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)
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 spectrum 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 background EEG. Therefore, the Signal-to-Noise Ratio (SNR) needs to be improved.
Signal-to-Noise Ratio – where is the noise coming from?

Artifacts

- blinking
- eye movements
- muscles
- respiration
- ballisto-kardiogram
- EKG
- EEG

!!!50 Hz/60 HZ!!!
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

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 repetitions.

- 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 from 16 single trials

ERP average from 221 single trials
Event Related Potential – Butterfly Plot
How can we investigate the ERPs?

NoGo P300 potentials from CPT OX tasks

EEG Voltage and Its Map
EEG power distribution in time and frequency during voluntary finger movement (onset time $= 0$) for electrode above sensorimotor cortex. Desynchronization (amplitude reduction) is visible for alpha and beta before the movement and their synchronization is present after the movement.
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

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

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

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.
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

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

P300 – the central player of the Brain Computer Interface (BCI) systems – typewriter
Face recognition specific N170 component

Face recognition specific N170 component

Other cognitive ERP component: N400

N400: ERP response to semantic incongruence.

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

Language-specific ERP components

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

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.

Motor ERP components:

They appear in those motor areas that initiate and execute movements. They reflect the synchronized 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.

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?
Error processing (potentials)

Cz

Error negativity

Error positivity

Dotted line: ADHD
Solid line: Healthy Controls

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)

Psychopathy: monitoring errors of self and others

Pe topographies, reduced ampl. when observing others’ actions

Erikson arrow flanker task
<< << << << << <<

Self error: no diff.

Others’ action: major reduction in Pe

Imapairment of sensorimotor gating in patients with schizophrenia

Sensorimotor Gating (P50)

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

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## Comparison of Techniques

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