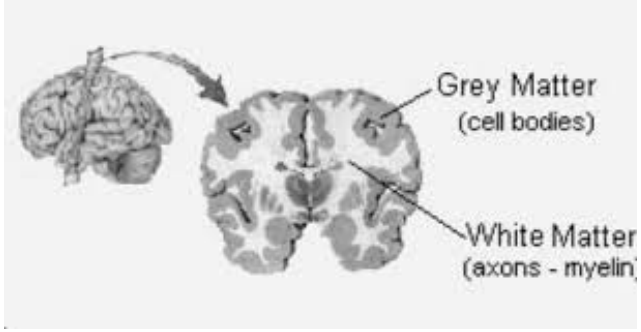
CSE588: Music, Mind, & Technology

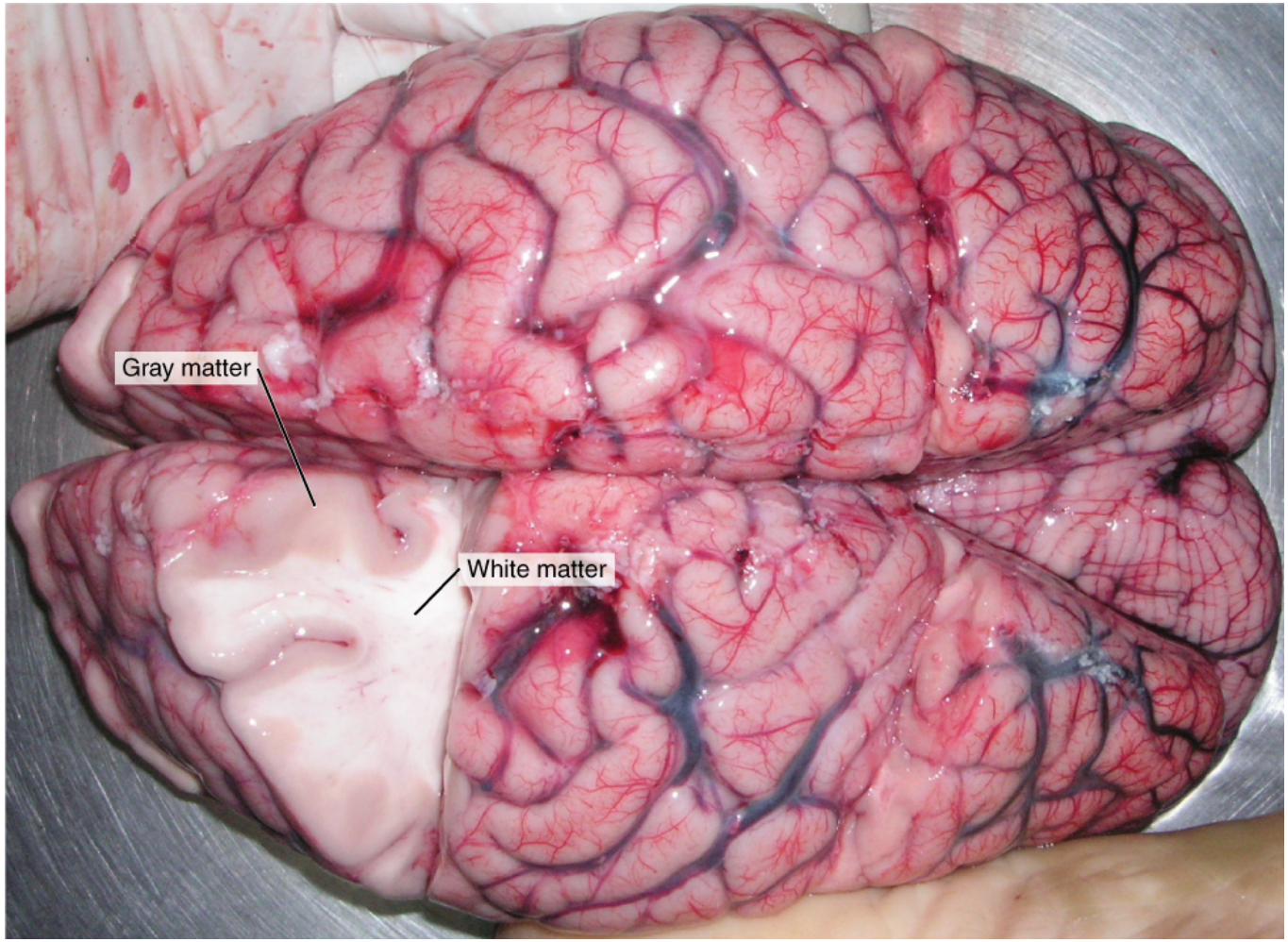
Dr. Vinoo Alluri

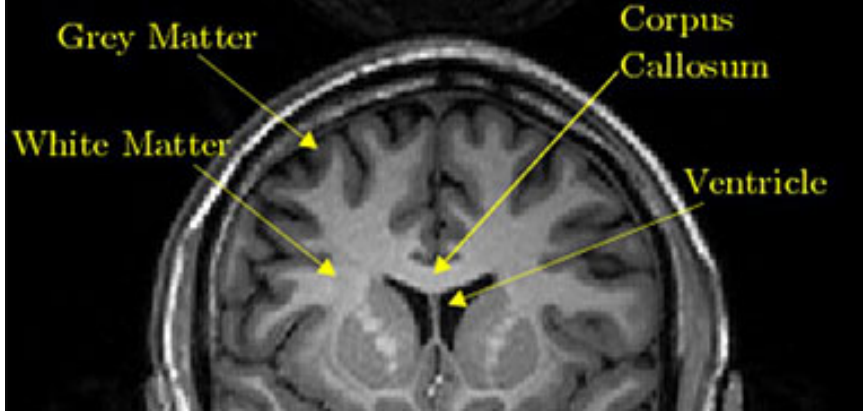
Neuromusicology

- a.k.a Cognitive Neuroscience of Music
- combination of cognitive neuroscience and empirical musicology

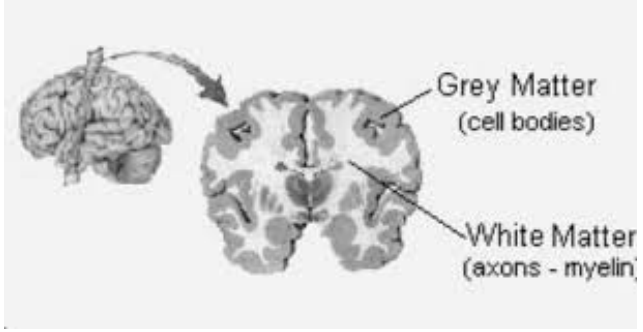
Brain

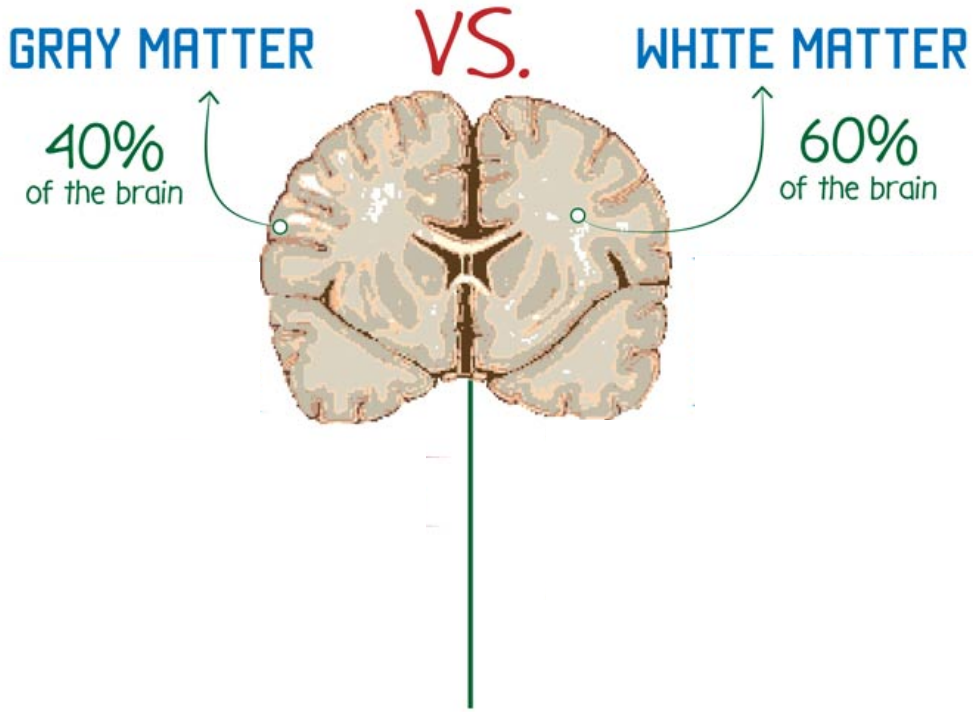

Grey Matter
(cell bodies)
White Matter
(axons - myelin)


Gray matter
White matter



Brain





SOURCES:
https://www.spinalcord.com/blog/gray-matter-vs-white-matter-in-the-brain
http://www.differencebetween.net/science/health/difference-between-grey-and-white-matter/
https://www.lorecentral.org/2017/06/grey-matter-vs-white-matter-main-difference.html
https://en.wikipedia.org/wiki/White_matter
https://en.wikipedia.org/wiki/Grey_matter

Brain

Structure vs **Function**

How to investigate the brain

- Behavioural methods
- Lesion studies
- Animal models
- Recording from single cells and cell populations
- Electroencephalography (**EEG**)
- Magnetoencephalography (**MEG**)

How to investigate the brain

- Positron Emission Tomography (**PET**)
- Magnetic Resonance Imaging (**MRI**)
- Electrocorticography (**ECoG**) or intracranial electroencephalography (**iEEG**)
- Transcranial magnetic stimulation (**TMS**)
- Optical imaging

Keep in mind …

- All research methods are limited
- The limitations differ between the methods
- All methods have "**The Best Question**", that is, the type of question that the methods answers with most accuracy and reliability
- When you have a **question**, you must choose the **method** accordingly
- When you have a **method**, you must choose the **question** accordingly

1. Behavioural methods “Listening tests”

- Many types of questions related to sound features, qualitative and quantitative
- Very time-consuming when accuracy is required
- Different test types for different age groups, types of subjects, etc.
- Typically possible after age 5 years
- Also, respiration, skin conductance, muscle relaxation etc can be measured (”lie detector”)

Example: loudness scaling

- **Question**: How is the perceived loudness of sound A related to the loudness of sound B?

- Possible study methods:

  - Magnitude estimation: Assign a number to the loudness of a sound

  - Magnitude production: Adjust the level of a sound to match a number

  - Ratio estimation: What is the loudness ratio of two sounds? (e.g. half, quarter, two, four, etc.)

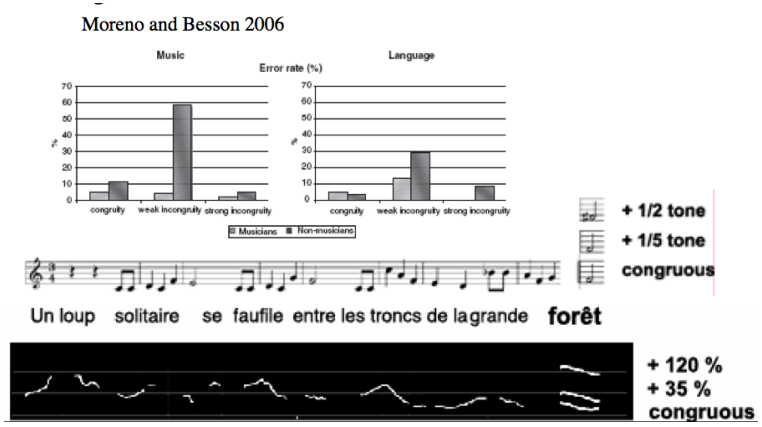
  - Ratio production: Adjust the level of the second tone so that it is half/quarter/twice as loud as the first tone

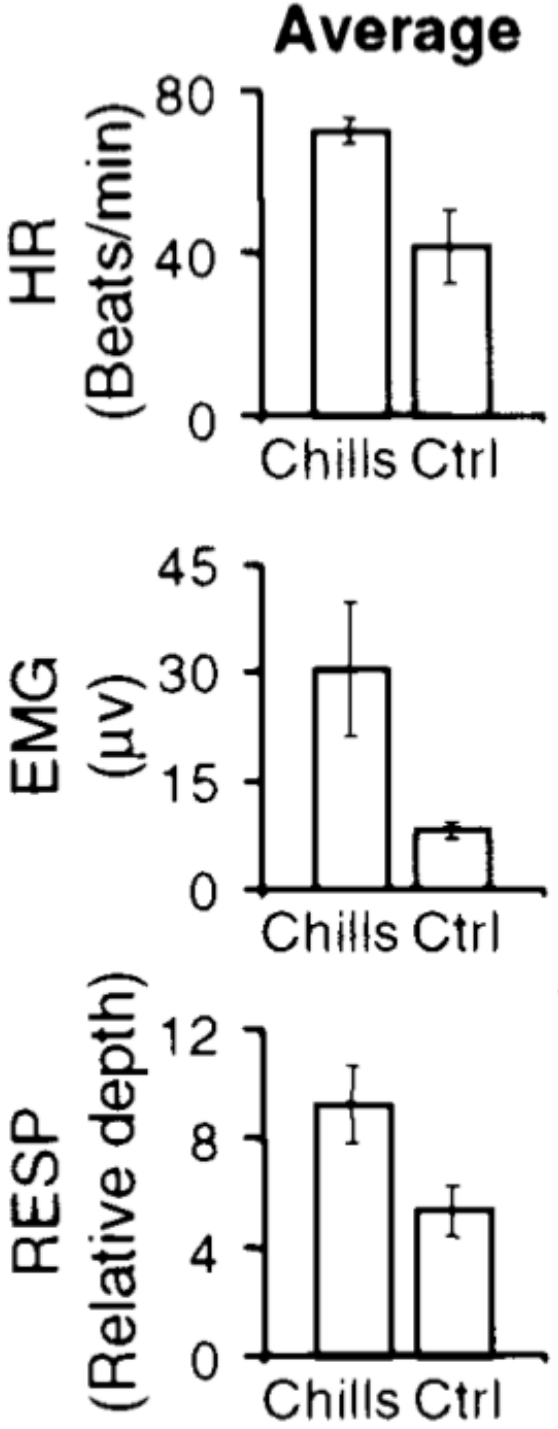
Example: incongruity identification

Question: How well do children notice changed pitches in music and speech? Does musicianship play a role here?

Children are asked to press the button when a melody or the prosody is ”wrong”.

Musicians are more accurate in both tasks.



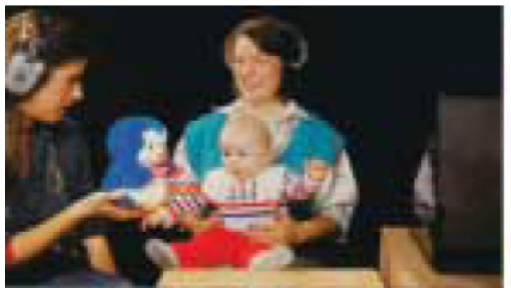


Example: Bodily reactions to emotional music

- Each subject brings own music that elicits ”chills”
- Measurements are performed from heart rate, muscle tension and respiration rate
- Each measure shows a clear difference compared to ”chill-music” from other subject

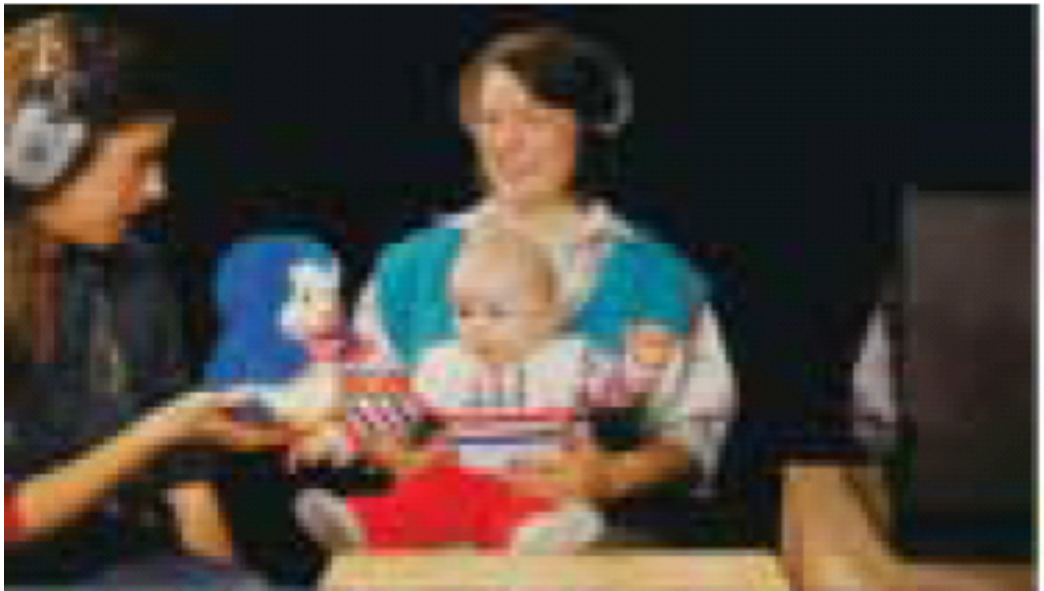
Head-turn method

- The **Infant Language Lab** at John Hopkins University (1999)



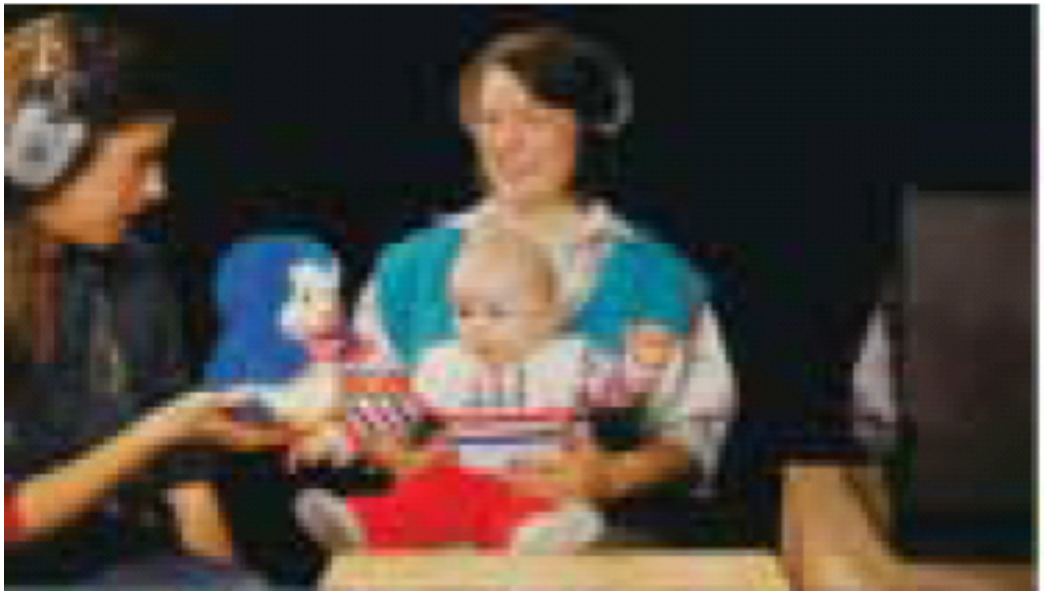
Head-turn method

- A puppet performance is ongoing on the right and is not related to the sounds.
- When the sounds are changed, a new performance is available for a very short time on the left.



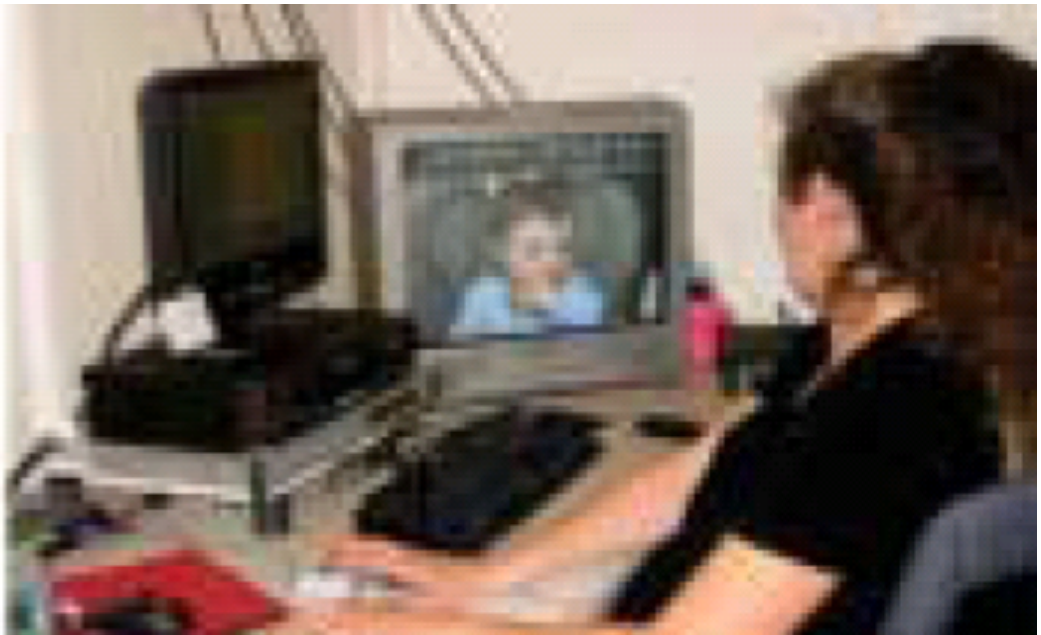
Head-turn method

- If the baby notices the change in the sounds, she/he has time to see the 2nd show
- Statistical analysis of the results
- **Question**: can she/he detect the change?



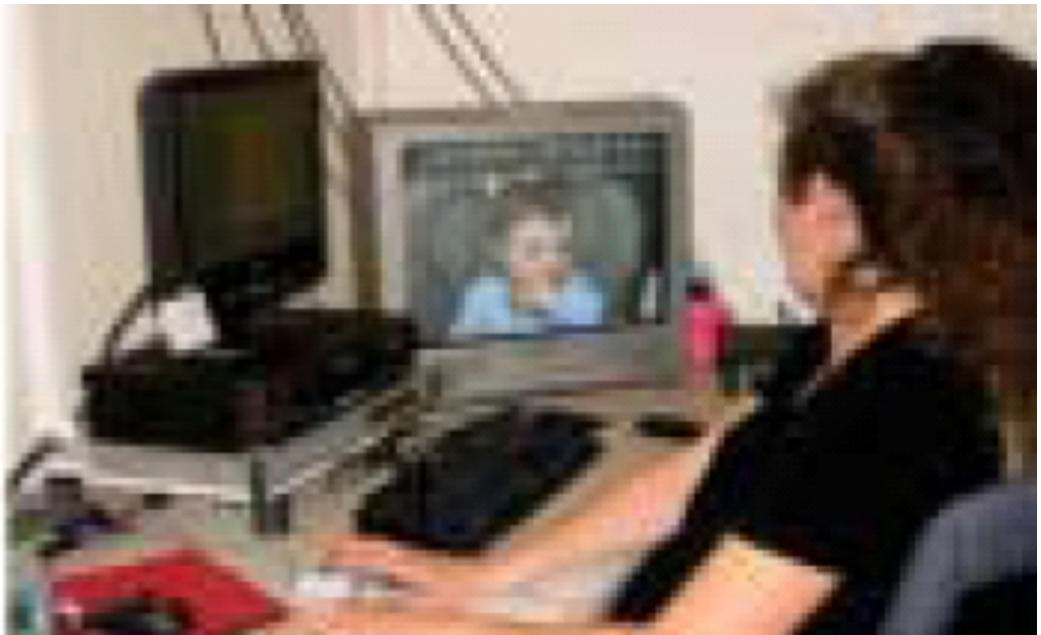
Auditory preference method

- When the baby watches the screen, sound 1 is played
- When the baby looks away, silence
- When the baby looks again, sound 2 is played, etc.



Auditory preference method

- Statistical comparison of looking times
- **Question**: Which sound is preferred by the infant?
- less than 4 months: familiar sounds
- over 8 months: novelty



2. Lesion Studies

- attempt to locate a specific location in the brain's cognitive function

"American Crowbar Case"

Phineas Gage

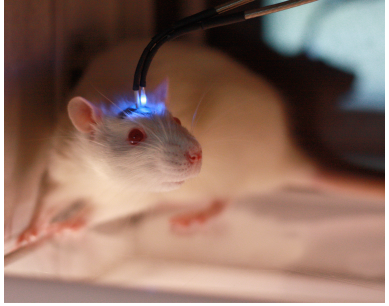
Harlow 1868

2. Lesion Studies

- attempt to locate a specific location in the brain's cognitive function
- brain injury - cognitive performance and comparison
- problems
  - fragmentation of processing
  - individual brains differ
  - cannot be repeated
  - **brain plasticity**

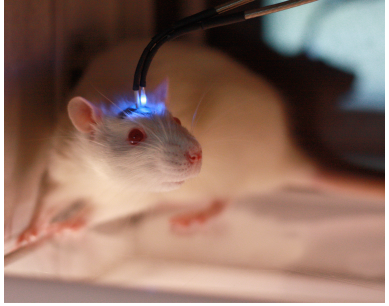
Phineas Gage

Harlow 1868



3. Animal models

Scientific problem	Animal model	
Action potential generation →		**Squid** Squids were used to study the mechanisms underlying action potential generation because of their giant axons, which allow the insertion of voltage-clamp electrodes (*5*).
Synaptic transmission →		**Frog** Frogs were used to study the mechanisms of synaptic transmission because of the simple behavior and large size of the synapses involved (*43*).
Retinal physiology and lateral inhibition →		**Horseshoe crab** Horseshoe crabs were used to study mechanisms of retinal physiology, including lateral inhibition, because of the accessibility of individual nerve cells and convenient structure of the compound eye (*44*).
Learning and memory →		**Aplysia** Aplysia was used to study the neurobiology of learning and memory because of its capacity for simple forms of learning and the easily identifiable and accessible neurons that mediate these behaviors (*45*).
Spatial representation →		**Rat** Rats were used to study the neural components of spatial representation (*46, 47*) because of their exploration behavior and size, which enables neural recordings during free behavior. The neuroethological approach taken in these studies is described by O'Keefe and Nadel [section 4.7.1 of (*46*)].

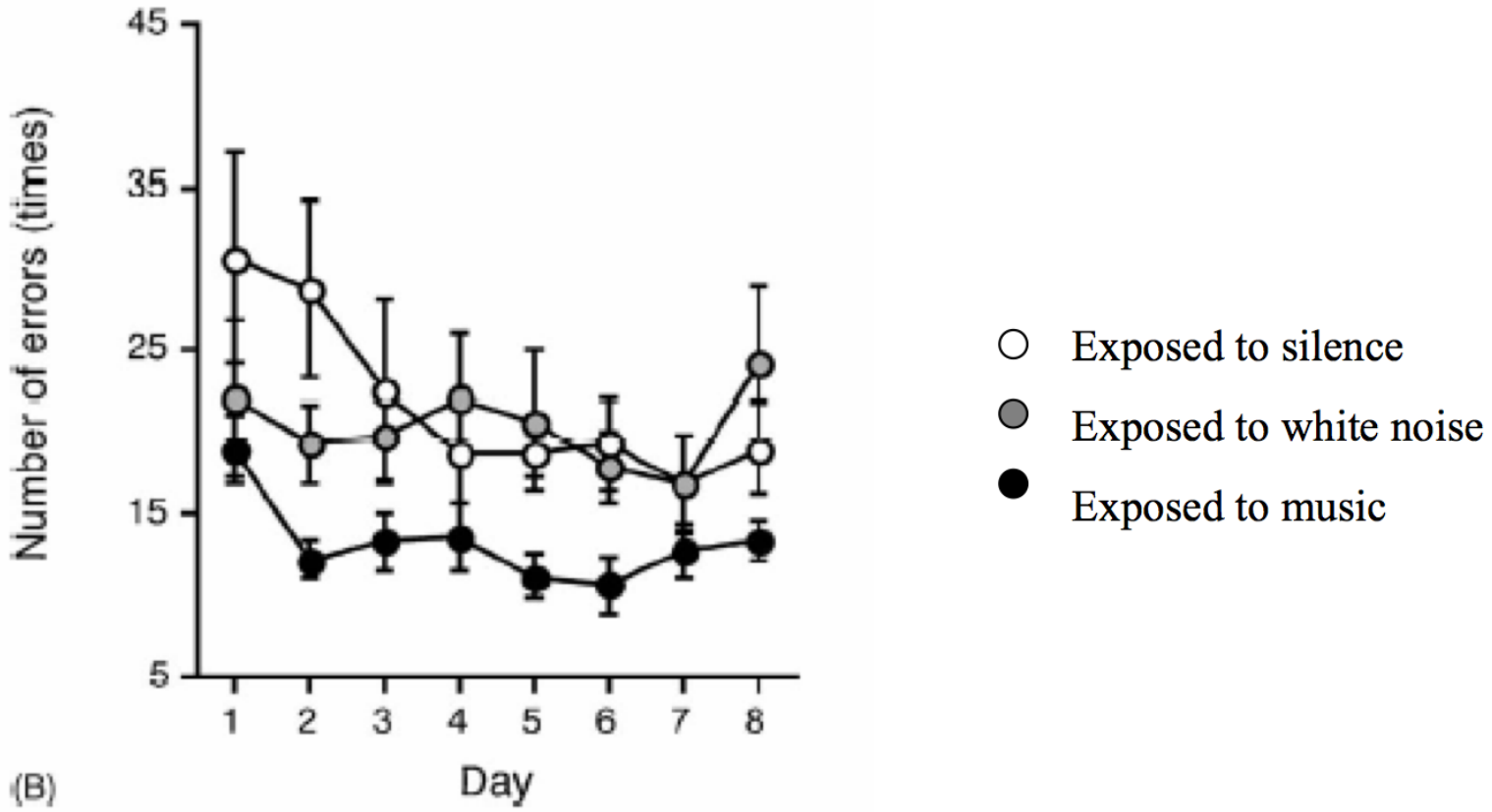


3. Animal models

- Monkey, rat, ferret and mouse are the most used animals to act as human models
- Monkey auditory system is very well known (but less well than the visual system)
- From animals, direct measurements from the brain are possible
  - Very accurate results in time and space dimensions
- Questions related to language and music are difficult to study

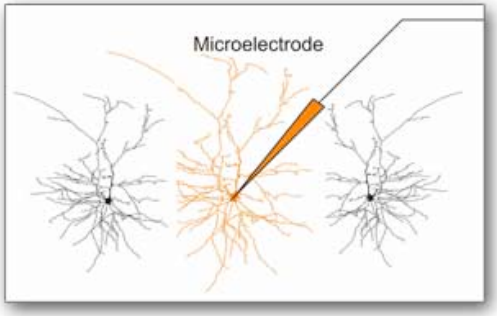
Question: Does music help mice concentrate better in a maze test?

Mice who had been exposed to music during the second half of pregnancy were faster and made less errors in the maze (Chikahisa et al., 2006)



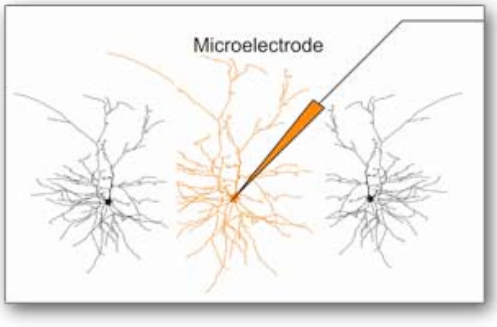
4. Single cell recordings

- A thin electrode picks up activity of a single or a small set of neurons
- Available in humans during brain surgery and in planning phase of operations to localize seizure origin prior to surgical treatment



4. Single cell recordings

- Typically patients are pre-operative epilepsy patients but sometimes also people suffering from severe mental illnesses or parkinson disease
- highest resolution of all brain imaging techniques
- up to fifty cells can be recorded at once



4. Single cell recordings

- Catherine Liegeois-Chauvel from Marseille is the pioneer of this work in the field of music
- Problem:
  - highly invasive
  - limited to few neurons
  - low generalisability

Where

fMRI, PET

EEG, MEG

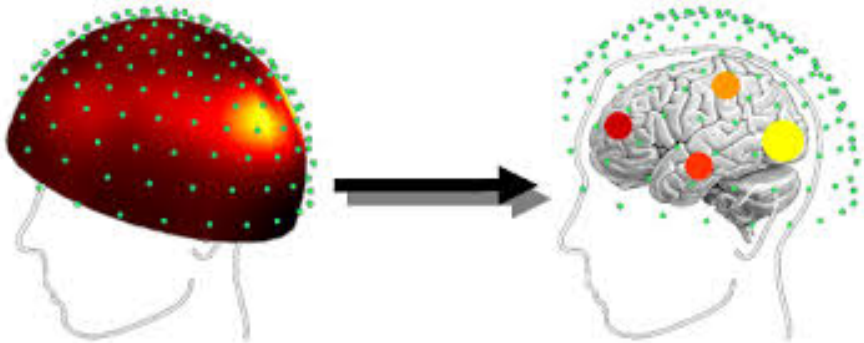
Warning!

When

- the are many important questions related to music that can not be answered with brain research
- always a trade-off

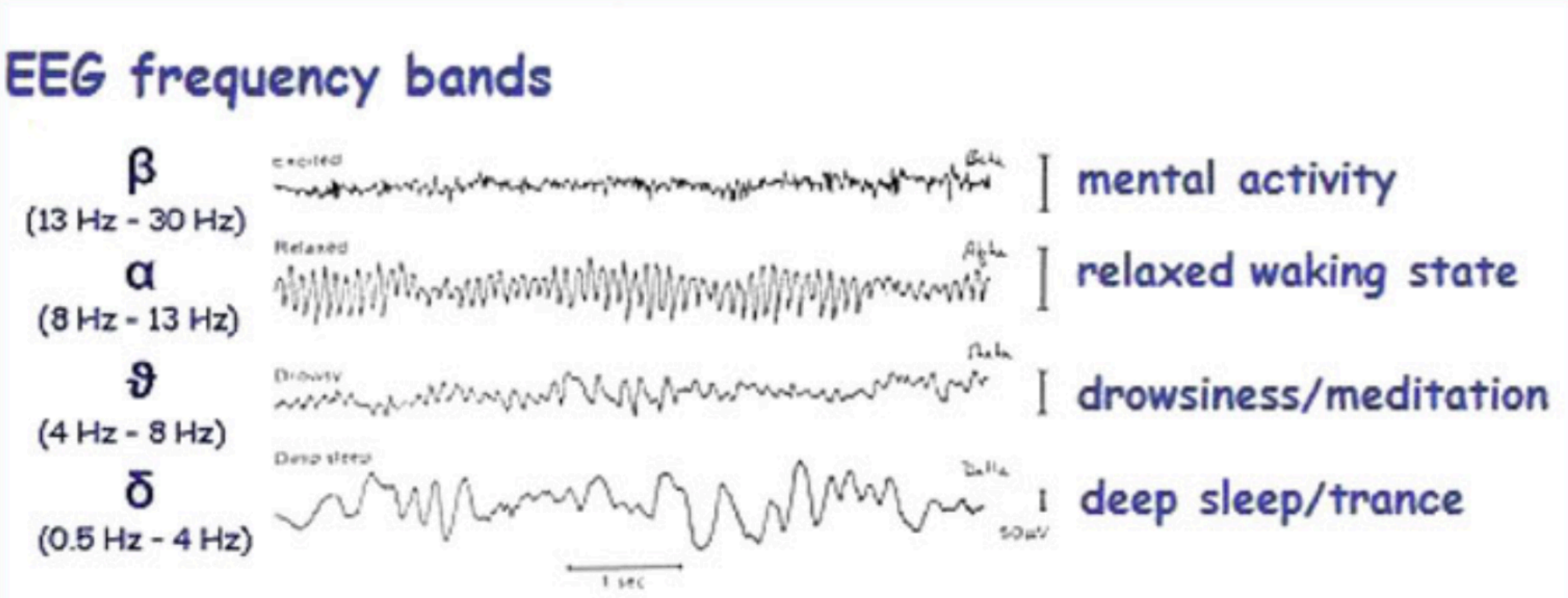
5. EEG and ERP

- electroencephalogram, event-related potentials
- the oldest and most established type of neuroscience methods
- electrodes placed onto the head's surface
- potentials recorded from the scalp are raw signals
- each potential appears as the sum of extracellular field potentials stemming from different cortical layers



5. EEG and ERP

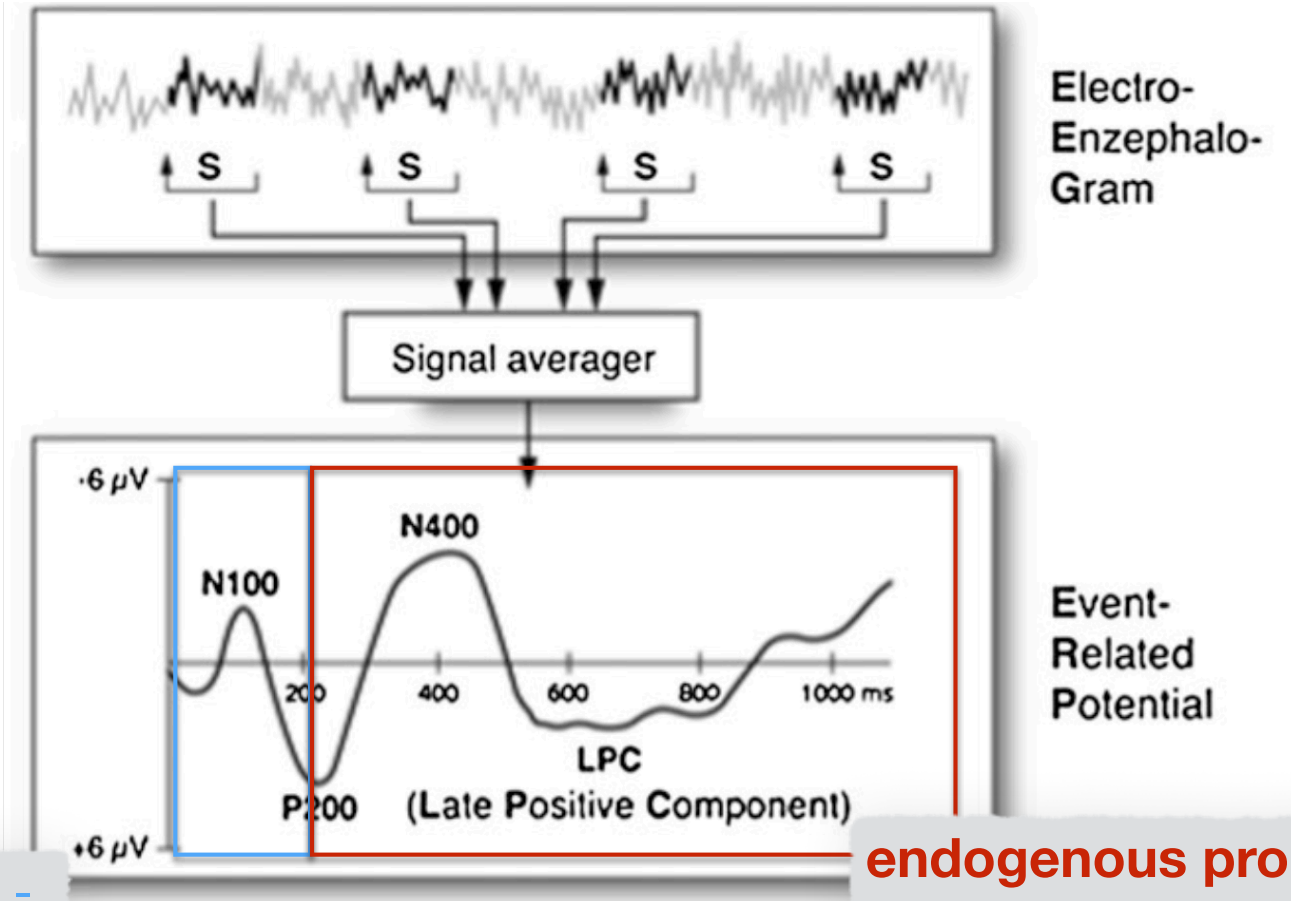
- often uses the Fast Fourier Transform algorithm (FFT) to separate four main frequency bands from each other (δ, θ, α, β)



5. EEG and ERP

- nowadays quite cheap
- possible to do for all age groups starting from birth
- comfortable for infants and children, adults, elderly people, patients, etc.
- possible to move during the experiment, play a musical instrument etc.

5. EEG and **ERP**



potential

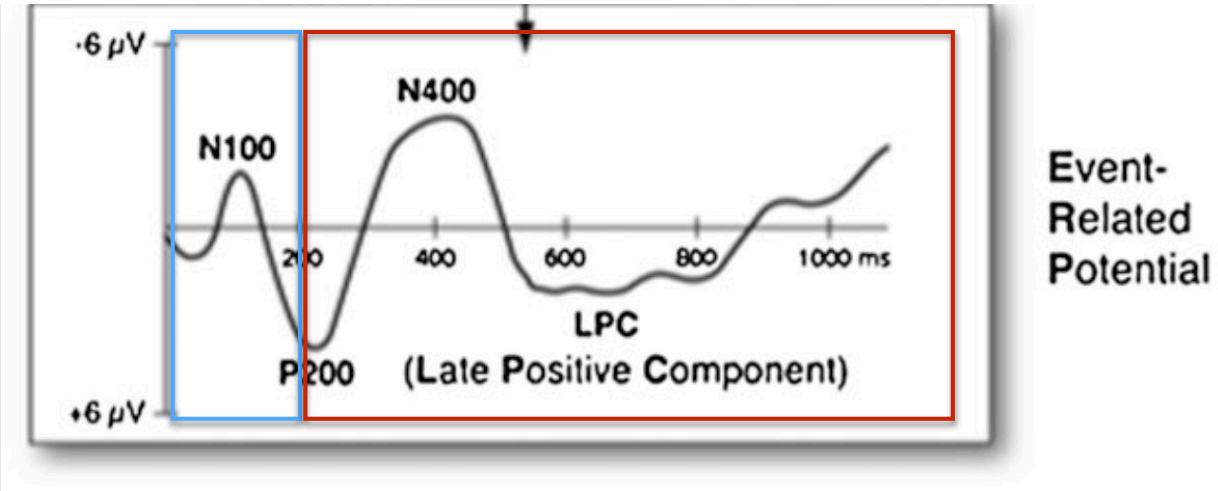
latency

grand average ERPs

exogenous processes - determined by stimulus features such as frequency, ntensity or presentation rate

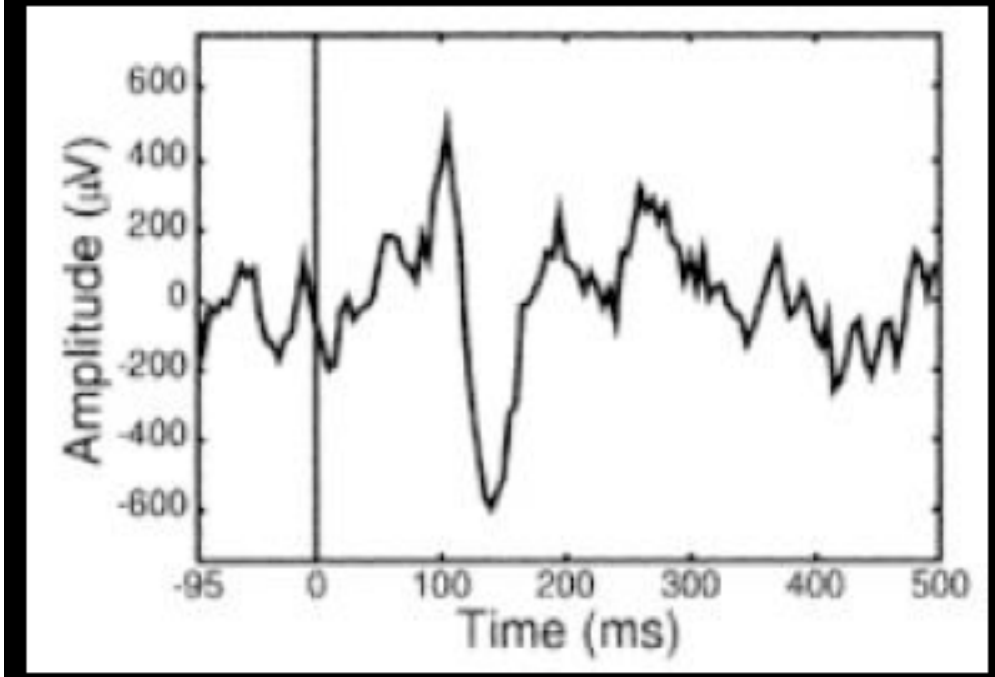
endogenous processes - reflecting some task-related cognitive processing steps for which attention is required

5. EEG and **ERP**

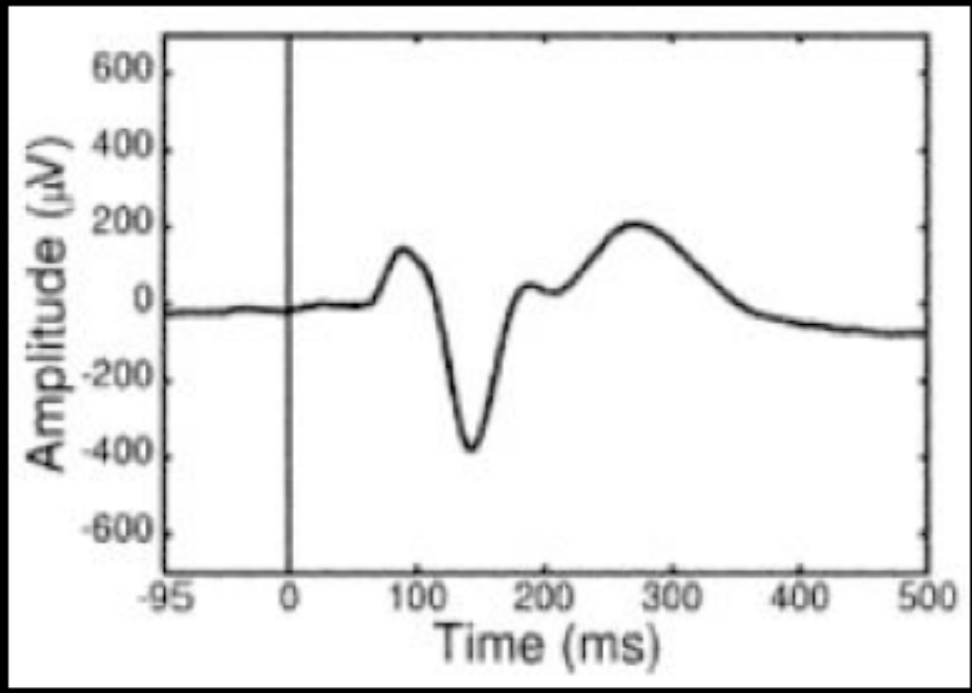


Exogenous potentials	Endogenous potentials
- Depend on physical features of the sensory stimulus.	- Do not depend on physical features of sensory stimulus. They can be evoked, just with stimulus expectancy, even in the absence of stimulus.
- Do not depend on the subjects' level of consciousness.	- Can change depending on the level of attention, its relevancy during the task and resources required for stimulus processing.
- Are not influenced by cognition processes.	- Related to cognition processing.

ERP derived from EEG



Single Trial: 100ms visual stimulus



Average of 200 trials to same stimulus

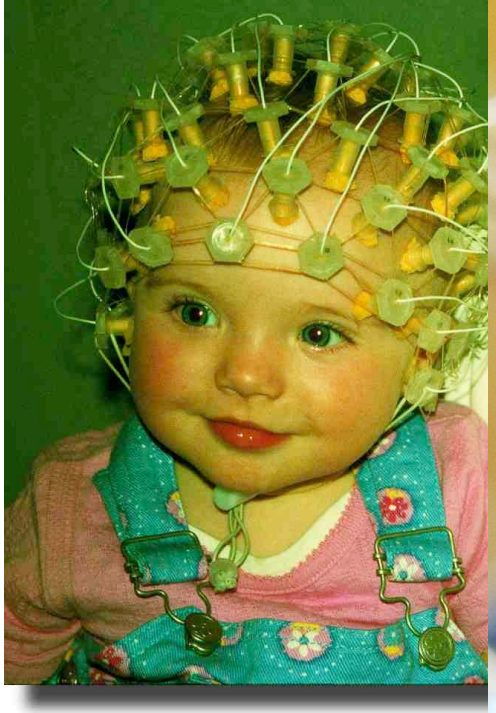
5. EEG and **ERP**

- EEG is averaged into event-related potentials or ERP according to the onset of an event/ stimulus
- temporally very accurate
- direct measure of action in the nerve cells
- best question:
  - *"How does this **process*** change in the brain if I change the task or stimulus?"*

***process**= perception, memory, attention, ...

5. EEG and **ERP**

- problems
  - participants might have changed attentiveness during recording
  - brain responses are prone to habituation, i.e. amplitudes will be reduced the more familiar, or predictable, the often-repeated stimuli are
  - grand average ERPs are produced at the expense of individual brain responses (conclusions regarding individual processing strategies cannot be drawn from the final product)

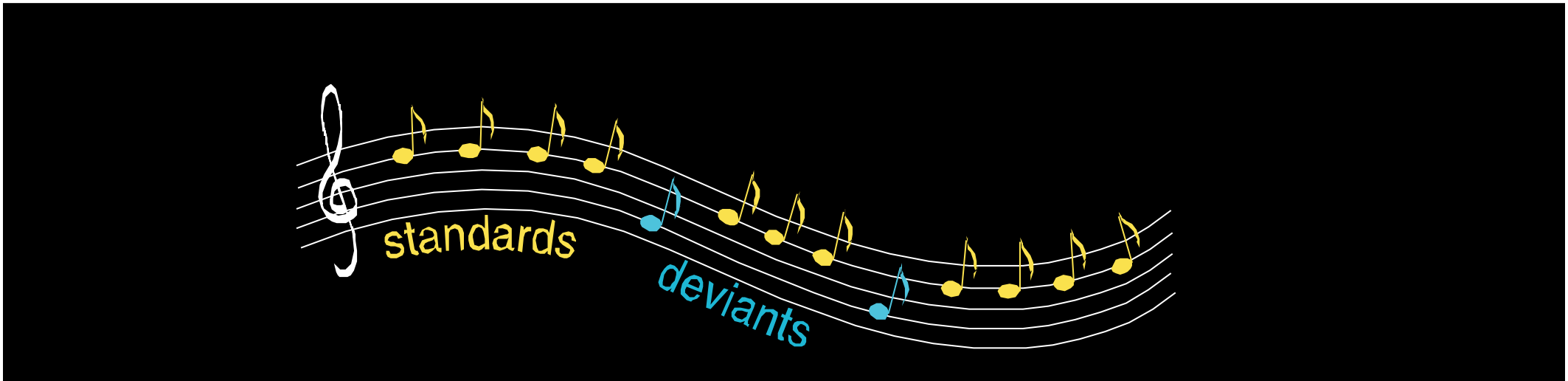


ERP in infants and neonates

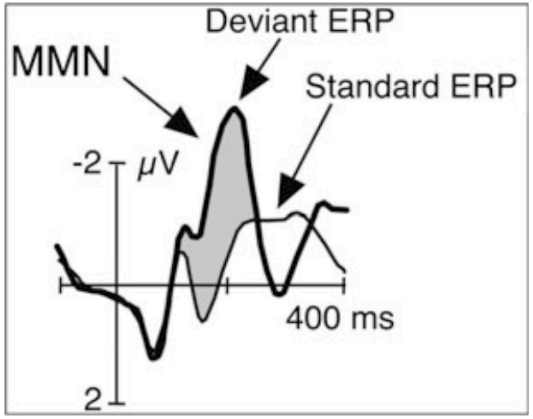
The more channels you have (up to 100), the better spatial accuracy you can achieve.

Mismatch Negativity **(MMN)**

- ERP to a change in a sound stream or in general to an odd stimulus in a sequence of stimuli
- Reflects the action of short-term memory
- Does not require attention
- In infants, recorded during sleep



Memory trace



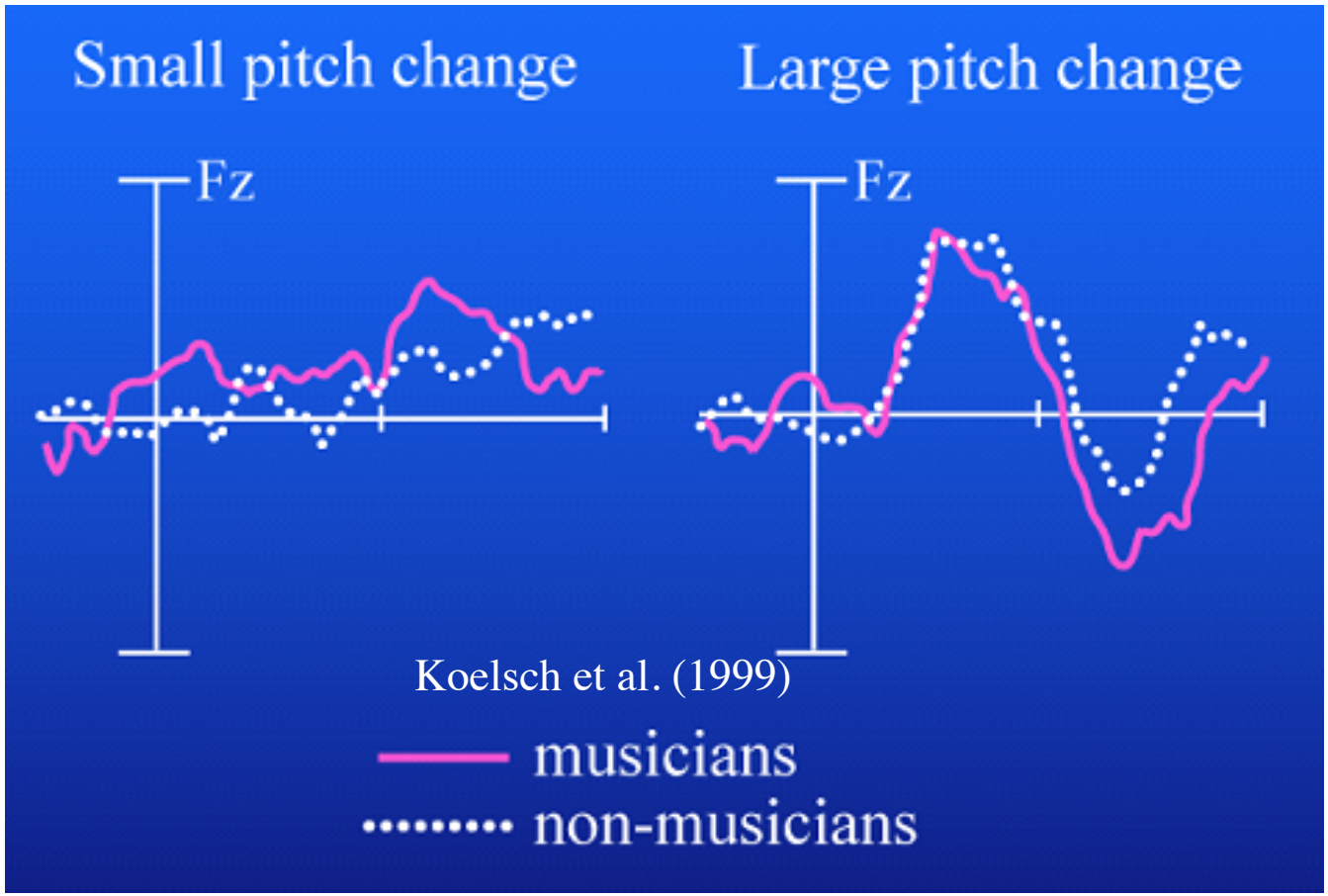
S S S d S S d S

- Standard sounds automatically build up the memory trace
- A new sound is compared to the trace
- If a difference between the incoming sound and the trace is observed, MMN is elicited
- perfect for **preattentive** (automatic) processes

Näätänen&Winkler:The concept of auditory stimulus representation in cognitive neuroscience. Psych Bull vol.125 (2000)

Example

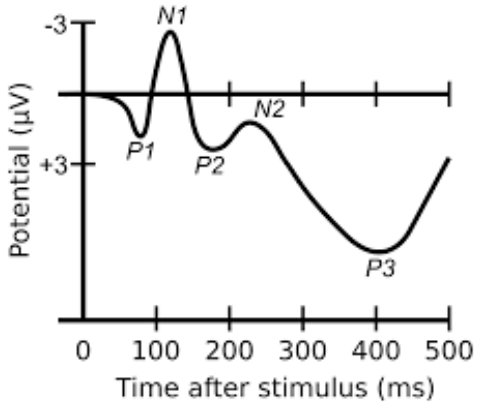
- ERP: G-major chord, sometimes slightly mistuned
- Musicians brains notice a smaller difference



These *processes* can be studied

Sound onset	Sound selection	Attention
Expectancy	Comparison	Memory trace
Re-allocation of attention	Semantics	Error

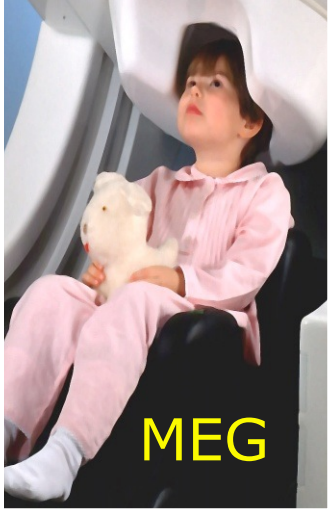
These *ERPs* reflect the processes



Sound onset P50, N1	Sound selection PN, P300	Attention N1, PN, P3a, P300
Expectancy N1, MMN	Comparison MMN	Memory trace MMN
Re-allocation of attention P300,LDN,RON	Semantics N400	Error RON

6. MEG

- provides the most accurate resolution of the timing of nerve cell activity -- down to the millisecond
- not available in all hospitals and research centers
- Possible to do for all age groups including foetuses



6. MEG

- temporally very accurate, records directly the activity of neurons, can separate hemispheres well, has potential also for sound source location analysis

- Best **question**: ”How does this ***process***** change in the brain if I change the task or the sounds?” ”Do these two processes have the same locations in the brain?”

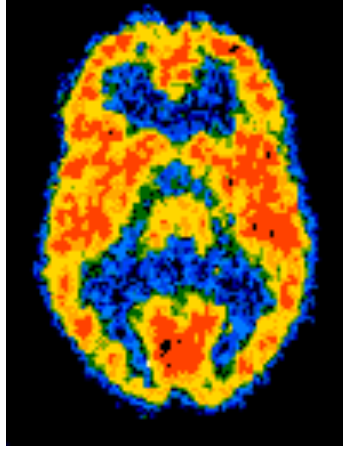
- Problem: low SN ratio

****process***= perception, memory, attention, ...

7. PET

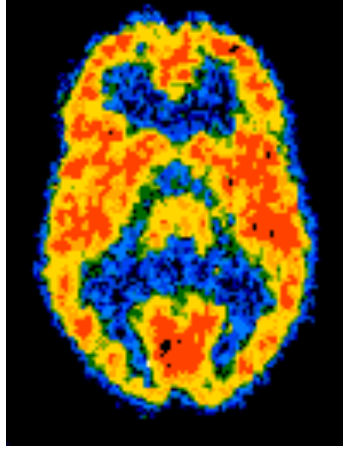
- positron emission tomography (1970s)
- observe metabolism
- energy consumption (oxygen and glucose) serves as an indicator to precisely localize brain activity
- Injection of radioactive substance
  - only one recording per male adult per year
- active cells consume the radioactive glucose
- PET can also be used to track neurotransmitters

PET

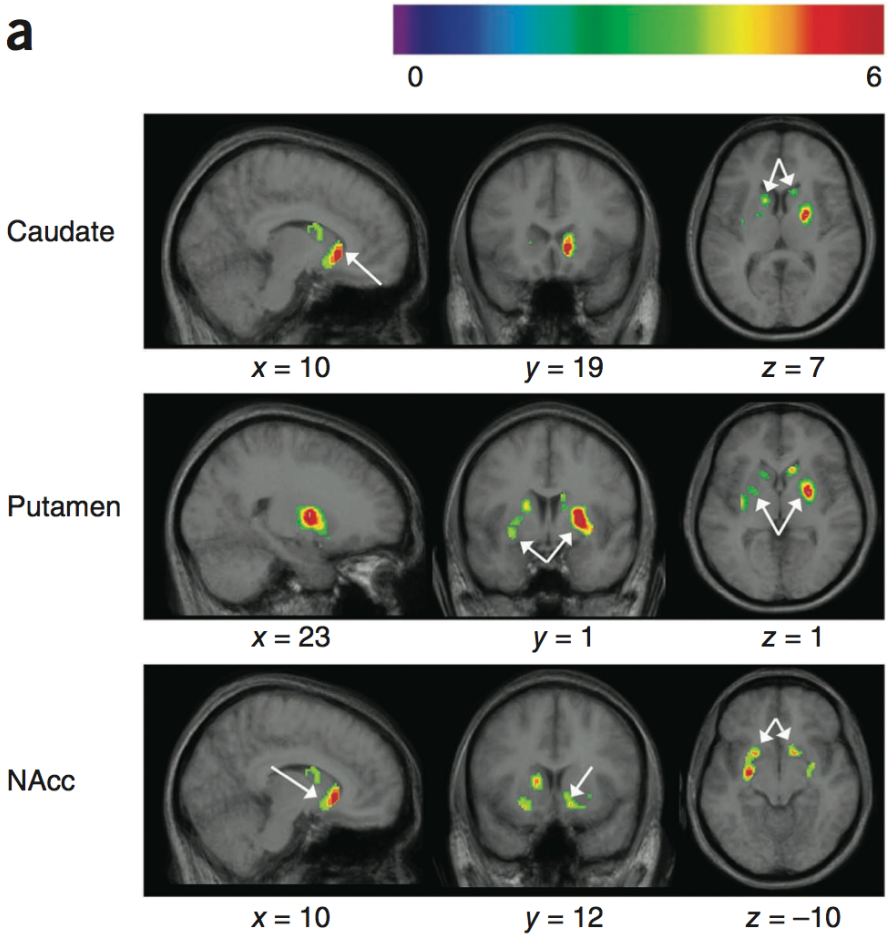


- use of PET decreasing after fMRI was invented
- quite accurate spatial resolution
- upto approx. 30 minutes
- Best question:
  - ”Which areas in the brain are active in this task?”
  - ”Which areas change their activity if I change the task or the sounds?”
  - ”Is this transmitter important in this task?”
  - ”Is there a difference in the activity of this transmitter between these two groups of participants?”

PET



- Problems:
  - Only slow metabolic activity can be imaged
  - Exposure to radiation
  - Very Expensive to run



Salimpoor et al., 2011

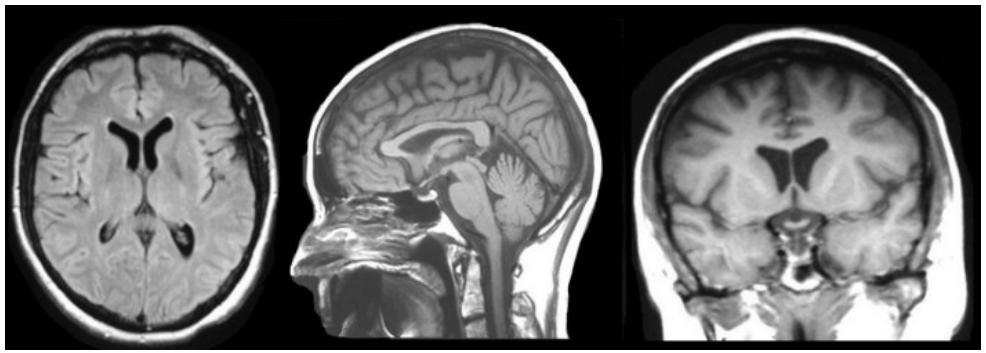
8. MRI and fMRI

- MRI or magnetic resonance imaging is structural imaging (”picture” of brain tissue)

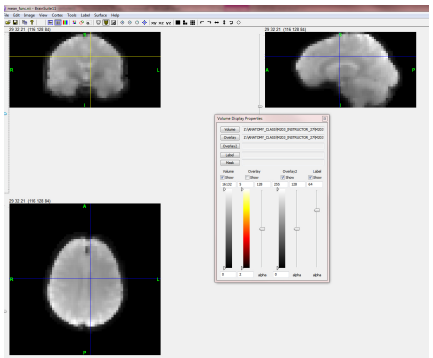
- fMRI is functional imaging, this is what the public knows to be ”brain imaging”

Structure vs **Function**

MRI

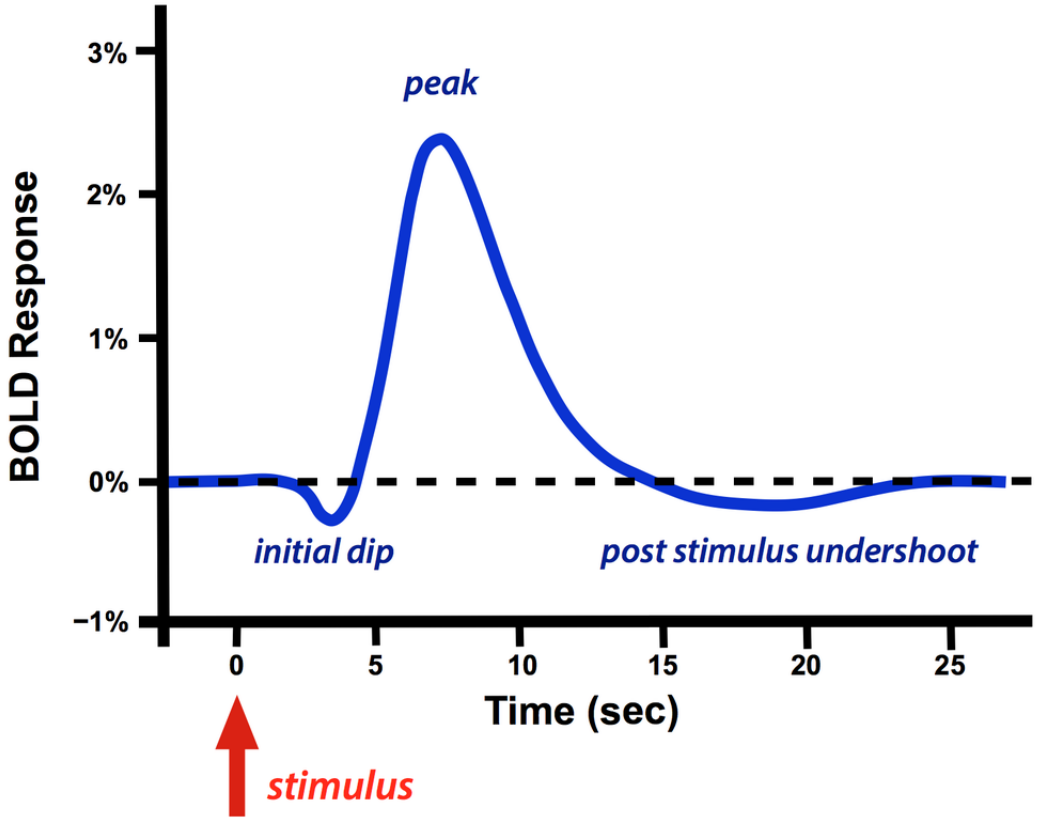


fMRI



fMRI

- picture of changes in blood oxygenation level



fMRI

- picture of changes in blood oxygenation level
- very accurate spatially (~2,00,000 voxels)