EEG as a tool to study infant's cognition

Cogiter

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What does neuroimaging brings to the study of infants cognition?

Neuroimaging is the link between cognition and our understanding of how cognitive process are implemented in the brain.
In developing populations the question entails another aspect:

→What is the relation between brain maturation and cognitive development?

Behavioral reports are hard to obtain with infants due to their limit motor abilities and many times we can find neural markers before observing a certain cognitive ability at the behavioral level

→Neuroimaging enables the study of cognition without the need of a behavioral report

- Infants move a lot
- Short attentional span (few data)
- We cannot provide instruction

- Non-invasive methods
- Easy to implement
- Not too susceptible to movement

What does EEG provides relative to other available neuroimaging techniques?

	EEG	fNIRS	fMRI
Susceptible to movement	+++	+++	
Invasive	+	+	+++
Spatial resolution		++	++++
Temporal resolution	+++	+	
Cost	+	+	++++

EEG signal is better characterized (at least in adults) than fNIRS signal

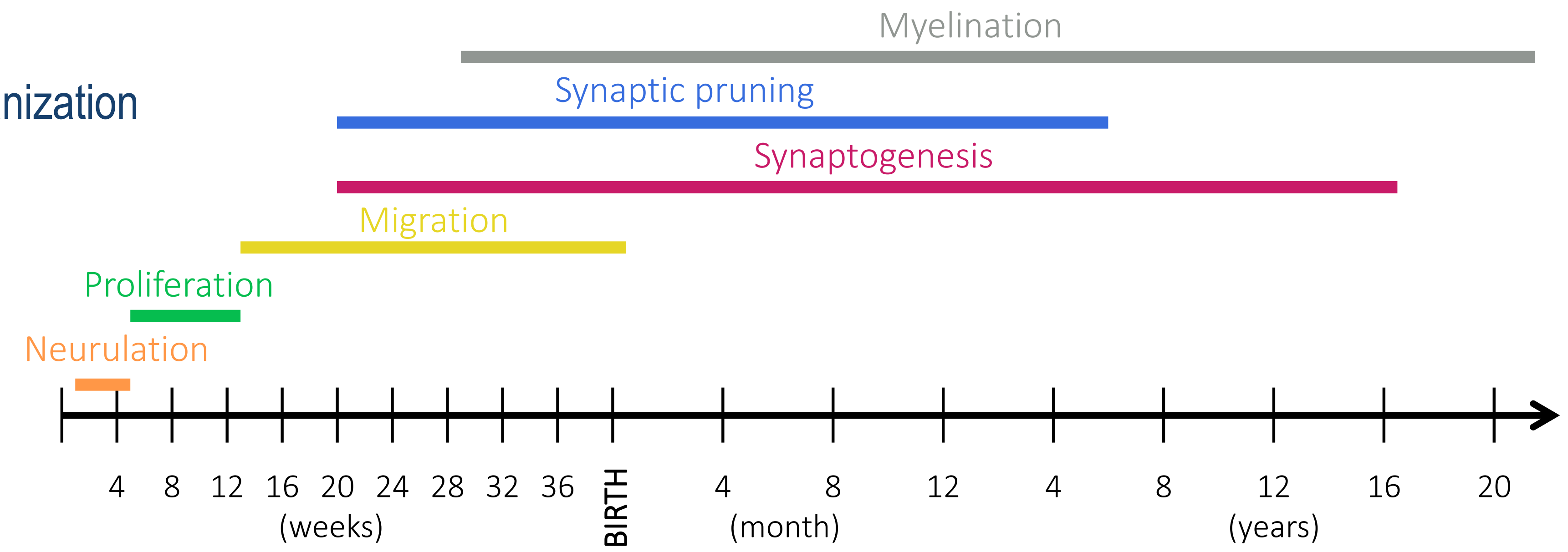
Difficulties

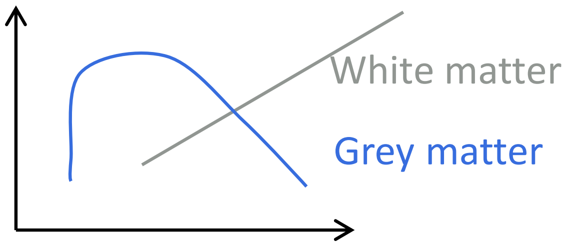
Reduce attention, fussiness

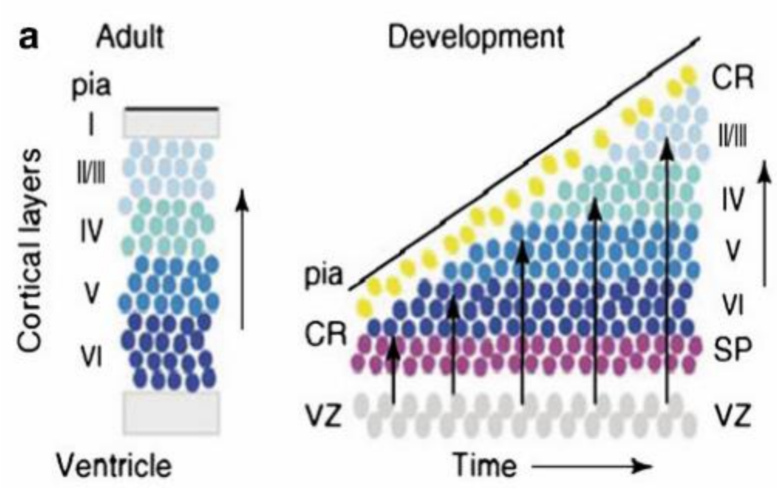
EEG signal in infants differ from adults and it changes during development

EEG signal in infants

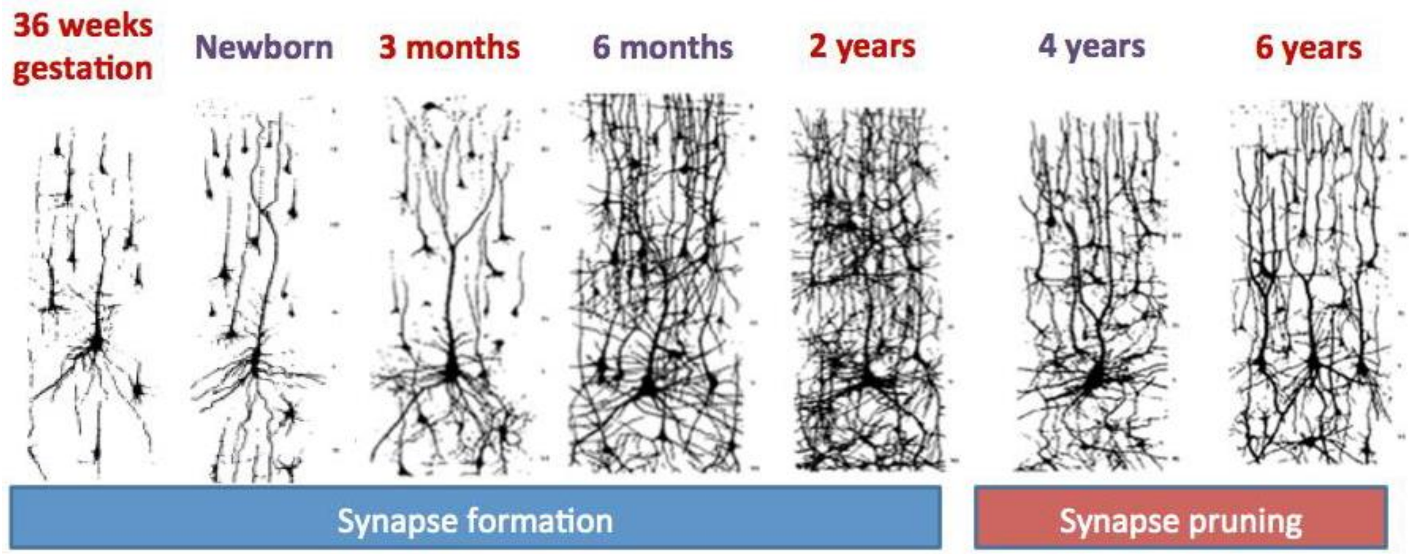
Developmental changes in cortical organization







Stiles & Jernigan, Neuropsychol. Rev., 2010



EEG signal in infants

Signal changes during development

- developmental changes in cortical organization
  (synaptic density, synaptic pruning, myelination)

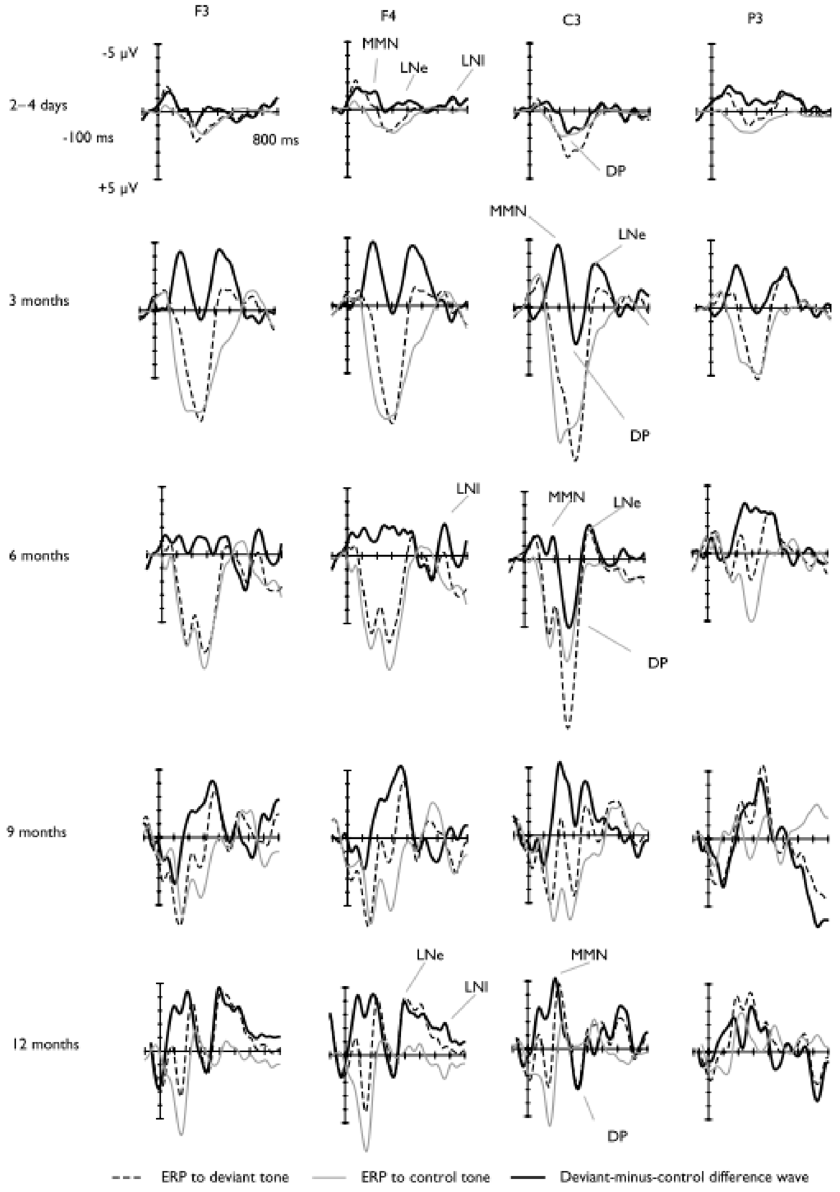
- and other maturational processes
  (skull thickness and closing of the fontanel)

Changes in the **ERPs**
in amplitude, latency, polarity

With age

- Latencies decrease (myelination)
- Peak responses emerge (more synaptic efficiency)
- Amplitudes show an inverted U-shape (**parallels synaptic density**)

Changes in random **background activity**
power at lower frequency bands is much higher than in adults



Kushnerenko et al Neuroreport, 2002

Doing EEG with infants

Data is noisy…

Aligning the signal to specific events and averaging could potentially reduce the intense background activity

But we have…

Intense random background activity at low frequencies	Short experiments few trials	More motion artifacts

more noisy data
less well defined ERPs

Doing EEG with infants

Acquisition methods

High density electrode systems (Geodesic Sensor Net) 64, 128 and up to 256 electrodes

The location of the electrodes is not fixed across participants, but the distance between electrodes is the same.

Advantages

- No conductance gel is required
- Easy to put
- High density, reference to the average (and potentially source localization...)

Disadvantages

- More moving artifacts because the net is not fix to the scalp
- Risk that electrodes dry

Testing procedure

- Infants are usually tested in their parents lap
- Quiet room and as less as possible distractor stimuli around
- The preparation procedure has to be short.

Majority of the studies have not used methods to localize the electrodes in the scalp, but some recent technological advances enabling a fast localization are promising! (e.g. 3D cameras, photogrammetry)

Doing EEG with infants

Tasks: general considerations

- Tasks can be adaptation of adults protocols but need some modification
  - No explicit instructions
  - In general no response from the infant is expected.
  - Timings may have to be adapted (usually longer) and usually stimuli and conditions simplified
  - Stimuli have to be attractive for the infants in order to keep they engaged as longer as possible.
    - Nevertheless experiments are short (usually they do not resist more than 10 minutes).
    - In younger infants (pre-terms, infants younger than 2-3 months) automatic processing can be study during sleep enabling longer recording times.
- EEG can be easily combined with eye tracker, with is a good way of addressing weather infants are attentive and can provide a behavioral measure

EEG signal in infants

Basic pre-processing and analysis

- **Band-pass filter** (high-pass between 0.1 to 1Hz and low pass between 15-30 Hz)
- Epoching
- Artifact detection (based on fast changes of the signal and high amplitudes)
- Bad channels interpolation (and artifacts correction)
- Average referencing
- ERPs
  - baseline correction (usually using 100-200ms pre-stimulus)
  - Statistical analysis on predefine electrodes and time windows of interest, or methods like cluster based permutation analysis
- Source localization…
- Time Frequency Analysis as in adults data (the patter of responses may differ)

Many denoising techniques developed for adult data do not seem to give very good results on infant data

It does not work very well…
- Data is too noisy
- Physical parameters related with anatomical structures (e.g. skull, cortical gyri and sulci) differ for adults
- Is hard to obtain electrodes position

Examples of some common protocols implemented in infants studies

Event Related Potentials (ERPs) – time domain analysis

Event Related Oscillations (EROs) – time frequency analysis

Fast Periodic Stimulation / Frequency Tagging

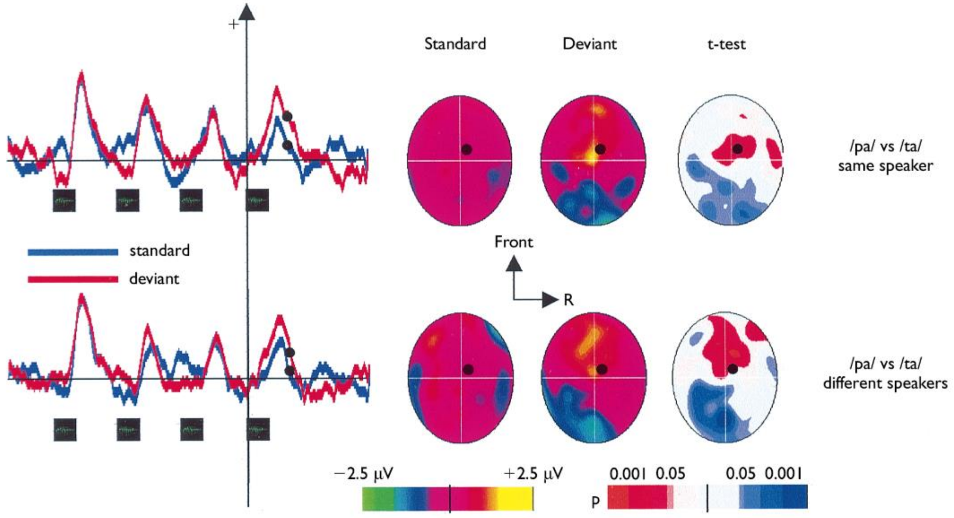
EEG paradigms in infant studies

Tasks: ERPs, mismatch responses and odd-ball paradigms

Odd-ball paradigms can be used to address weather infants can discriminate different stimuli using

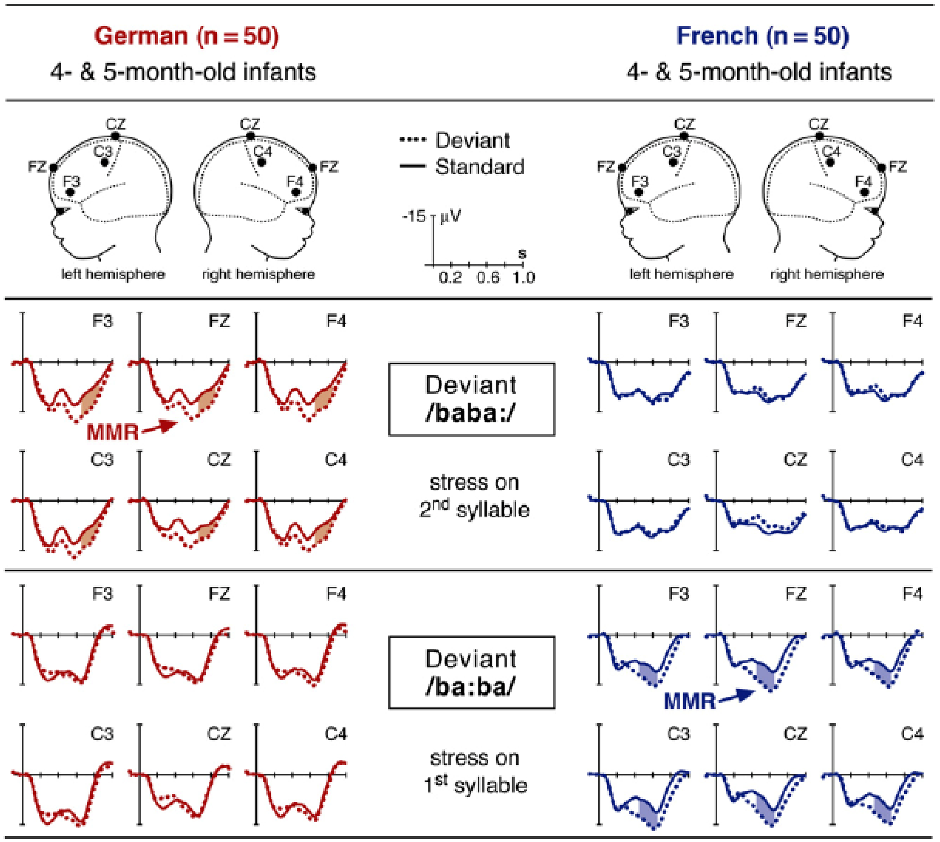
- Classical odd-ball paradigms
- Familiarization follow by a test phase with 50% of A and 50% of B

Phonemes categorization in neonates



Dehaene-Lambertz & Peña, Neuroports (2001)

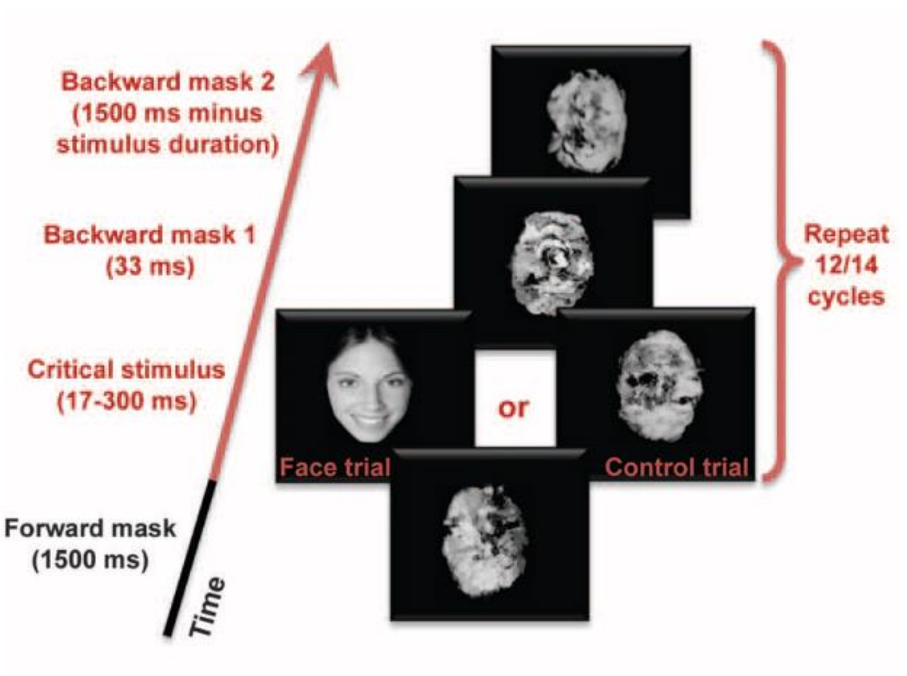
Discrimination of stress patterns at 4 month-old

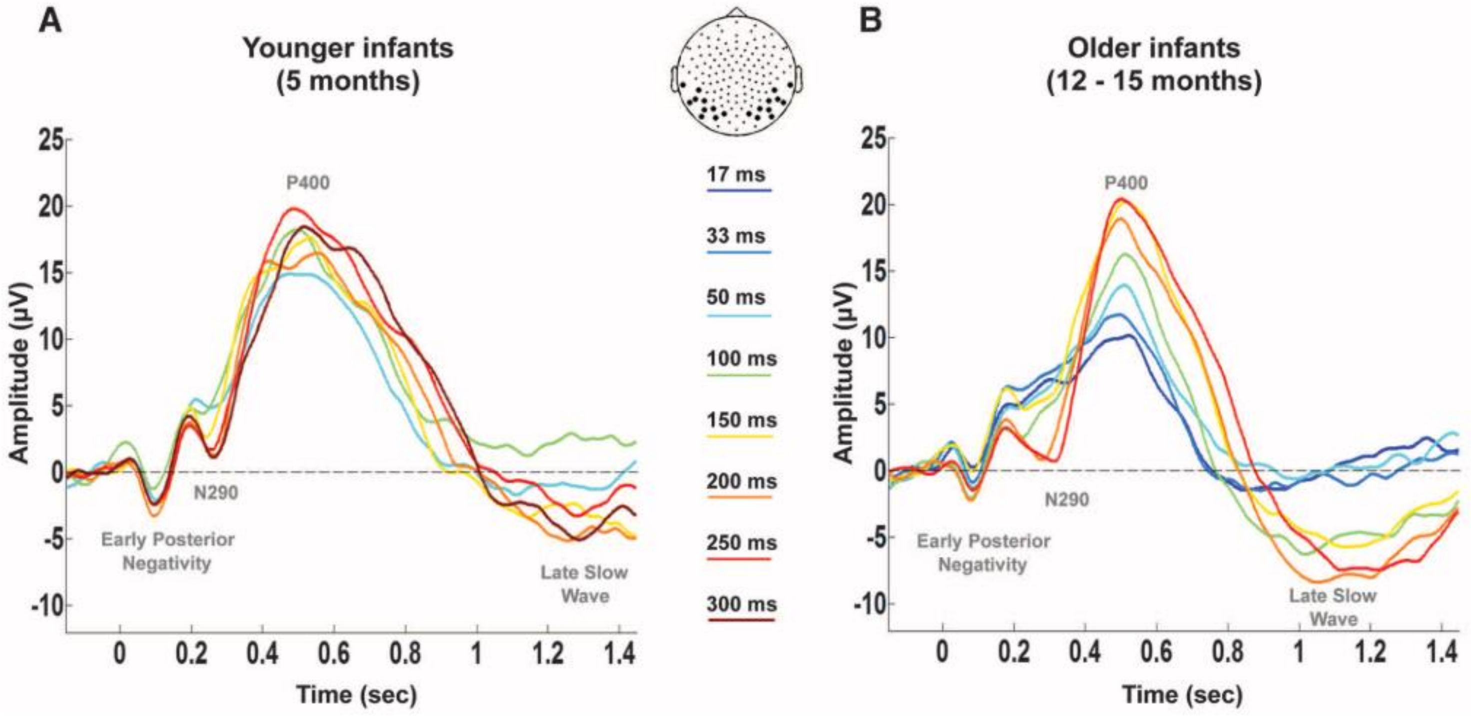


Friederici et. al, Current Biology (2007)

EEG paradigms in infant studies

Tasks: ERPs to investigate higher cognitive functions

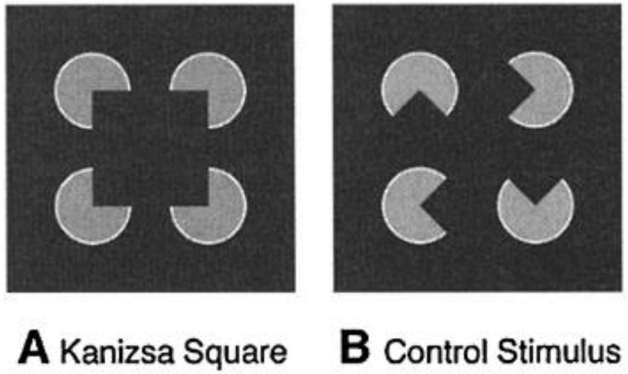


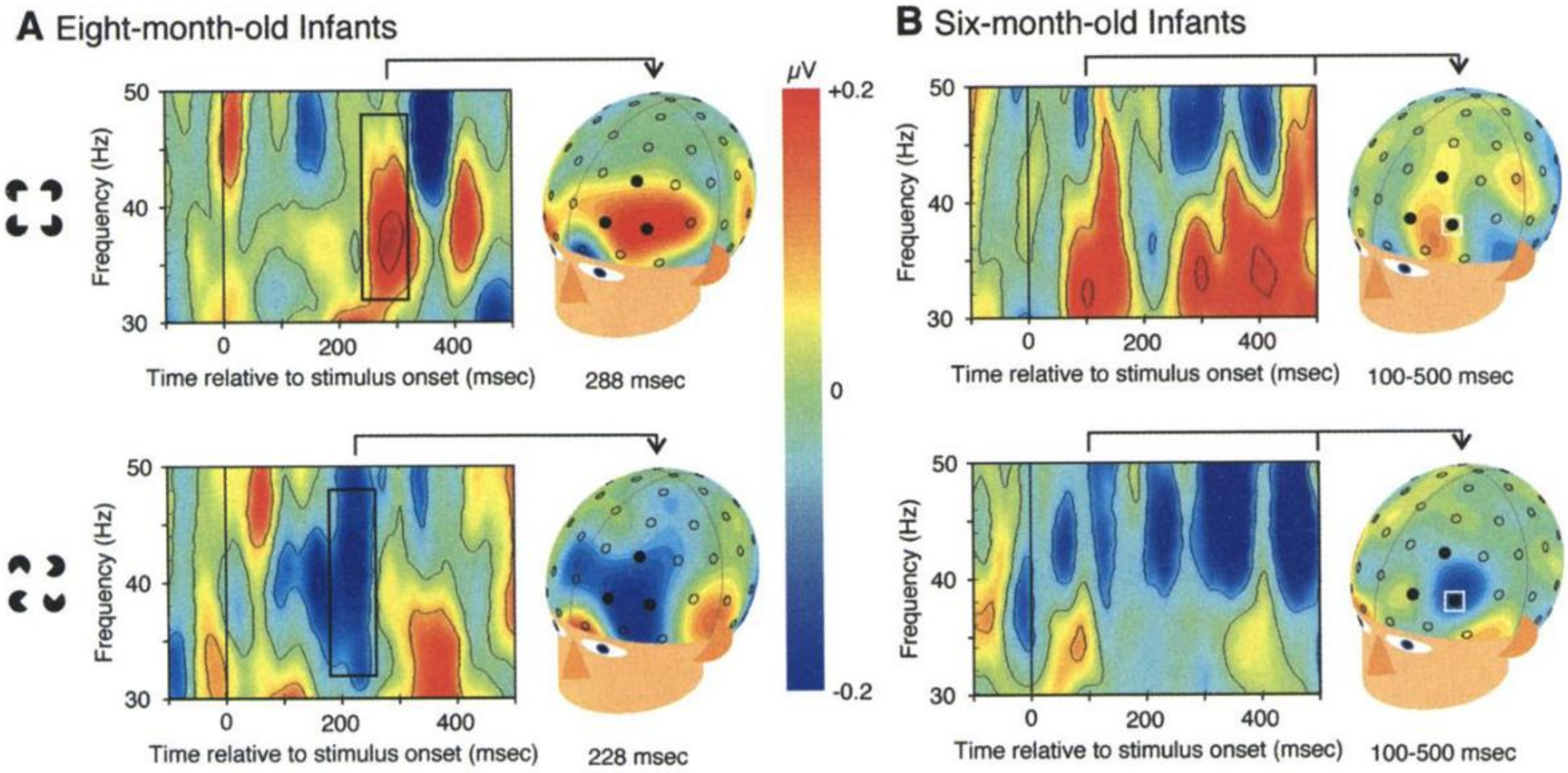


Kouider et. al, Science (2013)

EEG paradigms

Tasks: EROs - time frequency analysis





Csibra et al., Science (2000)

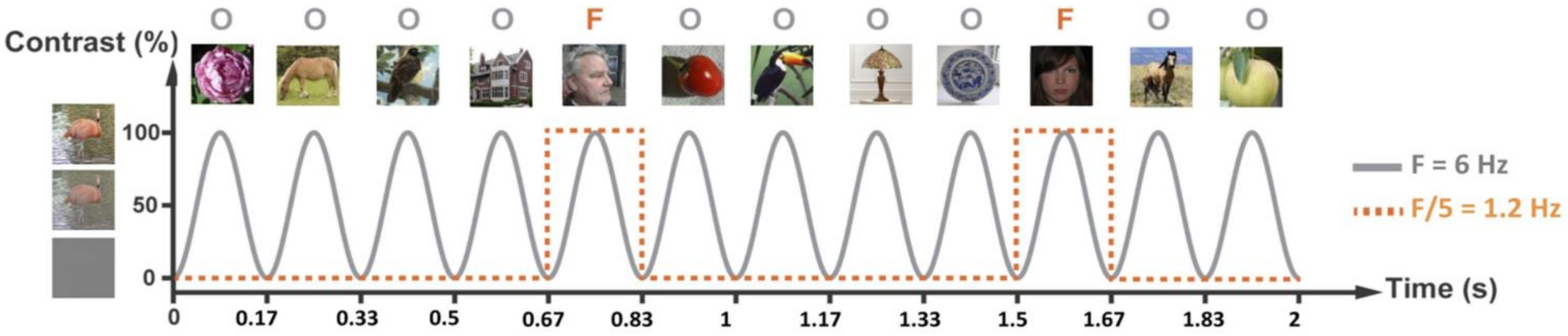
EEG paradigms in infant studies

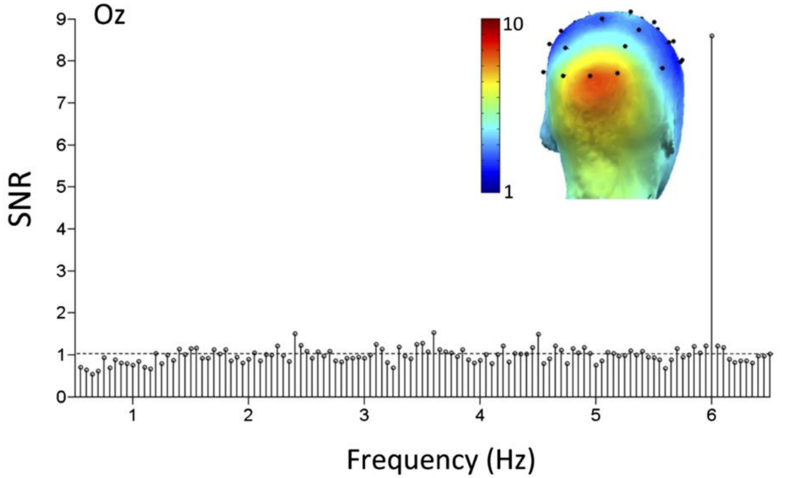
Tasks: Fast Periodic Visual Stimulation

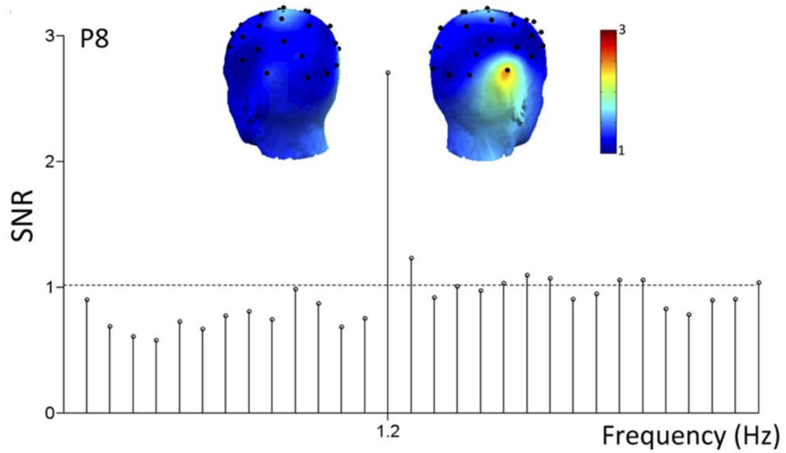
Presenting a stimulus repeatedly at a certain frequency induces a stable brain. This approach can be used to investigate neural oscillations link to more abstract aspects in the sequences of events (study of higher cognitive functions)

Relative to classical ERPs it provides

- Higher signal to noise ratio
- Shorter stimulation times are required
- Infants are interested on it!







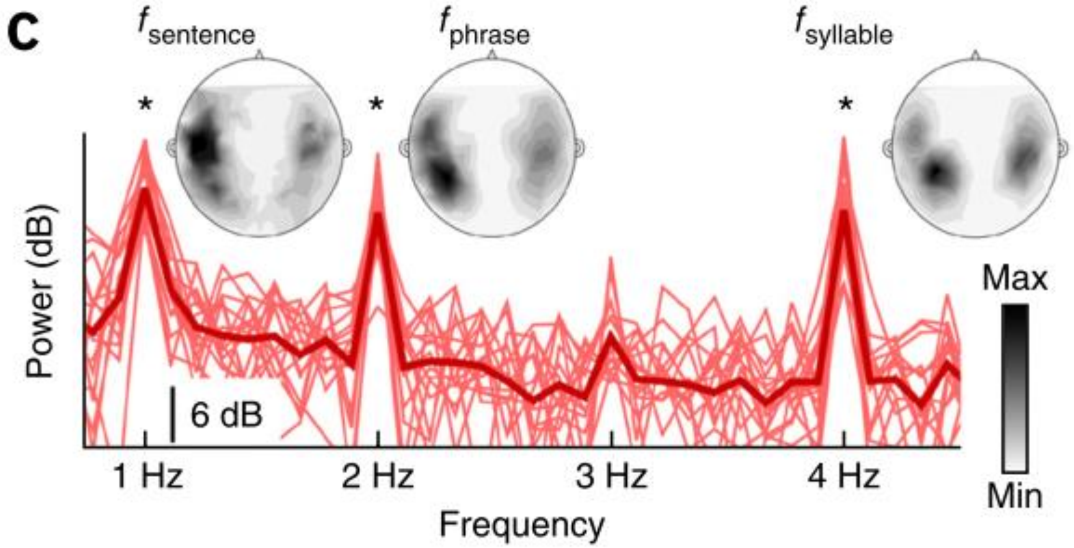
de Heering & Rossion, eLife (2015)

EEG paradigms in infant studies

Tasks: Neural Entrainment

Synchronization of EEG/MEG signal to rhythmic properties of the stimulus

- Acoustic properties of the stimulus are reflected in the power spectrum of the neural response *(Huan Luo and David Poeppel , 2007)*
- Periodic abstract properties of the stimulus appear reflected as well *(Ding et al. 2015; Kabdebon et al. 2015)*



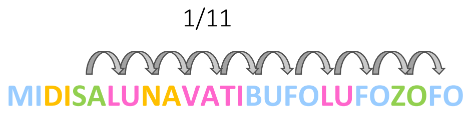
Ding et al. Nature Neuroscience (2015)

EEG paradigms in infant studies

Tasks: Neural Entrainment

Silence
Approx.. 2 minutes

Random
Approx.. 4 minutes



Structured (long)
Approx.. 3 minutes

Structured (short)
Approx.. 4 minutes

Sleeping neonates hearing to a continuous stream of syllables that could be random or conformed pseudo-words

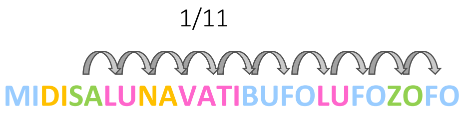
- Neural entrainments at the syllabic rate?
- Neural entrainment at the word rate?

EEG paradigms in infant studies

Tasks: Neural Entrainment

Silence
Approx.. 2 minutes

Random
Approx.. 4 minutes



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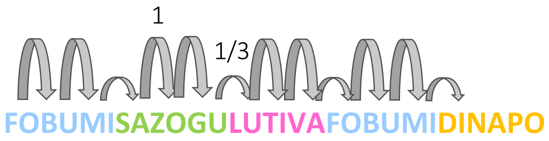
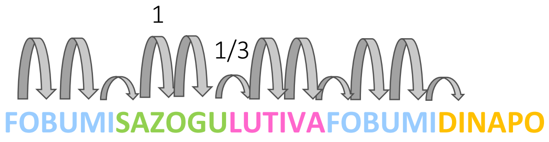
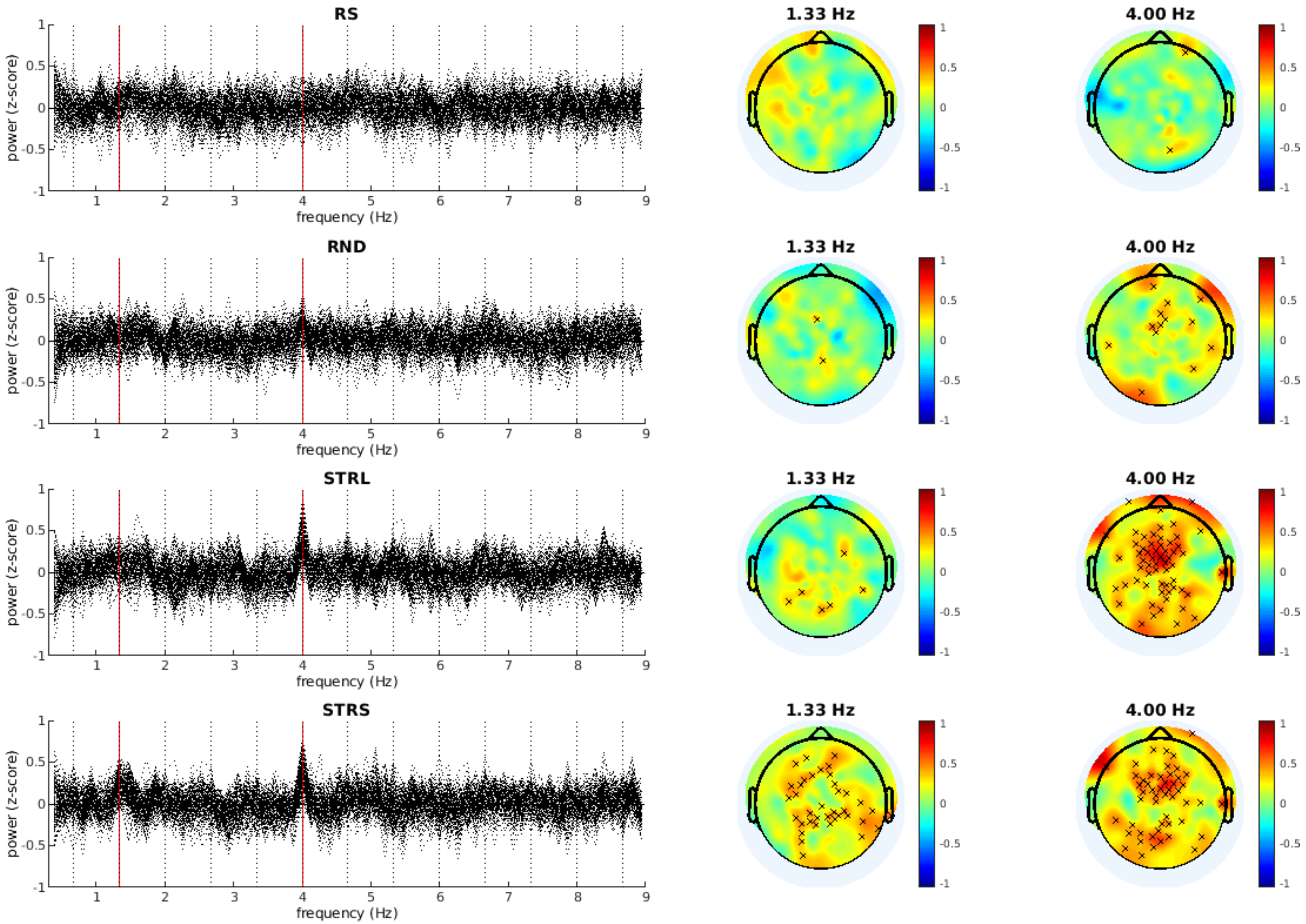


Structured (short)
Approx.. 4 minutes



Power Spectrum (SNR)



Summary

- Protocols apply in adults can be used to infant studies, but require some adaptations
  - Infants reduced attention → Attractive paradigms, but short testing…
  - Infants cognitive capacities are not the same →Simpler experiments
  - The responses are not the same than in adults and changes along development → More difficult to have clear hypothesis on what to expect

- The activity is not so well "organized" (stronger "random" background activity); therefore, many analysis methods develop for adults do not seem to work so well.

- We still need
  - to develop pre-processing and analysis techniques better fit for infants data
  - a better understanding of the EEG signal in infants and its changes during development

- Nevertheless, EEG has been and remains as an important tool to study infants cognition

- Testing protocol relaying on frequency tagging approaches seem a promising paradigm for the study of some aspects of infants cognition (next talk!)

Thanks!