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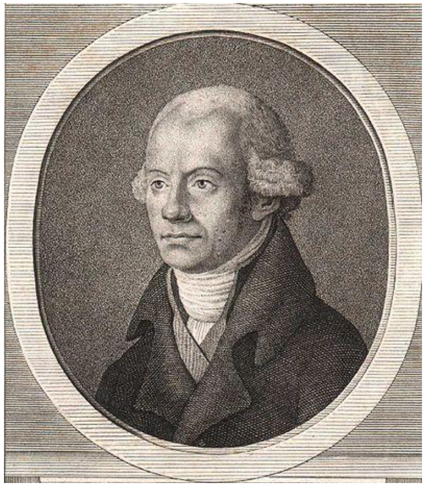
PSYC 10009: INTRODUCTION TO BIOLOGICAL PSYCHOLOGY

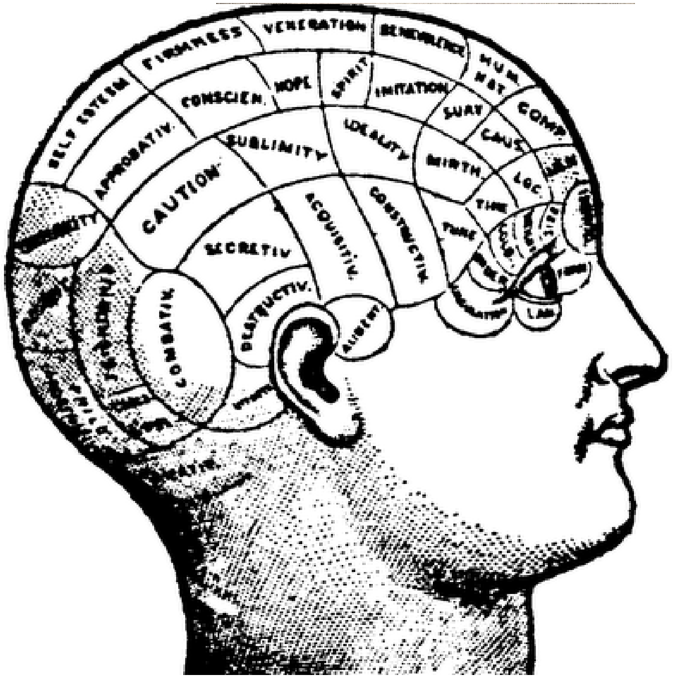
Lecture 5: Investigating the brain

Objective

- Review existing techniques for investigating the structure and the activity of individual neurons, populations of neurons and the whole brain

- Franz Joseph Gall (1758 – 1828), a German neuroanatomist
- **Phrenology**: correlation of brain anatomy (skull shape) with behaviour/personality





Modern methods for investigating the brain: an overview

1. **Examining the effects of brain damage**
   - brain injury, brain lesions
   - simulations of the above in the lab (stimulating electrodes, TMS)
2. **Recording electro-magnetic activity of single neurons or of populations of neurons**
   - Single cell recordings
   - Electroencephalography (EEG) & Magnetoencephalography (MEG)
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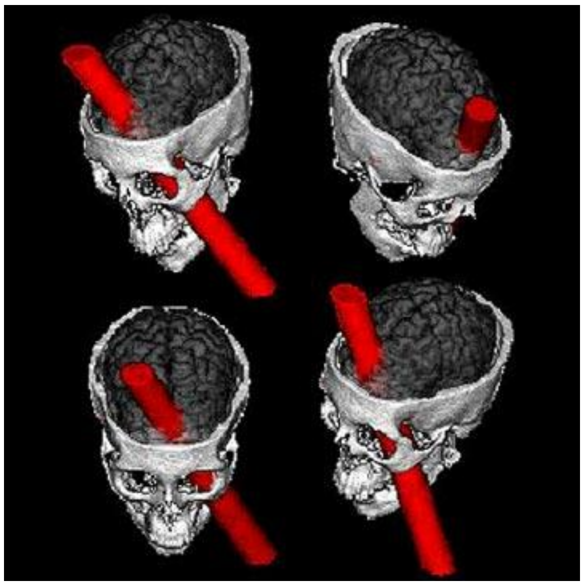
Brain Injury & Brain Lesions

Frontal Lobe damage (Phineas Gage)



Corpus callosotomy

He cannot say what the object is because the right hemisphere, which receives the information from the hand, has been disconnected from the more verbal left hemisphere. Results are similar for visually presented stimuli and sound information.

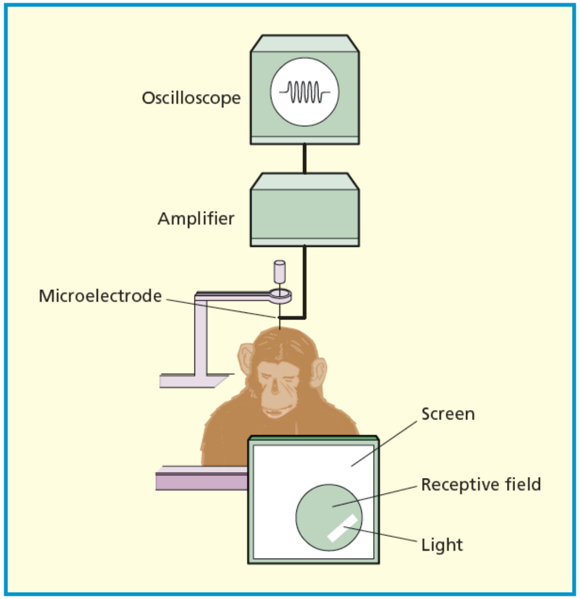
Broca's aphasia

Patients with lesions to Broca's area in LH (left inferior frontal gyrus, BA 44&45) have telegraphic speech (*"Son ... University ... Smart ... Boy ..."*). Broca's area has been viewed as the seat for sentence structure

- Correlation of the loss of specific cognitive, perceptual, motor or emotional function with the area of brain damage

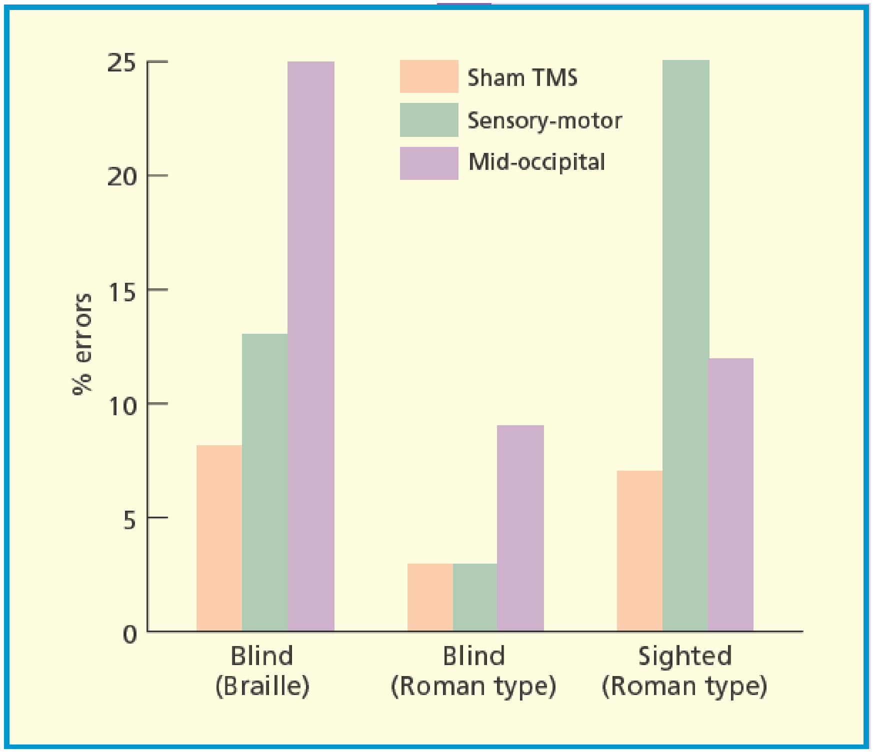
Simulating a brain lesion

- Examination of effects of stimulating some brain area
  - In lab animals or in open-brain surgery (invasive): stimulating electrodes
  - In healthy participants (non-invasive): **transcranial magnetic stimulation (TMS)** Neurons are excited/inhibited by externally applied time-varying electromagnetic fields generated by a coil located above the head



- Visual cortical areas can be activated by somatosensory input in blind but not sighted subjects
- Can the visual cortex can process somatosensory information in a <u>functionally relevant way</u> in blind people?

- Stimulation of the visual cortex impaired tactile reading in blind subjects, but not in sighted subjects
- → blindness from an early age causes the visual cortex to be recruited to a role in somatosensory processing



Cohen et al (1997) Nature. Figure from Ward's textbook

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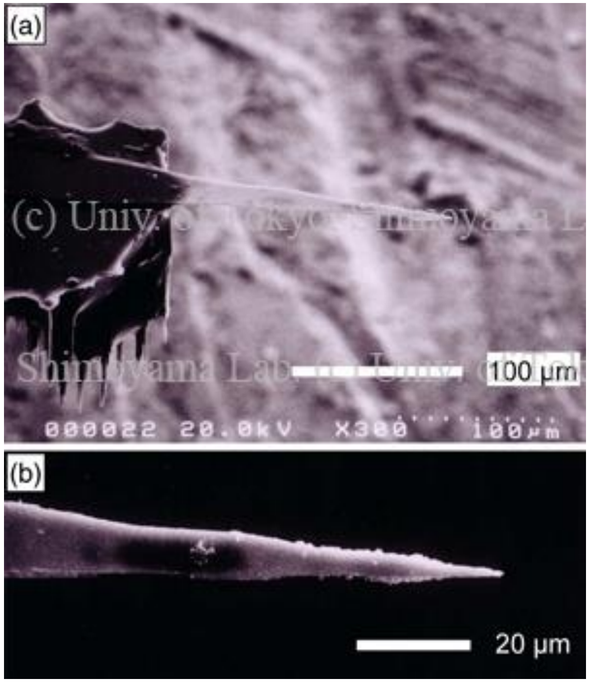
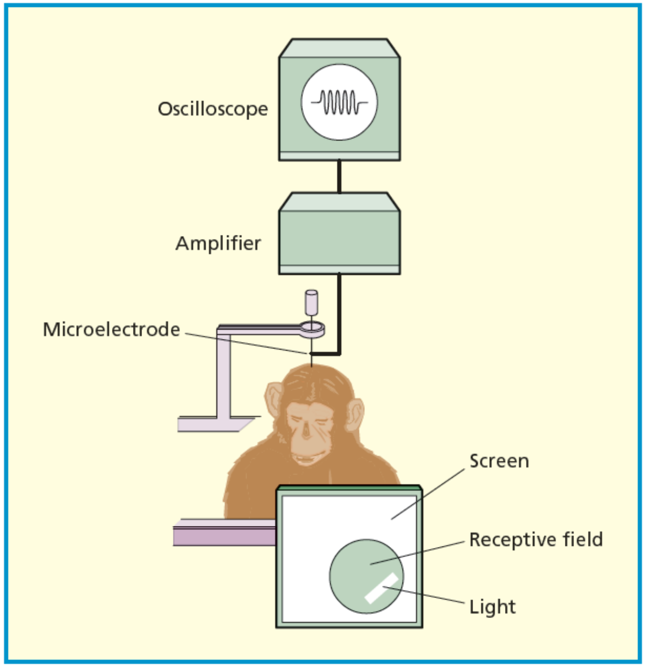
Recording electro-magnetic activity of single neurons

- *Single-neuron* behavior can be examined through the use of microelectrodes which impale the cells of interest ('single cell recordings')
- A "nano lead" - a submicron scale electrode – is implanted implanted into axon (intracellular) or outside axon membrane (extracellular)
- Records neural activity of a single neuron (but doesn't stimulate it)

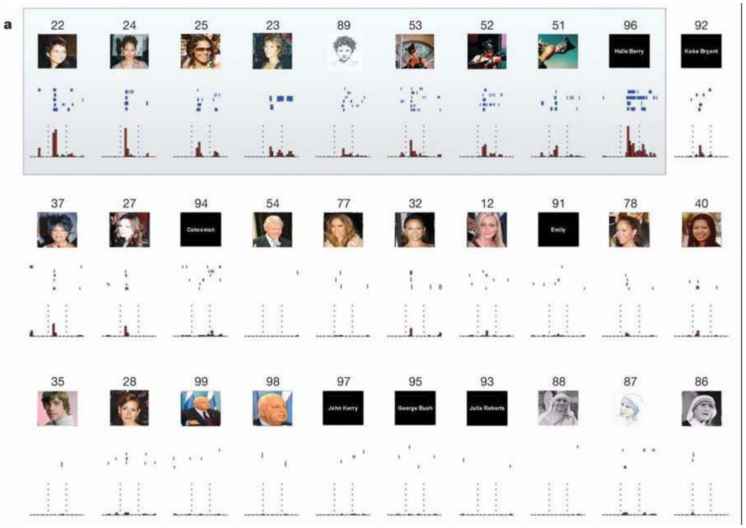




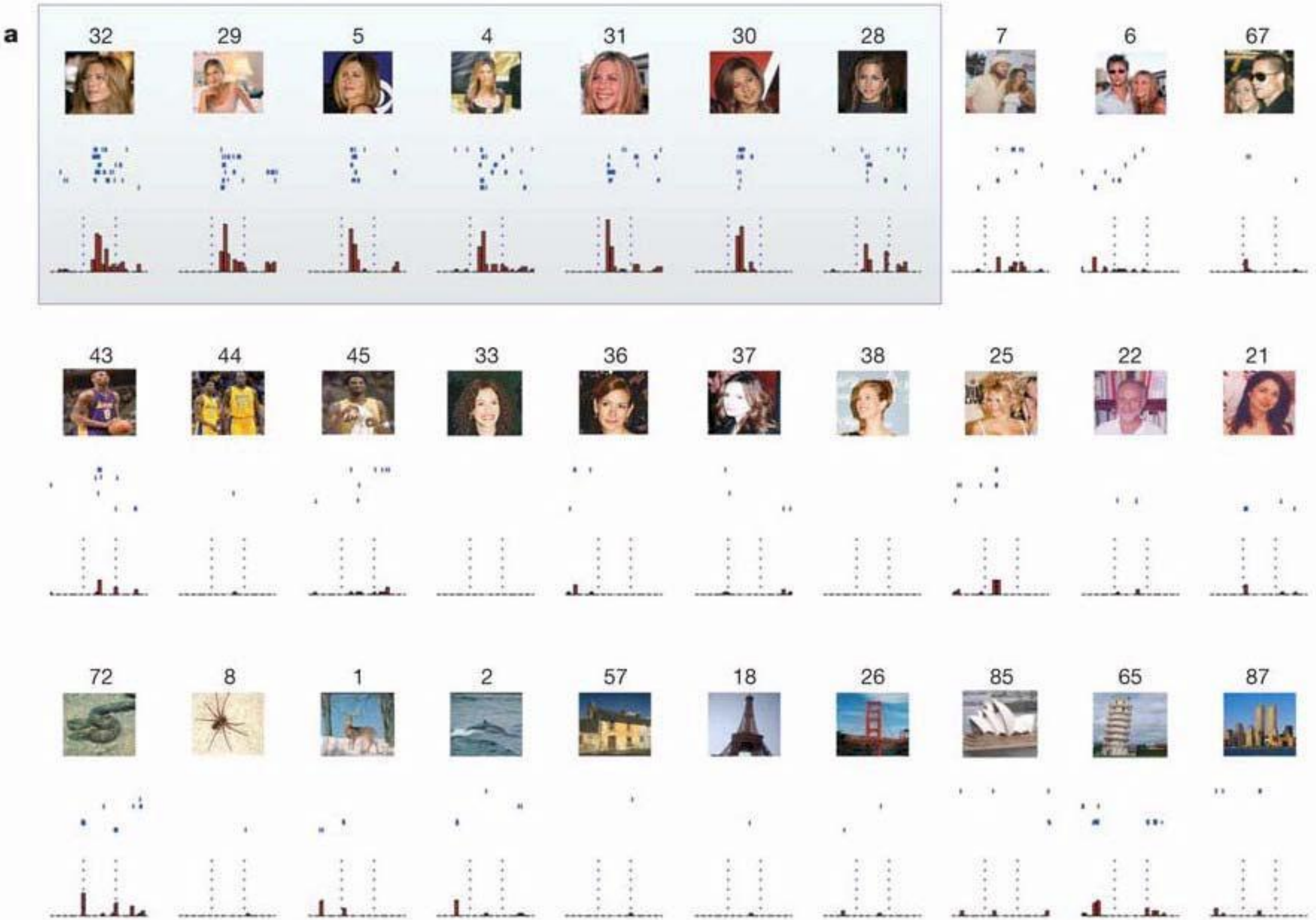
Source: *http://www.leopard.t.u-tokyo.ac.jp/research/shuzo/shuzo2.html, Ward (2010)*

Grandmother cells

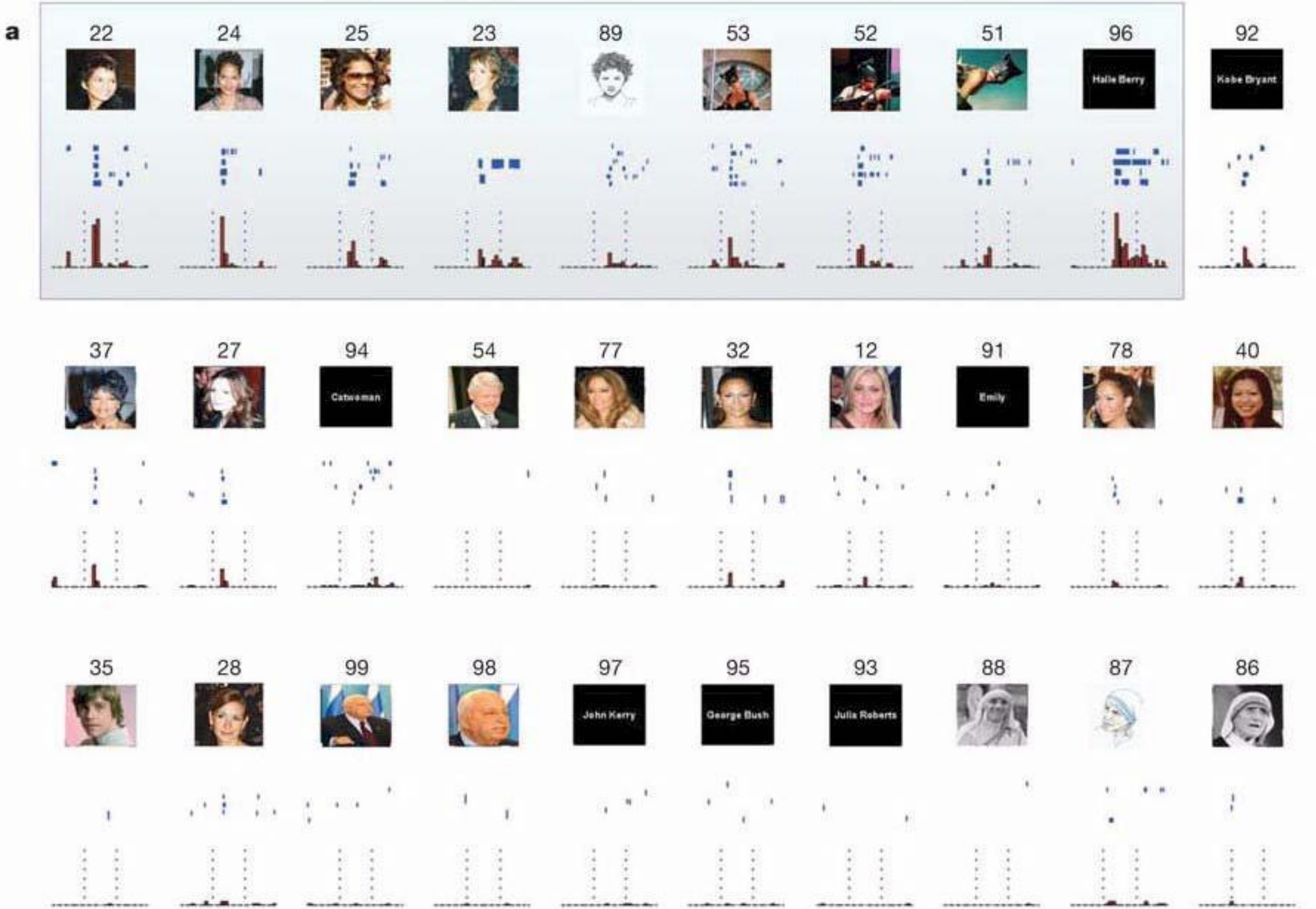
- Evidence of hierarchical organization in vision, but what sits at the top of the hierarchy?
- A **grandmother cell** hypothetically responds to only one stimulus
- Quiroga et al (2005): single-cell recordings of cells in the hippocampus that recognise specific people



Jennifer Aniston neuron



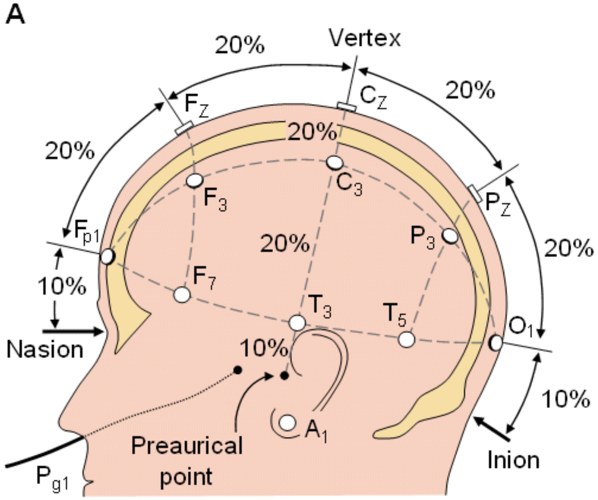
Halle Berry neuron

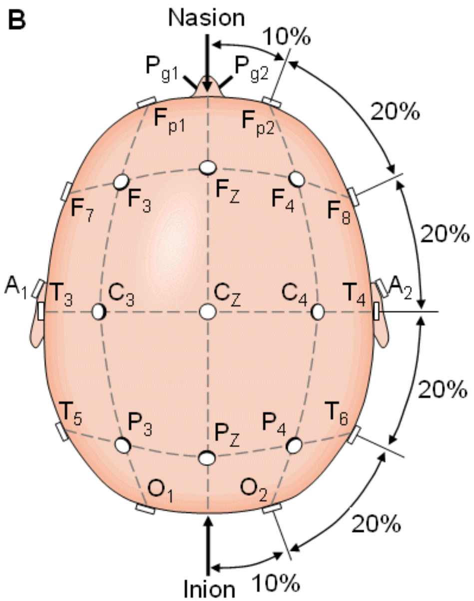


Recording electro-magnetic activity of populations of neurons

Electroencephalography (EEG) a technique measuring electrical brain activity on the scalp

– sensitive to postsynaptic dendritic currents generated by a population of neurons that are active in synchrony





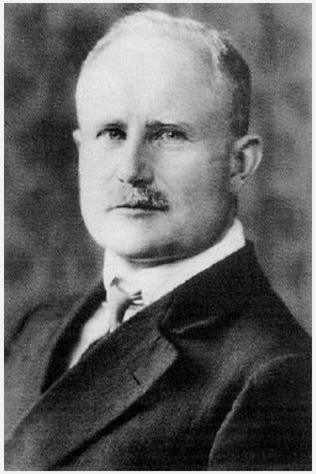
Placement of electrodes on the scalp:

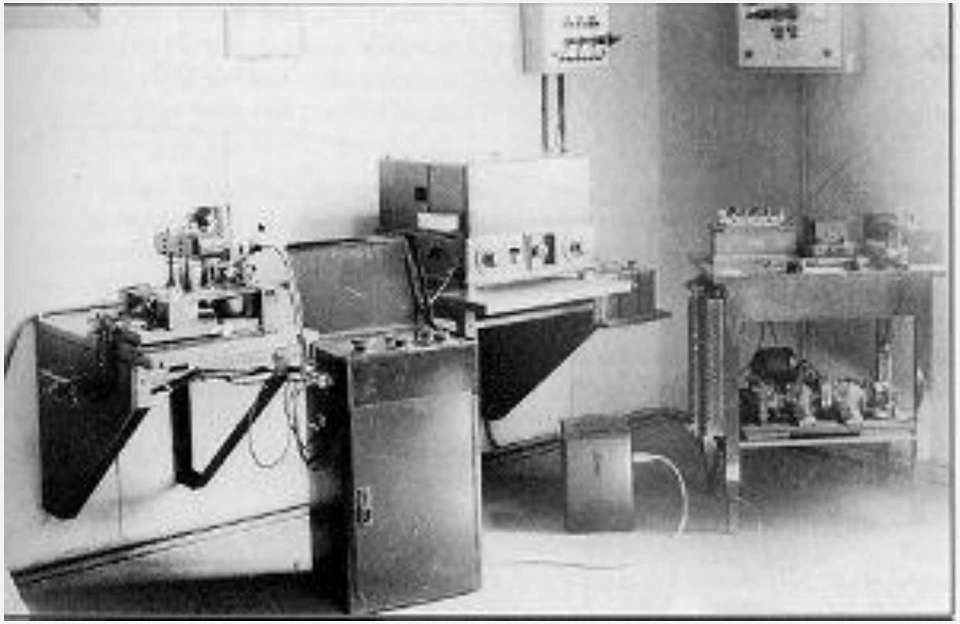
F – frontal
C – central
P – parietal
O – occipital
T – temporal

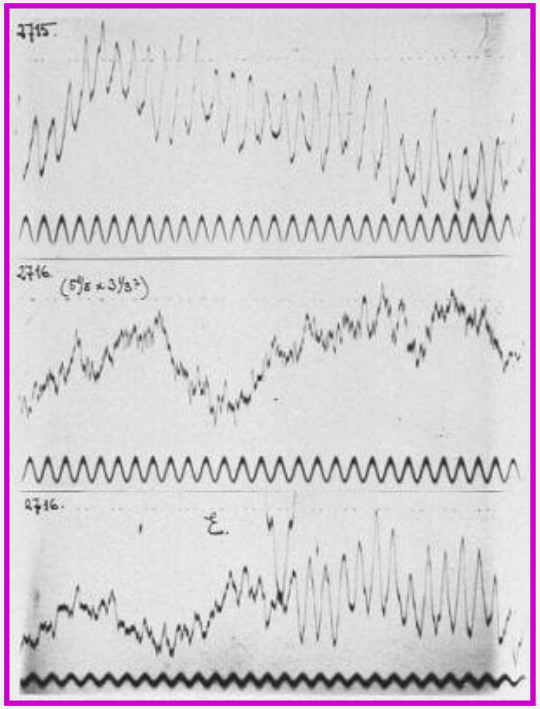
Important: the activity recorded at each channel cannot necessarily be attributed to neural activity underneath the channel

History of Electrophysiology

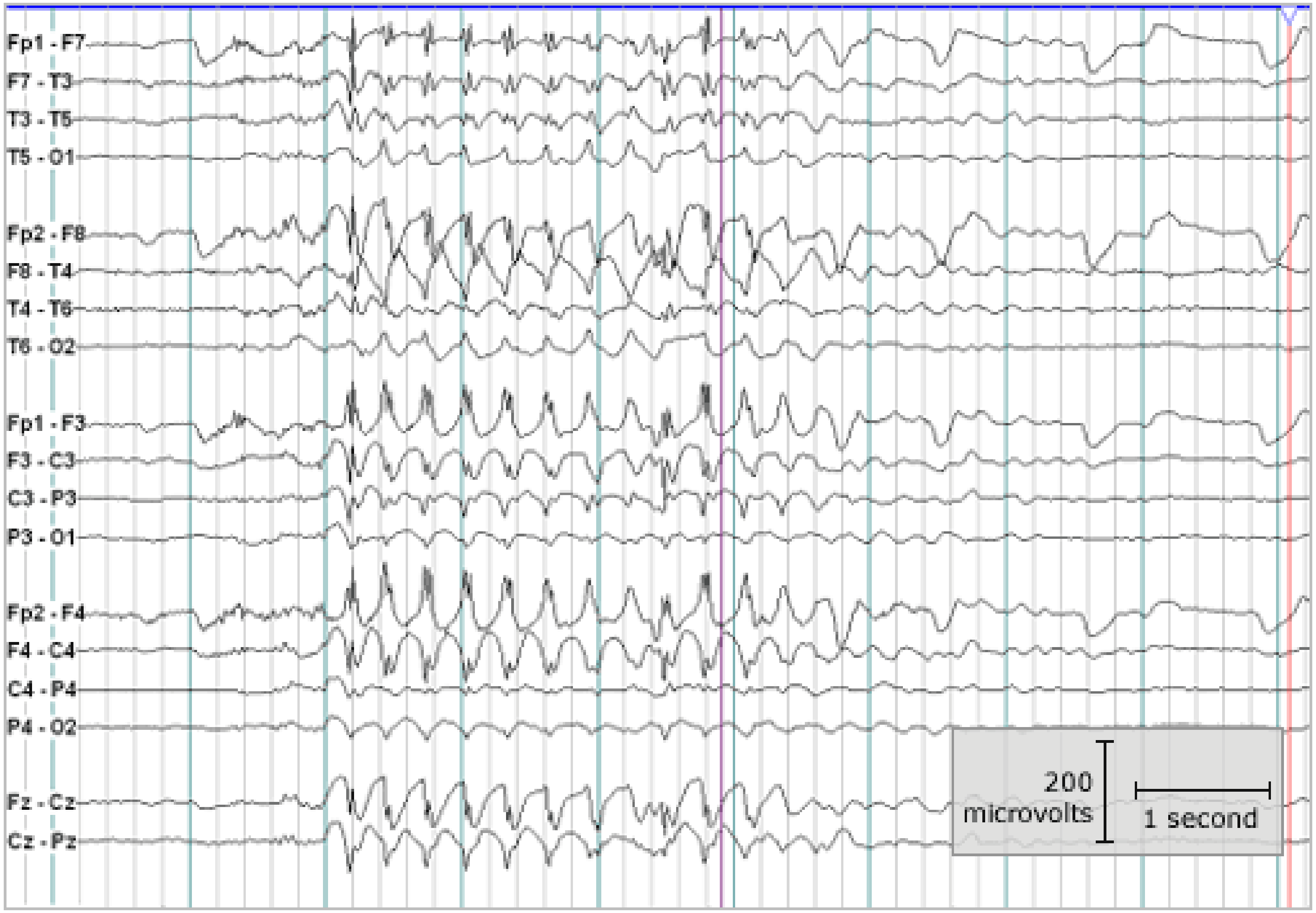
- Hans Berger, a German psychiatrist (1873-1941)
- The first person to prove the record electric potentials from the human brain on the scalp using an amplifying machine (an electroencephalograph).
- 1929 in Jena, Germany: first recording of human brain







Epilepsy



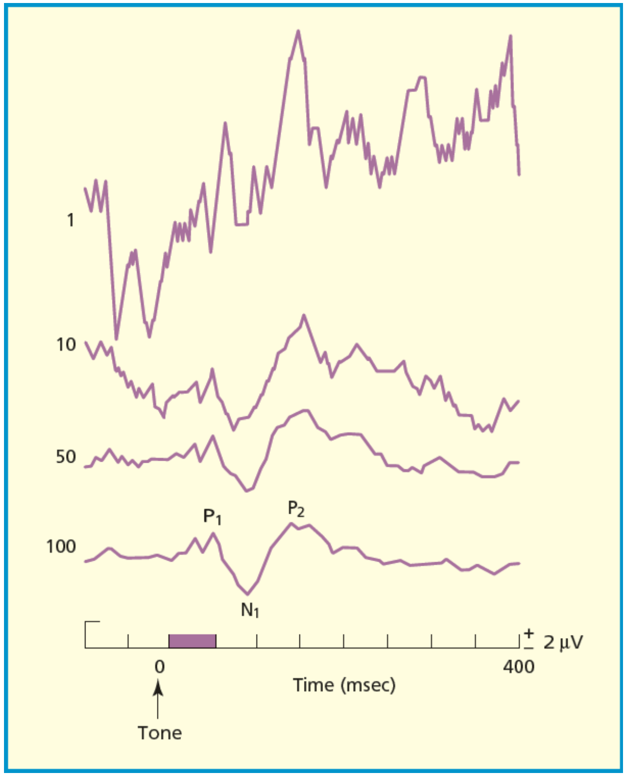
This EEG displays an abnormal discharge called a generalized ‘spike and wave.’
Source: http://www2.massgeneral.org/childhoodepilepsy/medical/index.htm

Event-Related Potentials (ERPs)

- **Event-Related Potentials (ERPs) -** EEG activity time-locked to an external event (e.g. sound, visual signal, response etc)
  - Usually averaged across multiple occurrences of the same event to reduce noise

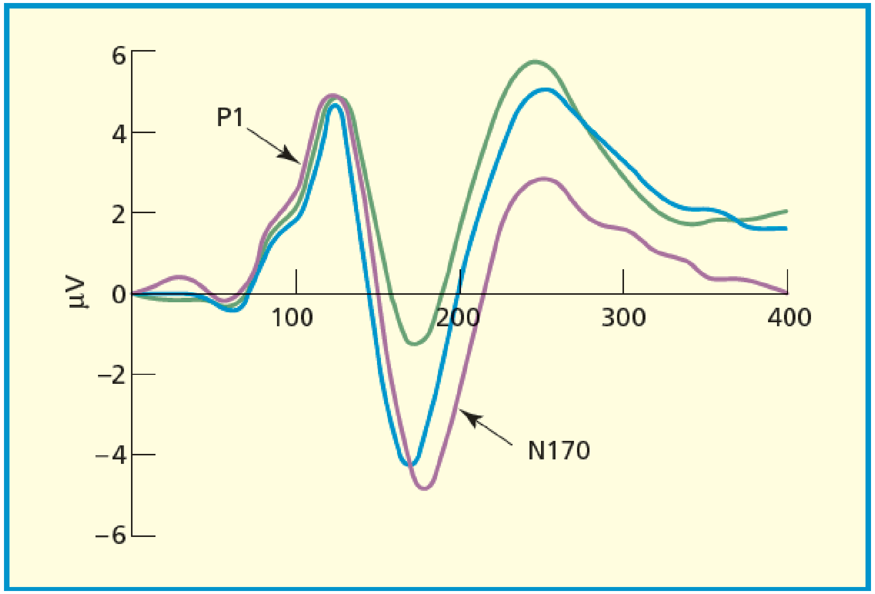
- ERP signal is directly related to neural activity conducted instantaneously to the scalp → excellent *temporal resolution*

- ERP signal on the scalp is (often) a sum of signals from different brain sources whose locations are difficult to infer → poor *spatial resolution*



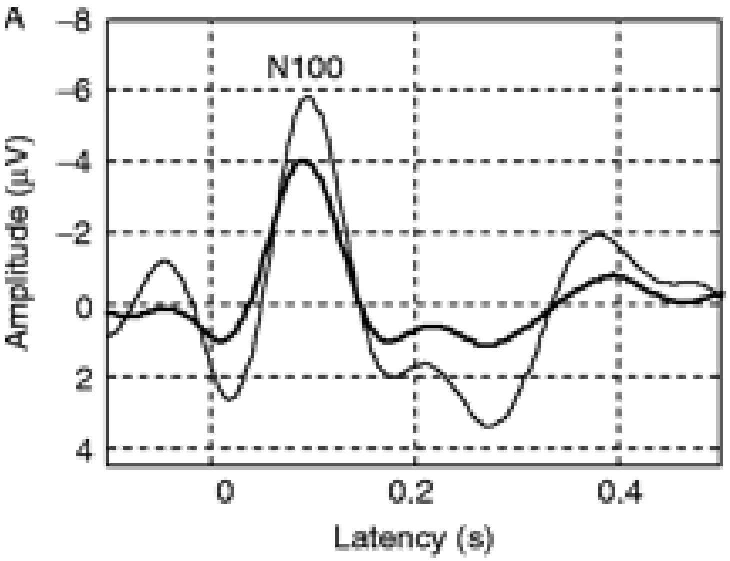
Some ERP components

- The N170 is relatively specialized for faces



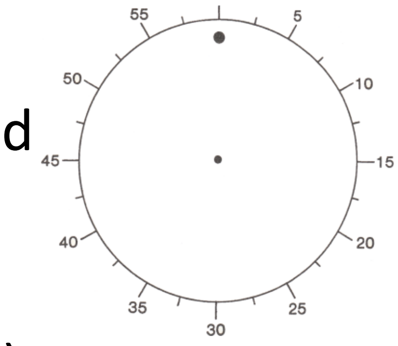
Responses from a temporal electrode for human faces (purple), animal faces (blue) and other objects (green) (Bentin et al, 1996)

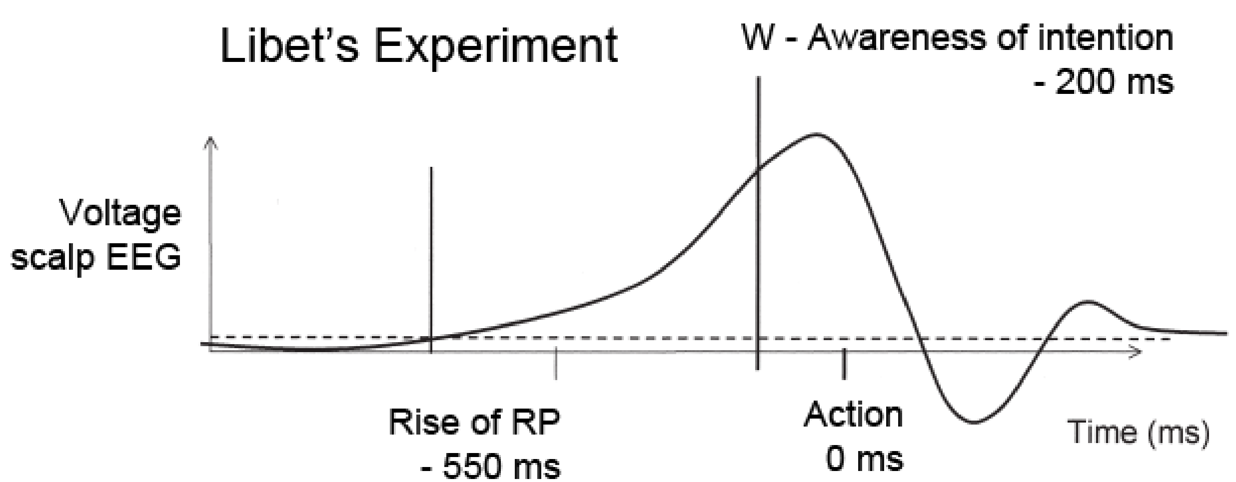
- The N100 response to sounds from the auditory cortex



How can consciousness be studied?

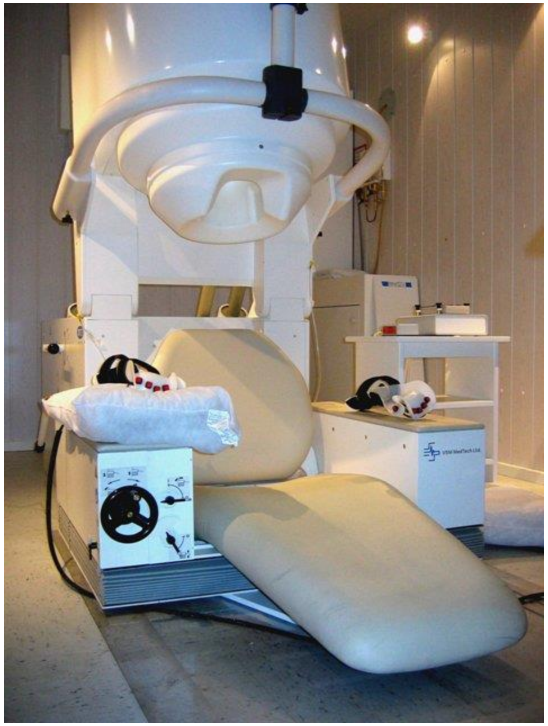
- Benjamin Libet's 1983 experiment
  - Subjects asked to move a wrist at an arbitrary time and report when they made the decision to move(by noticing the position of a dot circling a clock face)
  - Brain activity also recorded ('readiness potential' = RP)
  - brain activity started 350 ms before the decision → conscious wish is the outcome of unconscious activity ?





http://www.informationphilosopher.com/solutions/scientists/libet/clock.html

Recording electro-magnetic activity of populations of neurons



Magnetoencephalography (MEG) – recording of magnetic fields produced by electrical currents in the brain using arrays of SQUIDs (superconducting quantum interference devices)

MEG	EEG/ERP
Signal unaffected by skull, meninges, etc.	Signal affected by skull, meninges, etc.
~~Poor at detecting deep dipoles~~	~~Detects deep and shallow dipoles~~
More sensitive to activity at sulci	Sensitive to gyri and sulci activity
Millisecond temporal resolution	Millisecond temporal resolution
Potentially good spatial resolution (2–3 mm)	Poor spatial resolution
Expensive and limited availability	Cheaper and widely available

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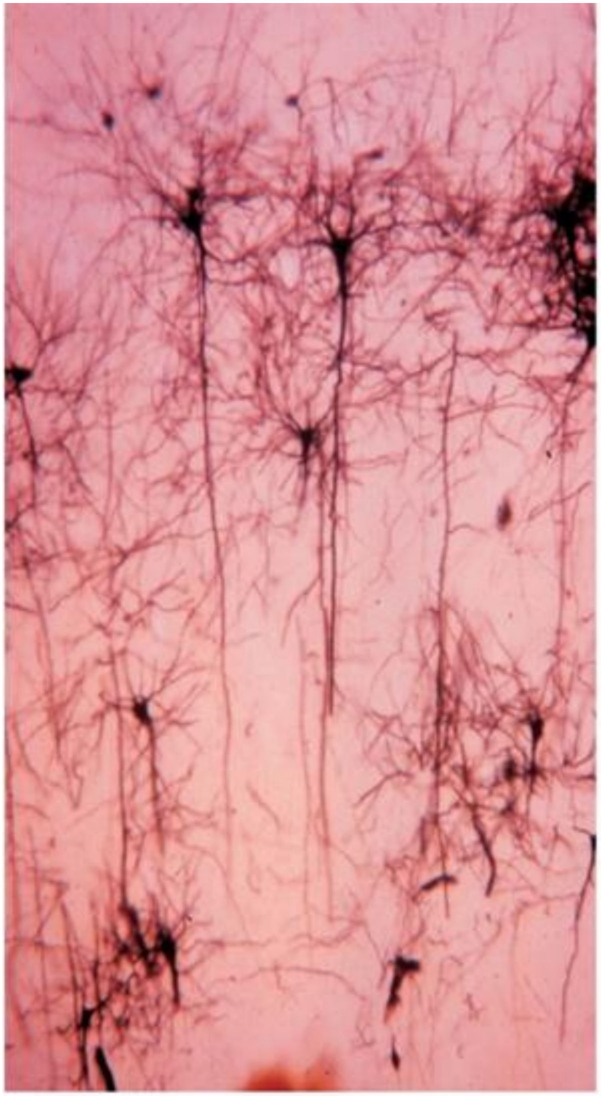
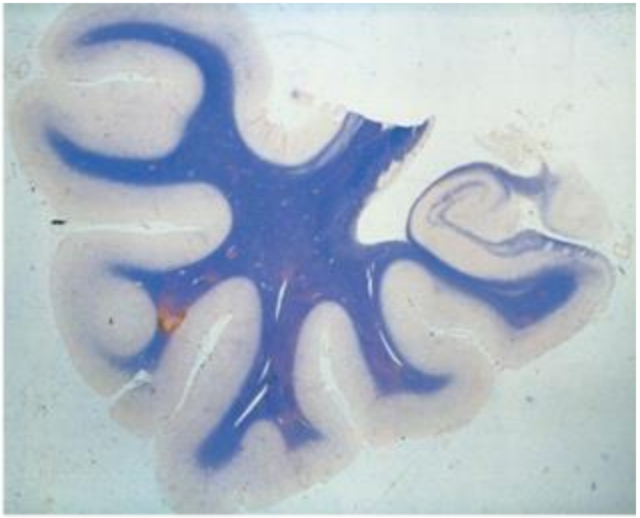
Imaging an individual neuron’s structure

- Neuronal staining techniques
- The Golgi stain method randomly stains about 5% of neurons, making them visible against the background of neural “chaos” (used by Ramon y Cajal to formulate ‘the Neuron Doctrine’)

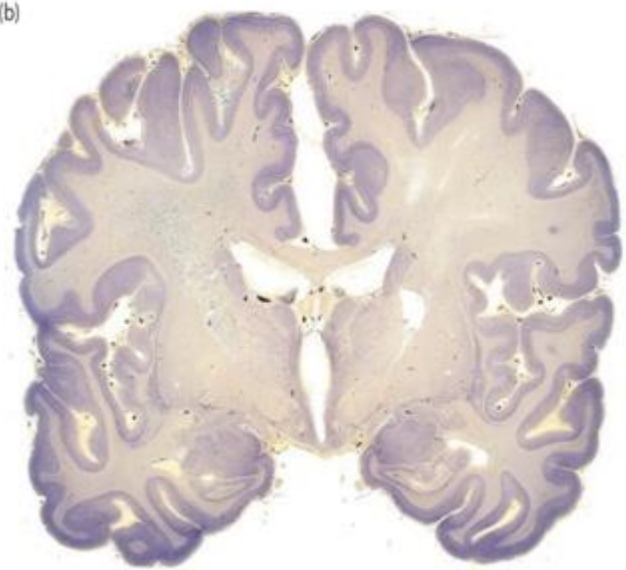


(a)

Imaging a population of neurons



(b)



(c)

- **Myelin stains** (top picture) are taken up by the fatty myelin that wraps neurons and thus identify neural (= axonal) pathways
- **Nissl stains** (bottom picture) identify cell bodies of neurons

Imaging the brain's structure: Structural Imaging

- **Structural imaging** uses the fact that different types of tissue (skull, gray matter, white matter, cerebrospinal fluid) have different physical properties in order to construct detailed <u>static</u> maps of the brain
  - Computerized tomography (CT scan)
  - Magnetic resonance imaging (MRI)

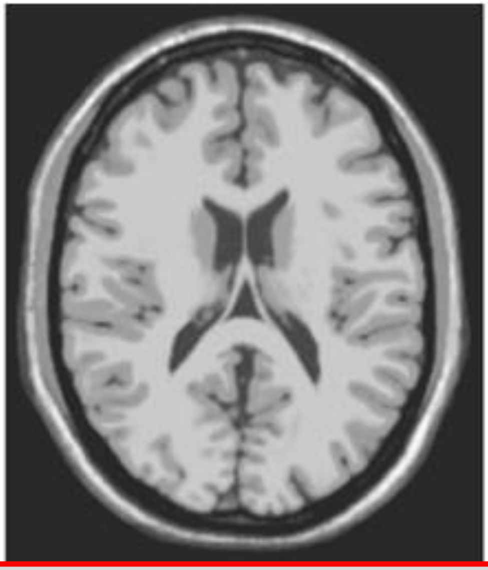
- *Limitations*: correlation does not mean causation; cause-and-effect directionality unknown (Did the behaviour result into or was caused by the brain abnormality?)

Structural Imaging: CT

- **Computerized Tomography**
  - A dye is injected into the blood
  - A series of X-rays is sent out from different angles
  - A computer combines the X-rays into a series of horizontal sections of the brain
- CT is based on the fact that X-ray (i.e. radiation) absorption varies with the tissue density
  - Bone absorbs the most (appears white)
  - Cerebrospinal fluid absorbs the least (black)
  - Gray and white matter is intermediate (gray)

Structural Imaging: MRI

- **MRI** (magnetic resonance imaging):
  - a strong magnetic field (= magnetic pulse) is applied and then ceased
  - the energy released by molecules in the tissue as a result of the pulse is measured; differently charged molecules respond differently to the pulses, hence the energy signals reveal brain structures with different molecular composition (e.g., clearly shows brain hemorrhage)
  - brain images are plotted on the basis of such measurements



MRI & CT scans reveal little about the **function** of different areas of the brain

Imaging the brain’s activity: Functional imaging

- Functional imaging is designed to measure the moment-to-moment variable characteristics of the brain associated with changes in cognitive processing

- Functional imaging methods:
  - Positron Emission Tomography (PET)
  - Functional Magnetic Resonance Imaging (fMRI)

Functional Imaging: fMRI

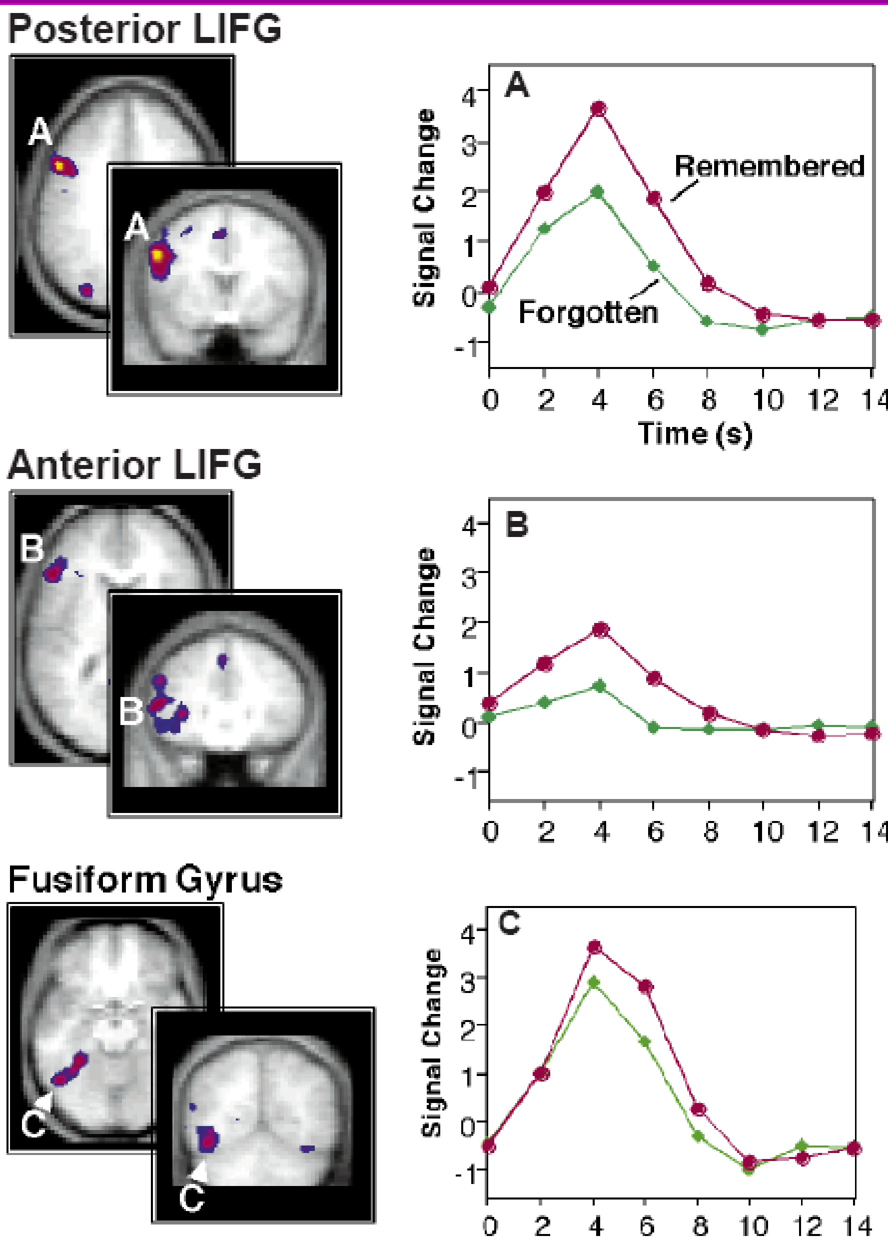
- **fMRI (functional Magnetic Resonance Imaging)**
- measures brain activation by detecting the increase in oxygen levels in active neural structures
  - Active neurons consume oxygen and convert oxyhemoglobin into deoxyhemoglobin

- Measures the concentration of (de)oxyhemoglobin in the blood – this called the BOLD response (Blood Oxygen Level Dependent contrast)
- The change in BOLD response over time is called the *hemodynamic response function*
- The Hemodynamic Response Function peaks in 6–8 seconds, which limits the temporal resolution of fMRI

Building Memories (Wagner et al 1998)

Functional MRI of word processing:

The indicated areas were more active when participants were processing words that they later remembered than when they processed words that were not remembered (Wagner et al, 1998)



Functional Imaging: PET

- **Positron Emission Tomography (PET)**
- Measures local blood flow into a brain region
- Radioactive tracer injected into blood stream
- Tracer takes up to 30 seconds to peak

PET	fMRI
• Based on blood volume	• Based on blood oxygen concentration
• Involves radioactivity (signal depends on radioactive tracer)	• No radioactivity (signal depends on deoxy-hemoglobin levels)
• [redacted]	• [redacted]
• Temporal resolution = 30 seconds	• Temporal resolution = 1–4 seconds
• Effective spatial resolution = 10 mm	• Spatial resolution = 1 mm
• [redacted]	• [redacted]
• Sensitive to the whole brain	• Some brain regions (e.g. near sinuses) are hard to image
• [redacted]	

Ward (2011)

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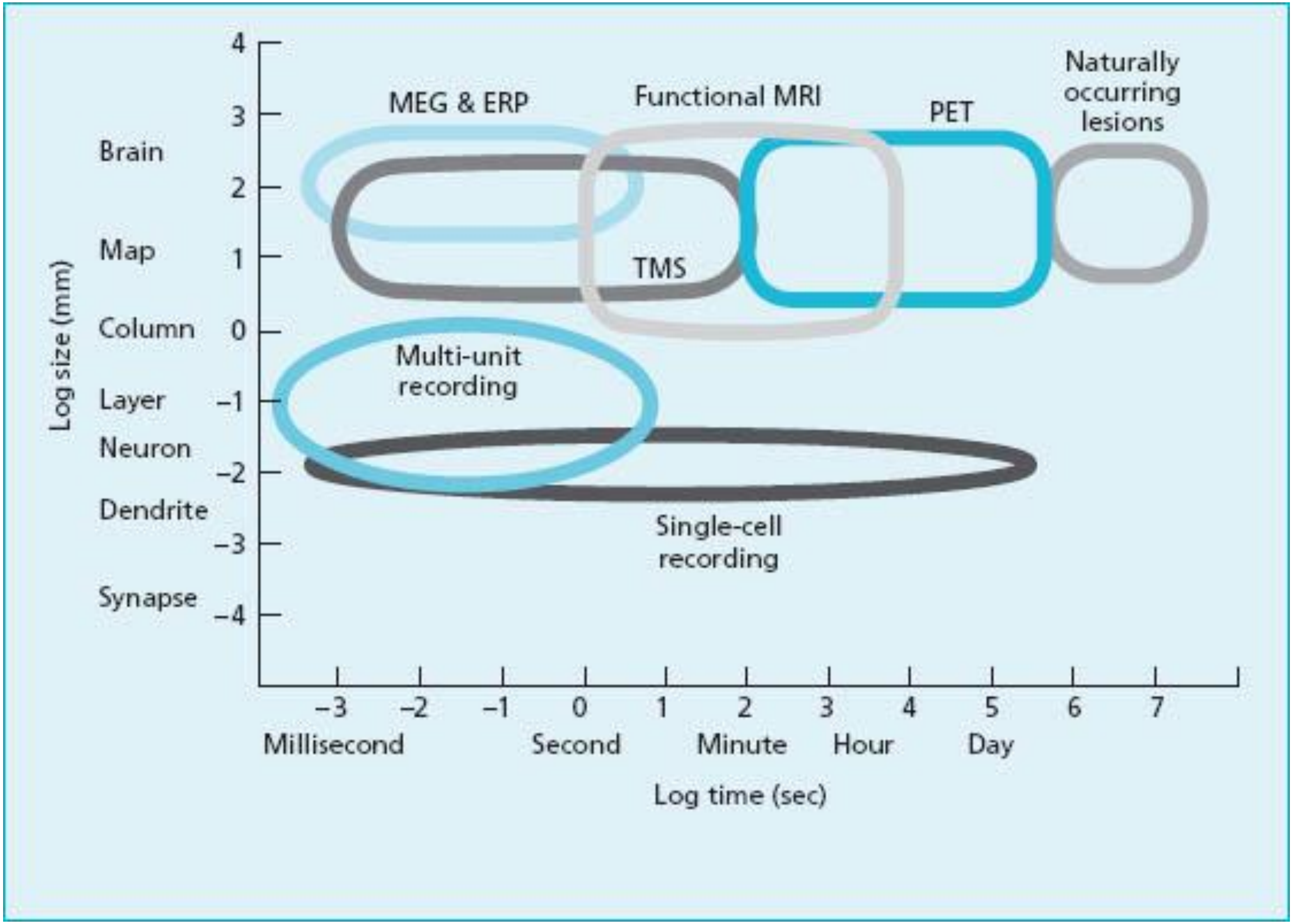
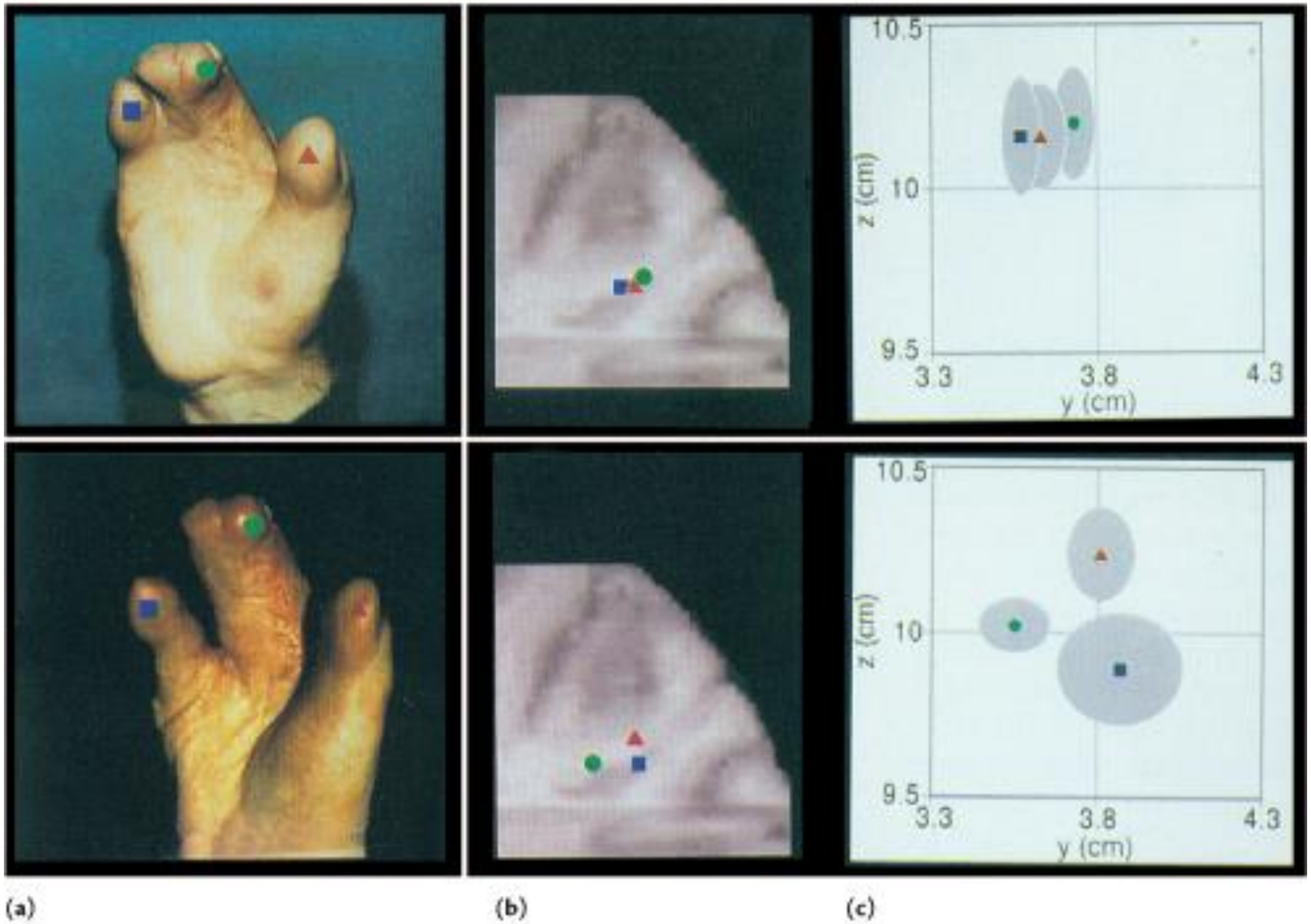
Summary of methods for investigating neurons and the brain



Brain plasticity: Syndactyly

FIGURE 3.26 Changes in the Somatosensory Area Following Surgery for Syndactyly.



(a) The hand before (top) and after (bottom) surgery. (b) Images (coronal) showing brain areas responsive to stimulation of the fingers before and after surgery. (c) Graphic representation of the relative size and location of the responsive areas.

SOURCE: From "Somatosensory Cortical Plasticity in Adult Humans Revealed By Magnetoencephalography," by A. Mogilner et al., 1993, *Proceedings of the National Academy of Science*, 90, pp. 3593–3597.

- Syndactyly – a condition in which fingers are connected by skin tissue
- Finger representations become separate already within 7 days after surgery

Brain plasticity: Phantom pain

- Phantom Pain: 80% to 90% of amputees experience phantom in the missing limb
- In these individuals neurons from other body areas invade the area that normally receives input from the missing limb
- Therapies that relieve phantom pain prevent or reverse this reorganization
  - Using a functional prosthesis or the mirror box illusion reverses the cortical reorganization and provides pain relief.
  - The mirror box effect: activates mirror neurons in the area that once served the missing limb; this activity is interpreted as real touch and movement, and this stimulates reorganization

Flor et al., 1995, *Nature*

The symbols represent the location of sensitivity to touch of the fingers (squares) and the lips (circles); black symbols are from a patient with phantom pain and white symbols from a patient without phantom pain. By looking at the homunculus superimposed on the left hemisphere (opposite the intact arm), you can see that the circles and the squares are in their normal locations. In the right hemisphere, opposite the amputated arm, lip sensitivity in the patient with the phantom pain (black circle) has migrated well into the area ordinarily serving finger sensitivity.

http://www.oregonlive.com/health/index.ssf/2009/12/post_25.html

Selected readings

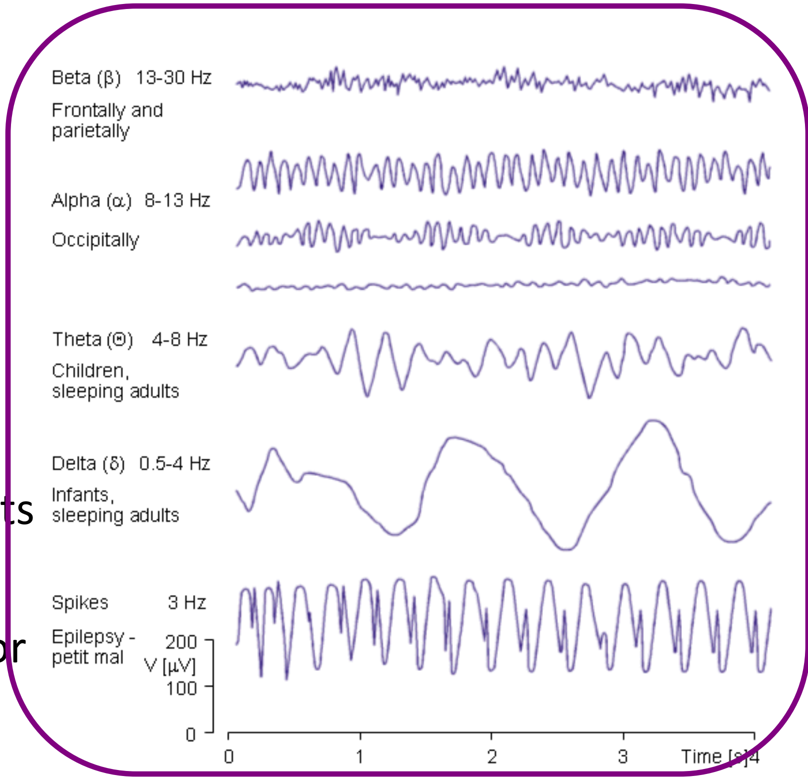
- SGW, chapter 3
- Kalat, module 4.3 'Research methods' from chapter 4
- Garrett, B. (2011) "Brain & behaviour", 3rd edition. SAGE Publications (or previous editions)
  - Chapter 4 "The methods and ethics of research"
- Ward, J. (2006). The student's guide to cognitive neuroscience. *Hove and New York*.

References:

- Cohen, L. G., Celnik, P., Pascual-Leone, A., Corwell, B., Faiz, L., Dambrosia, J., ... & Hallett, M. (1997). Functional relevance of cross-modal plasticity in blind humans. *Nature*, *389*(6647), 180-183.

For the curious: Basic EEG rhythms

- **Delta (.5-4 Hz),** most prominent frontally in adults & posteriorly in babies
  - seen normally in babies and in sleeping adults
- **Theta (4 -7 Hz),** seen normally in young children; in drowsiness or arousal in older children and adults or in meditation
  - excess theta for age represents abnormal activity (e.g. due to focal subcortical lesions)
- **Alpha (8-12 Hz),** bilaterally in the posterior regions (higher on the dominant side)
  - emerge with closing of the eyes and with relaxation and attenuate with eye opening or mental exertion
  - abnormally diffused and not responsive to external stimuli alpha in coma
- **Beta (12-30 Hz)** , most evident frontally; linked to motor behavior -attenuated during active movements
  - absent or reduced in areas of cortical damage
  - the dominant rhythm in patients who are alert or anxious or who have their eyes open



- **Gamma (30-100 Hz)** , represent binding of different populations of neurons together into a network for the purpose of carrying out a certain cognitive or motor function