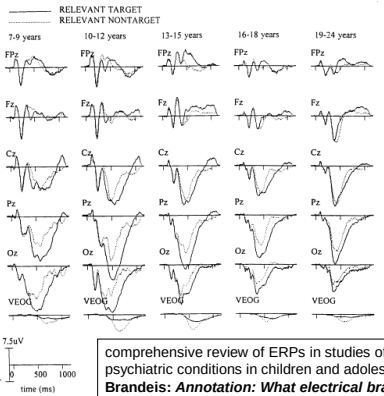


Endogenous ERPs:

P300 from neurologic, psychiatric, and miscellaneous subject populations (top to bottom Pz, Cz, Fz electrodes). Note that both peak amplitude and latency can be affected by disease processes

Polich and Herbst Int J Psychophysiol 2000; 38: 3-19

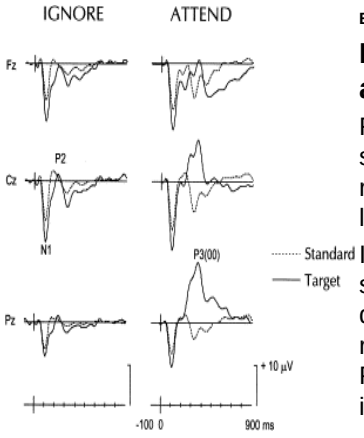
Positivity upwards



Endogenous ERPs:

P300 for different age groups

comprehensive review of ERPs in studies of normal development and psychiatric conditions in children and adolescents: **Banaschewski and Brandeis:** ***Annotation: What electrical brain activity tells us about brain function that other techniques cannot tell us – a child psychiatric perspective.*** **Journal of Child Psychology and Psychiatry 2006**



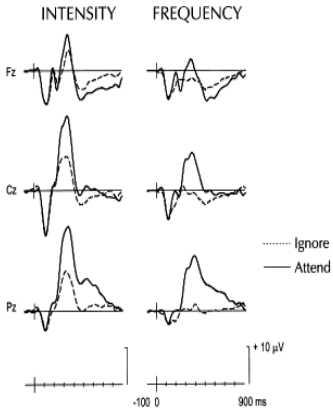
Endogenous ERPs:

P300 depends on attention

Frequent standard stimuli (dashed line) vs rare target stimuli (solid line)

In the Attend condition, subjects were asked to detect the target, and rare stimuli elicited P300 which was absent in the Ignore condition.

Positivity upwards. Müller-Grass and Campbell Int J Psychophysiol 2002; 46: 177-195



Endogenous ERPs:

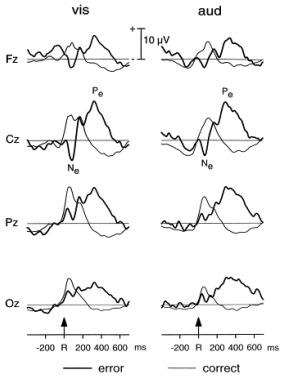
P300, elicited automatically

Standard tones 80 dB, 1000 Hz. Rare tones either loud, 100-dB, or 2000-Hz deviant.

P300 to intensity target much larger than to frequency target (P3b)

With stimuli ignored, large P300 still observed for loud-intensity deviant (but different topography, P3a)

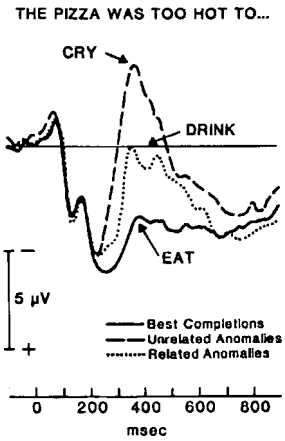
Positivity upwards. Müller-Grass and Campbell Int J Psychophysiol 2002; 46: 177-195



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.

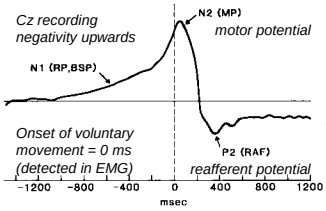
Falkenstein et al. Biol Psychol 2000; 51: 87-107

Endogenous ERPs, N400: semantically incongruent (but syntactically correct) sentence endings amplitude proportional to the degree of incongruence



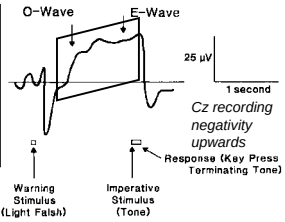
Fabiani et al., in: Handbook of Psychophysiology, 2000

Spoken language understanding studied with electric and magnetic brain signals: see review **Hagoort Phil Trans R Soc B 2008**



Movement-related potential preceding voluntary movement RP, readiness potential *("Bereitschaftspotential", Kornhuber and Deecke 1965*) maximum contralateral to responding limb

Contingent negative variation, CNV in S1-S2 paradigm
William Grey Walter 1964
Orienting wave
Expectancy wave (could be same as readiness potential)



Fabiani et al., in: Handbook of Psychophysiology, 2000

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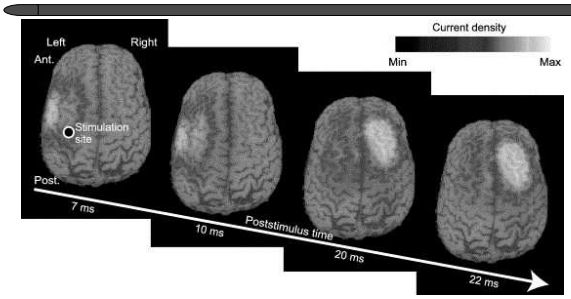
Outlook: EEG/ERP combined with TMS



- transcranial activation to left motor cortex at 0 ms
- neuronal activation (measured with EEG) spreads to contralateral hemisphere 20 ms after stimulus
- activation shown as MCE calculated from EEG

Komssi and Kähkönen Brain Res Rev 2006

1:30

Summary and web resources

- ERPs obtained through time-locked averaging to improve "signal to noise ratio"
  - under assumption (!) that ongoing EEG is noise
- exogenous vs endogenous ERPs depend on physical properties of stimulus vs interaction between subject and event

http://www.psychology.nottingham.ac.uk/staff/mxs/MScCognNeurosciNeuroimaging