Systems Neuroscience

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Language processing

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http: www.ini.unizh.ch/~kiper/system_neurosci.html

Communication

- Different forms
  - Verbal (speech)
  - Sign (gestures)
  - Writing (symbols)
- Important social behaviors
- Have made cultural evolution possible
- Enabled discoveries to be cumulative
  - Knowledge passed from generation to generation

ANIMAL COMMUNICATION MECHANISMS serve the purpose of identifying members of a species

Innate: dance of honeybees: it uses arbitrary conventions to describe objects distant in both space and time

Innate communication systems coupled with learning: birdsongs, primate (alarm) calls

HUMAN LANGUAGE: allows to designate an infinitely large number of items, actions, properties; allow to express relationships between events, such as temporal order and causation.

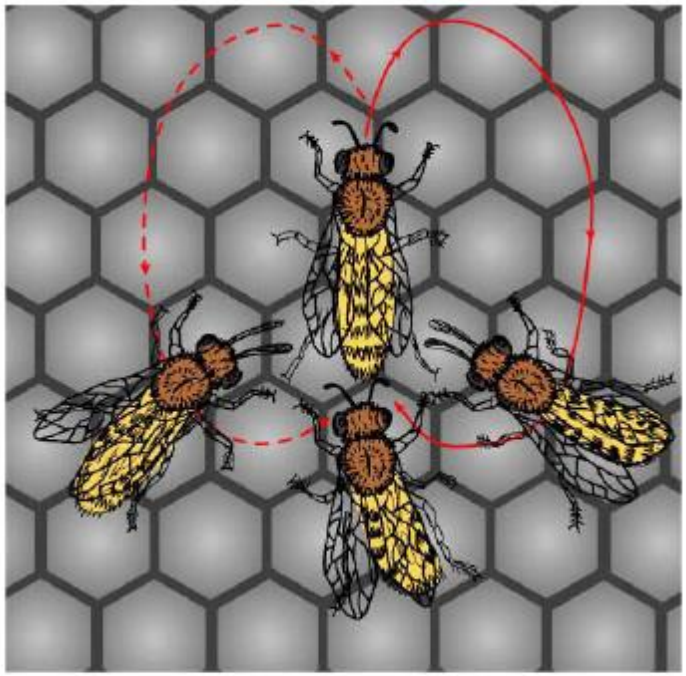
Human language requires synchronization of fine movements with cognitive activity (breathing, articulation, vocal control, manual and facial gesture, hearing, planning, memory). Role of basal ganglia and 'mirror neurons'; sign language.

Lateralization and localization of the language functions are similar as in animal communication. Other features, such as seasonal variation in the size of birdsong nuclei are not relevant to human language.

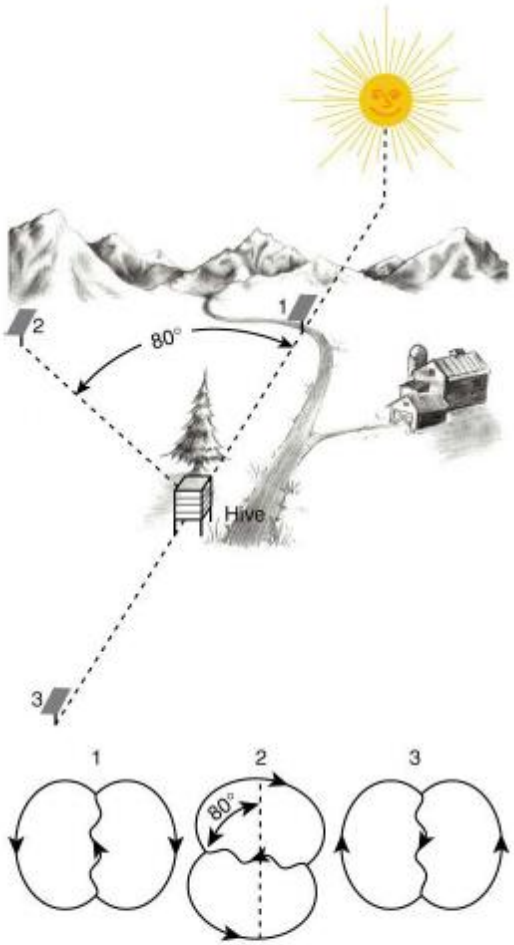
Chomsky: theory of an innate 'universal grammar"

Pinker-Bloom: language evolved by natural selection

Innate knowledge and learning in the development of language abilities

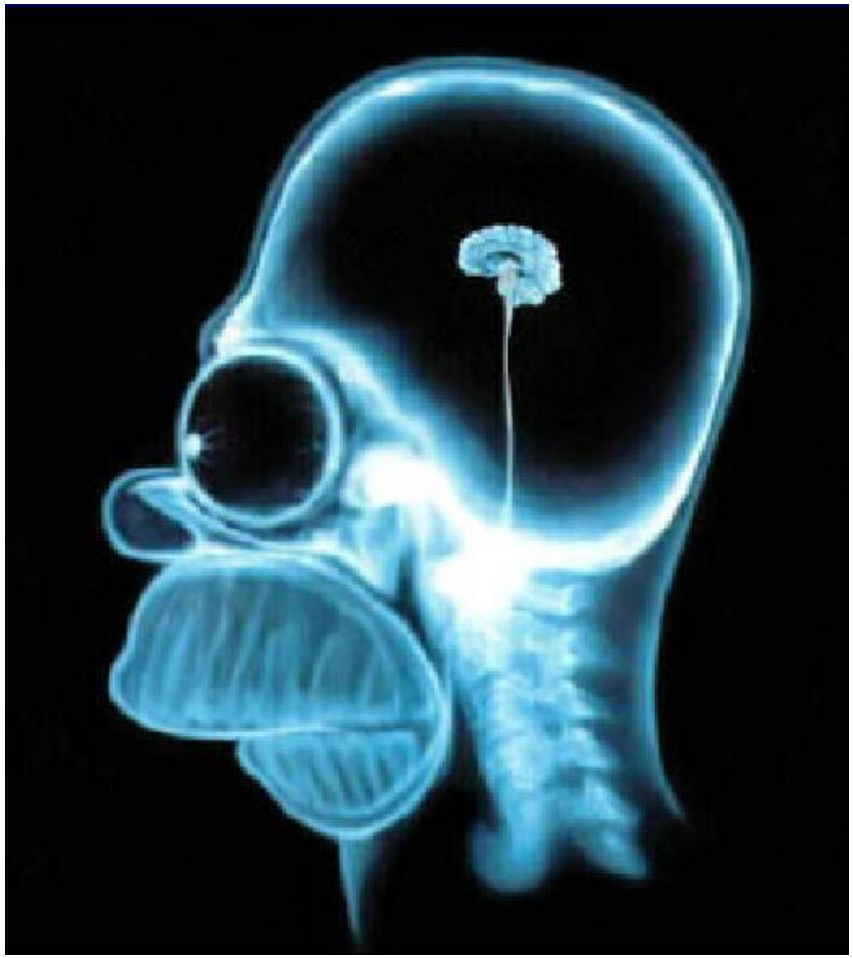


The waggle dance of honeybees follows a figure eight. Direction is encoded into the dance as the angle of the waggle runs left or right of vertical on the comb, which corresponds to the angle to the food relative to the sun's azimuth in the field.



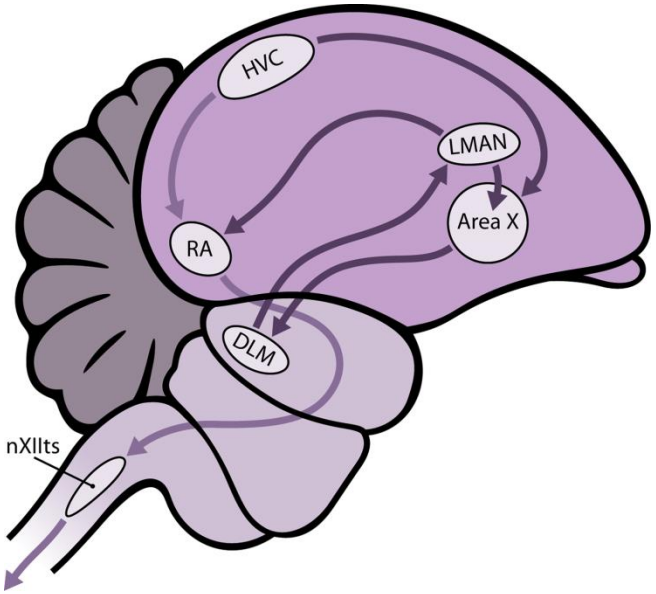
Language Acquisition

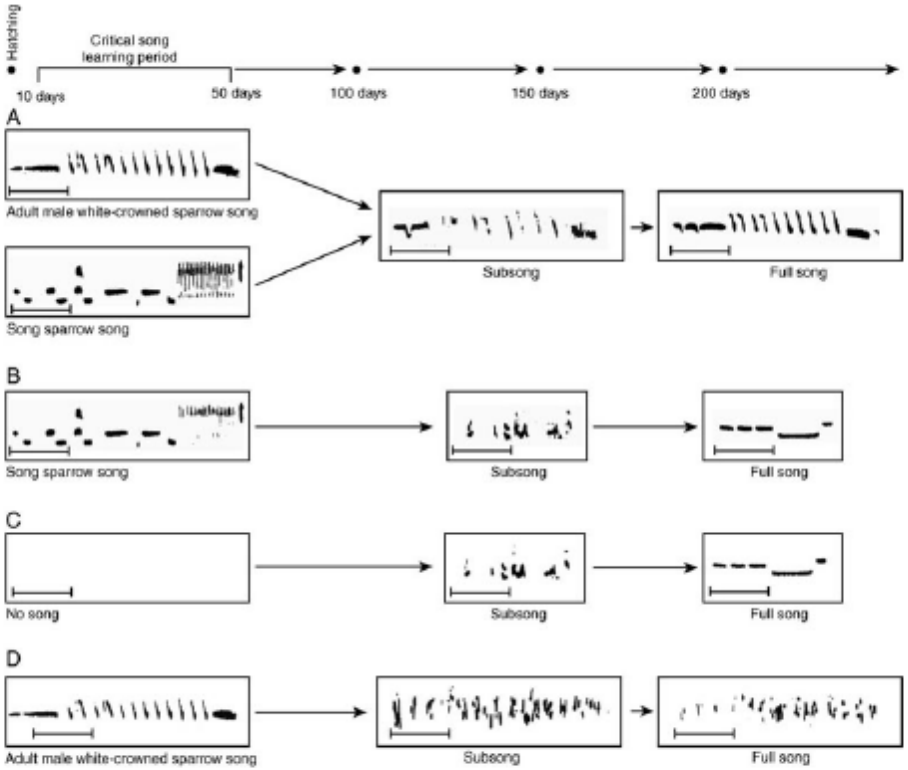
- Modularity (Chomsky, 1959)
  - Is there a language “mental organ”? Or does it arise from more primitive functions?
- Is it unique to humans?
  - What causes the difference?
  - Evolution of Language:
    - Gestures were important
- Language and thought
  - Are they interrelated?
- Universal grammar?



Birdsong

- Similar to human languages in sensitive period
- Stages of development:
  - Initial exposure to the song of tutor (father)
  - Successive approximation of produced song to the stored model
  - Crystalization of the song in permanent form
- Deafening and distorting studies by Konishi
- Brain damage studies confirm vocal control centers view
- neurogenesis





Birdsong development in most species is characterized by a sensitive period during which a song of the species must be heard. Later, during subsong (preparation for singing), the bird practices making notes and assembles them into the correct order and pattern (A). Birds not allowed to hear their species' song sing a schematic version of the song (B and C); birds deafened before subsong cannot sing (D). [Caplan and Gould, 2003].

Nonhuman Primates

- Vocalizations look preprogramed, serving specific purposes only
- Initiated by sub-cortical areas like limbic system
- But for vocalization and decoding, they also use left hemisphere
- Unique cases
  - Kanzi
  - Washoe (ASL)
  - Sarah (tokens)

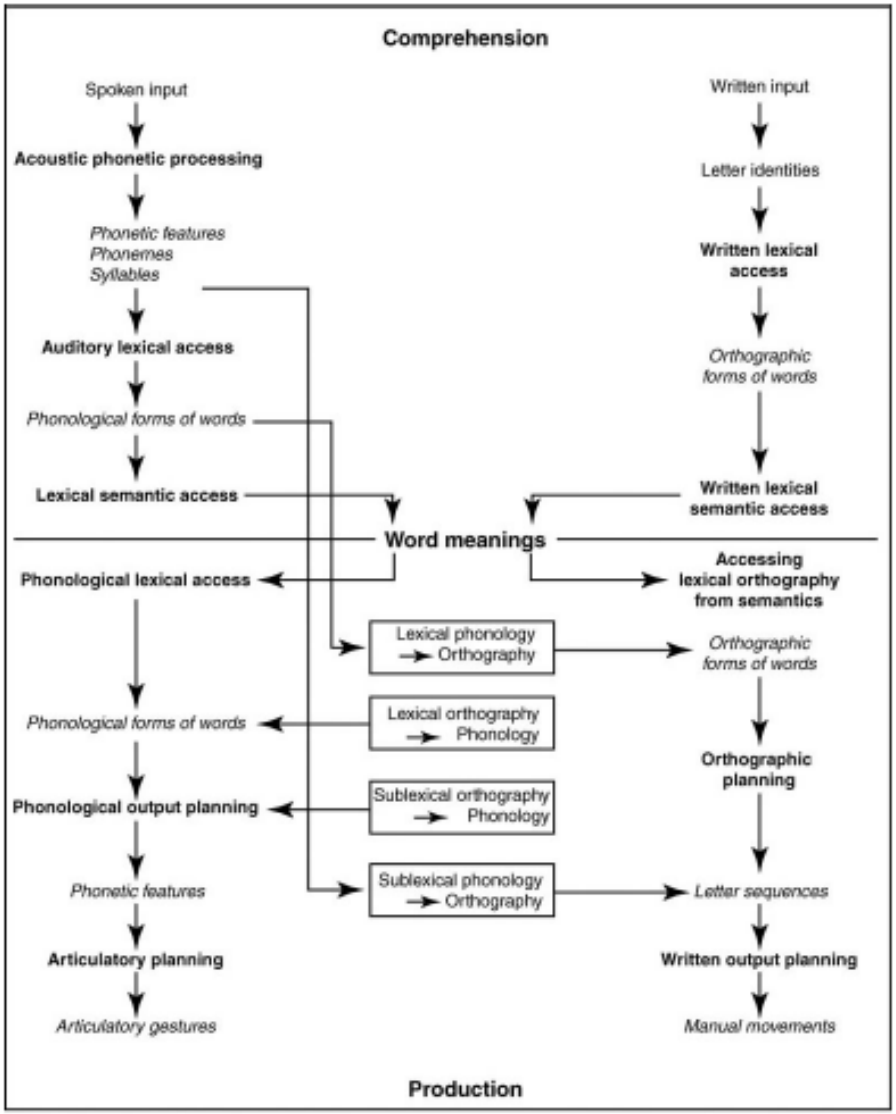
THE FAR SIDE By GARY LARSON

What is Language?

- Grammar
  - Phonetics, morphology, syntax, semantics
- Symbol usage
- Ability to represent real-world situations
- Ability to articulate something new
- Intention to communicate
- Duality, productivity, arbitrariness, interchangeability, specialization, displacement, and cultural transmission (Linden 1974)

"An infinitely open system of communication"

Rumbaugh, 1977



A model of the major psycholinguistic operations involved in processing simple words (Caplan and Gould, 2003)

Language & Cognition

Why language is important

Only species to use language with syntactic and productive properties.

Syntax: rules governing legal word order. We have implicit knowledge of syntax.

Sentence meaning depends on word meaning & word order.

The dog bit the man.

The man bit the dog.

Colourless green ideas sleep furiously.

Language and Cognition

Why language is important

Language comprehension is rapid and automatic.

Involves integration of word meaning, syntax, context & knowledge.

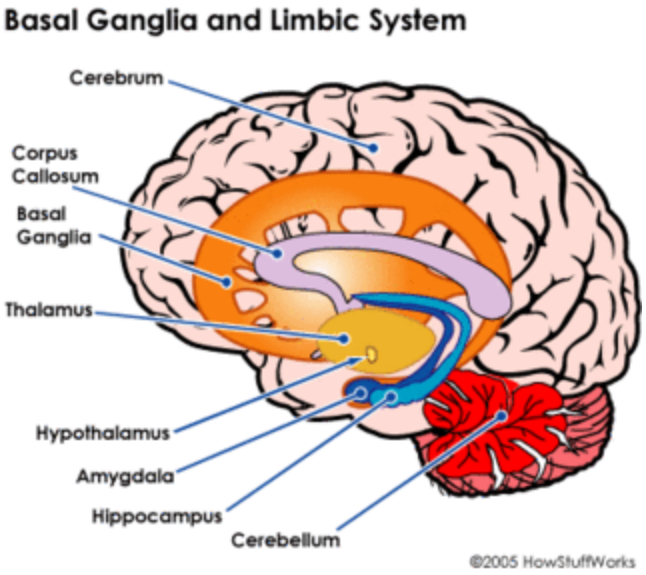
Take roughly 250 msec to read individual words.

State color of ink used for following words:

RED
GREEN
BLUE
GREEN
RED
BLUE

Stroop task

Language & Cognition



Why language is important

Language <u>production</u> is rapid.

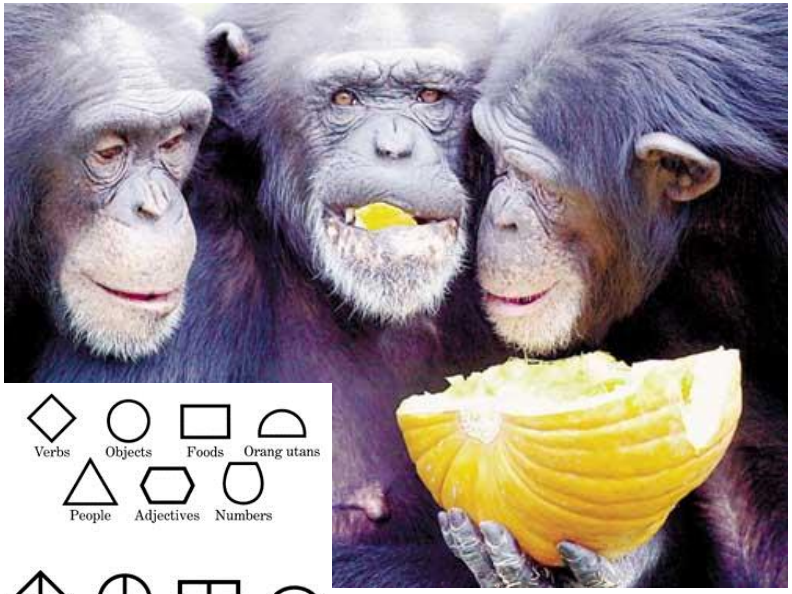
Involves overlapping stages of planning *message*, selecting *words and structure*, sequencing *production of component sounds* and controlling *articulation*. [Levelt, 1987]

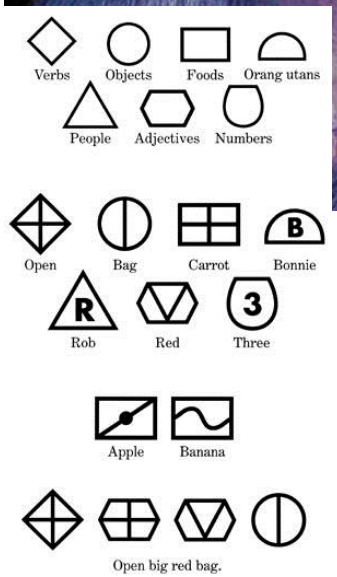
<u>Dialog</u> is rapid and highly interactive. Suggests interactive sequence of *comprehension*, *cognition* & *production*.

Alex

Teaching Language to Apes

- Why teach language to apes?
- Throughout the history, all efforts to teach speech to animals have failed
- ASL was taught to chimpanzees to some extent
- Lana Project at Emory University:
  - Try to teach Yerkish to chimps (computerized symbols)
  - Chimps are able to form novel and meaningful chains





Teaching Language to Apes

Why [try to teach apes language]? What is there to suggest we would listen to anything an ape could tell us? Or that he would be able to tell us of his life in a language that hasn't been born of that life?... Maybe it is not that they have yet to gain a language, it is that we have lost one

(Adams & Carwardine 1993)

Deep Down and Internal Representation

- Savage-Rumbaugh believes that
  - Language ability of chimps is underestimated
  - Chimps can understand speech (but can’t produce)
  - Language comprehension comes before speech for several million years
  - Intention to communicate is important
- Pinker says “they just don’t get it…”

Language Disorders

- Egyptians reported speech loss after blow to head 3000 years ago
- Broca (1861) finds damage to left inferior frontal region (Broca's area) of a language impaired patient, in postmortem analysis

Language Disorders

- In language disorders
  - 90-95% of cases, damage is to the left hemisphere
  - 5-10% of cases, to the right hemisphere
- Wada test is used to determine the hemispheric dominance
  - Sodium amytal is injected to the carotid artery
  - First to the left and then to the right

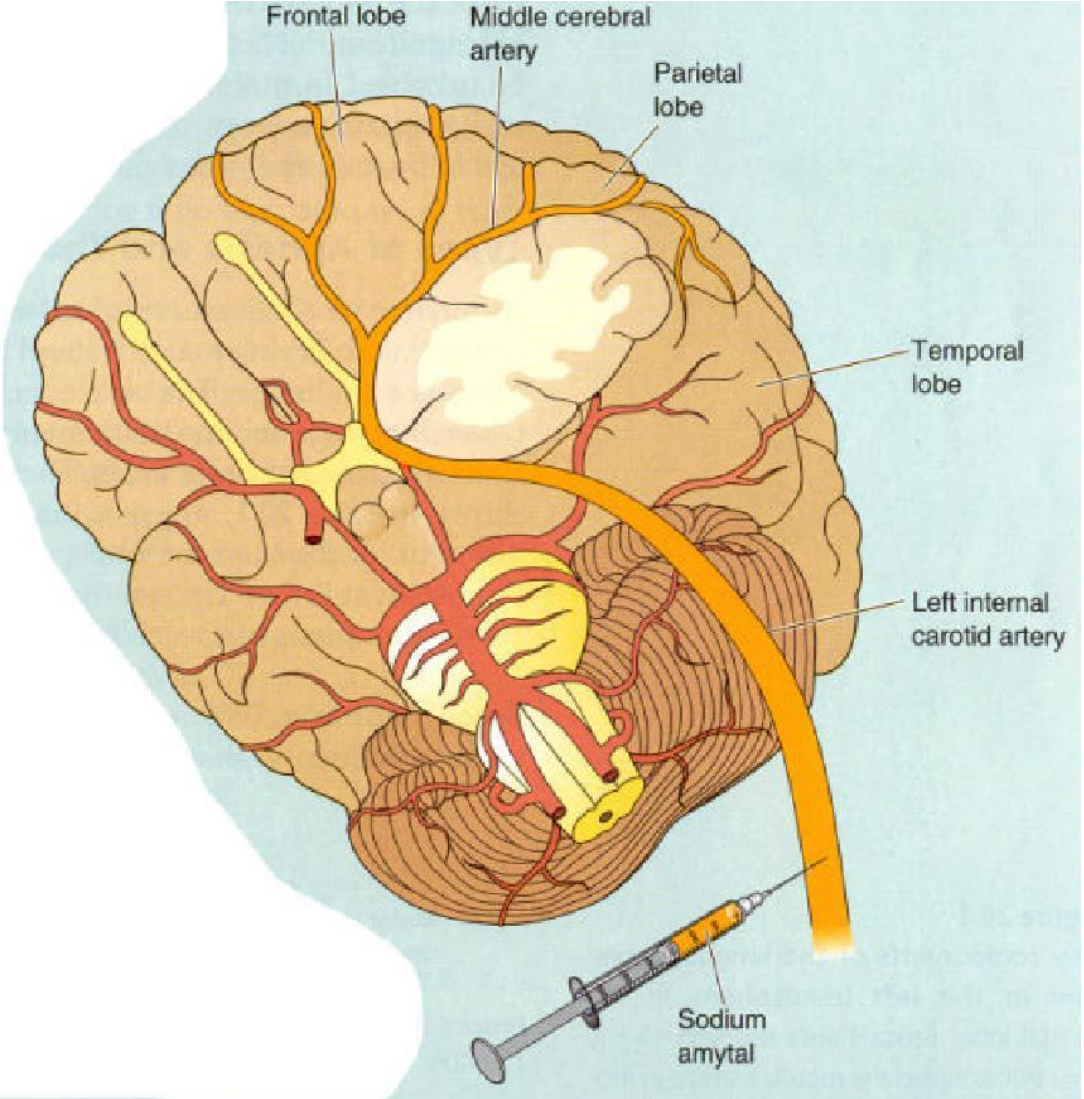
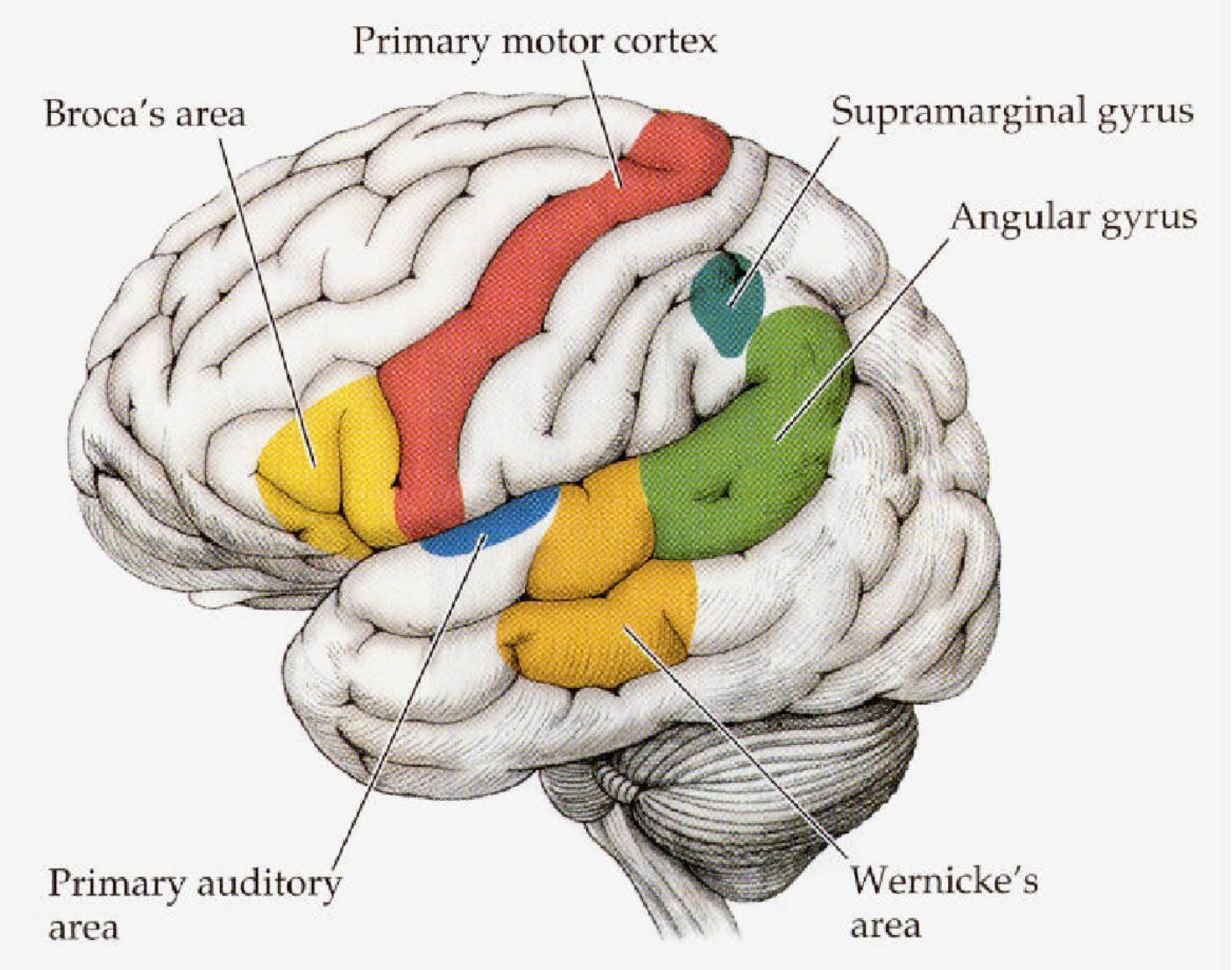
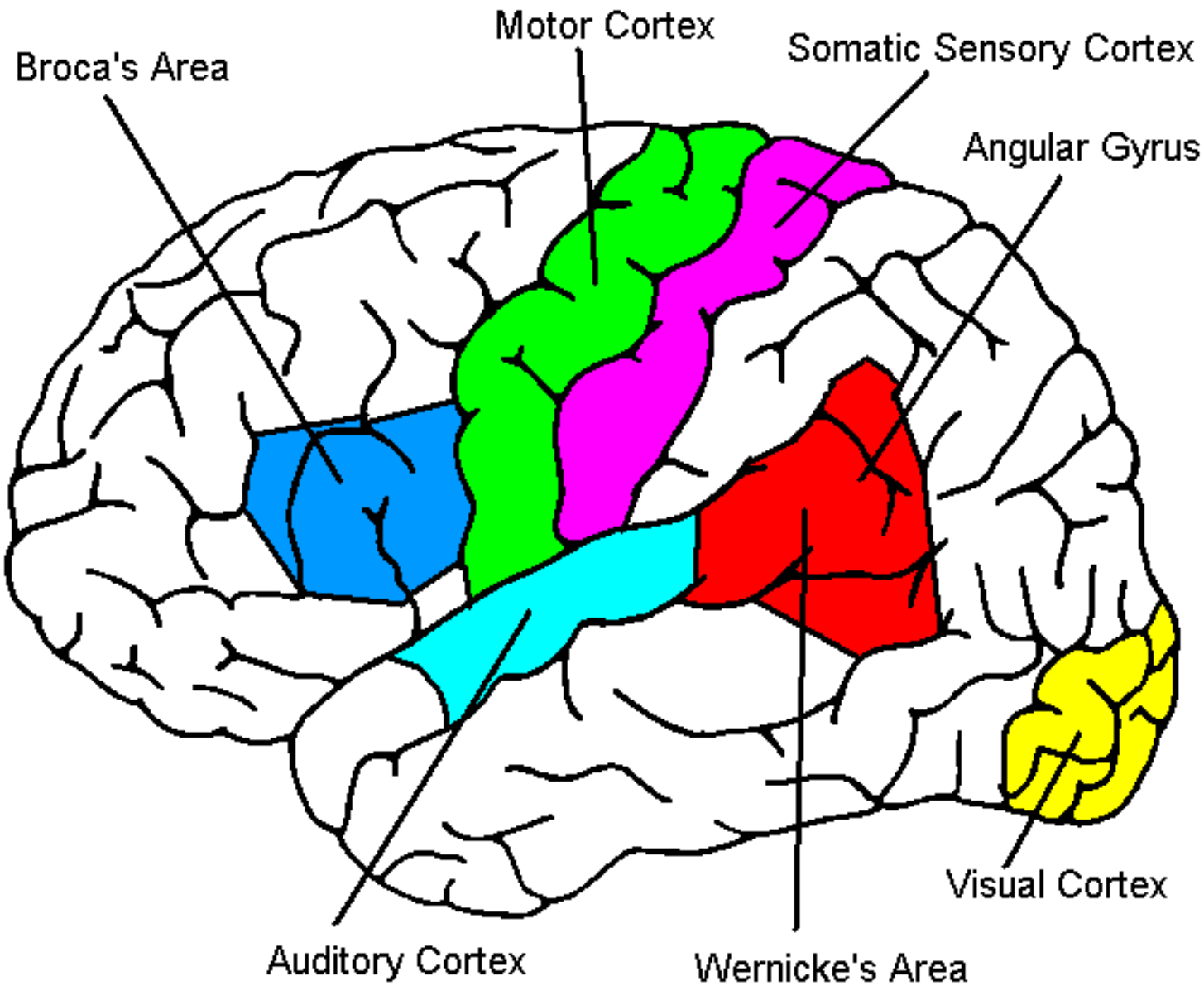


Table A Hemispheric Control of Speech in Relation to Handedness

		SPEECH REPRESENTATION (%)		
HANDEDNESS	NUMBER OF CASES	LEFT	BILATERAL	RIGHT
Right	140	96	0	4
Left	122	70	15	15

Brain areas involved in Language

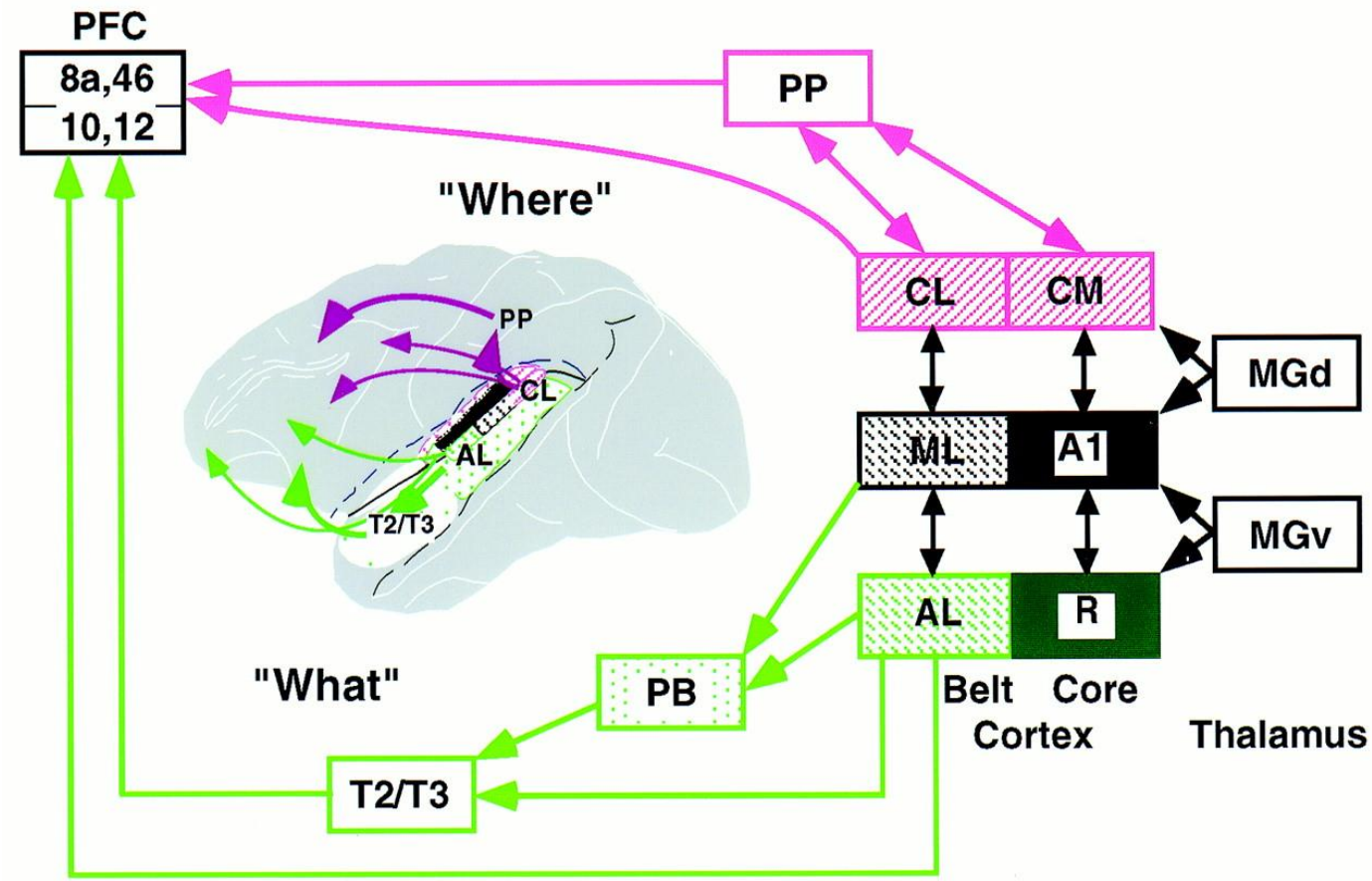



Motor Cortex
Broca's Area
Somatic Sensory Cortex
Angular Gyrus
Visual Cortex
Auditory Cortex
Wernicke's Area

Auditory "what" and "where" streams.

dorsal "where"-stream, (red)

ventral "what"-stream (green)

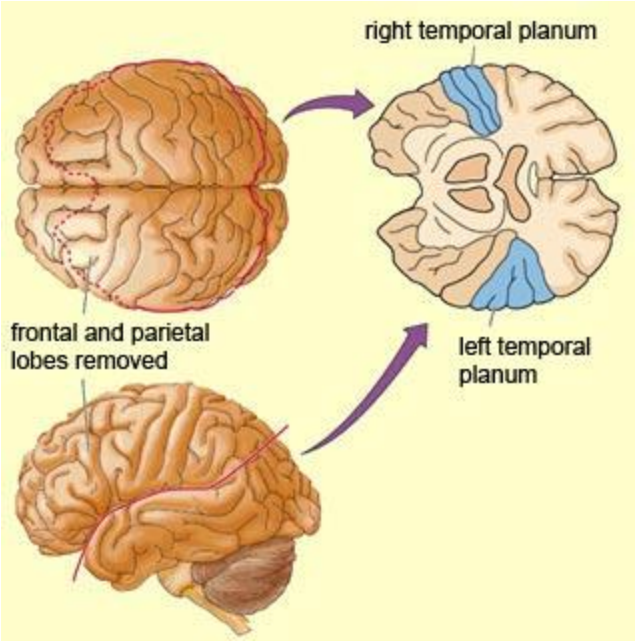


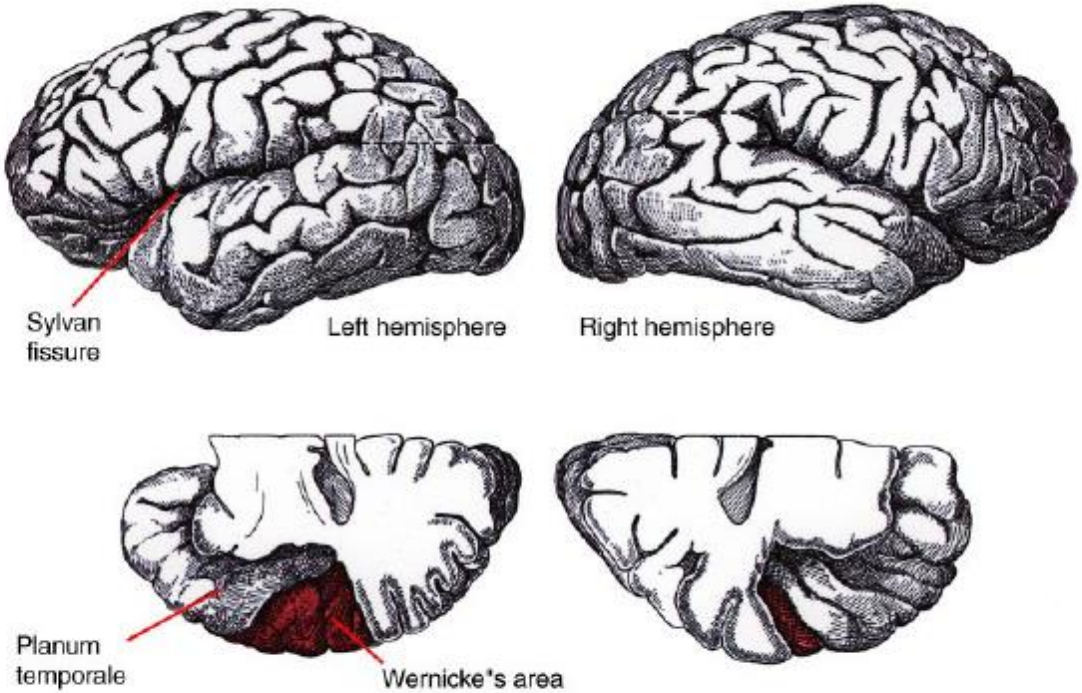
PFC prefrontal connections
PP posterior parietal cortex
PB parabelt cortex
CL caudolateral belt area
ML mediolateral " "
AL anterloateral " "
MGd and MGv, dorsal and ventral parts of the MGN (medial geniculate nucleus)

Lateralization of the Brain

- LH more specialized for the analysis of sequences of stimuli that occur quickly but sequentially (comprehension and production).

- RH more specialized for the analysis of space and geometrical shapes and forms that occur simultaneously.
  - Involved in organizing a narrative (selecting and assembling the elements of what we want to say)
  - understanding prosody (rhythm and stress)
  - recognizing emotion in the tone of voice
  - Understanding jokes



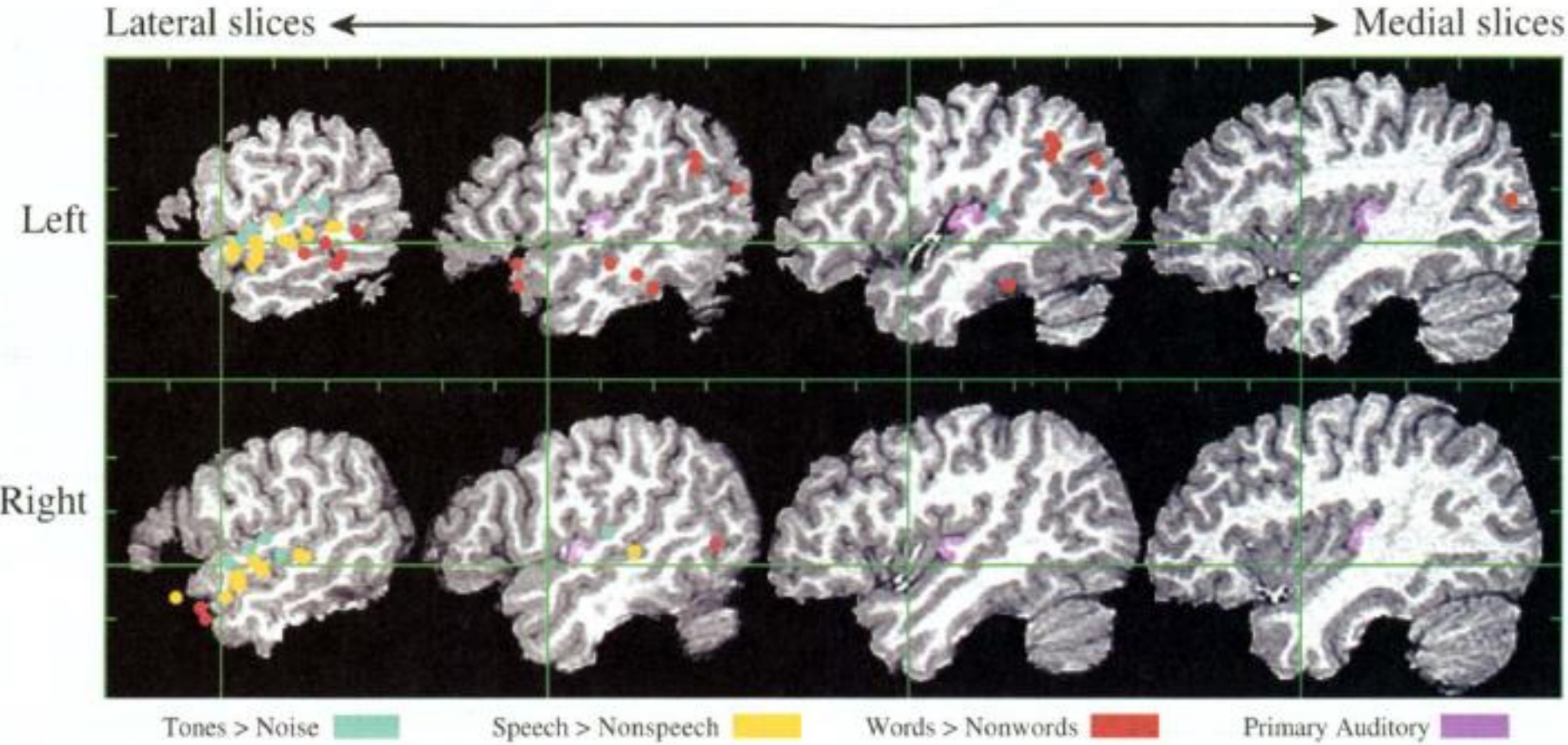


Depiction of a horizontal slice through the brain showing asymmetry in the size of the planum temporale related to lateralization of language

Lateralization of functions

- Left-hemisphere:
  - Sequential analysis
    - Analytical
    - Problem solving
  - Language

- Right-hemisphere:
  - Simultaneous analysis
    - Synthetic
  - Visual-Spatial skills
    - Cognitive maps
    - Personal space
    - Facial recognition
    - Drawing
  - Emotional functions
    - Recognizing emotions
    - Expressing emotions
  - Music


Lateral slices
Medial slices
Left
Right
Tones > Noise
Speech > Nonspeech
Words > Nonwords
Primary Auditory

Language Disorders

- ***Paraphasia***:
  - Substitution of a word by a sound, an incorrect word (“treen” instead of “train”)
- ***Neologism***:
  - Paraphasia with a completely novel word (colloquialism or slang)
- ***Nonfluent speech***:
  - Talking with considerable effort
- ***Agraphia***:
  - Impairment in writing
- ***Alexia***:
  - Disturbances in reading

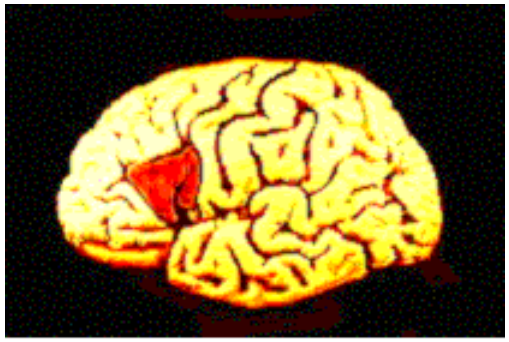
Three major types of Aphasia

- ***Broca's aphasia***
  - Slow, laborious, nonfluent speech
- ***Wernicke's aphasia***
  - Fluent speech but unintelligible
- ***Global aphasia***
  - Total loss of language

<u>Others</u>: Conduction, Subcortical, Transcortical Motor/Sensory

Broca's Aphasia

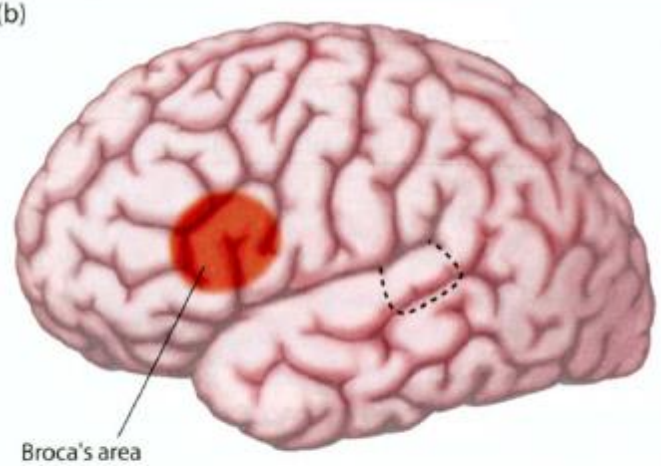
Brodmann 44, 45



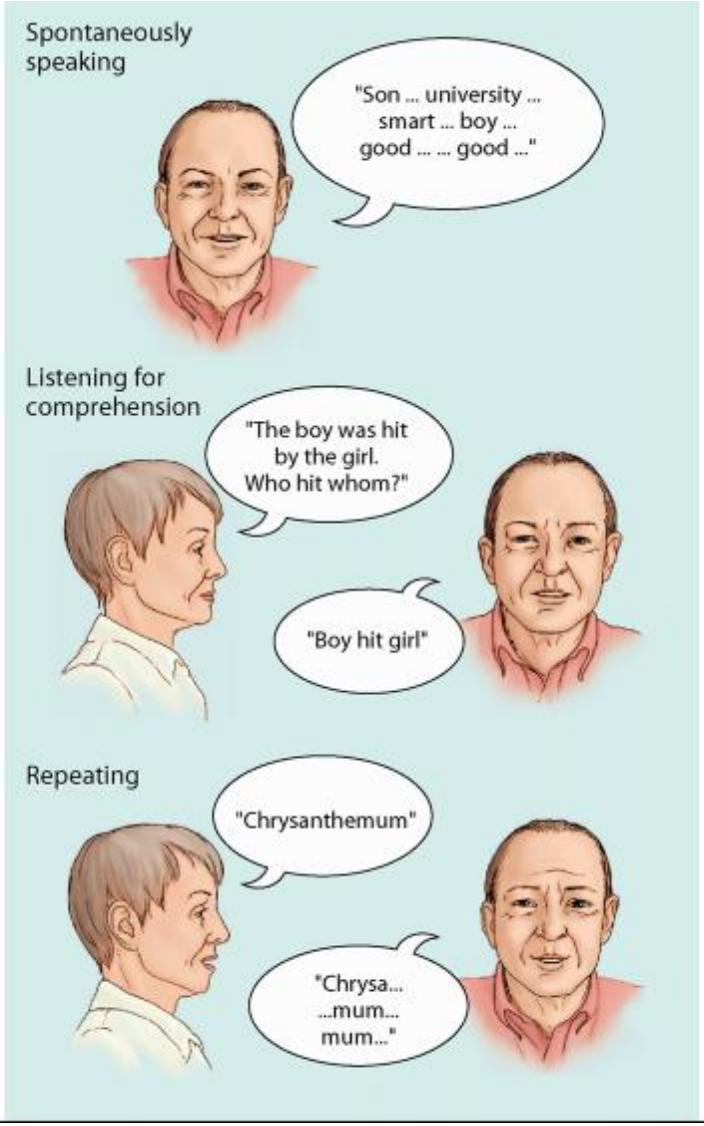
- Lesions in the left inferior frontal region (Broca's area), head of caudate nucleus, thalamus, etc.
- Nonfluent, labored, and hesitant speech (***articulation***)
- Most also lose the ability to name persons or subjects (***anomia***)
- Can utter automatic or overlearned speech ("hello"; songs)
- Have difficulty with function (the, in, about) vs content words (verbs, nouns, adjectives) (***agrammatism***)
- Comprehension relatively intact when other cues available (The man swat the mosquito vs the horse kicks the cow)
- Most also have partial paralysis of one side of the body (hemiplegia)
- If extensive, not much recovery over time

(a)

(b)



Broca's aphasia



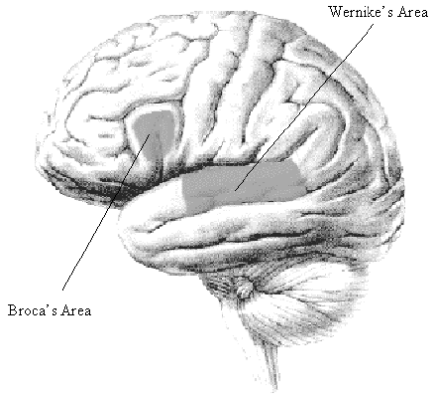
https://www.youtube.com/watch?v=f2IiMEbMnPM

Broca's Aphasia

- Broca's area contains "memories of the sequences of muscular movements (tongue, lips, jaw, etc) that are needed to articulate words" Wernicke (1874)
- But also more than just this…

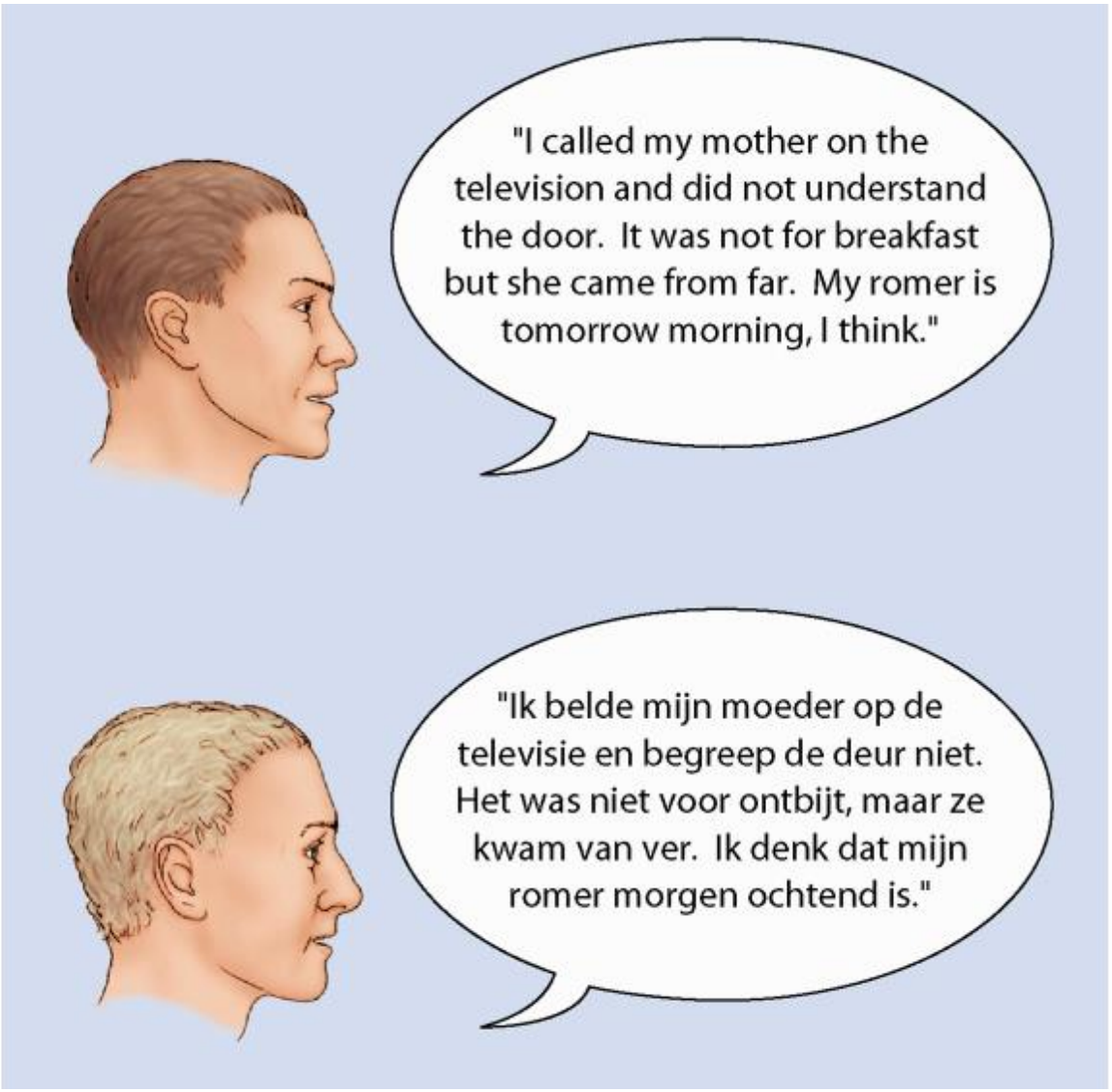
Wernicke's Aphasia

Brodmann 22, 30



- Lesions in posterior part of the left superior temporal gyrus, extending to adjacent parietal cortex
- Unable to understand what they read or hear (poor comprehension)
- Unaware of their deficit
- Fluent but meaningless speech
- Can use function but not content words
- Contains many paraphasias
  - "girl"-"curl", "bread"-"cake"
- Syntactical but empty sentences
- Cannot repeat words or sentences
- Usually no partial paralysis

Wernicke's aphasia



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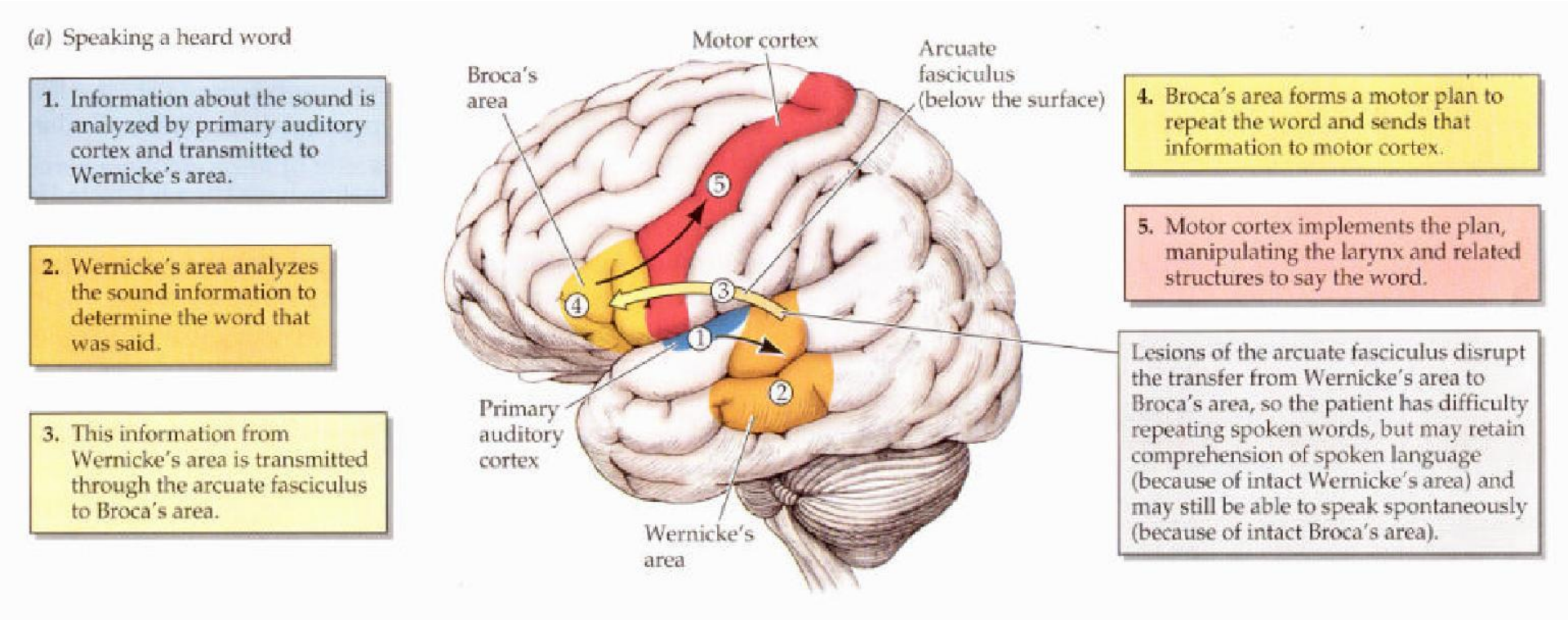
Wernicke-Geschwind Model

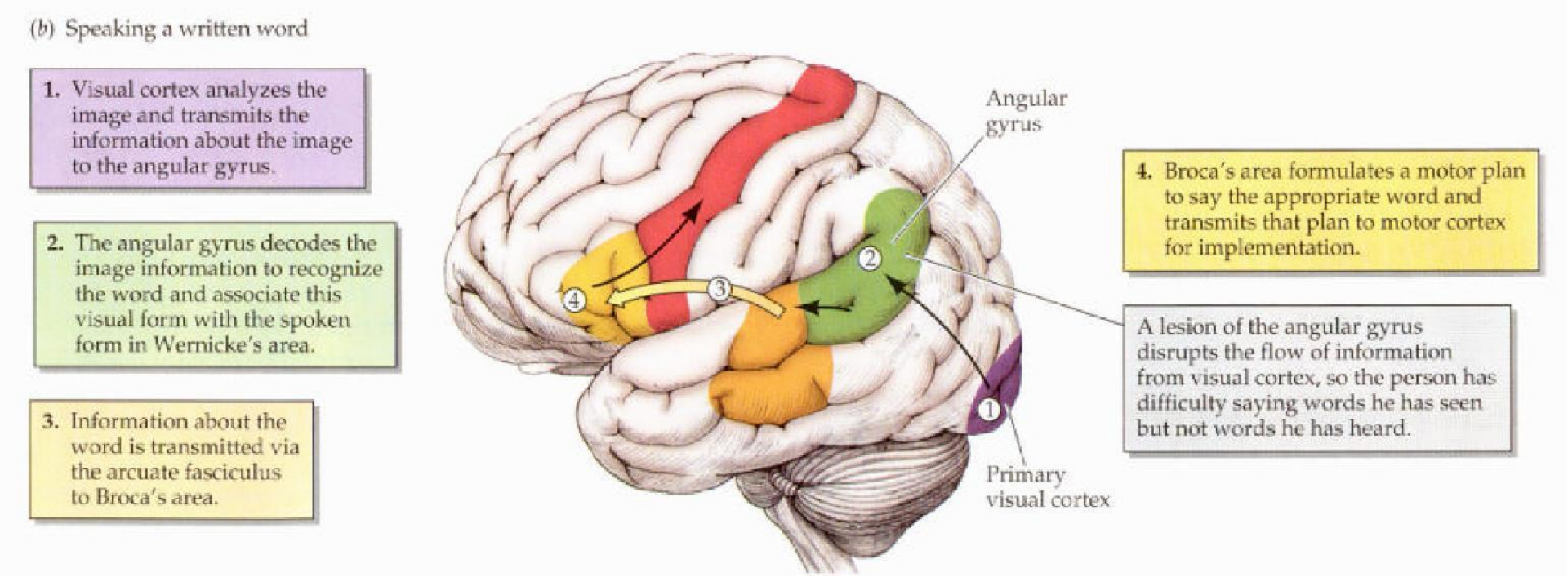
1. Repeating a spoken word



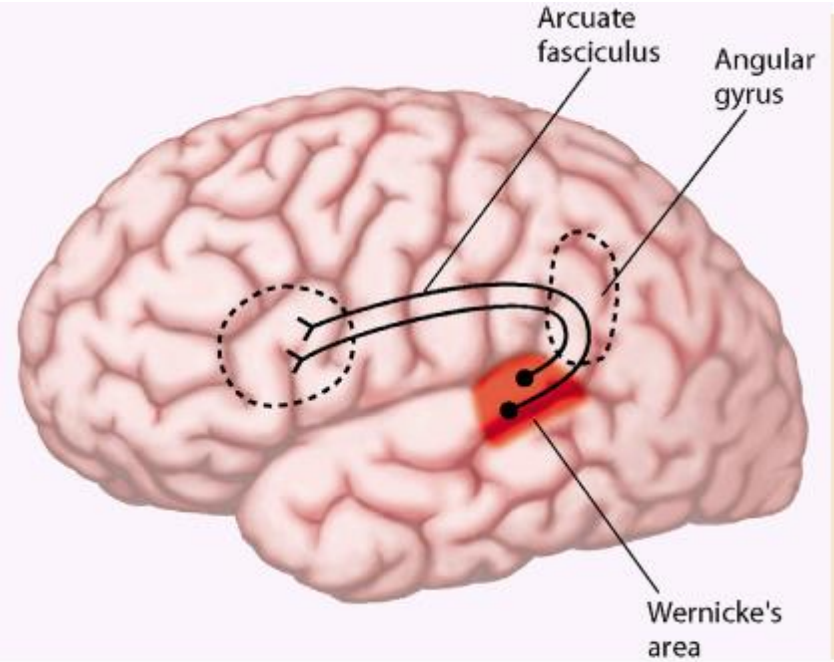
- Arcuate fasciculus is the bridge from the Wernicke's area to the Broca's area

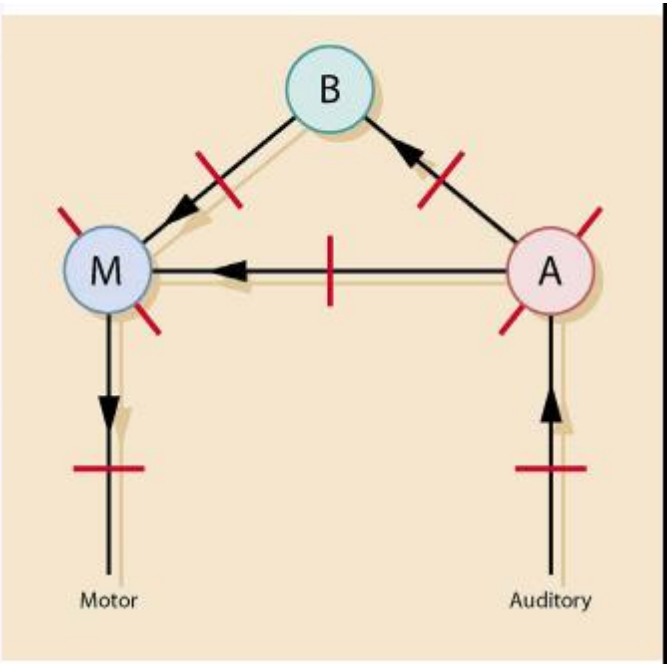
Wernicke-Geschwind Model

2. Repeating a written word



- Angular gyrus is the gateway from visual cortex to Wernicke's area
- This is an oversimplification of the issue:
  - not all patients show such predicted behavior (Howard, 1997)





Wenicke-Lichtheim-Geschwind model of language processing. The area that stores permanent information about word sounds is represented by *A* (*Wernicke area*). The speech planning and programming area is represented by *M* (*Broca area*). Conceptual information is stored in area *B (supramarginal, angular gyri)*. From this model it was predicted that lesions in the three main areas, or in the connections between the areas, or the inputs to or outputs from these areas, could account for seven main aphasic syndromes (Caplan et al., 1994; Gazzaniga, 2002).

Sign Languages

- Full-fledged languages, created by hearing-impaired people (*not* by Linguists):
  - Dialects, jokes, poems, etc.
  - Do not resemble the spoken language of the same area (ASL resembles Bantu, Navaho, and Japanese more than English)
  - Pinker: Nicaraguan Sign Language
  - Another evidence of the origins of language (gestures)
- Most gestures in ASL are with right-hand, or else both hands (left hemisphere dominance)
- Signers with brain damage to similar regions show aphasia as well

Signer Aphasia

- Young man, both spoken and sign language:
  - Accident and damage to brain
  - Both spoken and sign languages are affected
- Deaf-mute person, sign language:
  - Stroke and damage to left-side of the brain
  - Impairment in sign language
- 3 deaf signers:
  - Different damages to the brain with different impairments to grammar and word production

Spoken and Sign Languages

- Neural mechanisms are similar
- fMRI studies show similar activations for both hearing and deaf
- But in signers, homologous activation on the right hemisphere is unanswered yet

Dyslexia

- Problem in learning to read
- Common in boys and left-handed
- High IQ, so related with language only
- Postmortem observation revealed anomalies in the arrangement of cortical cells
  - Micropolygyria: excessive cortical folding
  - Ectopias: nests of extra cells in unusual location
- Might have occurred in mid-gestation, during cell migration period

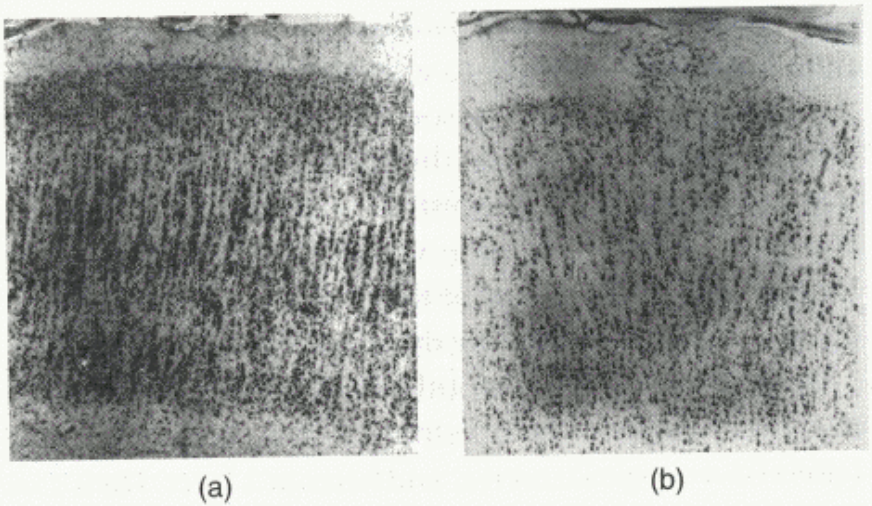


Figure 16.27
Photomicrographs of the left planum temporale (a portion of Wernicke's area). (a) A control subject. (b) A person with developmental dyslexia. Nissl stain.
(Photographs courtesy of A. Galaburda.)

Acquired Dyslexia = Alexia

- Disorder in adulthood as a result of disease or injury
- Deep dyslexia (pays attn. to wholes):
  - “cow” -> “horse”, cannot read abstract words
  - Fails to see small differences (do not read each letter)
  - Problems with nonsense words
- Surface dyslexia (pays attn. to details):
  - Nonsense words are fine
- Suggests 2 different systems:
  - One focused on the meanings of whole words
  - The other on the sounds of words

Electrical Stimulation

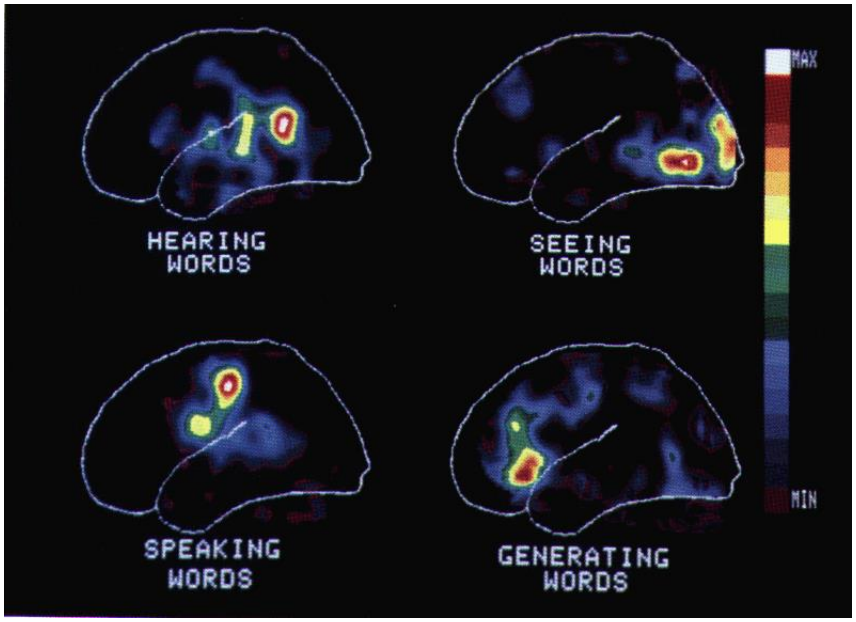
- Penfield and Roberts (1959): During epilepsy surgery under local anesthesia to locate cortical language areas, stimulation of:
  - Large anterior zone:
    - stops speech
  - Both anterior and posterior temporoparietal cortex:
    - misnaming, impaired imitation of words
  - Broca's area:
    - unable comprehend auditory and visual semantic material,
    - inability to follow oral commands, point to objects, and understand written questions

Studies by Ojemann et al.

- Stimulation of the brain of an English-Spanish bilingual shows different areas for each language
- Stim of inferior premotor frontal cortex:
  - Arrests speech, impairs all facial movements
- Stim of areas in inferior, frontal, temporal, parietal cortex:
  - Impairs sequential facial movements, phoneme identification
- Stim of other areas:
  - lead to memory errors and reading errors
- Stim of thalamus during verbal input:
  - increased accuracy of subsequent recall

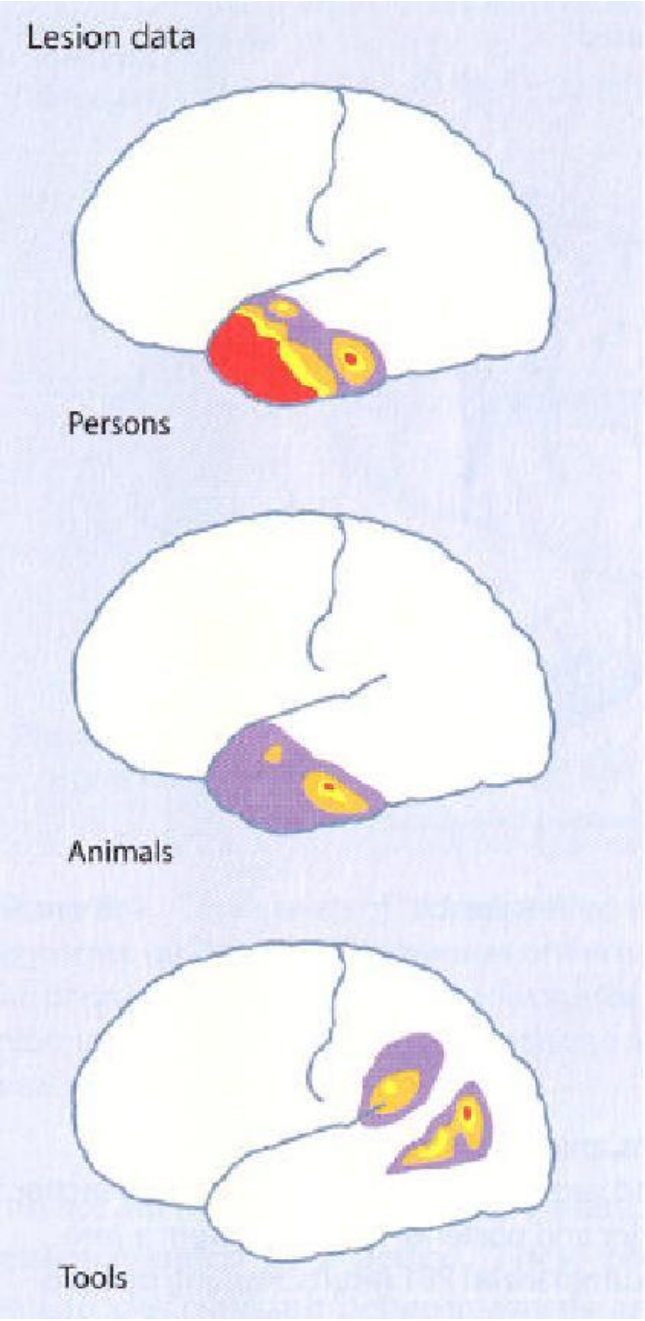
PET by Posner and Raichle

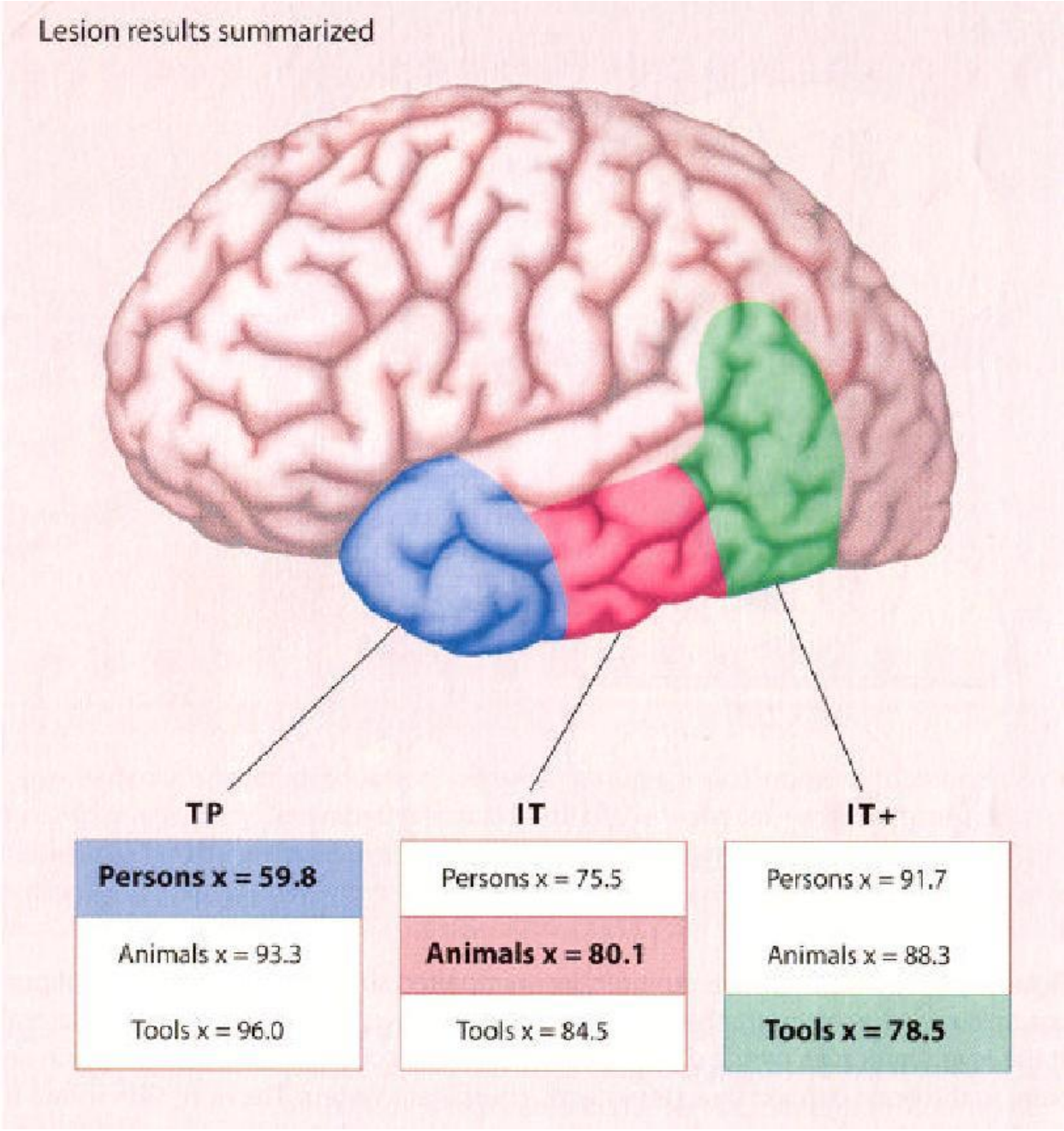
- Passive hearing of words activates:
  - Temporal lobes
- Repeating words activates:
  - Both motor cortices, the supplemental motor cortex, portion of cerebellum, insular cortex
- While reading and repeating:
  - No activation in Broca's area
- But if semantic association:
  - All language areas including Broca's area
- Native speaker of Italian and English:
  - Slightly different regions

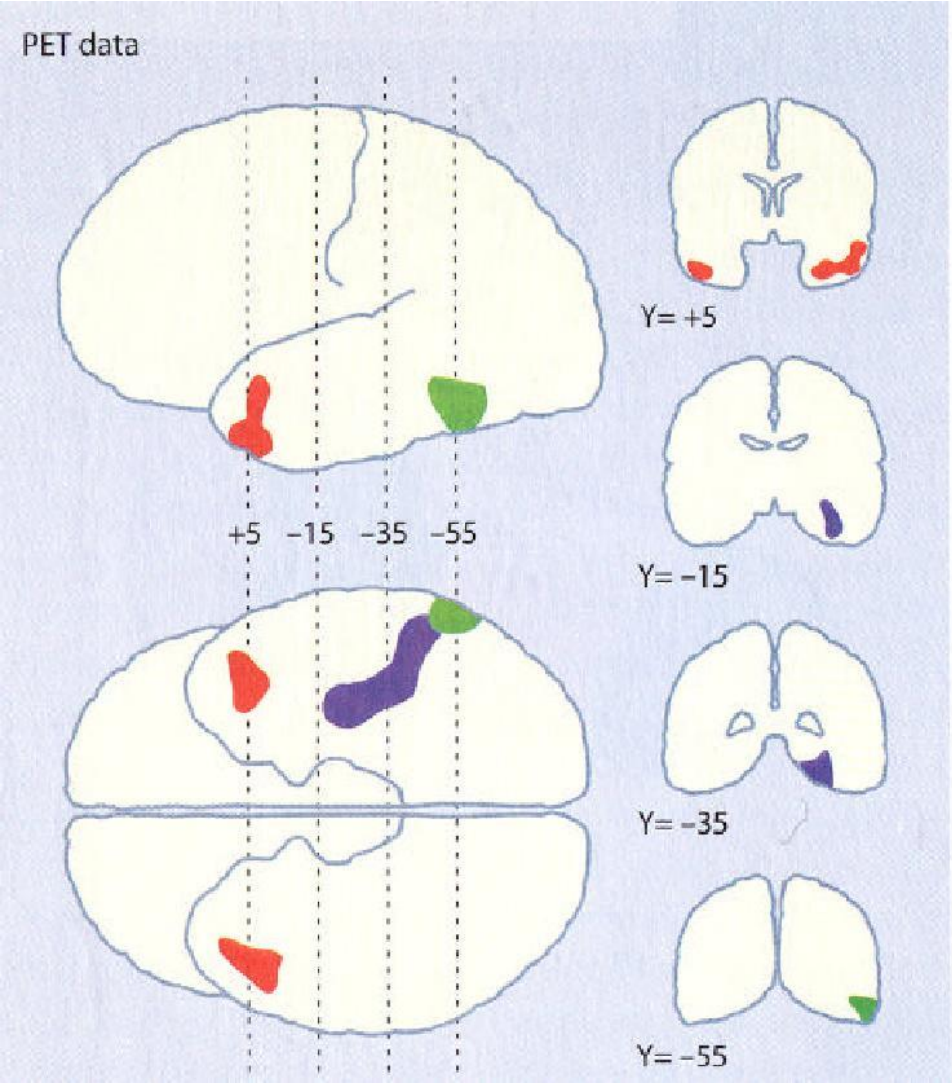


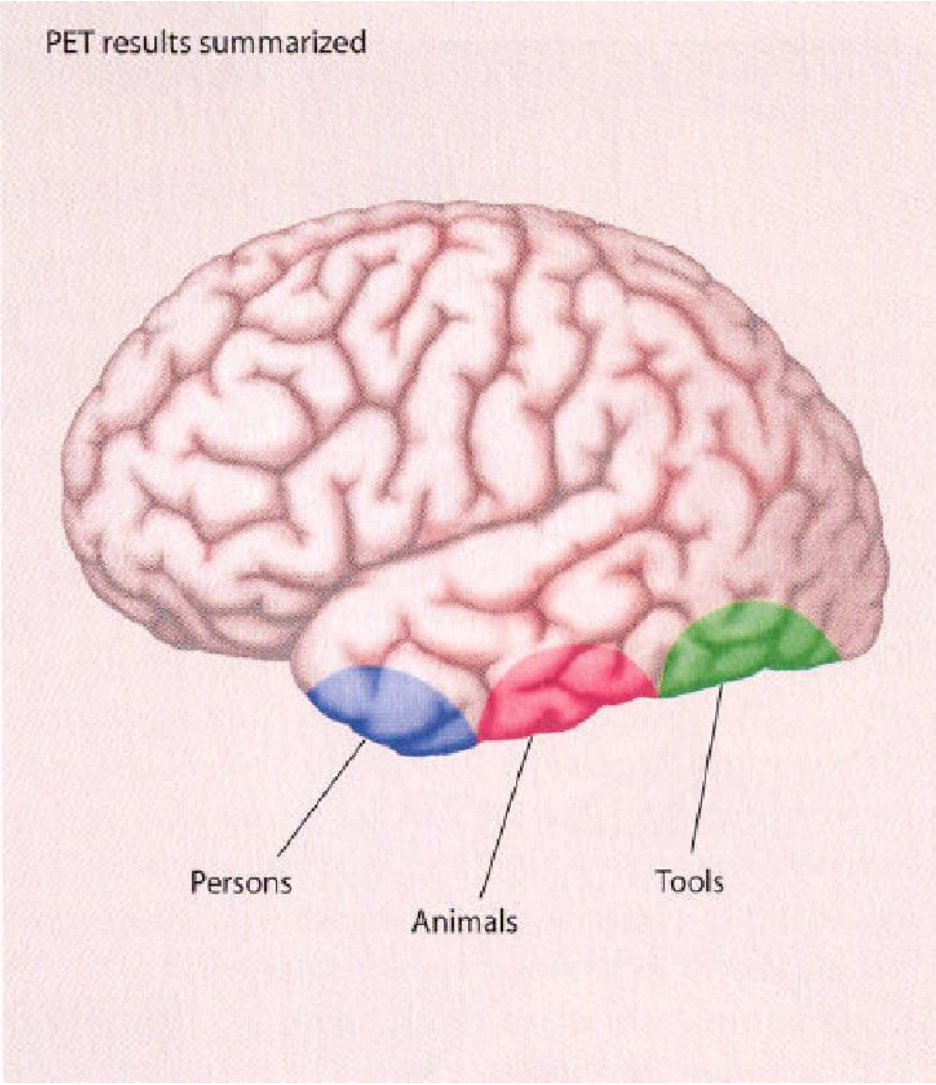
PET by Damasios

- Different areas of left hemisphere (other than Broca's and Wernicke's regions) are used to name (1) tools, (2) animals, and (3) persons
- Stroke studies support this claim
- Three different regions in temporal lobe are used
- ERP studies support that word meaning are on temporal lobe (may originate from Wernicke's area):
  - "the man started the car engine and stepped on the pancake"
  - Takes longer to process if grammar is involved


Lesion data
Persons
Animals
Tools


Lesion results summarized
TP
IT
IT+
Persons x = 59.8
Animals x = 93.3
Tools x = 96.0
Persons x = 75.5
Animals x = 80.1
Tools x = 84.5
Persons x = 91.7
Animals x = 88.3
Tools x = 78.5

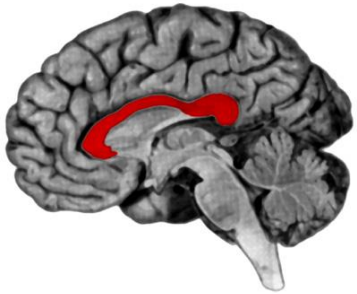

PET data
+5 −15 −35 −55
Y= +5
Y= −15
Y= −35
Y= −55


PET results summarized
Persons
Animals
Tools

Williams Syndrome

- Caused by the deletion of a dozen genes from one of the two chromosomes numbered 7
- Shows dissociation between language and intelligence, patients are:
  - Fluent in language
  - But cannot tie their shoe laces, draw images, etc.
- Developmental process is altered:
  - Number skills good at infancy, poor at adulthood
  - Language skills poor at infancy, greatly improved in adulthood
  - Guest speaker in the colloquium, Annette Karmiloff-Smith, claims the otherwise:
    - Development alters the end result of the syndrome (?)

Split-brain



- Epileptic activity spread from one hemisphere to the other thru corpus callosum
- Since 1930, such epileptic treated by severing the interhemispheric pathways
- At first no detectible changes (e.g. IQ)
- Animal research revealed deficits:
  - Cat with both corpus callosum and optic chiasm severed
  - Left-hemisphere could be trained for symbol:reward
  - Right-hemisphere could be trained for inverted symbol:reward

Left vs. Right Brain

- Pre and post operation studies showed that:
  - Selective stimulation of the right and left hemisphere was possible by stimulating different parts of the body (e.g. right/left hand):
    - Thus can test the capabilities of each hemisphere
  - Left hemisphere could read and verbally communicate
  - Right hemisphere had small linguistic capacity: recognize single words
  - Vocabulary and grammar capabilities of right is far less than left
  - Only the processes taking place in the left hemisphere could be described verbally

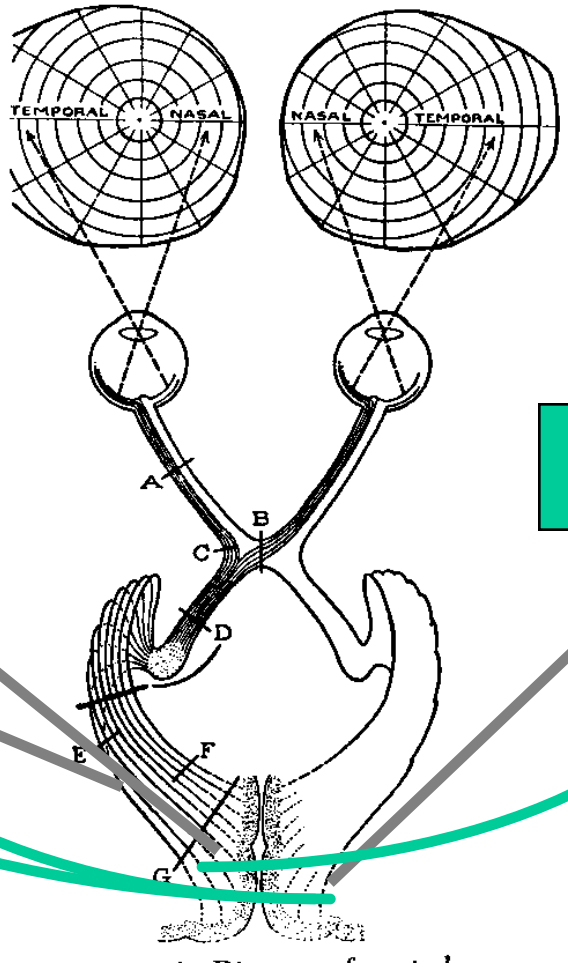
Normal Cortical Connections

Language
Dominant Side

Broca's Area

Motor Cortex

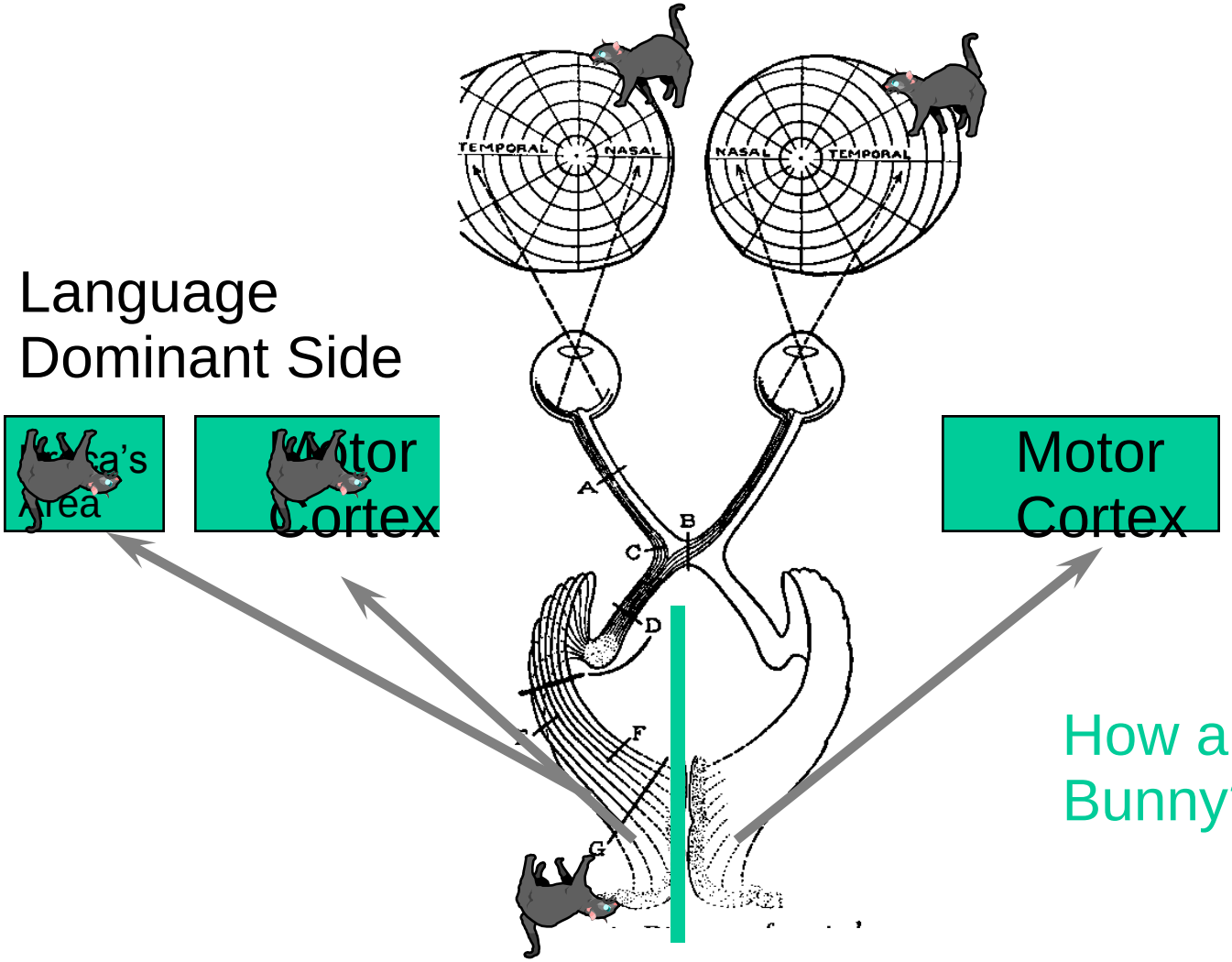
Motor Cortex



What changes if the corpus callosum is damaged?

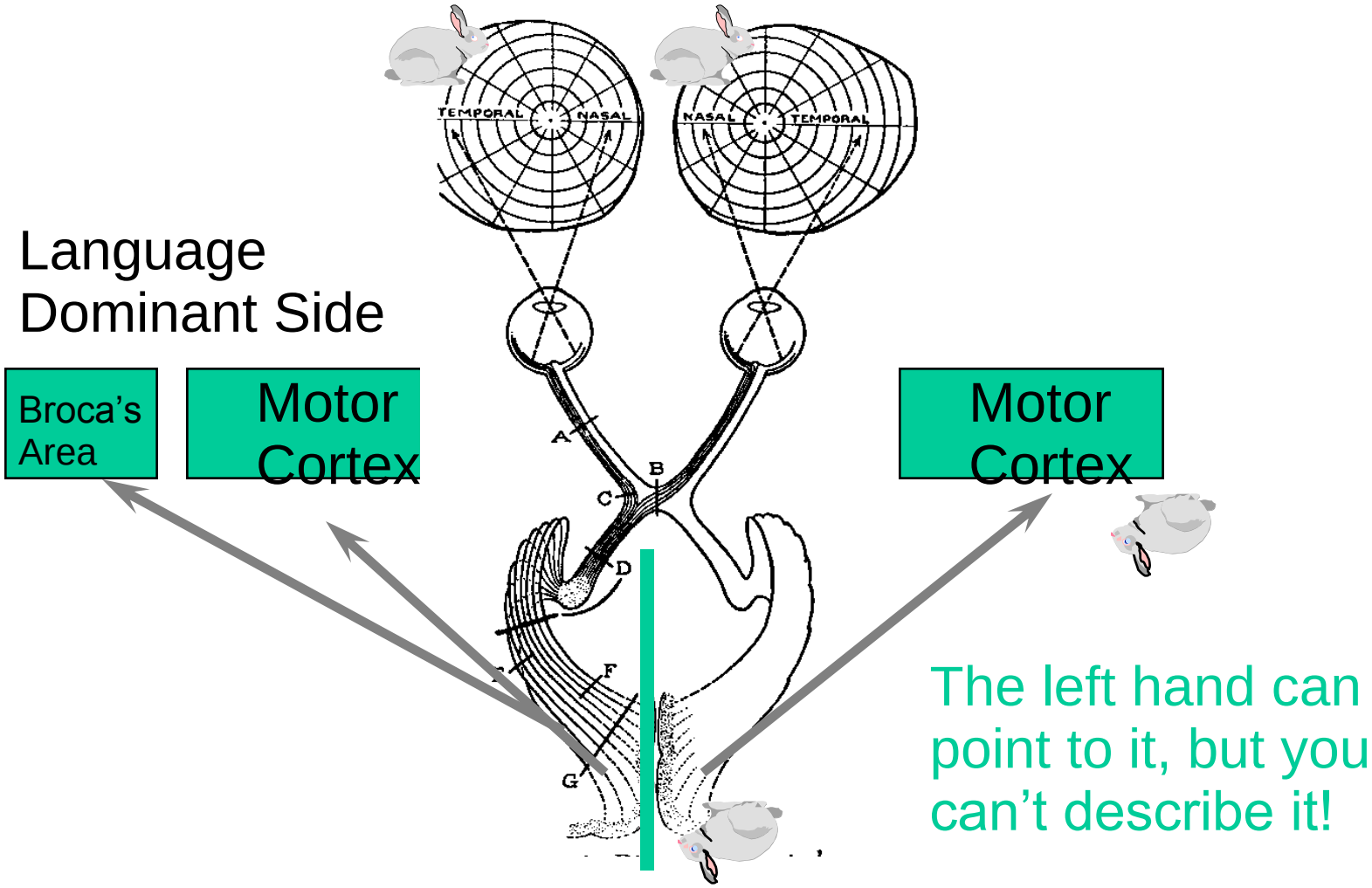
Callosal Connections

The Split Brain Studies



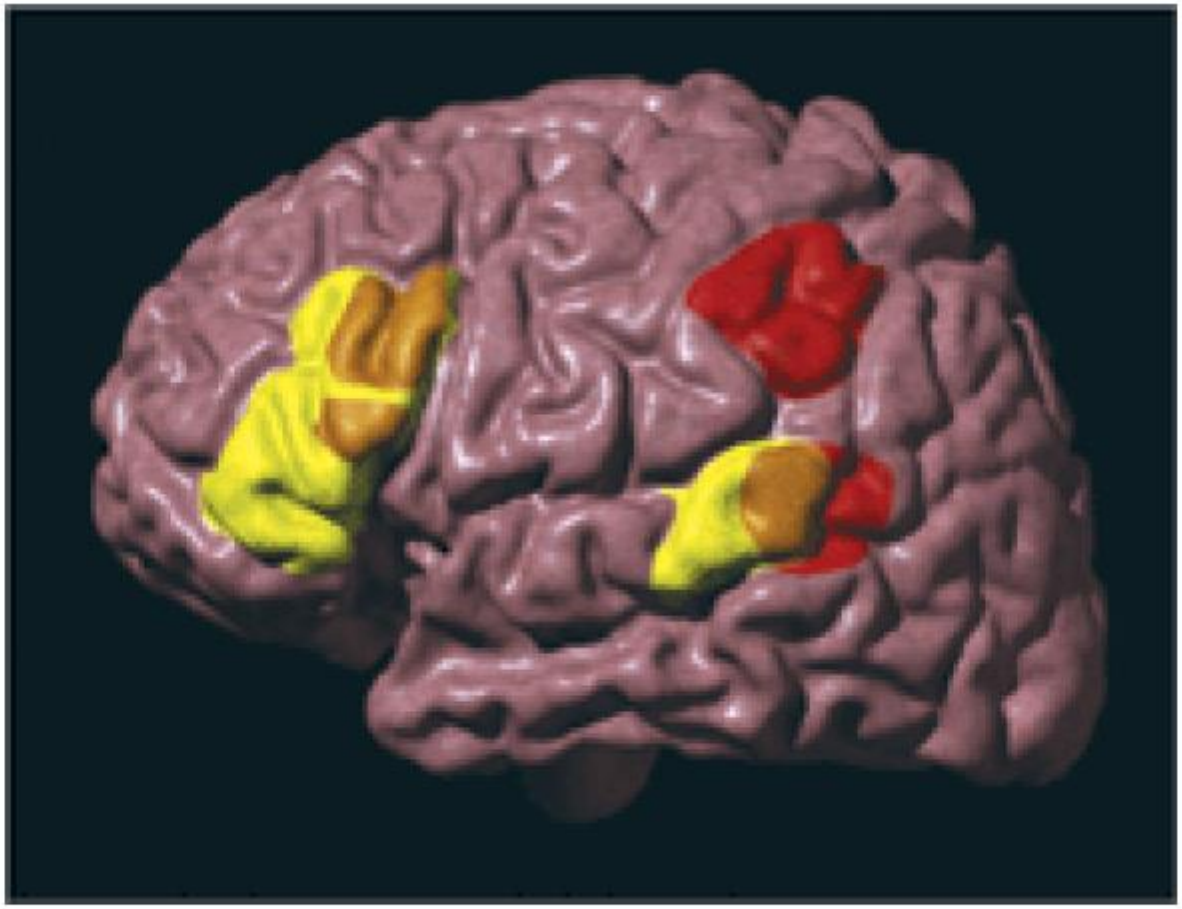
How about the
Bunny?

The Split Brain Studies



Other studies

- Right ear advantage in dicothic listening:
  - Due to interhemispheric crossing
- Words in left-hemisphere, Music in right
  - Supported by damage and imaging studies
  - But perfect-pitch is still on the left
- Asymmetry in planum temporale:
  - Musicians with perfect-pitch has 2x larger PT
  - Evident in newborns, thus suggesting innate basis for cerebral specialization for language and speech



Wired for imitation? Classic language areas--Broca's and Wernicke's (yellow)--overlap (orange) with areas critical for imitation (red). A. TOGA/UCLA

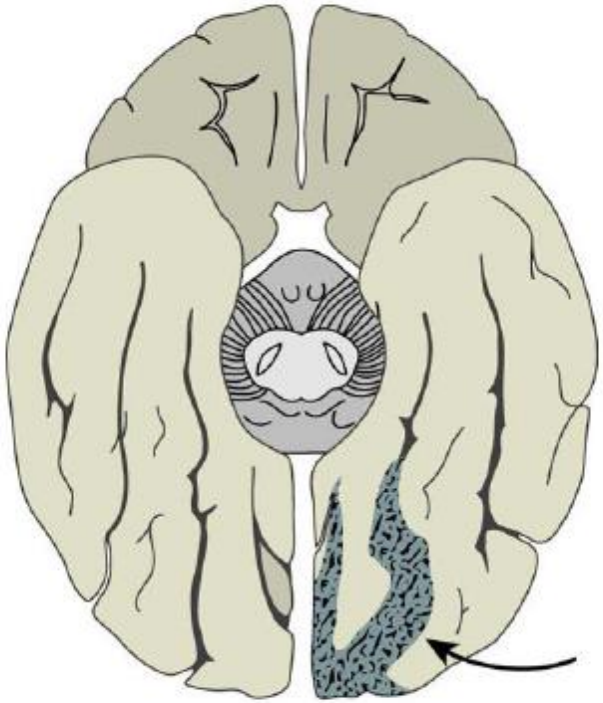


Diagram from Dejerine's 1892 paper showing the lesion that results in pure alexia. The lesion is shown from the inferior surface of the brain. It has destroyed the left visual cortex and interrupted fibers from the right visual cortex on their way to language centers in the left hemisphere

Broca's aphasia	speech output is slow, effortful, often misarticulated, missing function words, agrammatism	Disturbance in the speech planning and production mechanism	Posterior aspect of the IFG, insula, portions of the basal ganglia
Wernicke's aphasia	Fluent-sounding speech, composed of meaningless strings of words, sounds and jargon, the inability to name objects	Disturbance of the permanent representations of the sound structures of word	Posterior half of the STG, junction between the parietal and temp. lobes, including supramarginal and angular gyri, the white matter underlying W's area
Conduction aphasia	Disturbance of repetition and spontaneous speech (phonemic paraphasia)	Disconnection between the sound patterns of words and the speech production mechanism	Lesion in the arcuate fasciculus and/or cortico-cortical connections between W's and B's areas
Transcortical sensory aphasia	Disturbance of single word comprehension with relatively intact repetition	Disturbance in activation of word meanings despite normal recognition of auditory presented words	White matter tracts connecting parietal lobe to temporal lobe or portions of inferior parietal lobule
Transcortical motor apahasia	Disturbance of spontaneous speech, similar to Broca's aphasia with relatively preserved repetition, comprehension	Disconnection between conceptual representations of words and sentences and the motor speech production system	White matter tracts deep to Broca's area connecting to parietal lobe

Pure motor speech disorder	Disturbance of articulation, apraxia of speech, dysarthria, anarthria, aphemia	Disturbance of articulatory mechanisms	Outflow tracts from motor cortex
Pure word deafness	Disturbance of spoken word comprehension repetition	Failure to access spoken words impaired	Input tracks from auditory system to Wernicke;s area
Anomic aphasia	Disturbance in the production of single words, nouns. Intact comprehension, repetition	Disturbance of concepts, and or the sound pattern of words	Inferior parietal lobe or connections between parietal lobe and temporal lobe
Global aphasia	Major disturbance in all language functions	Disrupting of all language processing components	Large portion of the perisylvian association cortex
Isolation of the language zone	Disturbance of both spontaneous speech (sparce, halting speech) and comprehension, with some preservation of repetition, echolalia	Disconnection between concepts and both representations of word sounds and the speech production mechanisms	Cortex just outside the perisylvian association cortex

Finally

- Precision of stimulus analysis in the brain is reduced on the midline areas of the body
- Speech organs (vocal tract, tongue, larynx, etc.) are in the midline
- Asymmetry of motor control of speech areas (sidedness in language) provides unchallenged control
  - Observed in songbirds too
- But hemispheric dominance is not absolute, both sides are necessary:
  - After commisurotomy, left is better than right, but both are affected