Language and the Brain

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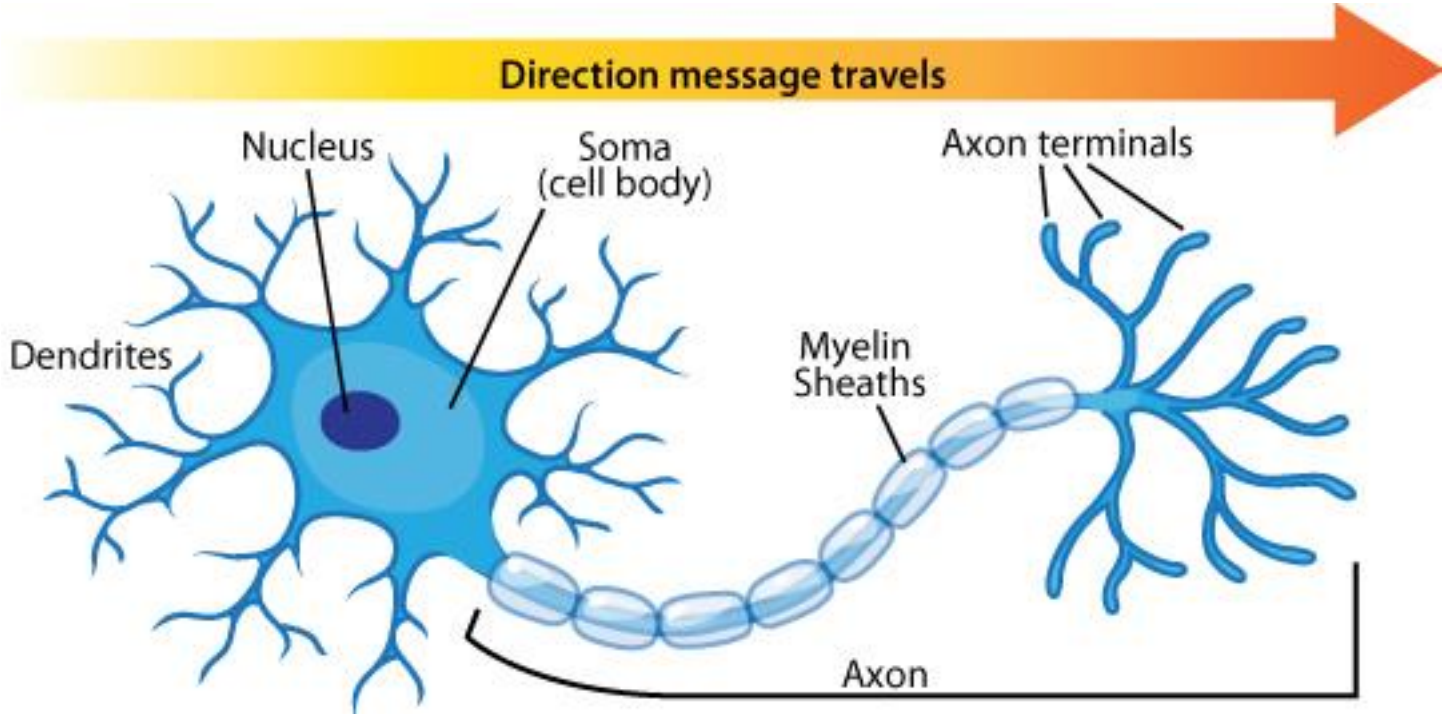
COGS 4780

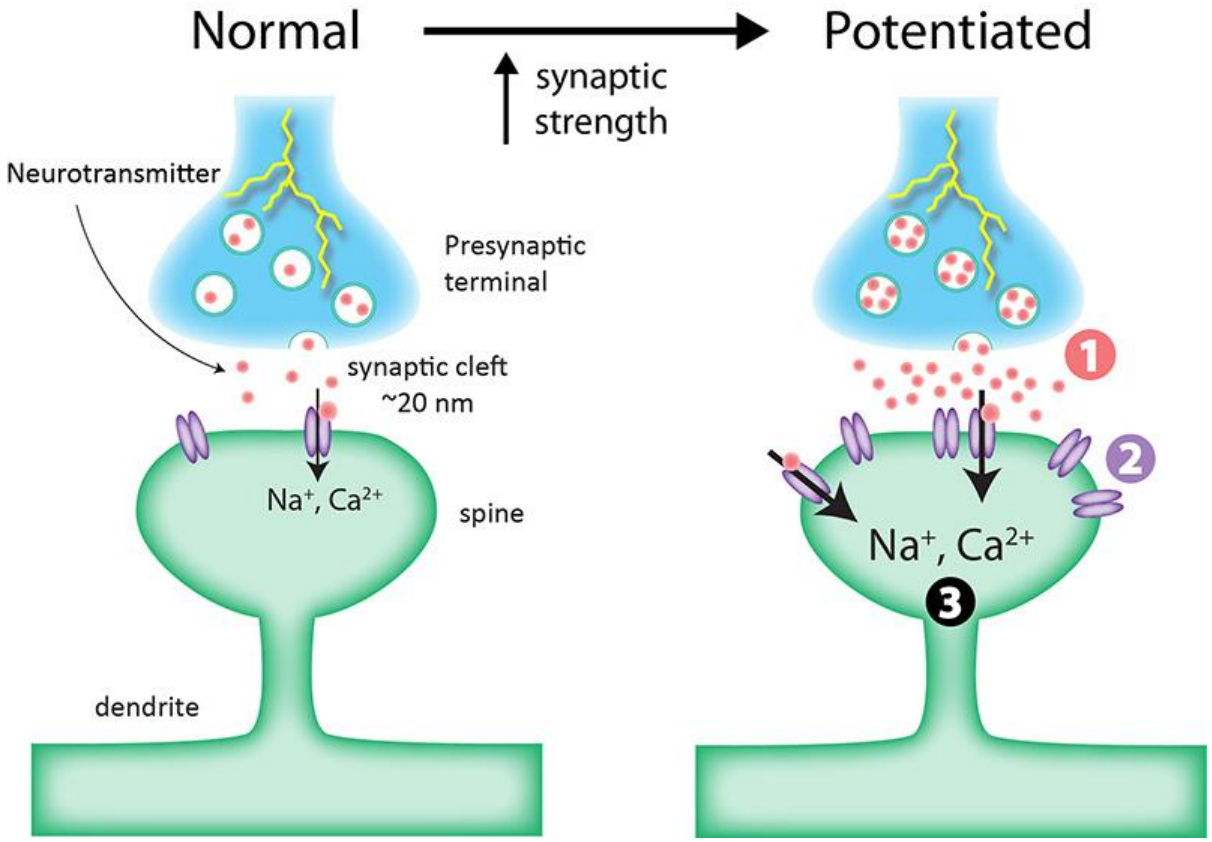
Neural Basics

- A neuron is the functional unit of the brain
- The transfer of signals between neurons is what leads us to have thoughts, actions behaviors… anything that a brain does



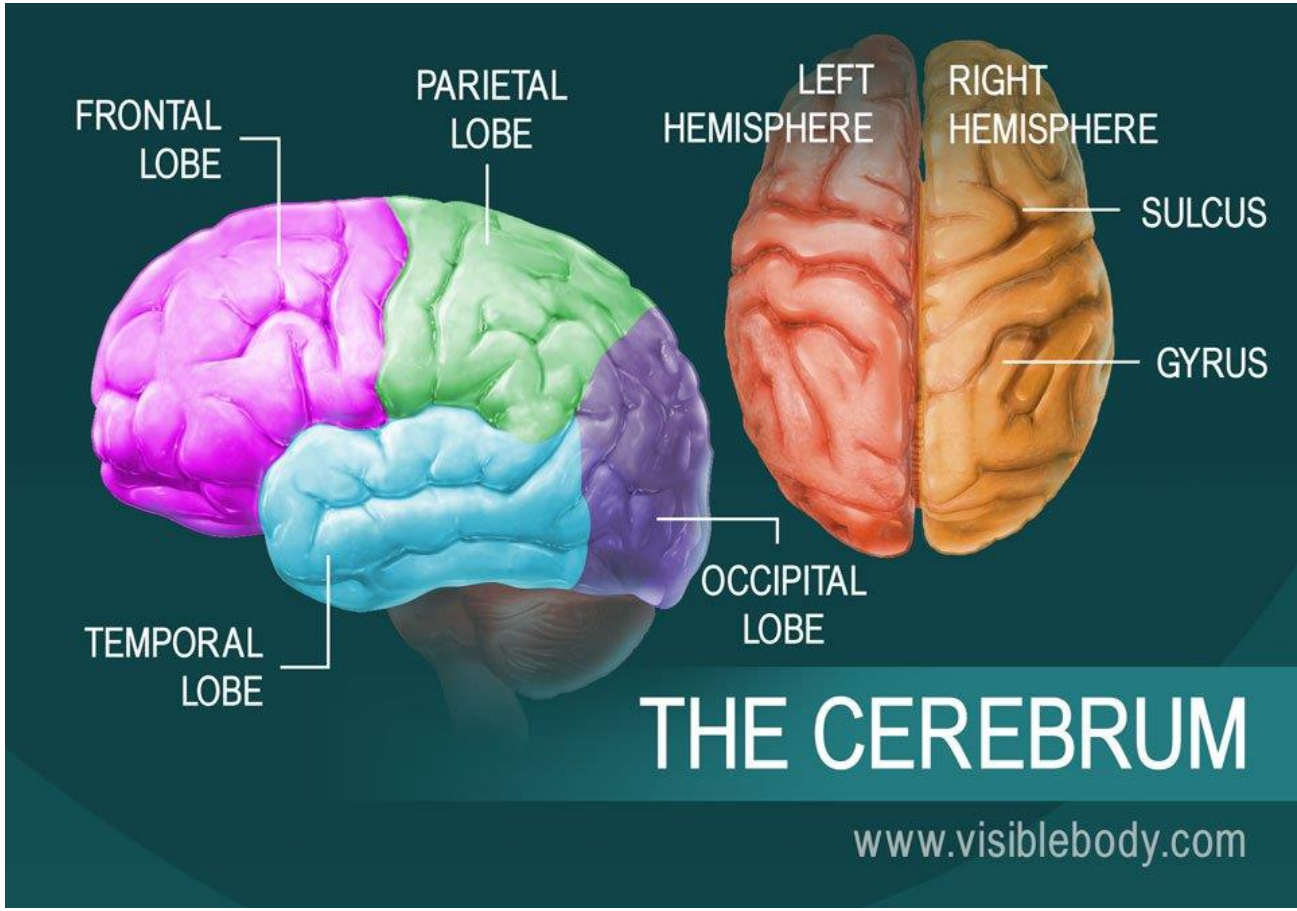
Networking

- **Hebb rule** – if two connected neurons are active simultaneously, the synapse between them is strengthened
  - "neurons that fire together wire together"
  - This leads to ***neural plasticity***
- Long-term potentiation is the mechanism that allows this



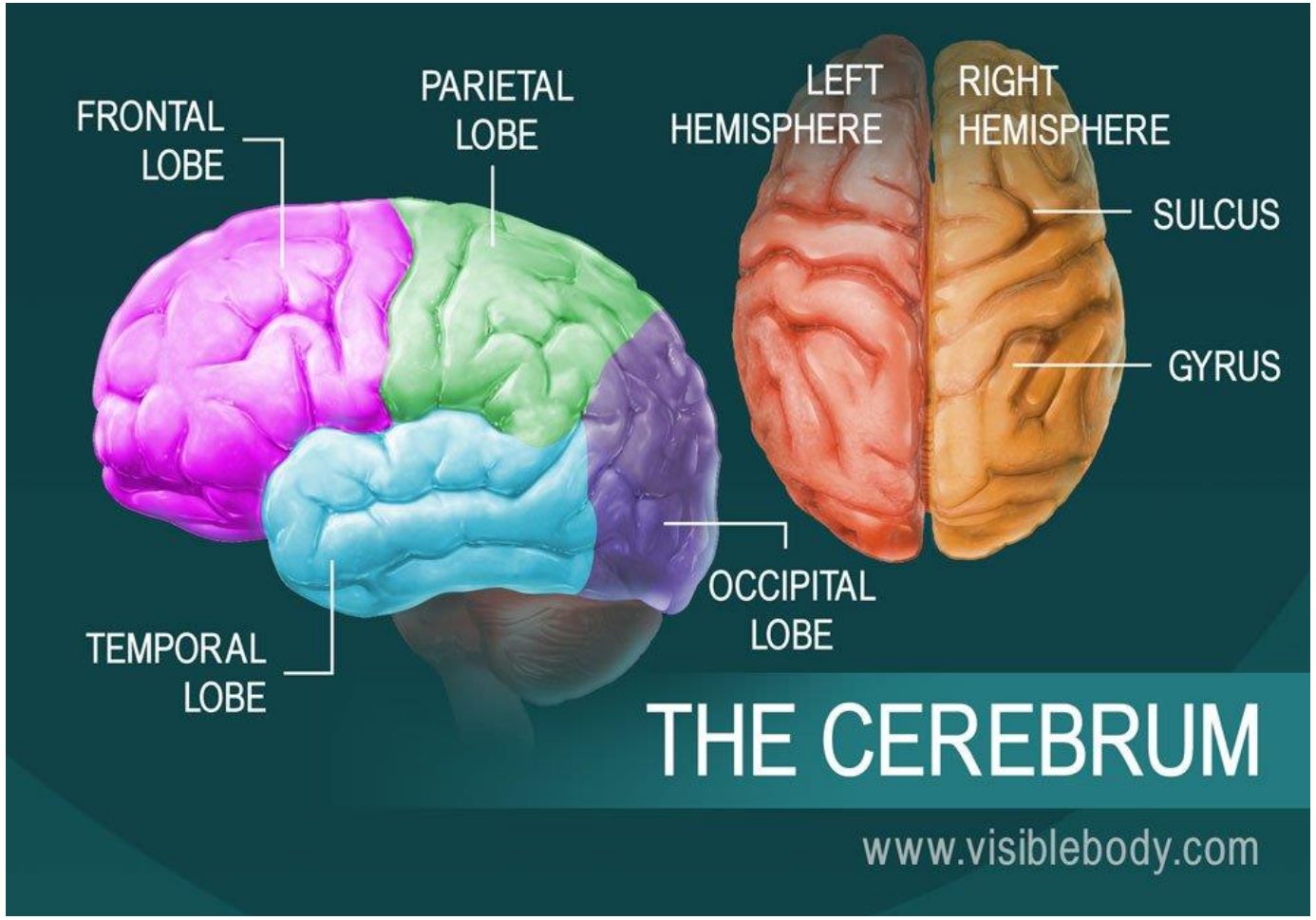
Brain Anatomy

- Two hemispheres connected by the **corpus callosum**
  - Shares information between the hemispheres
- **Contralateral** – left side of body = right side of brain, vice versa



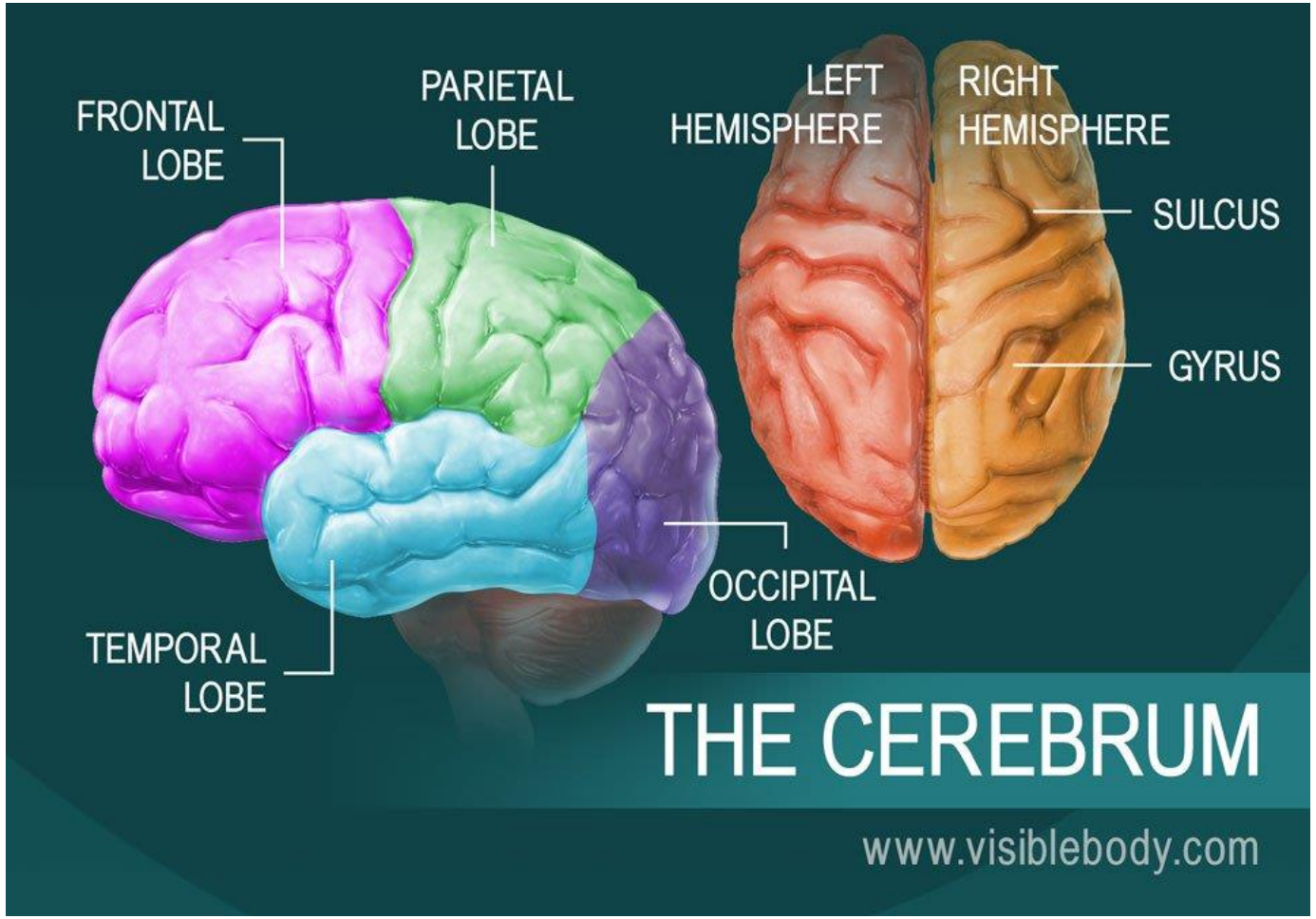
Brain Anatomy

- Four primary lobes of the **cortex** – the upper (evolutionarily newer) portion of the brain
- **Frontal lobe** – problem solving, language production, directing movement, reasoning, planning
- **Temporal lobe** – auditory processing, pattern recognition, language comprehension, ventral stream of vision, memory



Brain Anatomy

- **Parietal lobe** – attention, spatial processing (dorsal stream of vision), somatosensory processing
- **Occipital lobe** – early visual processing

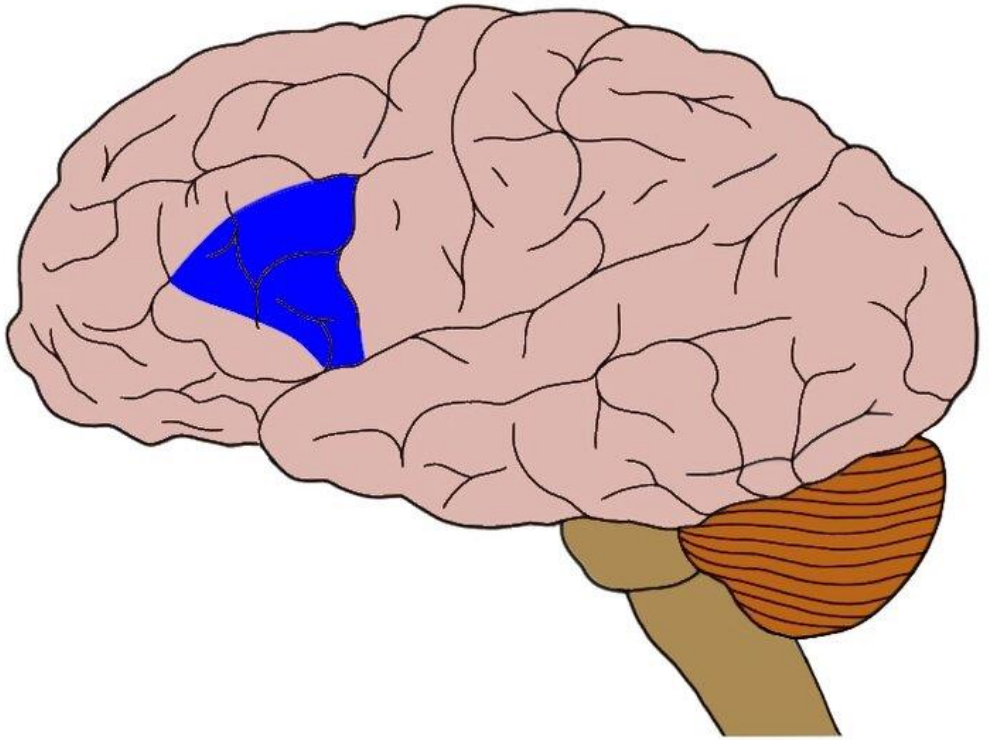


Lesion studies

- Early studies of language in the brain employed a method we didn’t talk about last time
- Lesion studies were case studies of individuals who had sustained brain damage
- The area of damage was mapped, and behavioral observations were taken
- Inferences were drawn to connect behaviors with corresponding brain regions
  - Especially if Patient A struggles with Task 1 but not Task 2 and Patient B struggles with Task 2 but not Task 1 – **double dissociation**

Lesion studies

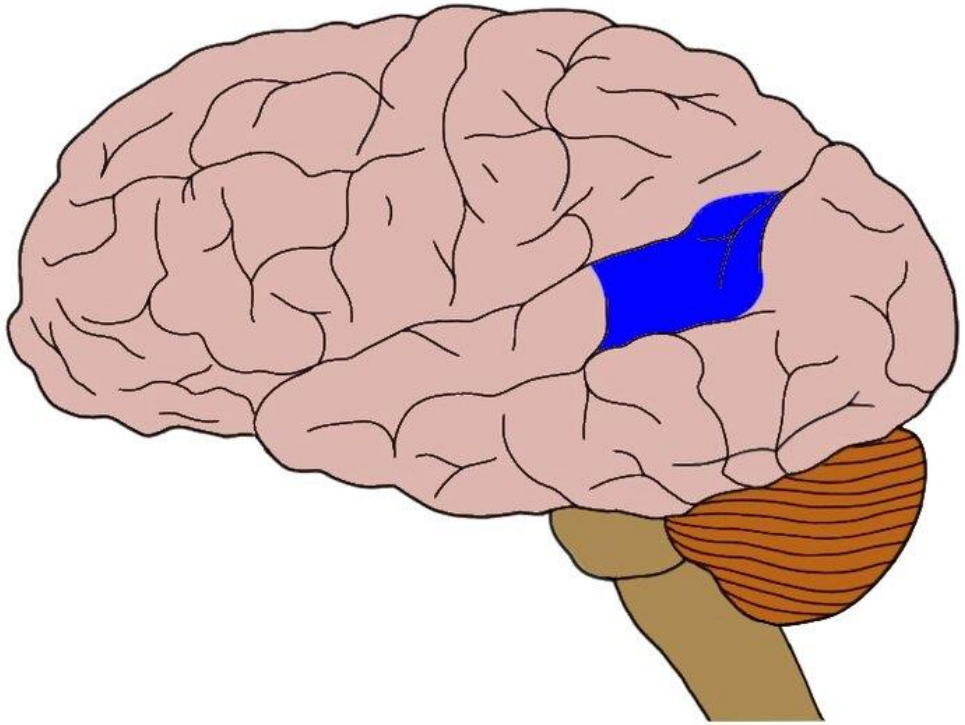
- In the 1860s, Paul Broca wrote about a patient who had significant language production difficulties but whose comprehension skills seemed intact
  - Broca believed in the compartmentalization of language functions in different parts of the brain, consistent with other lesion studies
  - Autopsy revealed significant damage to the left frontal lobe, as did others with similar behavioral deficiencies
    - → **Broca's area**



Lesion studies

- Still in the 1860s, Carl Wernicke observed a patient who was able to speak fluently but couldn’t understand spoken language
  - Autopsy revealed damage in a more posterior region (temporal lobe), again in the left hemisphere
  - → **Wernicke’s area**

- Establishment of Broca’s aphasia and Wernicke’s aphasia, two brain-related language deficiencies with different symptoms and different neural regions
  - The same aphasias emerge for individuals who use sign language



Lesion studies

- In the 1940s, with new technology available, epilepsy patients provided a new source of data
  - Parts of the brain were electrically stimulated while the patient was conscious
  - Temporary disruption of brain function, used to determine which parts of the brain did what functions
  - Stimulation of Broca's and Wernicke's areas did indeed impede language production and comprehension
- This technique revealed lots of variation – not every patient showed the same deficiencies after stimulation of these regions
  - Some showed no impairment at all, some showed language impairment when other areas were stimulated

Lesion studies

- The division between production and comprehension is not as clear as Broca and Wernicke believed
  - Some patients with damage to these areas have demonstrated no symptoms of the associated aphasias

- Newer techniques in lesion studies map **voxels** to track exactly where in the brain has experienced physical damage
  - Voxel mapping has led us to understand that language processes are distributed across multiple regions of the brain

Lesion studies

- Dronkers et al. (2004) studied patients with left hemisphere damage, right hemisphere damage, and no damage
  - Presented with a spoken sentence, participants had to select the matching picture
  - Different kinds of syntactic structures were used
    - Simple declaratives, possession, passive, relative clauses, negation, etc.
- Poor comprehension was linked to five distinct regions in the left hemisphere
  - Different regions were associated with different sentence types

Lesion studies

- Lesion studies have provided a lot of information, but are interpreted cautiously
- Understanding brain functions based entirely on what happens when things go wrong is not ideal
- Highly inferential
  - Especially regarding what happens in non-damaged brains
- Almost exclusively conducted on English speakers
  - Limits scope of conclusions

Lateralization

- **Corpus callosum** – bundle of fibers that connects the two hemispheres of the brain
- Split-brain patients were able to maintain fairly high functioning
  - Item felt with only right hand → able to name
  - Item felt with only left hand → unable to name
  - Same with right/left visual field
  - Same with right/left ear
- Language processes seem to occur mostly in the **left** hemisphere
  - But affected by handedness, familial handedness, brain/head size

Left Hemisphere Lateralization for Language in Right-Handers Is Controlled in Part by Familial Sinistrality, Manual Preference Strength, and Head Size

Nathalie Tzourio-Mazoyer,[1] Laurent Petit,[1] Annick Razafimandimby,[1,3] Fabrice Crivello,[1] Laure Zago,[1] Gael Jobard,[1,2] Marc Joliot,[1] Emmanuel Mellet,[1] and Bernard Mazoyer[1,3,4]

Localization

- Language certainly isn’t housed in one specific region of the brain
- Could think about language in the brain as a bunch of independent separate areas, each with its own specific purpose
  - Probably the wrong way to think about it, too

Localization

- Instead, functions are distributed and resources are shared
  - Some areas may be responsible for tasks involved in a wide range of processes
    - Many of which may even be nonlinguistic
  - Others may be more specific and only feature in a small number of processes

- Conversation is “likely to involve not only the cortical areas of importance for speech, but practically the whole brain, the left as well as the right side” (Larsen et al., 1978)
  - Right hemisphere seems to handle things like interpreting intonation and tracking discourse-level information

Localization

1 kick, step, walk, tiptoe, jump

2 type, throw, write, grasp, poke

3 lick, speak, bite, smile, chew

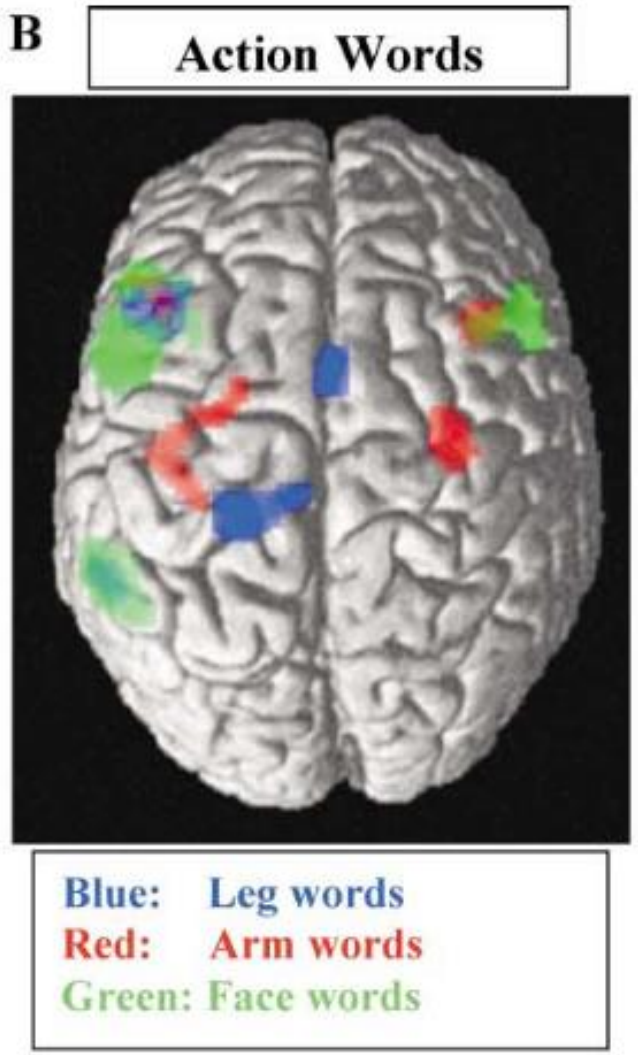
Localization

kick, step, walk, tiptoe, jump

type, throw, write, grasp, poke

lick, speak, bite, smile, chew

- These words activate different regions, some of which are the same as regions that are active when we move those body parts (Hauk et al., 2004)



Language system(s)

- Finding double dissociations in language research encouraged people to look for subsystems
  - Word recognition and syllable identification, for example, may belong to two different networks

- **declarative** vs **procedural** knowledge?
- **dorsal** vs **ventral** stream of vision?

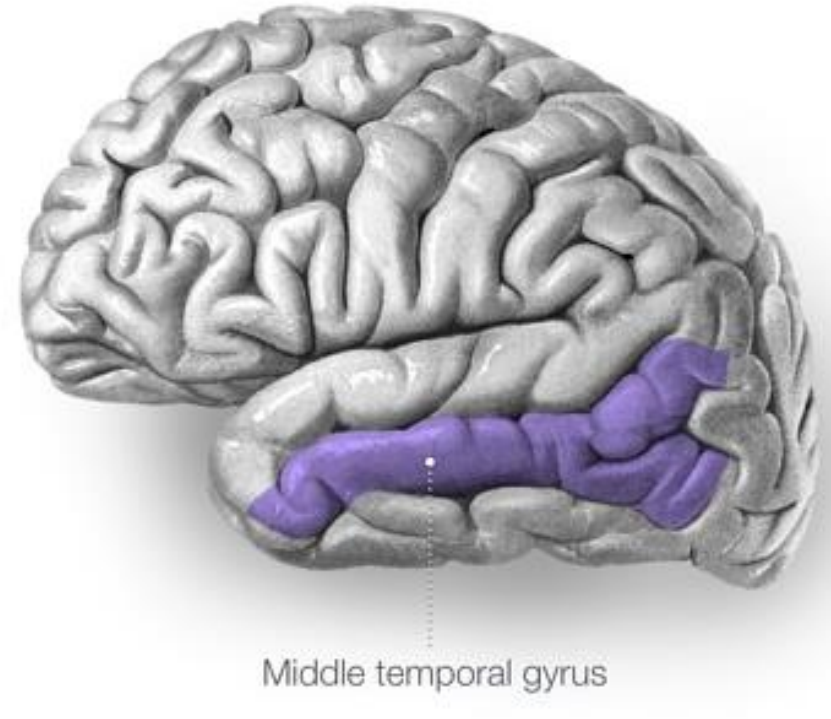
Language system(s)

- Dorsal and ventral streams of (auditory) language?
  - **dMRI** tracks water molecule diffusion in the brain
- The dorsal stream handles “how” information – processing of sounds, planning of articulation, etc.
- The ventral stream handles “what” information – word meanings

- Both are involved in syntactic structure
- Both are involved in both production and comprehension

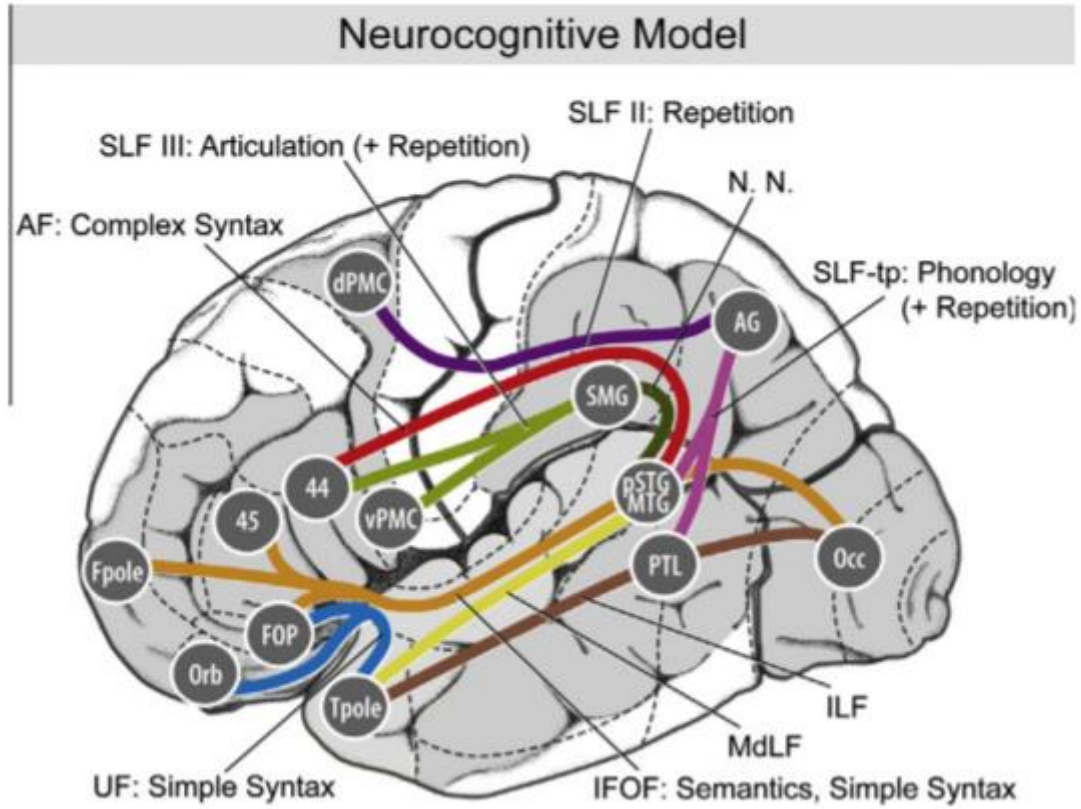
Language system(s)

- White matter pathways in the brain connect different regions
- Some regions (**MTG** – middle temporal gyrus) are hubs, connecting several different white matter pathways and appearing in many different language processes
  - This doesn't necessarily mean the MTG does many different things; may be the case that what it does do is utilized in many different processes



Language system(s)

- Even Broca's area and Wernicke's area may not really be all that specific
  - Each of these likely contains various parts with varying functions
- The concepts of these areas may still be useful, but as approximations/broader regions, rather than specific parts


Neurocognitive Model
SLF II: Repetition
SLF III: Articulation (+ Repetition)
N. N.
AF: Complex Syntax
SLF-tp: Phonology
(+ Repetition)
dPMC
AG
SMG
44
45
vPMC
pSTG
MTG
Fpole
PTL
Occ
FOP
Orb
Tpole
ILF
MdLF
UF: Simple Syntax
IFOF: Semantics, Simple Syntax

Insights into language learning

- When our brain does *language stuff*, it handles things differently from when we do *other stuff*
- English speakers appear to process tone in the right hemisphere; Mandarin speakers appear to process tone in the left hemisphere