Introduction to electroencephalography (EEG)

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PY 630 – Affective Neuroscience
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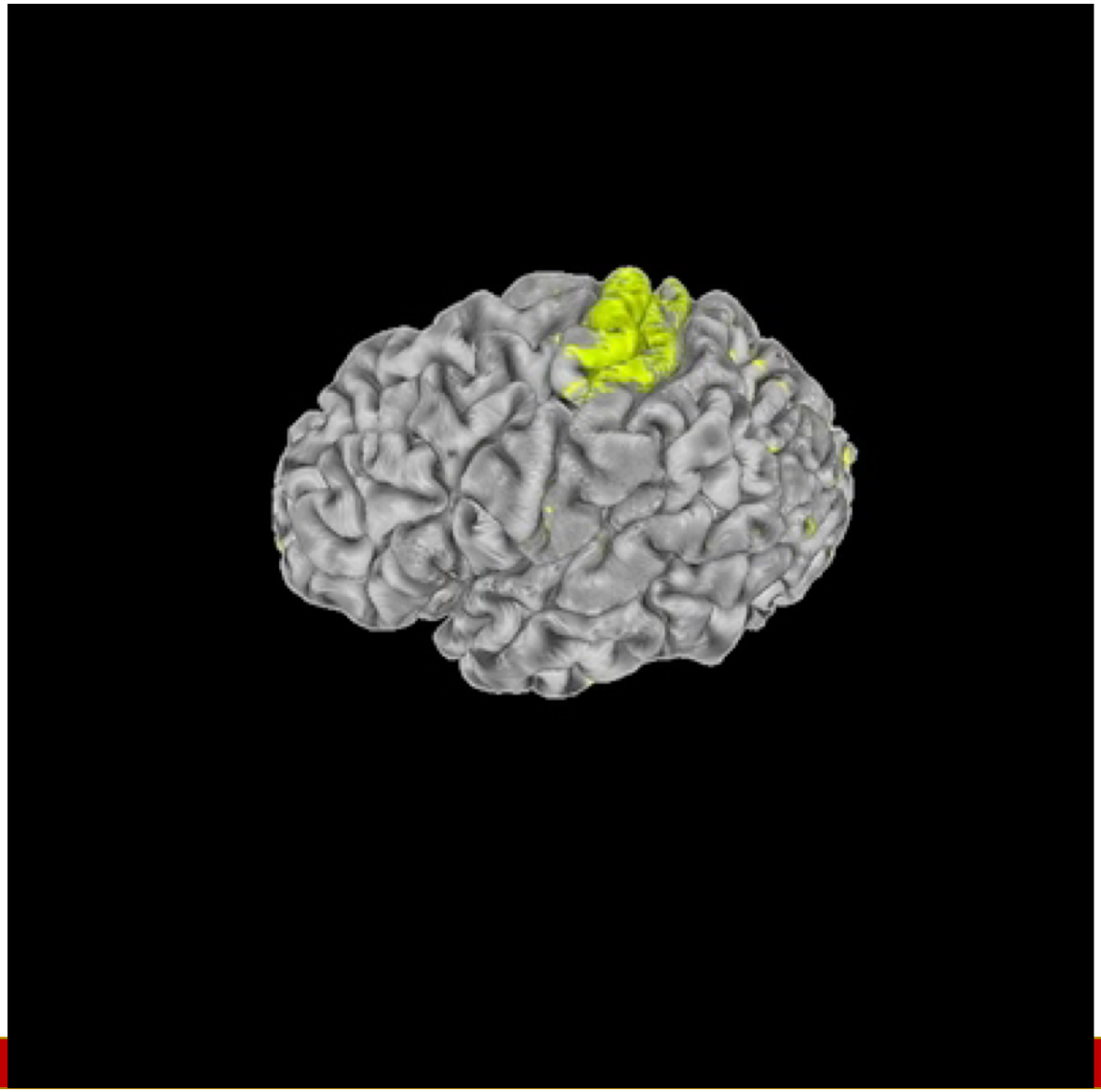
Don’t forget to record!

Overview

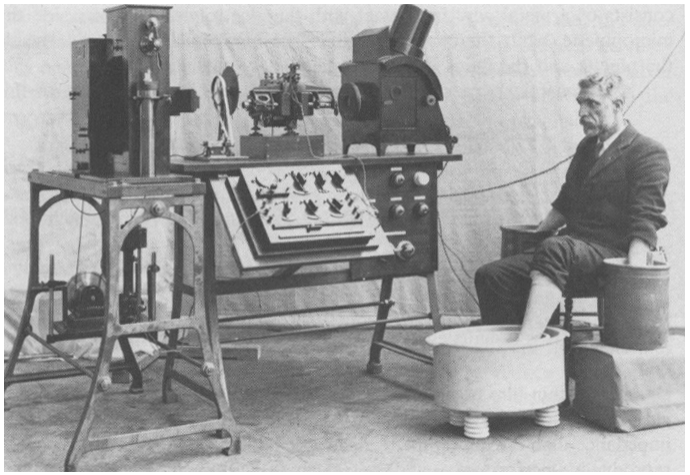
- EEG methodology
- Event-related potentials outcomes
- Spectral analysis outcomes

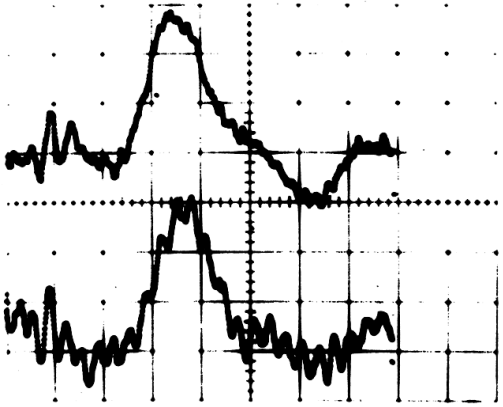
Advantages of EEG

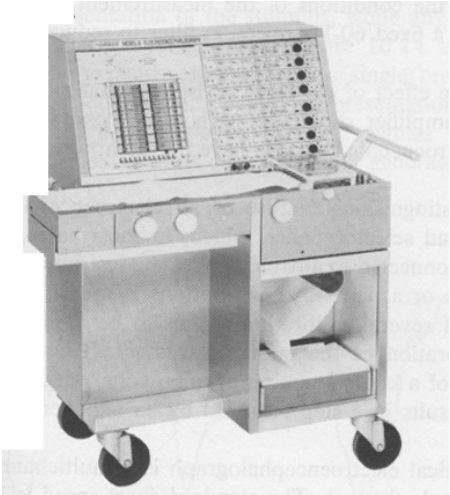
- Correlation with cognitive & physiological events
- Time resolution (ms)
- Spatial resolution
- Portability
- No age limits
- Useful with or without behavioral response
- Cost



History of electroencephalography (EEG)

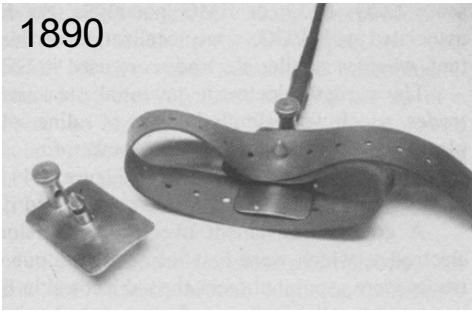


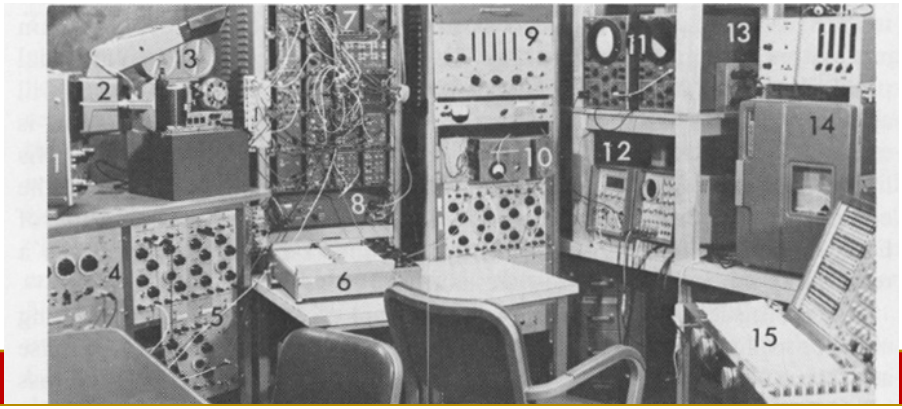




1950

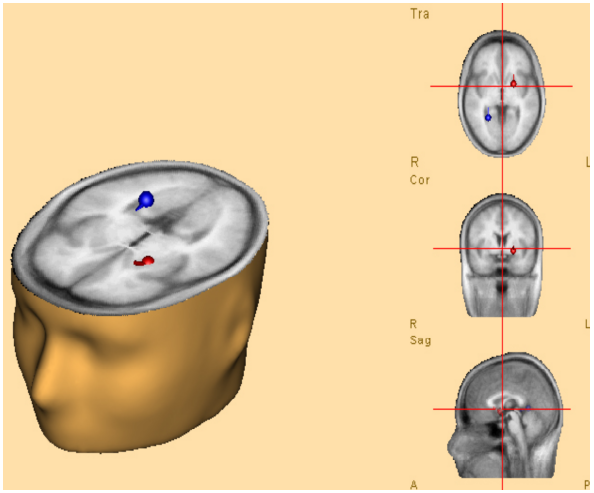
1890

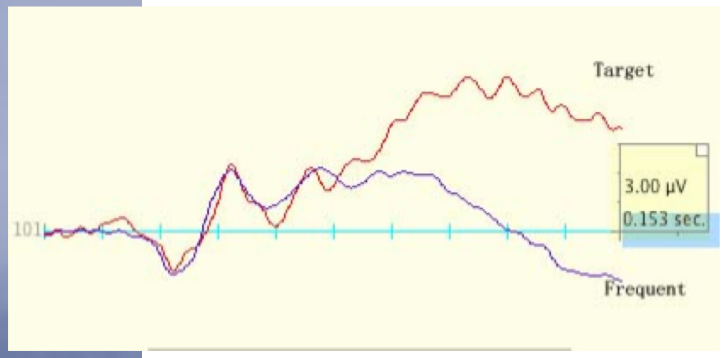




1970

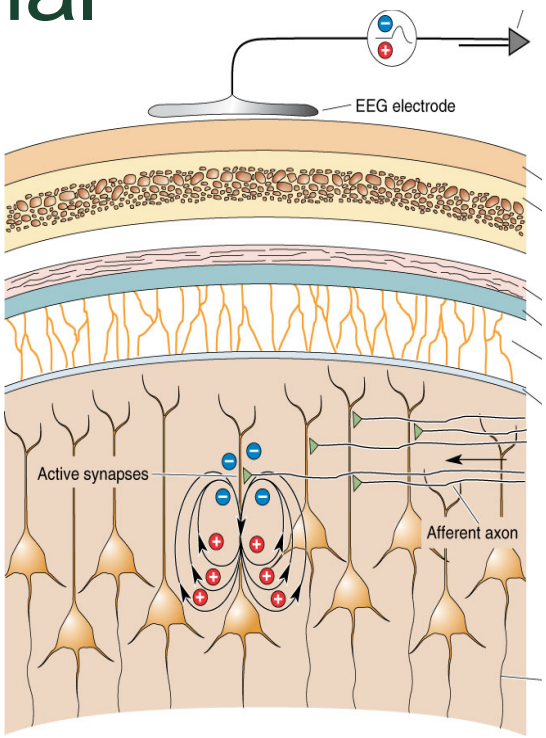
ERPs: Today!





The EEG signal

- The EEG signal: a summation of electrical fields generated by large neural populations
- Neuronal activity can be thought of as many small oscillators
- Activity from different frequencies and in different polarities will cancel out.

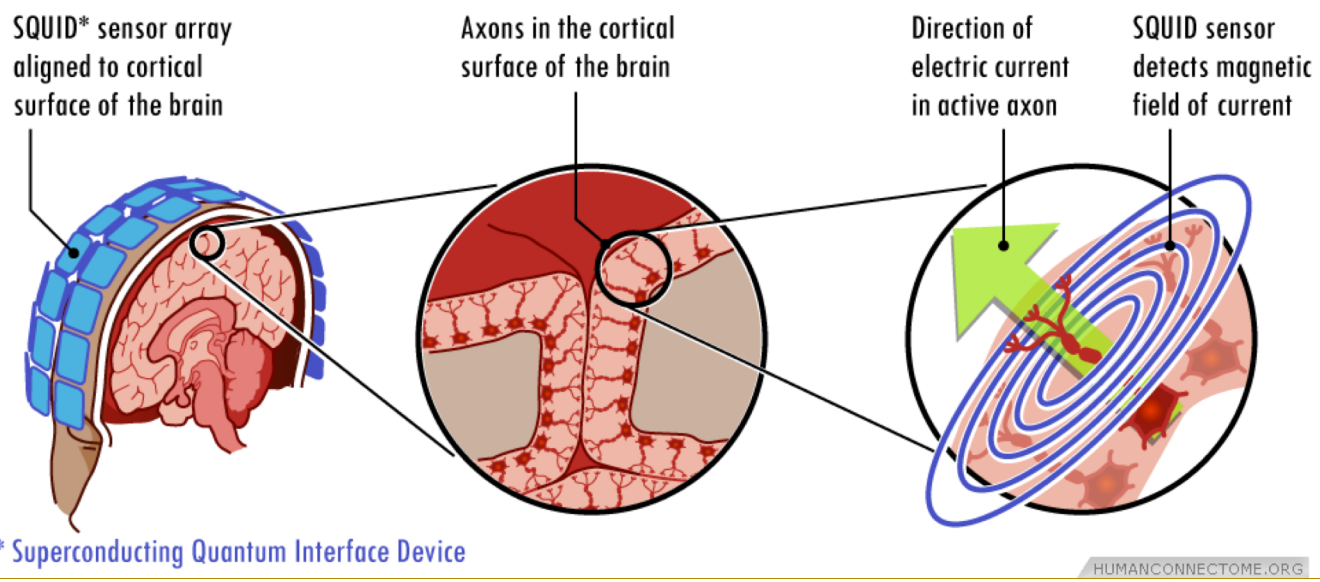


Decompose the EEG signal into different frequencies will reflect the ***synchronized*** activity in each frequency

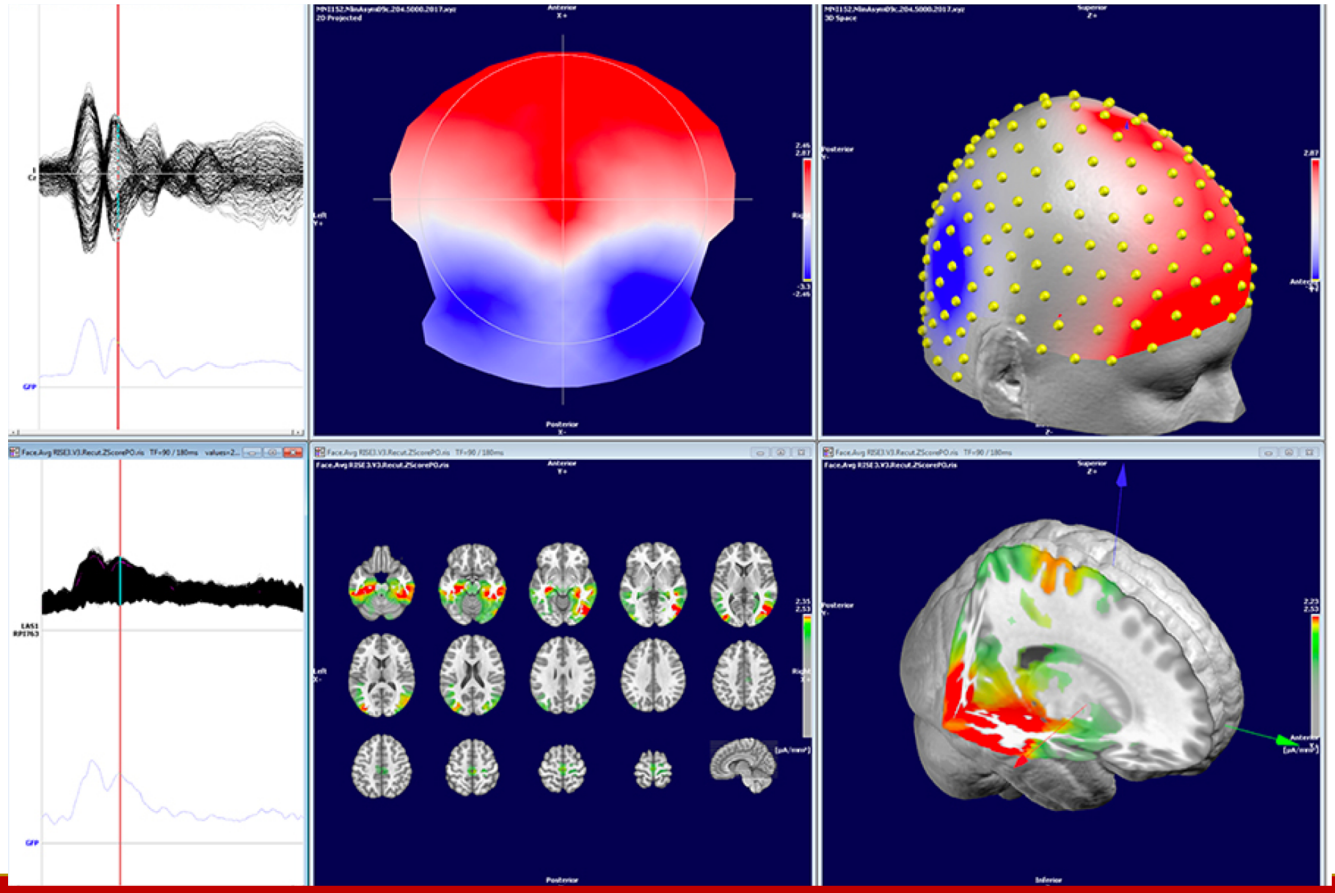
Dipoles

1. Dipoles perpendicular to surface (since cortex folds, not necessarily perpendicular to scalp surface).
2. Reflects differences in soma and dendrite ion flow across cortical layers.
3. Activity at scalp not necessarily result of ion movements immediately below electrode.

Caution: **Dipoles generated in one hemisphere may generate higher shifts in other hemisphere.**

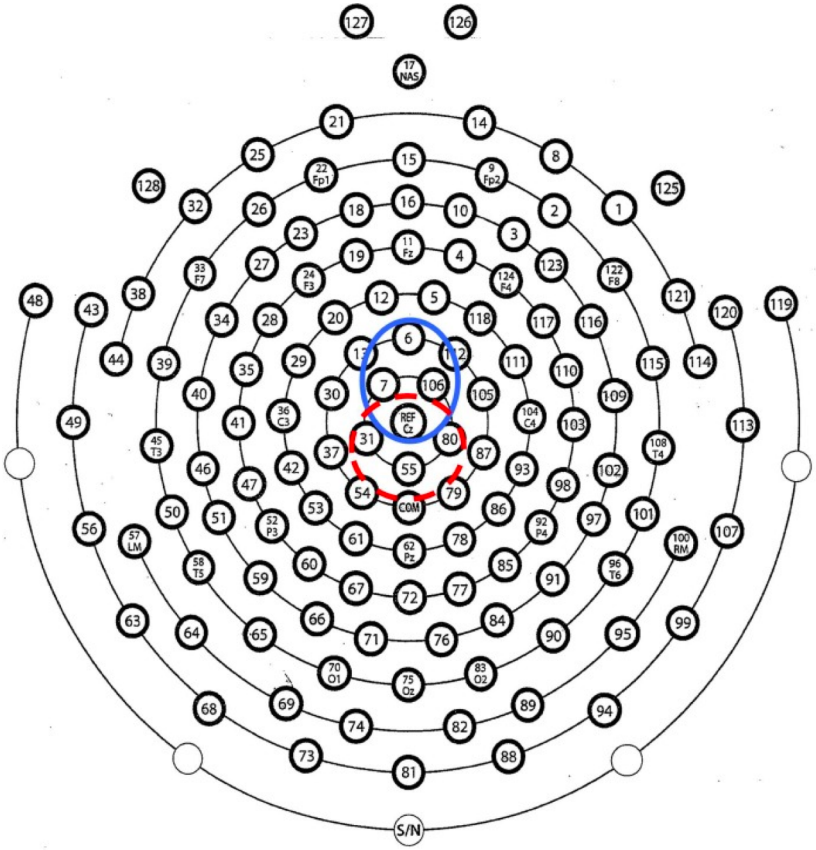


Dipole



EEG is inherently dynamic

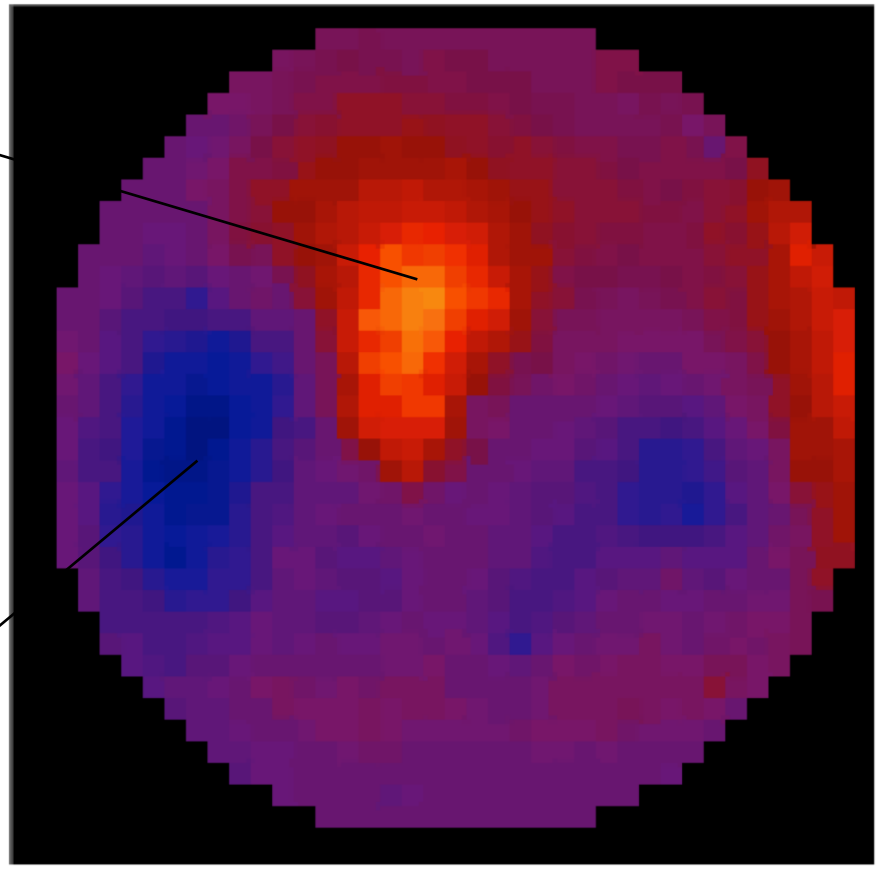
- Signal will naturally fluctuate and evolve at every data point
- We can record at every millisecond at every channel
  - High-density nets (>32 channels)



Front of Head

Increasing Positive Voltage

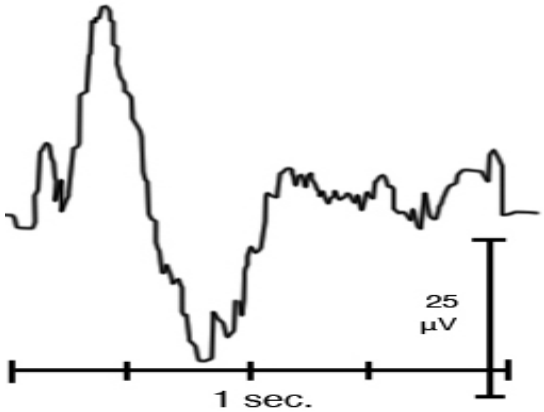
LEFT



RIGHT

Increasing Negative Voltage

Back of Head



Yellow

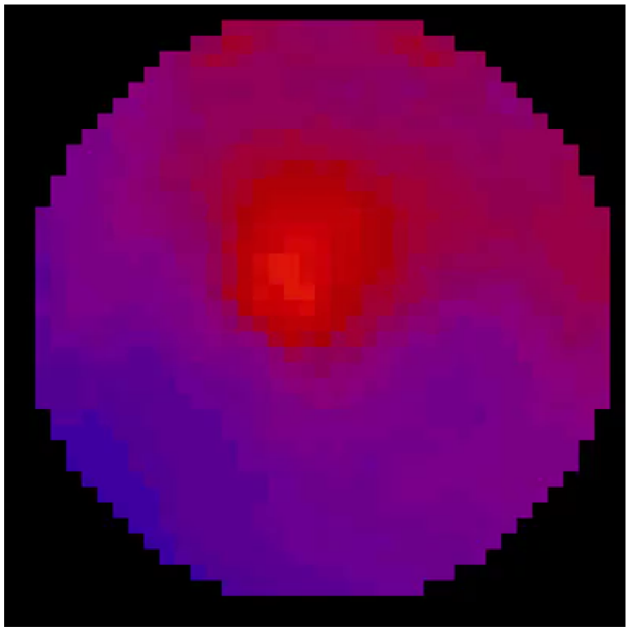
Red

Purple

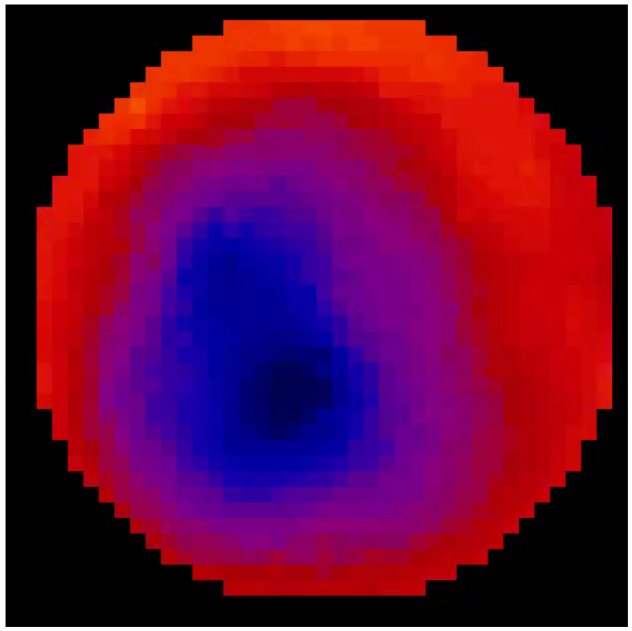
Dark Blue

ERP to speech syllable “ba”

Neonate



Adult

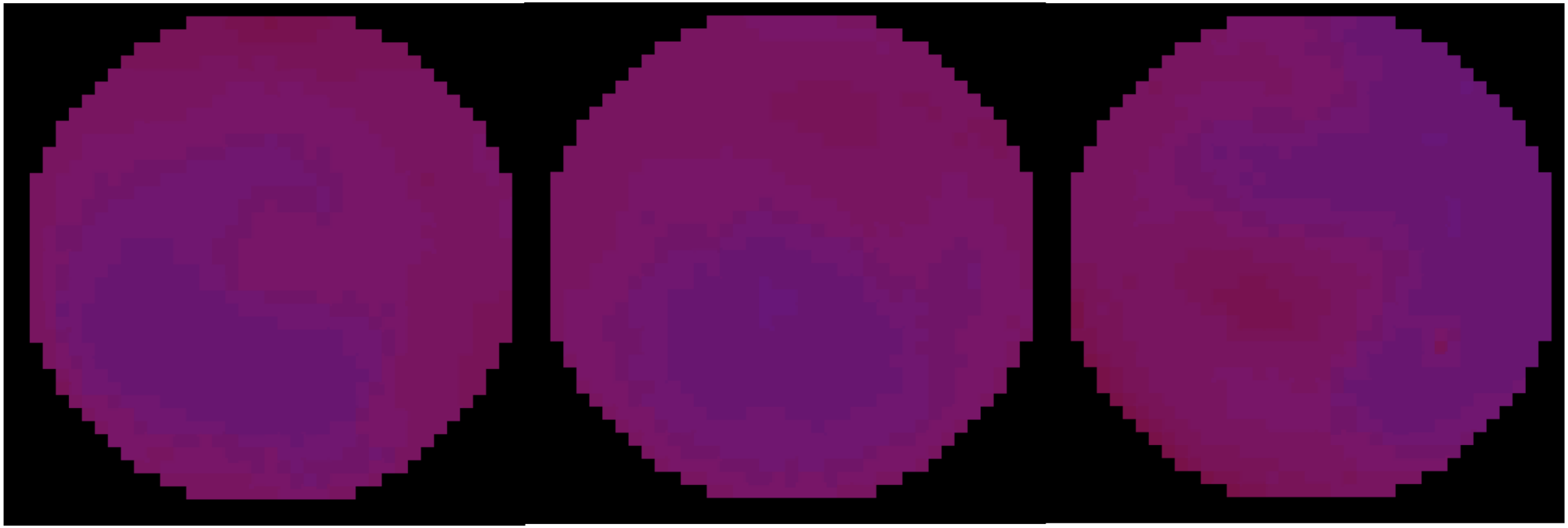


ERPs to CVC Words

Below Average Readers

Average Readers

Above Average Readers



Molfese & Erwin, 1981

EEG vs ERP

Spectral EEG

- Ongoing EEG signal
- Can be task related
  - (e.g., eyes open, eyes closed, watching X kind of video)
- But not necessarily task-locked
- Focus on “overall” information

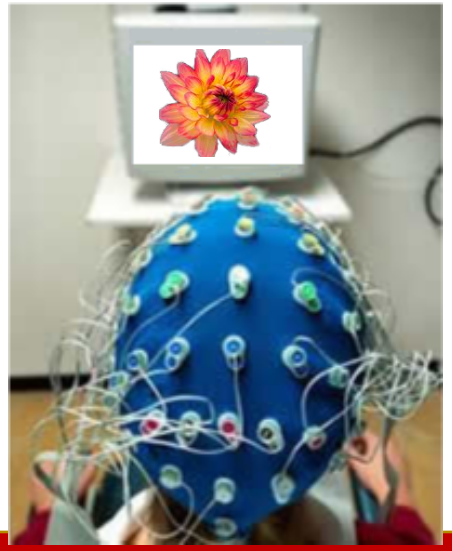
Event-related potential or

Evoked response potential (ERP)

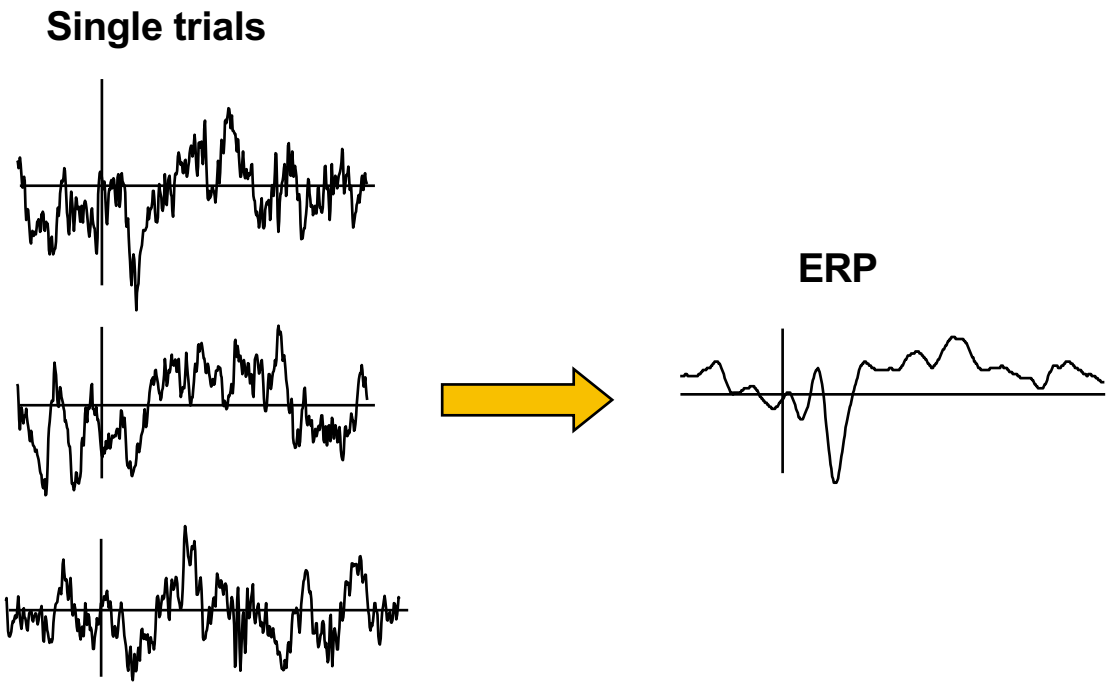
- Portion of Ongoing EEG
- Time-locked to stimulus onset
- Focus on temporal and spatial information
- Comparability across the lifespan

Event-Related Potential (ERP) Technique

Raw EEG



ERPs are not everything…



ERPs are not everything…

What we lose:

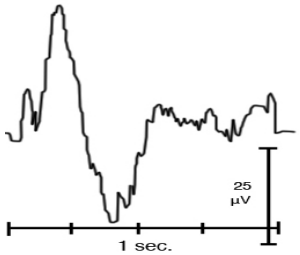
☺ Non event-related activity

☹ Event-related activity that is not phase-locked

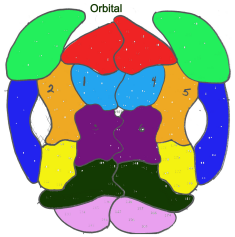
☹ Averaging has a “smoothing” effect – removes high-frequency information

☹ ERPs are a summation of activity in all frequencies, and do not show modulation of individual frequencies

What info do we collect?



- Time



- Space

- Person-specific characteristics
  - Demographics: Age, gender, SES, etc.
  - Constructs: Reading ability, temperament, emotion regulation, social responsiveness, IQ, etc.

Interpreting ERP ***components***

- Time-locked to an evoking or eliciting event or stimulus.
- Sequence of serially activated "processes" (components) detected at the scalp (or some biological surface) as distinct positive-negative fluctuations.

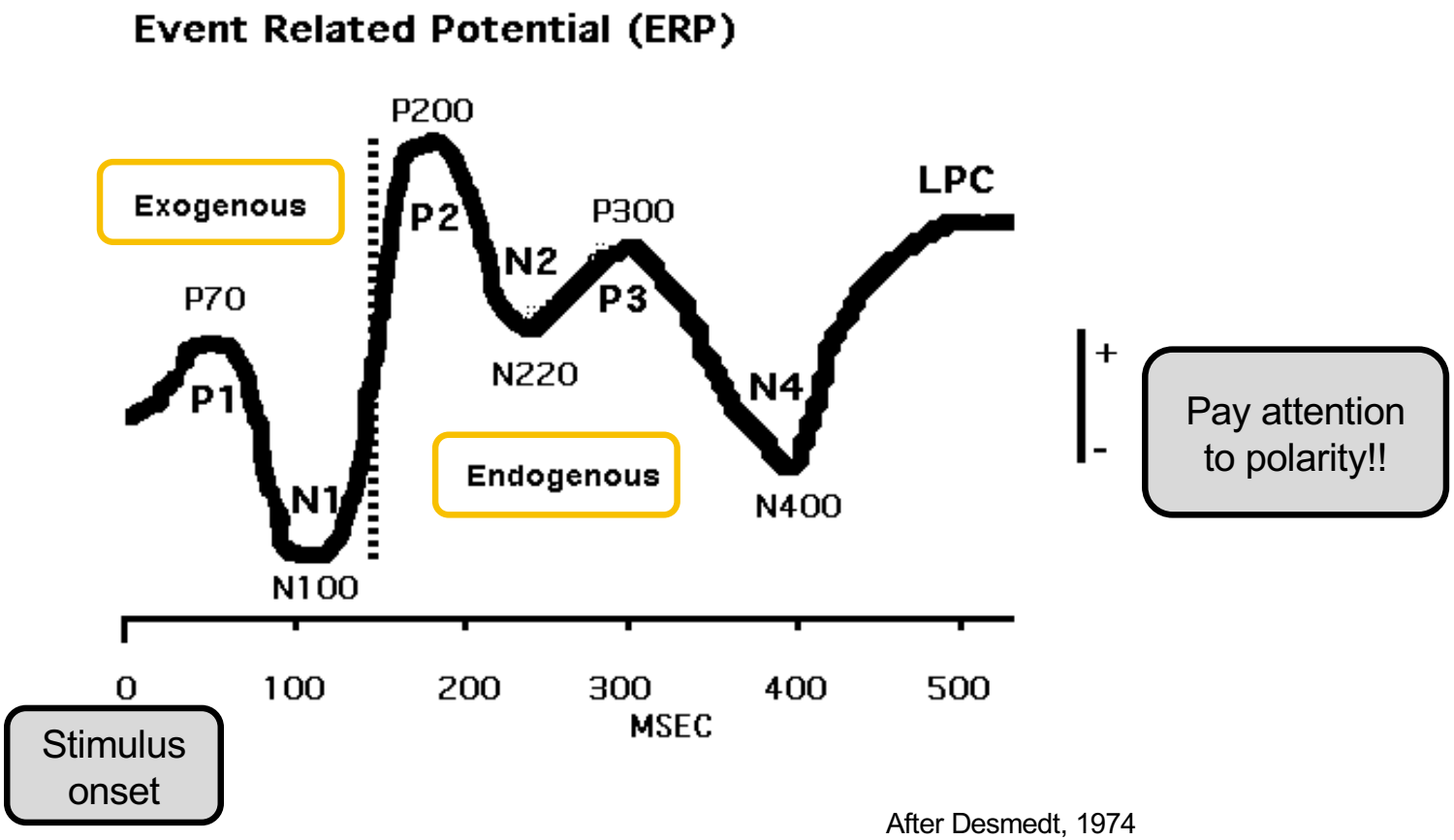
Measures:

(1) peak latency from evoking stimulus onset (ms)

(2) peak amplitude in microvolts μV

(3) polarity (deflection from baseline to + or -)

Interpreting ERP ***components***



After Desmedt, 1974

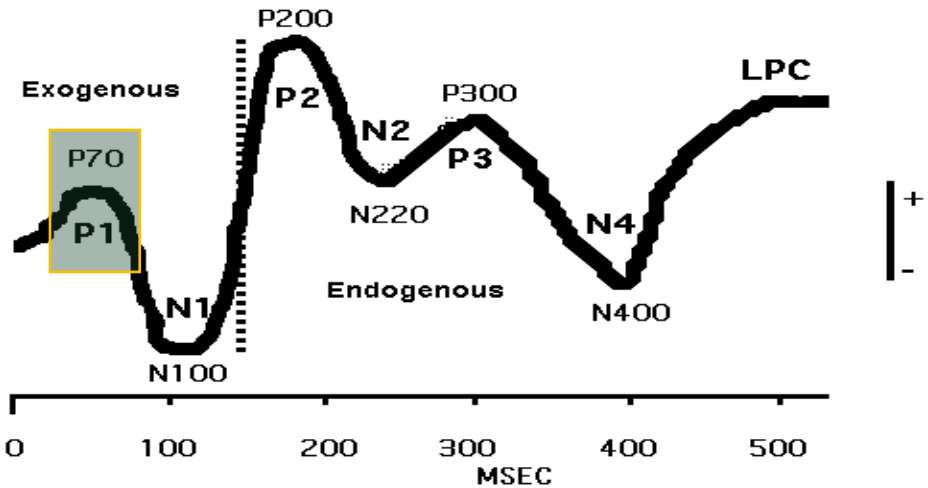
Interpreting ERP ***components***

- Peaks (positive or negative)
- Latency (post stimulus onset)
- Duration (e.g., slow wave)
- Scalp topography (maximal peak location)
- Source (location within the brain)

Remember that:

- Current flow across the scalp
- Produces latency shifts from one part of scalp to another
- Also produces amplitude shifts across scalp
- Signals sum across the scalp
  - large positive wave on scalp meeting large negative wave could sum to flat line!

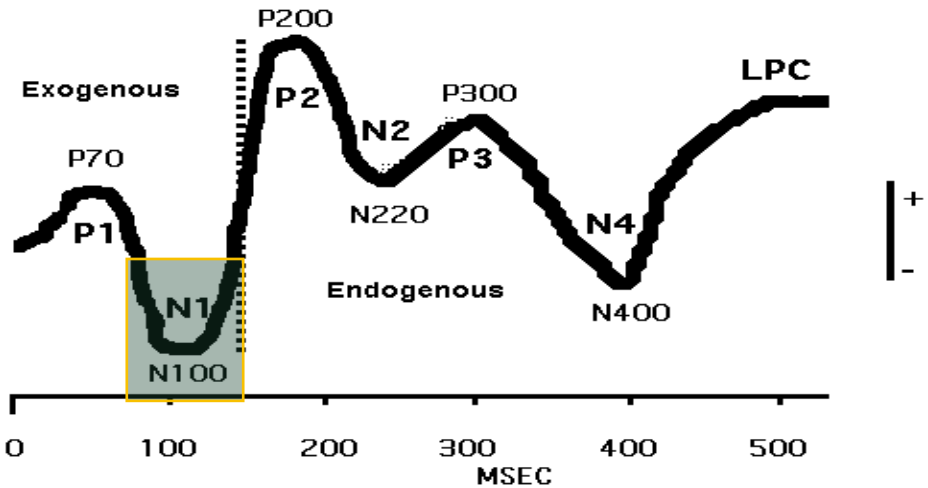
Time: Components



P1 / P50 / P70

- Peak amplitude and latency decrease with age (disappear, even)
- P50: Auditory inhibition → Sensory gating: 2 clicks presented quickly. 1st amplitude < 2nd amplitude. Reduced suppression in schizophrenia, neurodegenerative diseases.
- P1: Use pattern reversal (e.g. flickering checkerboard) task. Largest over occipital regions. May relate to attention / arousal.

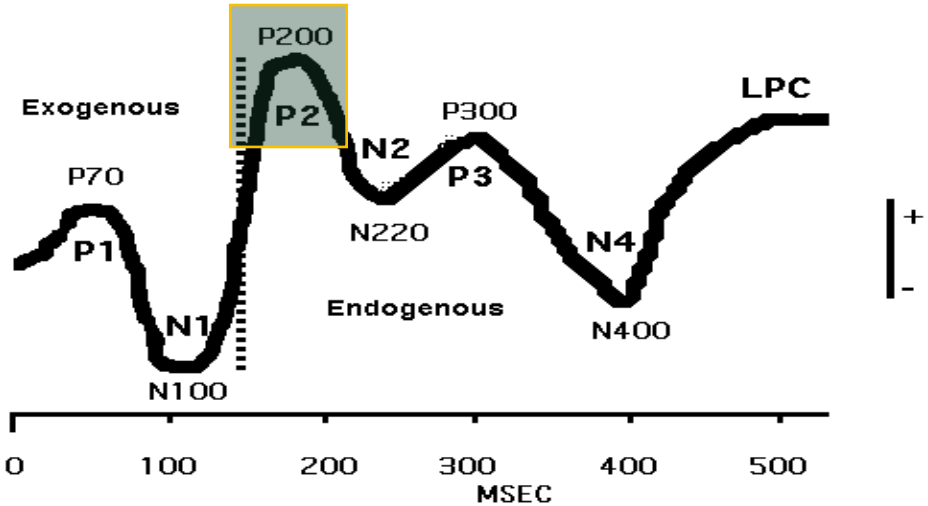
Time: Components



N1 / N100

- Selective attention to basic stimulus characteristics (necessary for later pattern recognition and discrimination processing).
- Auditory stimuli → larger N1 with shorter latency than visual stimuli (Hugdahl, 1995).
- Amplitude is larger in discrimination tasks, but smaller (if it exists at all) if short inter-stimulus intervals (ISIs).

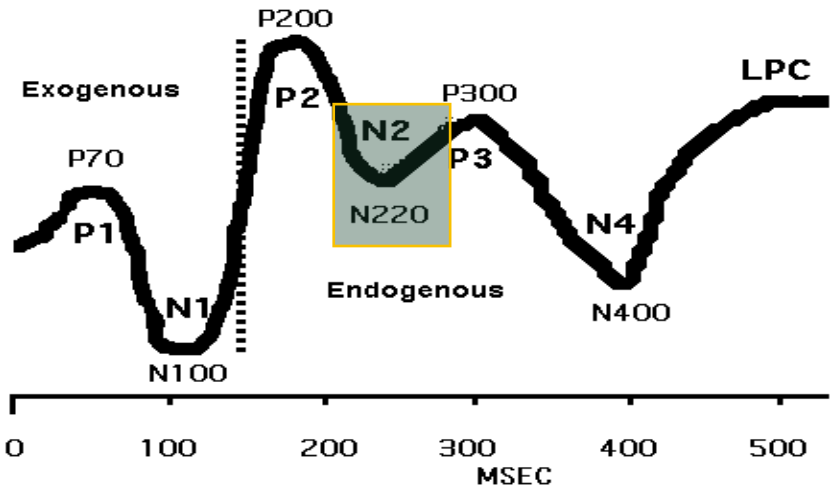
Time: Components



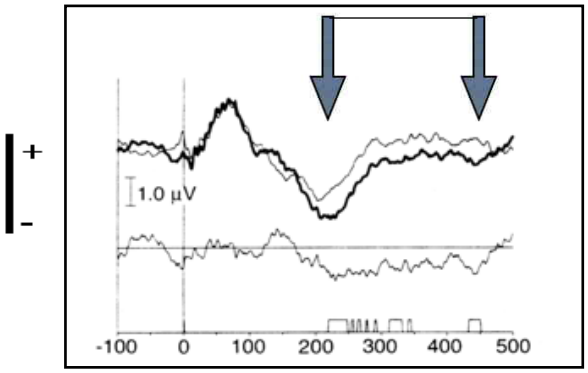
P2/ P200

- Low inter-individual variability and high replicabilty.
- Often occurs together with the N1, yet peaks can be dissociated.
- Can be double-peaked.
- Amplitude increases with complexity of stimuli.

Time: Components



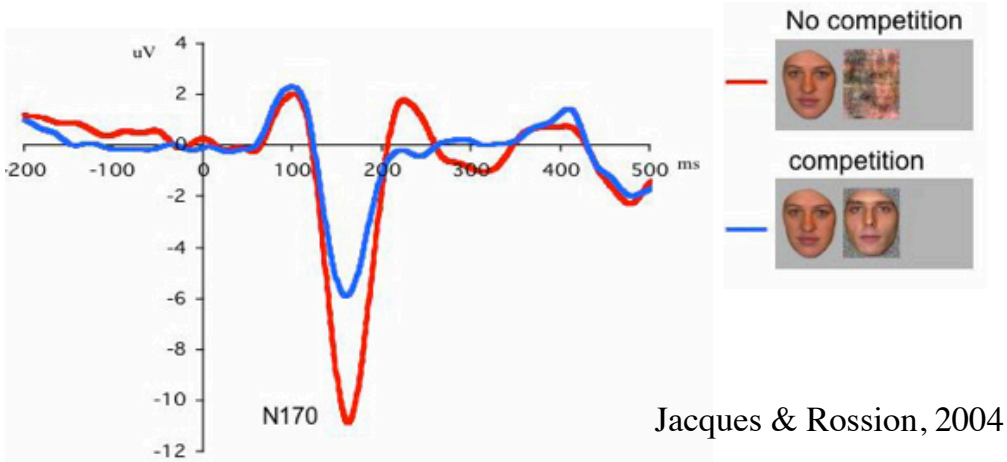
Mismatch Negativity



N2/ N200

- Like Mismatch-negativity (e.g. Oddball paradigm), detection of deviation of subject's expectation but N2 – only if subject is paying attention to stimuli. MMN – requires no attention!
- Interpretations: Orienting response, stimulus discrimination, target selection, response inhibition (e.g. Go-NoGo)
- N2 smaller in amplitude and shorter in latency for shorter ISIs.

Time: Components

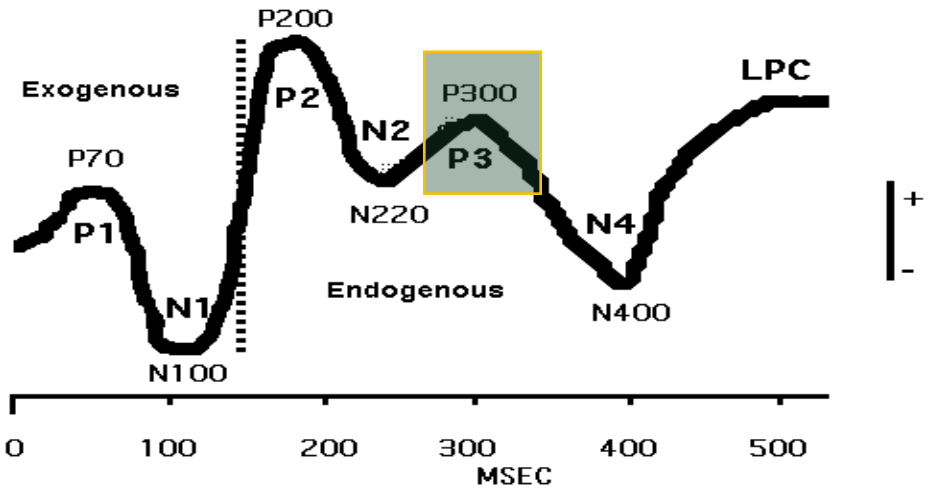


Jacques & Rossion, 2004

N170

- Human face-processing (face vs. natural or human-made objects)
- Turns out, not specific to faces but to expert object recognition! (Tanaka & Curran, 2001)

Time: Components



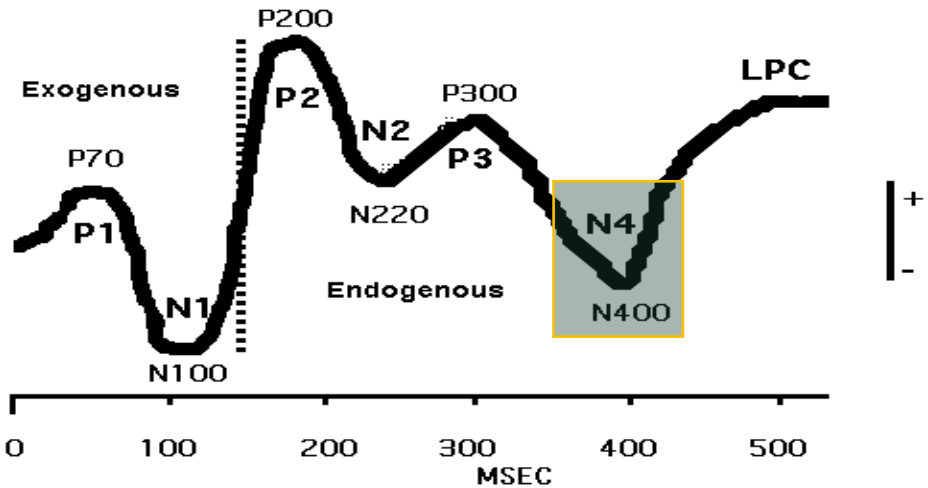
P3a/ P300a

- Orienting reflex
- Occurs when not required to actively respond to the targets
- Involuntary attention as well as inhibition (e.g. NoGo > Go)

P3b/ P300b

- Controlled processing
- Subject must pay attention and respond to stimuli. Also fewer targets → larger peak.
- Variability: Amplitude (attention, stimulus relevance). Latency: stimulus complexity

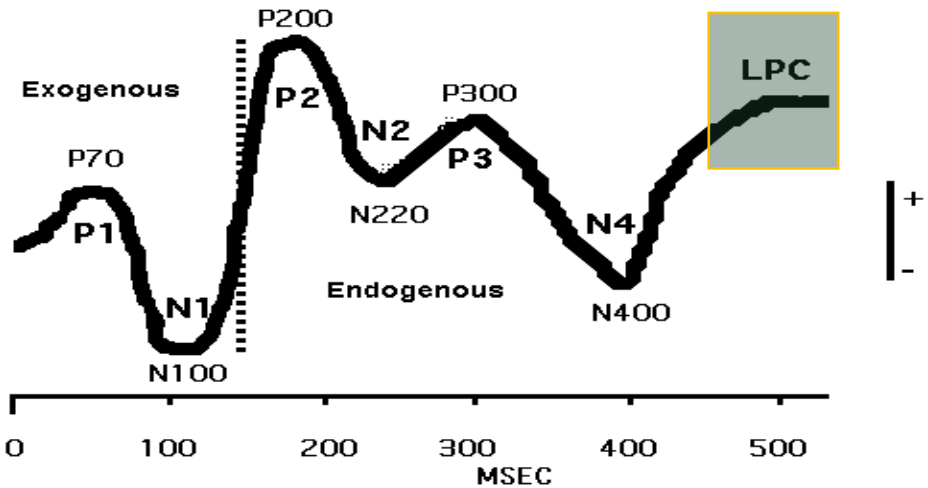
Time: Components



N4 / N400

- Larger for unexpected, low probability (e.g. sentence endings):
  - It was the first day at work.
  - He spread the warm bread with socks.
- Amplitude: Incongruent > Congruent
- Modality: Earlier in visual than auditory in temporal & frontal electrode sites.

Time: Components



Late positive component (also: late slow wave LSW; late positive potential, LPP)

- Explicit and implicit recognition memory: (e.g. “Old/new” effect)

ERP methods & considerations

- Review the participant characterization per usual
- Review experimental design
  - What is the stimulus “time-lock”?
  - Length of the ERP epoch
    - Was a baseline period included?
    - ERP epoch length relative to stimulus duration
- EEG protocol – device used:
  - Wet vs. dry net
  - Number of recording channels & number within ERP

ERP methods & considerations

- EEG protocol

*EEG was recorded from **32 AgAgCl active electrodes** (BrainProducts GmbH, Gilching, Germany) placed into an elastic EEG cap at the following positions of the 10–20 system80: F5, F3, FT7, FC5, FC3, T7, C5, C3, CP3, CPP5H, P7, P5, P3, F4, F6, FC4, FC6, FT8, C4, C6, T8, CP4, CPP6H, P4, P6, P8, Fz, Pz, and Cz (cf. Figure 7). Vertical and horizontal electrooculogram were recorded above and next to the right eye with electrodes FP2 and F10. An electrode **(TP9) at the left mastoid served as online reference**, while an electrode at the **right mastoid (TP10) was recorded for further re-referencing during offline analyses**. Position AFz served as ground electrode. Electrode impedance was kept below 10 kΩ (actiCAP Control, Brain Products GmbH, Gilching, Germany). The EEG signal was measured by means of BrainVision Recorder (Brain Products GmbH, Gilching, Germany) software with a **sampling frequency of 1000** Hz (amplified between 0.016–450 Hz) and filtered before digitalization by means of the analog/digital converter with an upper cut-off of 450 Hz (24 db/ oct) to prevent aliasing.*

Reference electrode

Sampling rate

Steber et al., 2020

ERP methods & considerations

Filter	Fix high/low frequencies
Segmentation	Need to chop up EEG into epochs/segments/trials
Artifact detection & rejection	Fix blinks, muscle movements, etc.
Baseline correction	ERP signal “level” may vary for each segment
Bad channel correction	Channels with poor signal (e.g impedance, bad electrode)
Averaging	Re-reference; combine trials

ERP methods & considerations

- EEG processing

*EEG data. EEG data was filtered offline with a **30 Hz low pass Butterworth zero phase filter** (high cutoff: 30 Hz; slope: 12 dB/oct). Data was then segmented from **−200 ms to 1500 ms** with 0 ms representing the time point of the pseudoword onset. An ocular correction based on the Gratton & Coles algorithm was applied to correct vertical eye movement artifacts. Overly contaminated channels were rejected manually from each segment by inspecting each segment visually for artifacts. Only subjects in whom at least 2/3 of all segments per condition (angry vs. happy vs. neutral) in at least 15 of all 29 scalp electrodes survived this procedure were included in the final analyses. This criterion applied to 48 of all 50 subjects. In the next steps, data was **re-referenced to averaged mastoi**ds (TP9, TP10) and a **pre-stimulus baseline of 200 ms** was applied. Event-related brain potentials (ERPs) were extracted by averaging the segments for each subject and each condition (angry prosody, happy prosody, neutral prosody). In addition, a 50-ms-analysis was performed in order to select the time windows for final statistical analyses. This analysis included ANOVAs on each electrode in consecutive **50 ms steps between 100 and 1500 ms** with the factor Condition for experimental halves separately. We decided to include the factor halves into all statistical analyses, as we wanted to control our results for potential habituation/repetition effects over the course of the experiment. Results from the 50-ms-analysis as well as visual inspection of the grand averages revealed **100–150 ms, 250–350 ms, 500–550 ms, 600–700 ms, and 700–900 ms to be the time windows** indicating differences between conditions, which were therefore were selected to perform further statistical analyses on.*

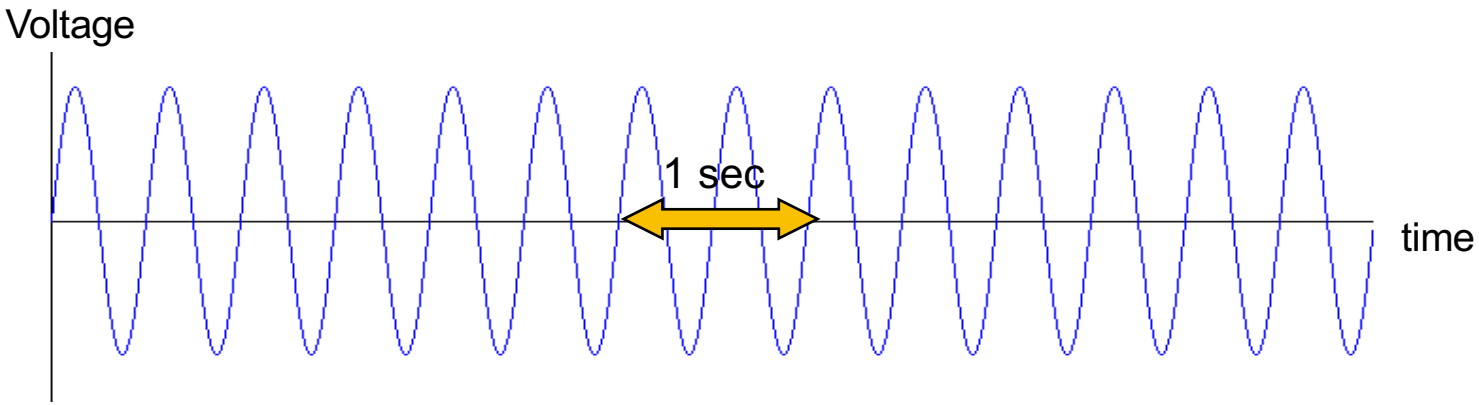
Time window for ERP

Electrodes for analysis

Steber et al., 2020

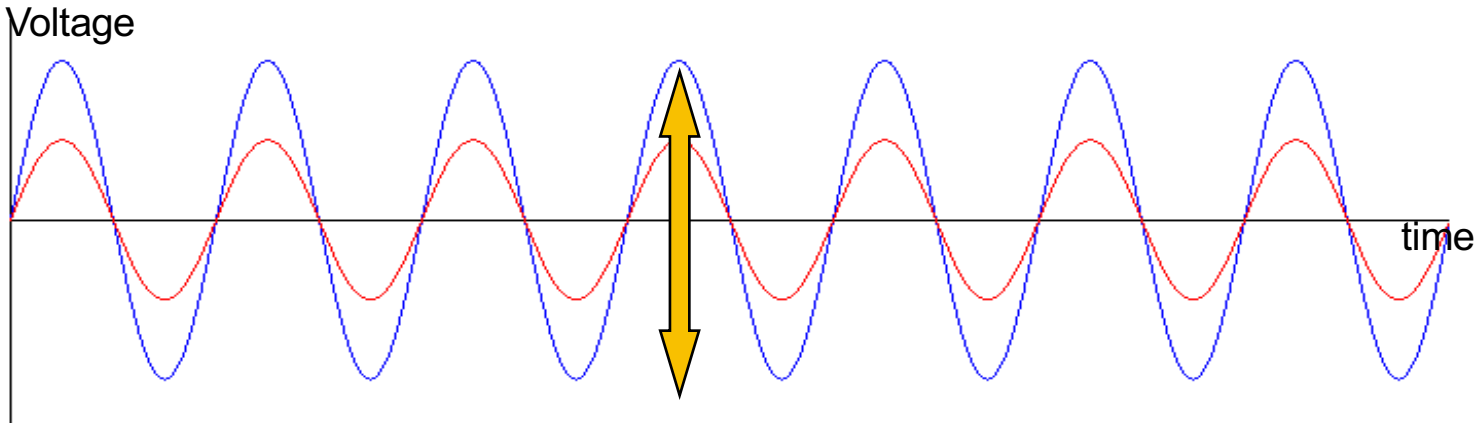
Properties of oscillations

Oscillation: Periodic modulation of voltage over time



Frequency=How many cycles are completed in one second.
Measured in Hz

Properties of oscillations



Amplitude = how "strong" is the oscillation at its peak

Measured in μV

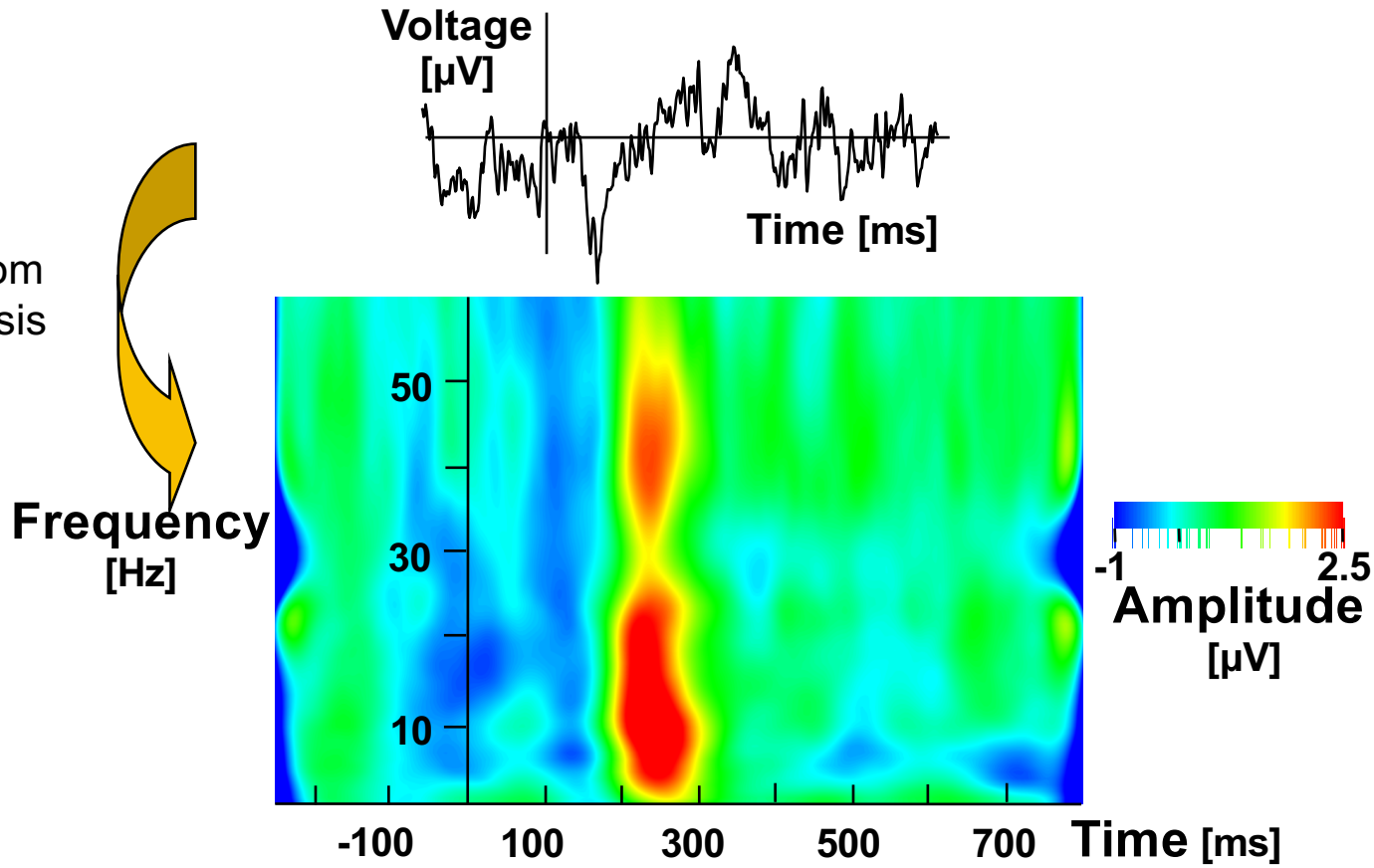
Power=Amplitude^2 [μV^2]

Frequency decomposition

- The “raw” signal (EEG/ERP): Voltage modulations over time
- Assumption: The signal is a linear combination of activity in different frequencies
- The goal: To see how activity in **different frequencies** changes over **time**

Time-Frequency plots

Amplitude information from wavelet analysis

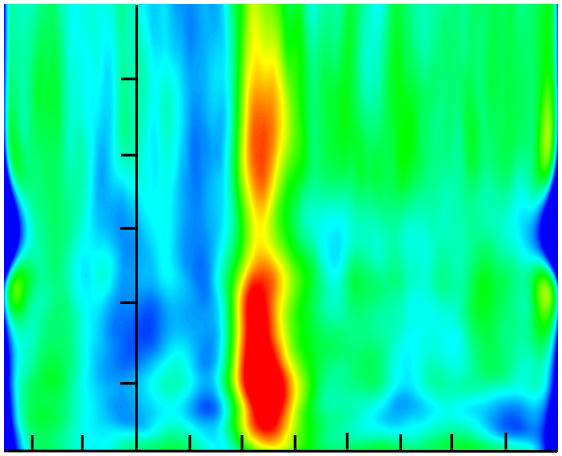


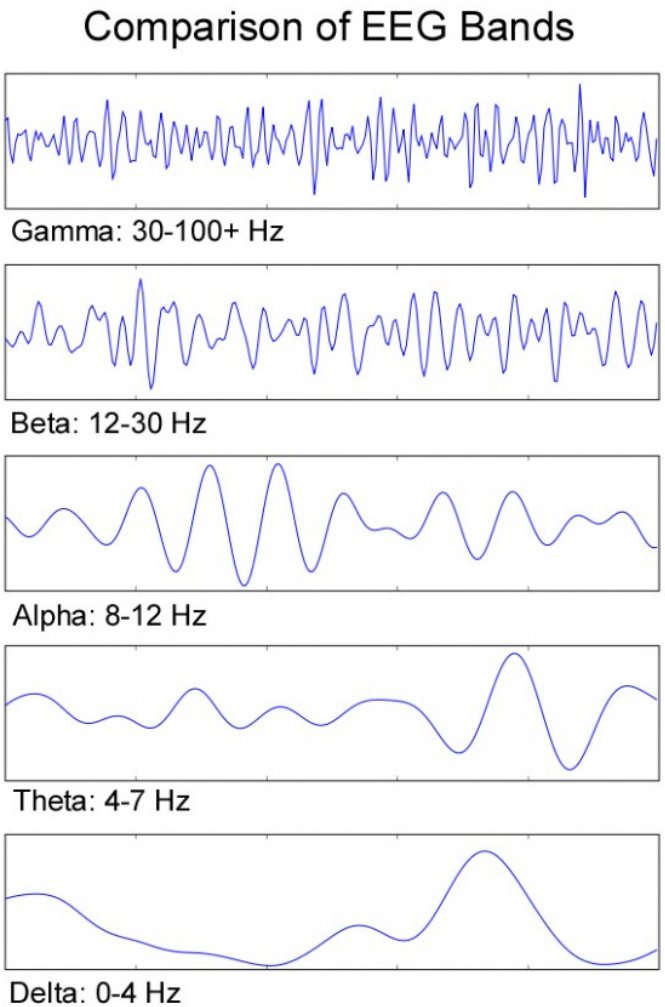
Zion-Golumbic & Bentin *In Press*

Interpreting time-frequency plots

What does enhanced amplitude mean?

- Larger degree of synchronization within a given set of neurons
- Larger area of synchronized neurons





Integrating information in different senses, perceptual integration of different features,

Active concentration

Relaxed, inhibition of control, closing eyes decrease correlated with increase in attention

Active inhibition

Adult slow-wave sleep, continuous attention

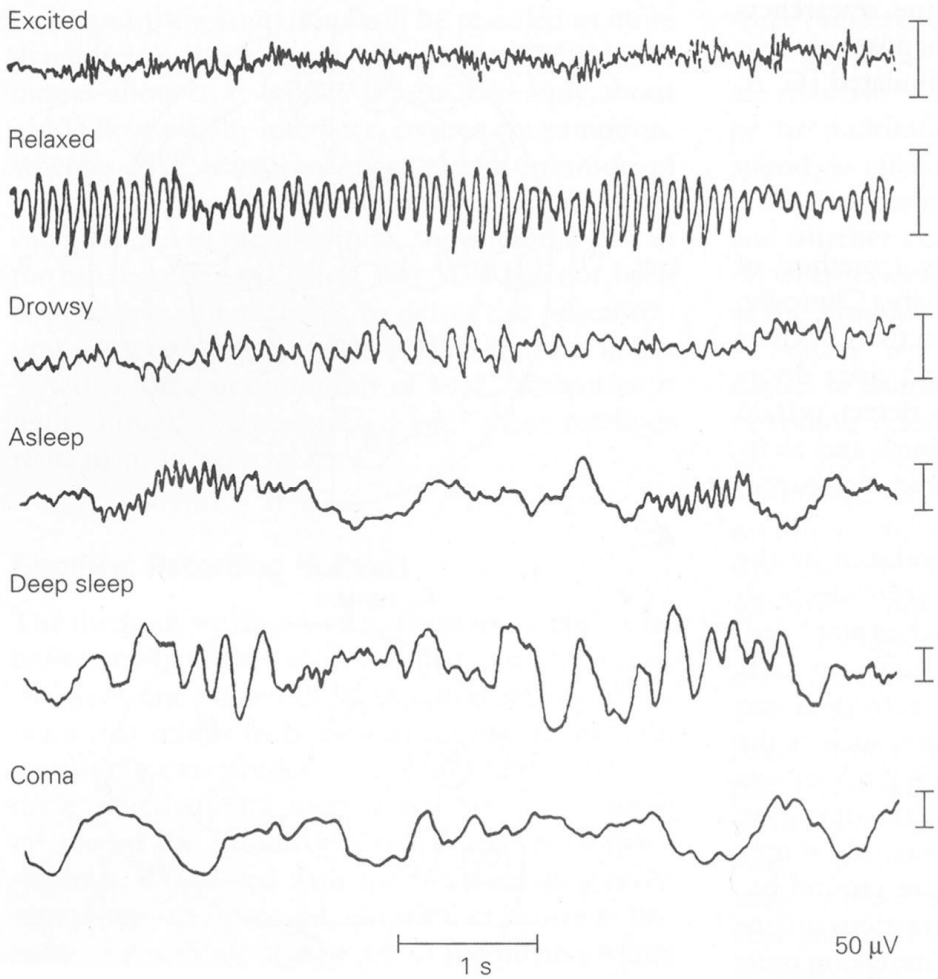
Ongoing EEG data -- Spectral components

Beta

Alpha

Theta

Delta



ERP methods & considerations

- Review the participant characterization per usual
- Review experimental design
  - Length of the EEG epoch?
    - Epoch length relative to stimulus duration
- EEG protocol – device used:
  - Wet vs. dry net
  - Number of recording channels & number within each epoch

Spectral methods & considerations

- EEG Protocol

Brain activities were recorded by an EEG (Mitsar Co., Ltd., Saint Petersburg, Russia). The device includes ***19 main electrodes (Fp1, Fp2, F3, F4, F7, F8, Fz, C3, C4, Cz, P3, P4, Pz, T3, T4, T7, T8, O1, and O2), two reference electrodes (A1 and A2),*** *and a ground electrode (Fpz), according to the 10–20 system of electrode placement. The data were collected using a* ***sampling rate of 250 Hz*** *and filtered in WINEEG software with a frequency band of 1 to 25 Hz with a notch filter of 45–55 Hz. Linked Ear references were used with all EEG. The electrolytic gel was applied and each site gently abraded until impedances were below 10 kOhm. Eyes-closed and eyes open conditions were used for recording signals that were 3 min each in duration. During the eyes-closed condition, we instructed the participants to place their hands on their knees, half-open their mouths, and avoid blinking or opening the eyes. The eyes-open condition had similar instructions except that we requested them to additionally fixate their eyes on a central point.*

Reference electrode

Sampling rate

Mosirian Farahi et al., 2019

Spectral EEG Pre-processing

Filter	Fix high/low frequencies
Segmentation	Need to chop up EEG into epochs
Artifact detection & rejection	Fix blinks, muscle movements, etc.
~~Baseline correction~~	~~ERP signal "level" may vary for each segment~~
Bad channel correction	Channels with poor signal (e.g impedance, bad electrode)
Averaging	Re-reference; ~~combine trials~~

Spectral methods & considerations

- EEG Protocol

After recording the signals, the data were saved in EDFC format in WINEEG and opened in Neuroguide software. The artifacts were rejected by automatic rejection method. The criteria of automatic rejection included drowsiness, eyemovement, and muscle with a high sensitivity. After that, a ***1-s at a 250 sample rate, artifact-free epochs*** *with a Hanning window (50% overlapping) was extracted through Neuroguide software and submitted to the Fast Fourier Transform (FFT; the resolution was 1 Hz). To address the aims of the study,* ***frontal alpha (8–12 Hz) asymmetry*** *indices were calculated by computing asymmetry scores* ***(log [left]–log [right])*** *for* ***mid-frontal (F3–F4****), frontal pole (Fp1–Fp2), and lateral frontal (F7–F8). Positive scores indicate greater alpha power at left compared to right frontal electrode sites, and therefore greater relative right-sided frontal activity. According to reliability of EEG recording, a split test was conducted. The split test showed that the reliability is 0.96 (SD: 0.02). The mean of alpha across the scalp in the eyes-closed condition was 64.52 (median: 61.30, SD: 31.72). To reduce artifacts in our data, eyes-closed condition was applied for analyzing data.*

Frequency window for spectral band

Electrodes for analysis

Mosirian Farahi et al., 2019

Wednesday's readings for discussion → Monday

- **Emotional prosody (ERP outcomes)**
  - Steber, S., König, N., Stephan, F., & Rossi, S. (2020). Uncovering electrophysiological and vascular signatures of implicit emotional prosody. *Scientific Reports*, *10*(1), 1-14. [note: ERP and fNIRS]
- **Trait-based correlates (Spectral outcomes)**
  - Moshirian Farahi, S. M., Asghari Ebrahimabad, M. J., Gorji, A., Bigdeli, I., & Moshirian Farahi, S. M. M. (2019). Neuroticism and frontal EEG asymmetry correlated with dynamic facial emotional processing in adolescents. *Frontiers in psychology*, *10*, 175.