Cognitive Neuroscience for AI Developers

Week 02 1/2 – Methods of Cognitive Neuroscience: Lesioning

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FACULTY OF ENGINEERING

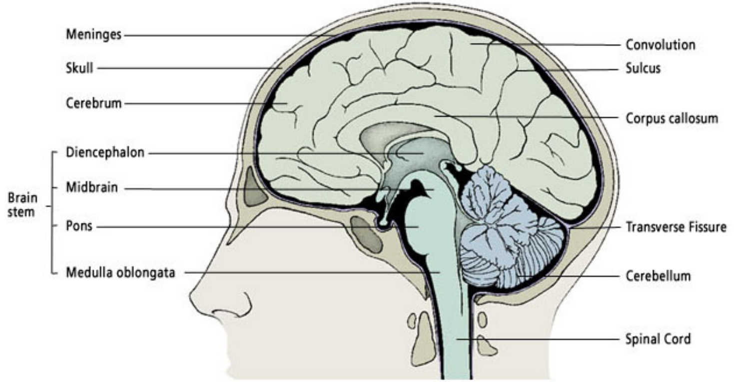
Lesion studies in general

But first: Very brief overview of brain anatomy

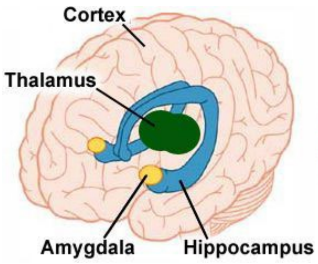
in detail: later lecture

- **peripheral nervous system**: transforms environmental stimuli into neuronal signal (-> spinal chord -> brain)
- **Brainstem**: pre-processing of the signal coming from periphery
- **Thalamus**: controls which signal is transmitted to cortex
- **Cortex**: Higher processing an perception: conscious perception, voluntary movements, language, math reading, memory storage and retrieval
- **Hippocampus**: spatial orientation, memory formation and distribution
- Brain is (nearly) mirror symmetrical
- **Corpus callosum**: nerve fibers connecting both hemispheres (especially cortex areas)

The Major Portions of the Brain Include the Cerebrum, Cerebellum and Brain Stem



https://www.atlantabrainandspine.com/brain-anatomy/



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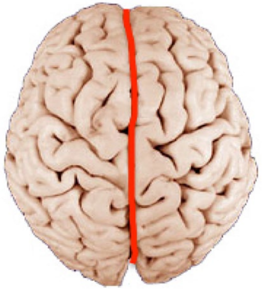

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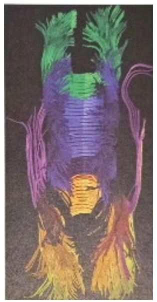


Cognitive neuroscience, Gazzaniga, Ivry, Mangun, 2014

Lesion studies

In general:

- to draw conclusions about function of a certain part of the brain by studying impairment / functional deficit caused by damage to this brain part
- Some kind of „reverse engineering" -> what can brain do without certain parts

Lesions e.g. due to

- injuries after accidents
- Disorders
- **surgeries** to treat e.g. epilepsy

Brain Disorders:

Vascular disorders

- Stroke: Bloodflow stops cause of occlusion of arteries
- Cerebral hemorrhage

Tumors

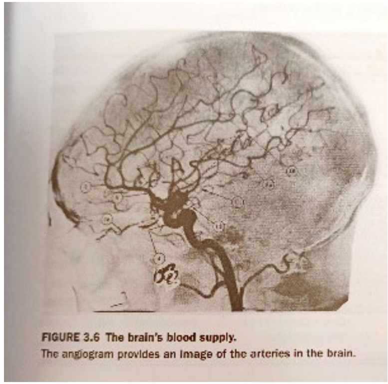
- Abnormal growth of tissue with no function (most caused by glial cells, benign, malignant)

Degenerative disorders

- E.g. Huntington disease, Alzheimer's disease, AIDS

Examples for brain disorders

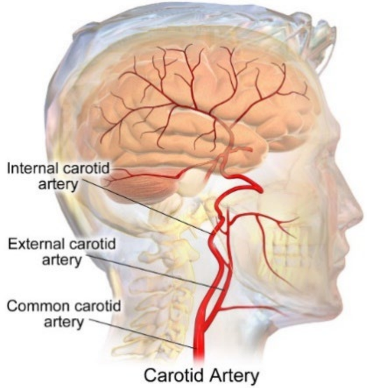
Vascular disorders:



Cognitive neuroscience, Gazzaniga, Ivry, Mangun, 2014

Blood supply of the brain: Angiography

- Injection of dye
- X-ray study



https://en.wikipedia.org/wiki/Internal_carotid_artery

- Stroke: occlusion of arteries
- Cerebral hemorrhage: breakage of blood vessels (e.g. high blood pressure)

Examples for brain disorders

<u>Degenerative disorders:</u>
2 examples

Alzheimer's disease
- Atrophy of the cerebral cortex and hippocampus
- Reason: unknown

Huntington disease
- Genetic
- Atrophy interneurons

MRI scan (Alzheimer's disease)

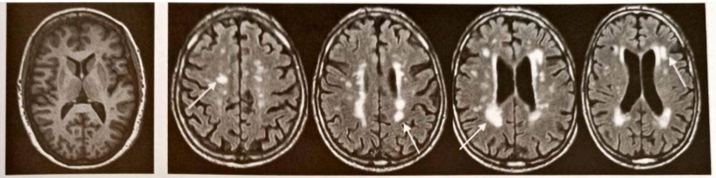


FIGURE 3.8 Degenerative disorders of the brain.
(a) Normal brain of a 60-year-old male. (b) Axial slices at four sections of the brain in a 79-year-old male with Alzheimer's disease. Arrows show growth of white matter lesions.

Cognitive neuroscience, Gazzaniga, Ivry, Mangun, 2014

Disorder	Type	Most Common Pathology
Alzheimer's disease	Degenerative	Tangles and plaques in limbic and temporoparietal cortex
Parkinson's disease	Degenerative	Loss of dopaminergic neurons
Huntington's disease	Degenerative	Atrophy of interneurons in caudate and putamen nuclei of basal ganglia
Pick's disease	Degenerative	Frontotemporal atrophy
Progressive supranuclear palsy (PSP)	Degenerative	Atrophy of brainstem, including colliculus
Multiple sclerosis	Possibly infectious	Demyelination, especially of fibers near ventricles
AIDS dementia	Viral infection	Diffuse white matter lesions
Herpes simplex	Viral infection	Destruction of neurons in temporal and limbic regions
Korsakoff's syndrome	Nutritional deficiency	Destruction of neurons in diencephalon and temporal lobes

Cognitive neuroscience, Gazzaniga, Ivry, Mangun, 2014

Famous examples of lesion studies and consequences

Lesion studies:
What we can learn from brain injuries

Source: wikipedia.org

- Phineas Gage 1823-1860

- American railroad construction foreman

- 1848 Gage survived a fatal accident
- large iron rod completely driven
  through his head,
- destroying brain's **left frontal lobe**,
- dramatic changes in **personality and behavior**

Source: wikipedia.org

His friends said: Gage is “no longer Gage“ !

Lesion studies:
What we can learn from brain injuries

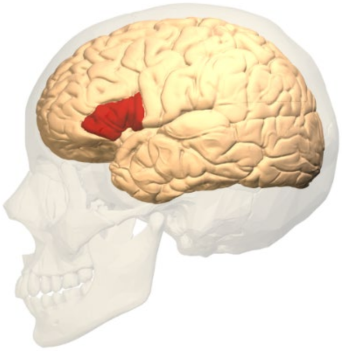
Source: wikipedia.org

Pierre Paul Broca (1824-1880)
French physician, anatomist and anthropologist

- 1861 he reported impairments in one patient (named 'Tan')
- Tan could understand language
- lost the **ability to speak** after injury to the **left posterior inferior frontal gyrus**

-> tan was only word he could say

-> brain region was named Broca's area (important for speech production)



Source: wikipedia.org

Lesion studies:

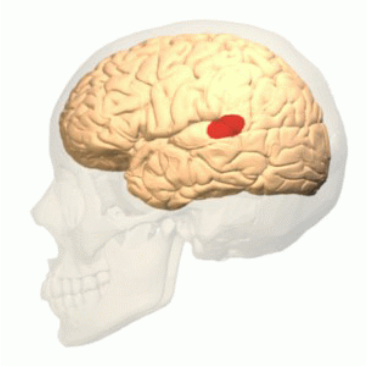
What we can learn from brain injuries

Source: wikipedia.org

Carl Wernicke (1848-1905)
German physician, anatomist, psychiatrist and neuropathologist

study of receptive aphasia (1876):

- impaired **comprehension of written and spoken language** after injury to the **left superior temporal gyrus**
- However he could speak (made no sense)



Source: wikipedia.org

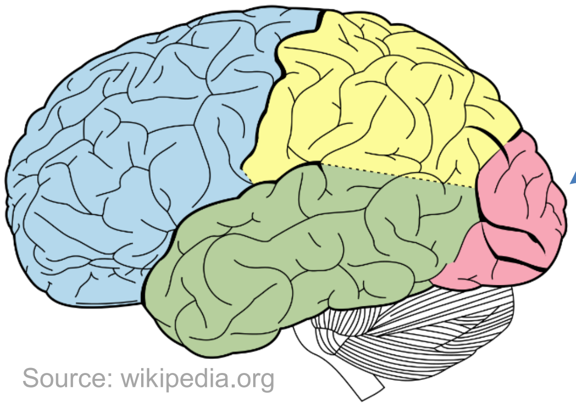
-> Wernickes‘s area (important for speech comprehension)

Lesion studies:

What we can learn from brain injuries

Cortical blindness

total or partial loss of **vision** in a normal-appearing eye caused by damage to the **occipital cortex**



Source: wikipedia.org

- Inability to report visual stimuli
- But however sometimes people behave as if the have seen the object
- People report to see nothing but are able to point towards the stimulus

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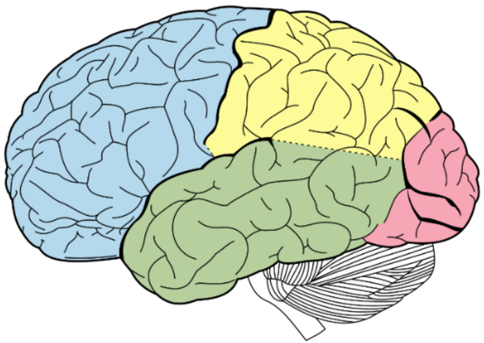
Lesion studies:
What we can learn from brain injuries



Source: wikipedia.org

Cortical blindness

How is this possible?

- 10 different pathways from eye to the brain have been identified (most important pathway superior colliculus, lateral geniculate body, V1)
- Other routes are evolutionary more ancient
- These routes were not removed but further routes were added

Lesion studies

(brain surgeries, epilepsy)

Epilepsy:

- Abnormal hyperactivity in the brain
- Leads to seizures -> loss of consciousness, shaking…
- Were often treated by lobectomies…. (lobectomy: resection of cortical lobe)
- After lobectomy -> scientific evaluation of the effects

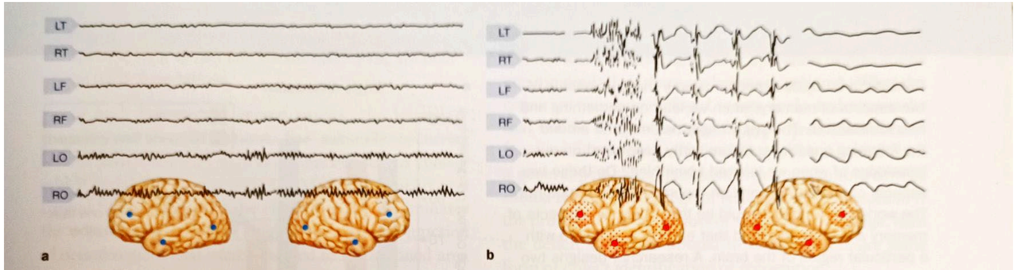
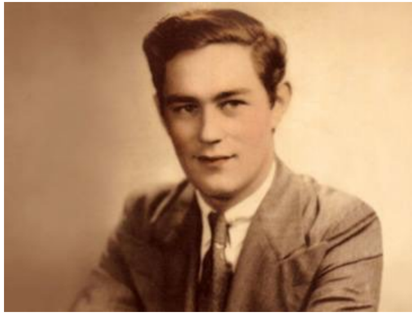


FIGURE 3.11 Electrical activity in a normal and epileptic brain. Electroencephalographic recordings from six electrodes, positioned over the temporal (T), frontal (F), and occipital (O) cortex on both the left (L) and the right (R) sides. **(a)** Activity during normal cerebral activity. **(b)** Activity during a grand mal seizure.

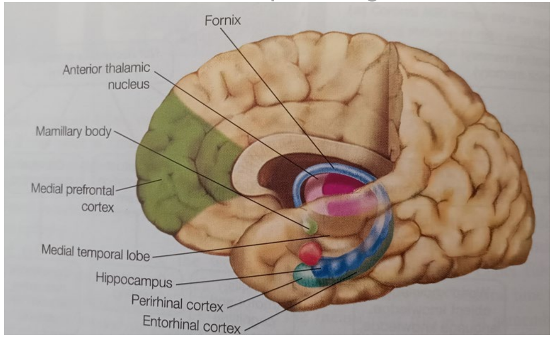
Cognitive neuroscience, Gazzaniga, Ivry, Mangun, 2014

Lesion studies:

What we can learn from brain surgeries



Source: wikipedia.org



Cognitive neuroscience, Gazzaniga, Ivry, Mangun, 2014

Henry Gustav Molaison, known widely as patient **H.M.**
1926-2008

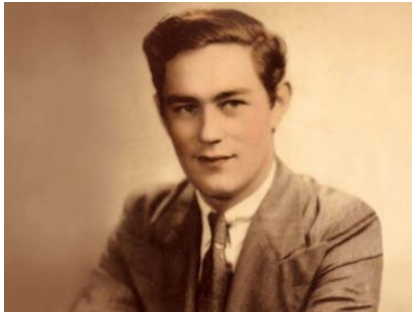
In 1953: bilateral medial temporal lobectomy:
surgical resection of the anterior two thirds of his hippocampi, parahippocampal cortices and entorhinal cortices
in an attempt to cure his epilepsy

Surgery was successful in controlling his epilepsy
severe side effect: he became unable to form new memories

H.M. was widely studied from late 1957 until his death in 2008

Lesion studies:

What we can learn from brain surgeries



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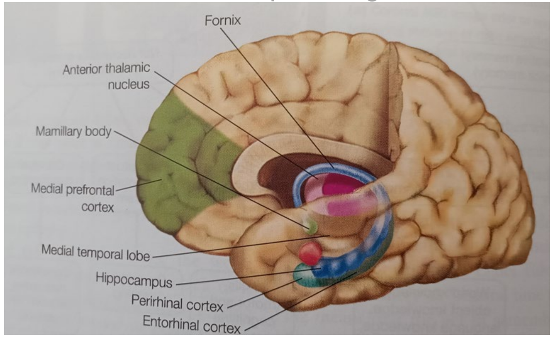


Cognitive neuroscience, Gazzaniga, Ivry, Mangun, 2014

His case played an important role in:

- development of theories that explain the link between brain function and memory
- development of cognitive neuropsychology branch of psychology that aims to understand how the structure and function of the brain relates to specific psychological processes

- Unable to form new explicit memories: experiences
- Only short-term memory of a few minutes
- Still able to learn new motor skills: playing an instrument

Lesion studies:

What we can learn from brain surgeries

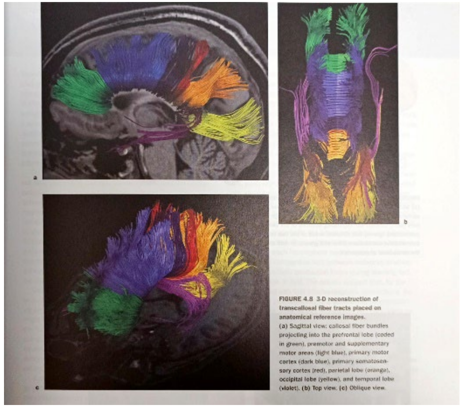
Source:
https://psych.ucsb.edu/people
/michael-gazzaniga

Michael Gazzaniga, Professor of psychology
born 1939

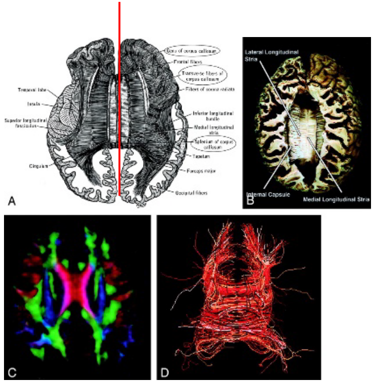
one of the leading researchers in cognitive neuroscience and the study of the neural basis of mind

Split-brain patients:
Dissection of the corpus callosum to treat epilepsy

-> Patient W.J.



Cognitive neuroscience, Gazzaniga, Ivry, Mangun, 2014



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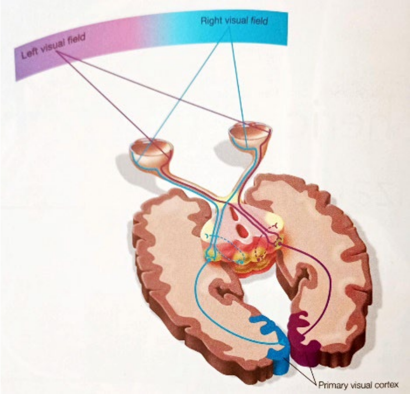
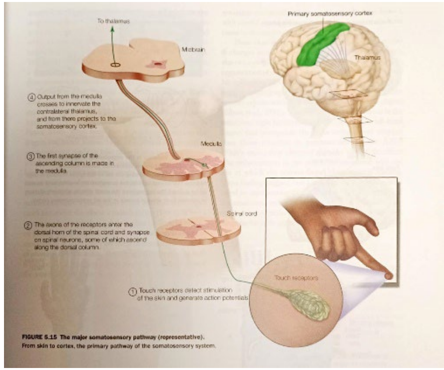
Cut brain along medial longitudinal fissure

Patient W.J.

- World War II paratrooper who got hit in the head with a rifle butt, after which he started having seizures
- Before his operation to try to fix the seizures, Gazzaniga tested his brain functions
- presenting stimuli to the left and right visual fields and identifying objects in his hands that were out of view. W.J. was able to perform these tasks perfectly
- -> Dissection of the corpus callosum

Important: sensory and motor pathways cross in the brain
-> right visual field, right hand input -> processed in left cortex
-> left cortex controls right hand





Cognitive neuroscience, Gazzaniga, Ivry, Mangun, 2014

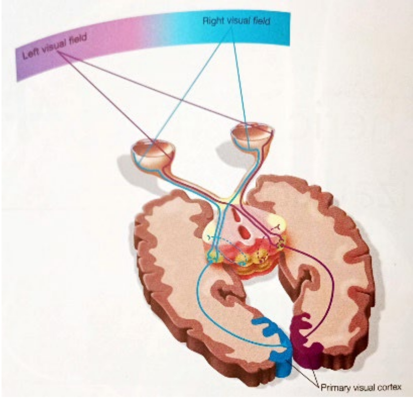
Patient W.J.

- After surgery: both hemispheres could not communicate with each other
- stimuli presented to the right visual field: could verbally report what he had seen
- stimuli presented to the left visual field: could not verbally report but press left button (right hemisphere)

-> lateralization of brain functions -> later in lecture

- conflicts between the hemispheres: left hand opens a door, right hand tries to stop left hand

Cognitive neuroscience,
Gazzaniga, Ivry, Mangun, 2014



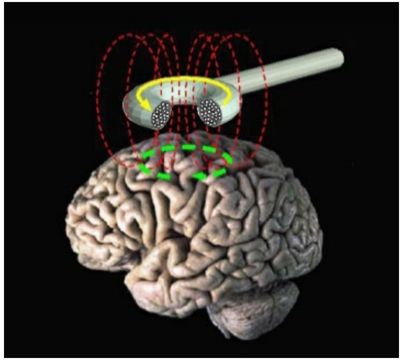

Source: wikipedia.org

Antonio Damasio, Professor of psychology, philosophy, neurology
born 1944

- Created world‘s largest data base of brain injuries
- Identified brain regions crucial to maintain different degrees of consciousness
- Explores relationship between brain and consciousness
- Developed his own theory how consciousness emerges in the brain
- Damasio's research in neuroscience has shown that emotions play a central role in social cognition and decision-making

Non-invasive lesion studies

Non-invasive, transient lesioning: Transcranial magnetic stimulation (TMS)



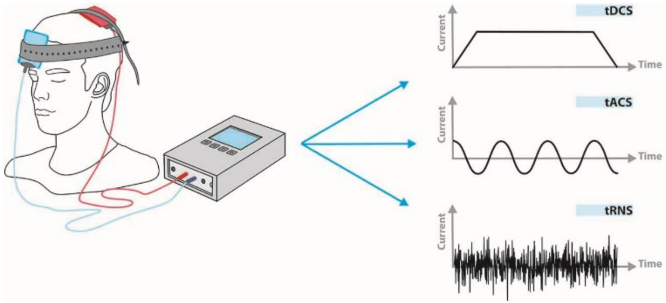
Source: wikipedia.org

- changing magnetic field used to cause electric current at a specific area of the brain through electromagnetic induction
- electric pulse generator connected to a magnetic coil, which is connected to the scalp
- stimulator generates changing electric current within the coil which induces a transient magnetic field
- magnetic field causes a second inductance of inverted electric charge within the brain itself -> hyperactivity -> area temporally switched off due to refractory period
- exact mechanisms of neural discharge not well understood
- used clinically to measure function of specific brain circuits in humans
- e.g. used to treat tinnitus

Non-invasive, transient lesioning:
Transcranial direct current stimulation (tDCS)

- Already the old Greeks used this method (electric torpedo fish) to numb people during and to alleviate pain during birth
- Today: two small electrodes (1-2mV)
- Neurons below the anode become depolarized -> more excitable
- Neurons below cathode become hyperpolarized -> less excitable
- Used to treat neurological conditions (e.g. chronic pain)

-> huge advantage of tDCS and TMS: people are their own control group



https://www.frontiersin.org/files/Articles/235394/fnhum-11-00159-HTML/image_m/fnhum-11-00159-g001.jpg

Lesion studies in animal experiments

- Frequently performed in animal experiments with cats or rodents
- Provides opportunity to systematically compare different lesions
- To draw conclusions about function of certain parts of the brain

Lesion studies in AI

PLOS | COMPUTATIONAL BIOLOGY

RESEARCH ARTICLE

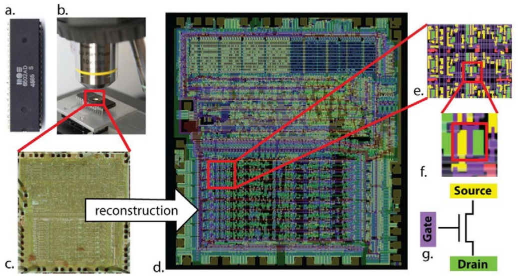
Could a Neuroscientist Understand a Microprocessor?

Eric Jonas[1]*, Konrad Paul Kording[2,3]

Jonas, E., & Kording, K. P. (2017). Could a neuroscientist understand a microprocessor?. *PLoS computational biology*, *13*(1), e1005268.

Lesion studies in AI

- Emulated micro-processor (MOS 6502) as model system -> used for Apple I, Commodore 64, Atari Video Game system
- Behavior of the model system -> Donkey Kong, Space invaders, Pitfall
- Perform experiments on this model



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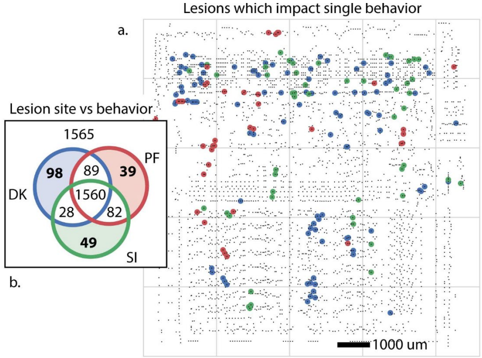
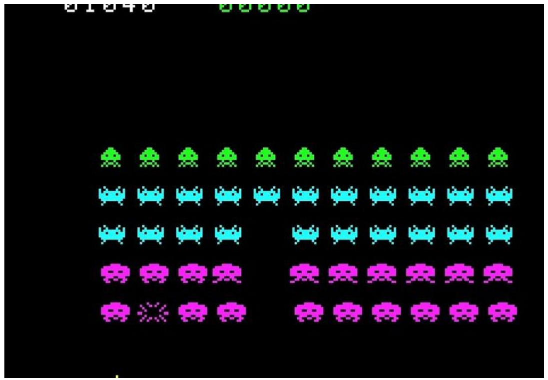


- Lesion each transistor individually
- In some cases the games do not boot



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https://www.spiegel.de/geschichte/30-jahre-space-invaders-a-947371.html

Lesion studies in AI

- In contrast to biological brains, AI systems can be completely read out
- Location and expansion of lesion can be controlled

- Lesioning of individual neurons, connections or layers to reverse-engineer function of an artificial deep neural network

- However if lesion studies are the right way to unravel the brain/AI is questionable

PLOS | COMPUTATIONAL BIOLOGY

RESEARCH ARTICLE

Could a Neuroscientist Understand a Microprocessor?

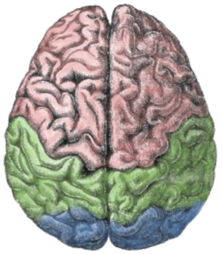
Eric Jonas[1]*, Konrad Paul Kording[2,3]

No!

Cognitive Neuroscience for AI Developers

Week 02 2/2 – Lateralization of Brain Function

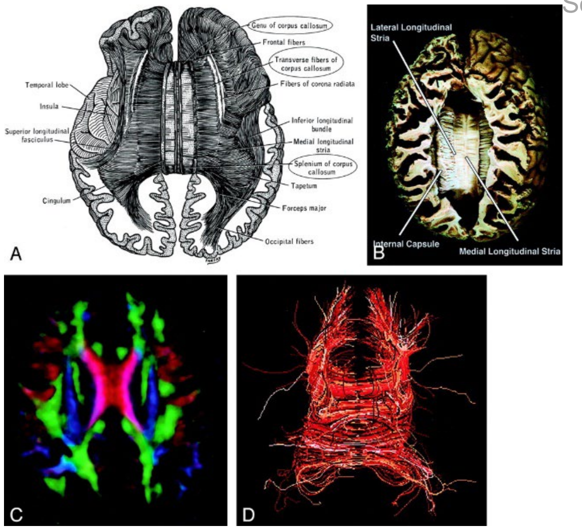
Lateralization of Brain Function



Source: wikipedia.org

Reminder:

- Each part of the brain exists twice: left and right side (except glands and corpus callosum)
- Cerebral Cortex: left and right hemisphere
- Corpus Callosum connects both **cortical** hemispheres
- Left hemisphere represents right side of the body and vice versa



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Lateralization of Brain Function

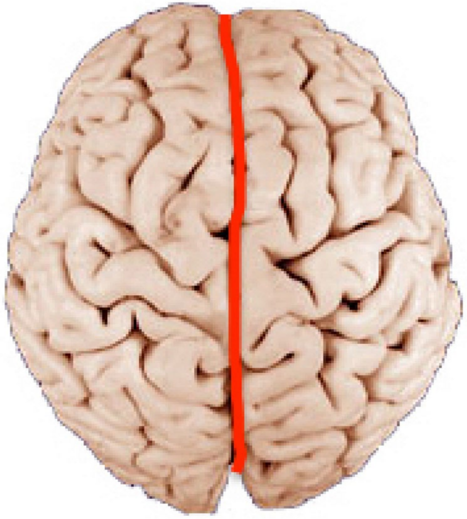
- **Lateralization**:
  - tendency for neural functions or cognitive processes to be specialized to one side of the brain
  - homologue cortex areas at both sides have different functions

- Best example is language:
  Broca‘s and Wernicke‘s area located exclusively in left hemisphere
  in 95% of right-handers and 70% of left-handers

Anatomical asymmetries

Left hemisphere shows:

- larger total specific gravity
- larger insular cortex
- larger gray matter (neurons‘ cell bodies) fraction
- larger inferior temporal lobe
- larger primary sensory areas
- smaller association areas

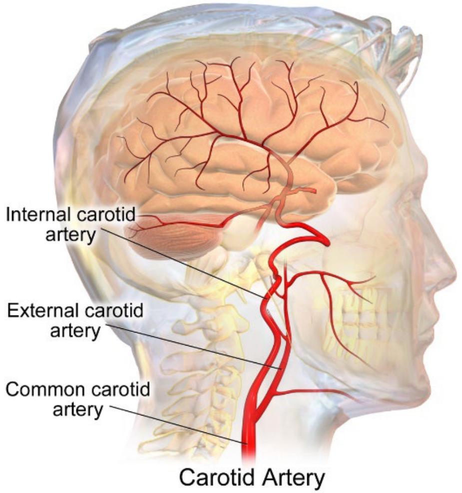


https://www.mdpi.com/2227-7080/5/2/16

Functional asymmetries - Methods

Reminder:

- neurological and neuropsychological studies of effects of brain injury (**lesions**) on cognitive abilities
- since the 1960s **split-brain patients**:
  connection between hemispheres surgically removed
- **Wada test**: hemispheres reversibly blocked:
  - Injection of amobarbital into carotid artery -> deep anesthesia of ipsilateral brain hemisphere



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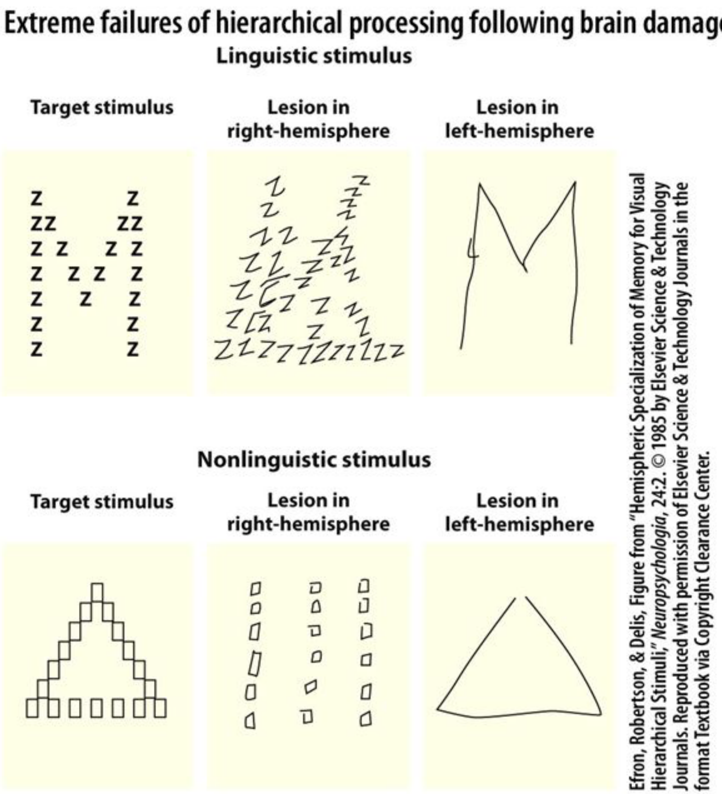
Wada test was used to evaluate the strong bias of language processing to the left hemisphere



- **Unilateral cortical lesion**
- Hierarchical stimulus: Letter or sign made of several letter or signs
- Lesion left: drawing only the big contours
- Lesion right: drawing only local elements
- **Right hemisphere:** extraction of big picture
- **Left hemisphere:** more detail oriented

Functional asymmetries

Left hemisphere:

- Language: Word detection/generation
- Verbal
- Right visual field
- Right body motor control
- Reading
- Problem solving
- **Sequential processing** (math…)
- **Analytic**

Right hemisphere:

- Melody, Pitch, Intensity
- Non-verbal
- Left visual field
- Left body motor control
- Drawing, **face recognition**
- Visio-spatial tasks
- Parallel processing

Theory of mind

- **Theory of mind refers to our ability to understand that other individuals have thoughts, beliefs and desires**

- When lateralized at all -> to the right side

- **Shocking finding:** if information of beliefs of others is in right hemisphere and in split brain people is not transferred to left hemisphere (speaking)

  -> that would have an huge effect on moral reasoning -> was not found

- Also left hemisphere can do processing needed for belief attribution (but slow)

The interpreter

- We know: **Causal inferences are a specialized ability of left hemisphere**

  -> left hemisphere is the interpreter

- In split brain patients: left hemisphere tries to find explanations for actions initiated by right hemisphere
- Example 1: „stand up“ presented to right hemisphere

  -> person stands up

  -> ask person „Why did you stand up?“

  -> left hemisphere creates plausible explanations „I wanted a coke“

- Example 2: ”Why are you upset?” -> “The experimenter upsets me!”

Split brain patients and consciousness

- **Split-brain patients do not report differences in conscious experiences!**
- Left brain hemisphere acts like there was never a right hemisphere
- Perhaps consciousness is not a single generalized process

  -> emergent property out of thousands of modules

  -> modules compete for attention
- *„This dynamic moment-to-moment cacophony of systems comprises our consciousness“ (from Cognitive Neuroscience, Gazzaniga)*
- However: We do not hear the chattering -> the interpreter is crafting this narrative
- Also explains **Anosognosia:** people with brain lesions are unaware of problems and deny that they have problems

-> *more on consciousness in later lecture*

Hemispheric specialization in Nonhumans

Chickens and pigeons:

Better discriminate food and non-food items presented to right eye
-> left hemisphere

Better respond to unique properties of objects (color, size, shape) and better learn exact localization of objects presented to left eye
-> right hemisphere

Birdsong: left hemisphere

Source: collinsdictionary.com

Source: collinsdictionary.com

Potential causes and advantages of lateralization

Computational Considerations I

- As there are many different theories: evolutionary….-> focus on comp. considerations
- Larger primary motor and sensory areas at left side
  -> enables higher resolution, more fine-grained representation
- Smaller association areas at left side
  -> enforces more compressed representation, focus on smaller patterns
- Smaller primary motor and sensory areas at right side
  -> enforces smaller resolution, more compressed representation
  -> left hand can be controlled in a less fine-grained way
- Larger association areas at right side
  -> enables to represent more, larger patterns

Computational Considerations II

- Left hemisphere: sequential-analytic processing
- Right hemisphere: holistic-parallel processing
- Hemispheric specialization may emerge because certain tasks benefit from one processing style or another
- Speech as a continuous stream: rapid segmentation into component parts
- Visual-Spatial representations: coherent whole, not just component parts

Computational Considerations III

Asymmetry may

- be a more efficient and flexible design principle
- reduce redundancy across hemispheres
- allow for no-cost extension: expands cortical capacity

Summary

- Research on laterality has provided important insights into brain function
- Split-Brain patients were valid to understand how perceptual and cognitive processes are distributed in the cortex
- Two hemisphere do not present information in identical manner
- In most people the left hemisphere is dominant for speech and language
- Left hemisphere has the ability to interpret events and to construct theories (the interpreter)
- Right hemisphere is important for facial recognition