Neurophonetics

Semester 2

Week 2

With thanks to Claire Timmins for providing some of the slides

What is neurophonetics?

- “Neurophonetics deals with neurogenic impairments of the motor act of speaking and of the perceptual processes of spoken language understanding, with the aim of unravelling the neural organization of speech motor control and speech perception.” (Ziegler 2008: 491)
- “Neurophonetics aims at the elucidation of the brain mechanisms underlying speech communication in our species” (Hertrich & Ackermann 2012)
- “To the extent that phonetics is a subdiscipline of linguistics, neurophonetics can be viewed as a subdiscipline of neurolinguistics” (Ziegler 2008)

Neuroanatomy

Physical reality

Crumpled/lumpy

- 3-4 months of development, surface of brain FOLDS up.
- Lot of tissue squeezed into small area

Jelly-like (“blancmange”)

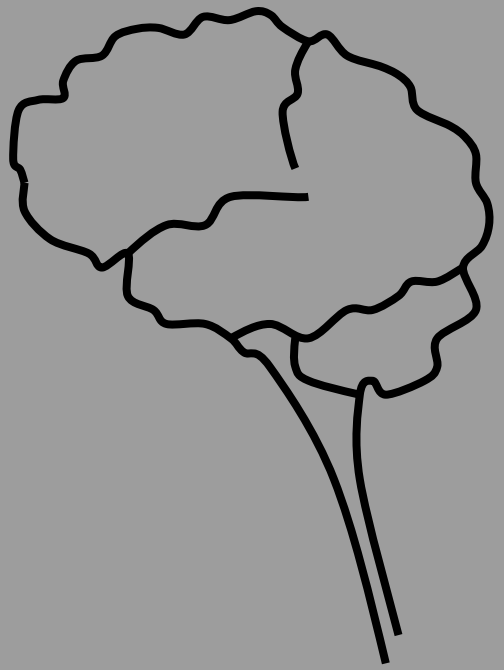
Brain surgery

- Skull sawn to remove top (cranium)
- Brain is mobile within skull but keeps shape due to skull

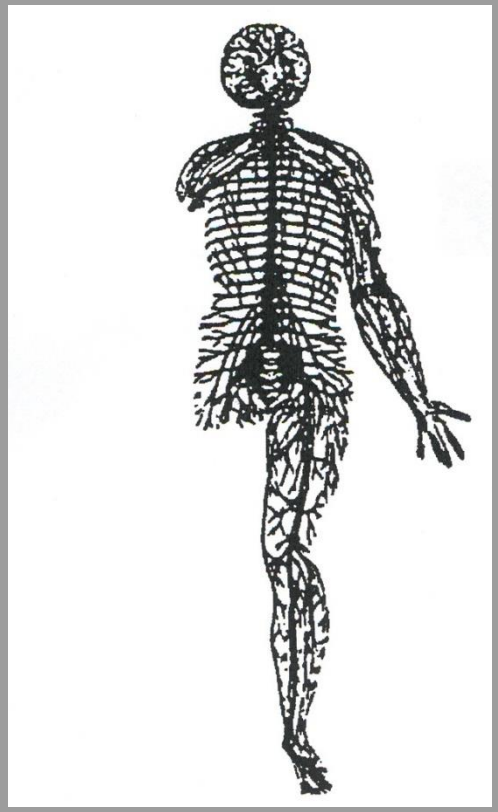
Intracranial recording for epilepsy. Surface of human brain in situ.
Robert Ludlow. Wellcome Trust Image Awards winner 2012.

Central and peripheral nervous system

CNS



PNS



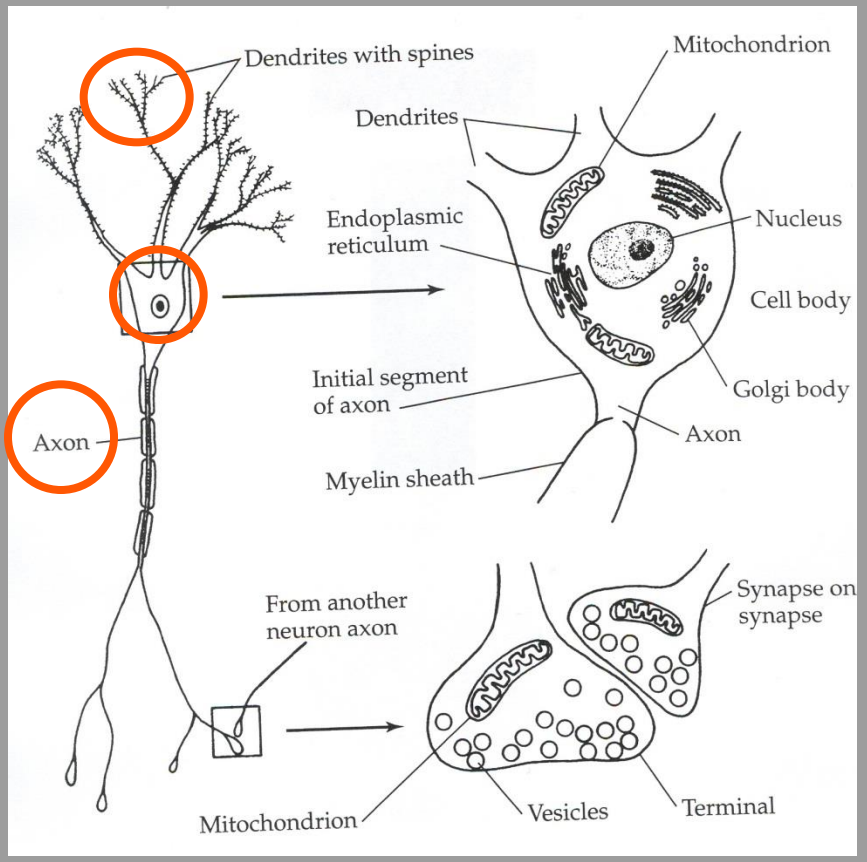
Divisions of the PNS:

Spinal / Cranial nerves; Efferent (away from CNS) vs Afferent (towards CNS) nerves

Neurons (brain cells)

- Neurons transmit information to other neurons, or to muscles (to make them contract)

- **Firing**: electrical action potential travels down axon to **synapse** (junction)
- Release of neurotransmitter either **excites** or **inhibits** the post-synaptic cell



Cerebrum, cerebral cortex

- Cerebrum = 2 hemispheres
  - Each hemisphere is divided into 4 lobes
- Cerebral cortex = surface of cerebrum
- Cortex can be divided into areas of functions
  - e.g. language, personality, vision, audition
  - e.g. motor and sensory functions

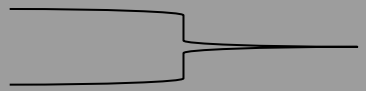
Left and right hemispheres

Equal size/proportion

Some functions are different across the two hemispheres

Some functions are the same

- MOVEMENT
- SENSATION



Planning & execution cross sides

Hemisphere functions

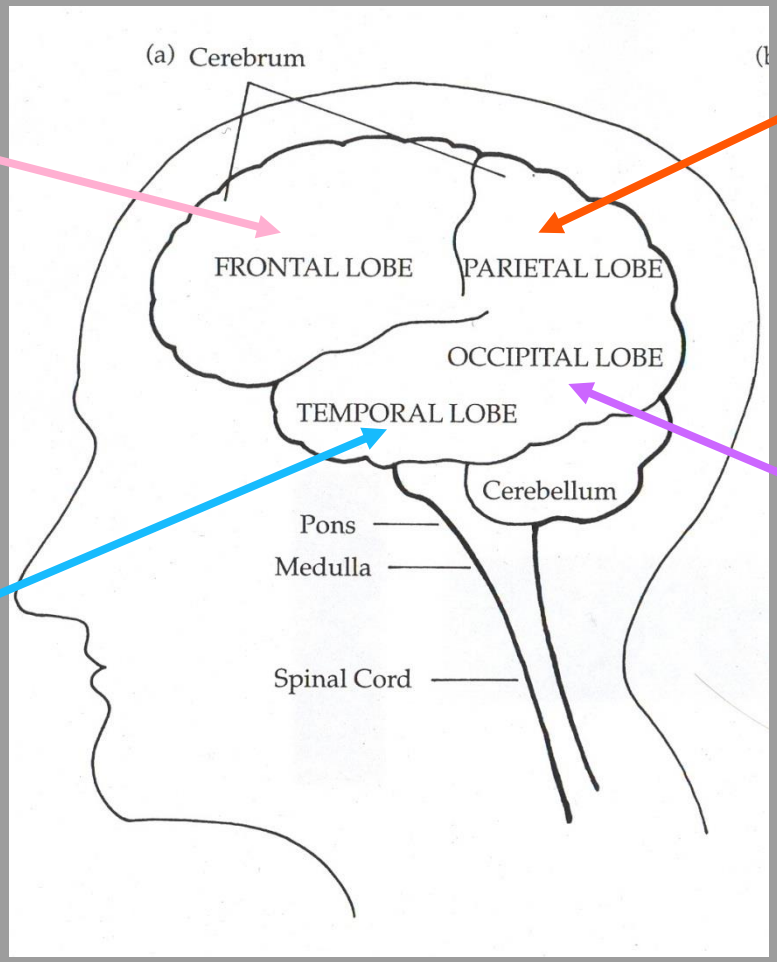
Each hemisphere has specific processing strengths. e.g.

- Left
  - important for language processing, mathematical functioning
- Right
  - important for processing visual and spatial information, musical and artistic functions

Lobes of the cerebrum

"Planning" / "Control"

"Association", "Spatial attention"



"Vision"

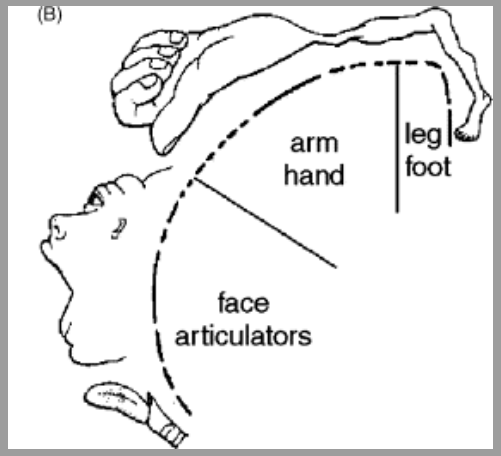
"Recognition (inc. hearing)"

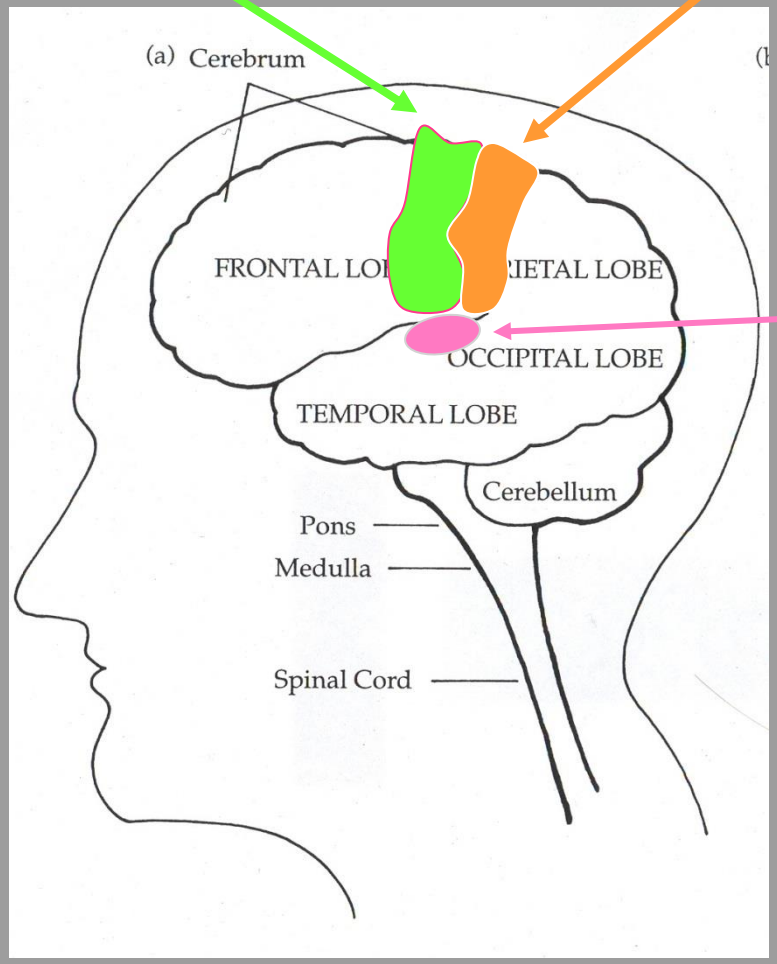
Source: Kent and Tjaden (1997)

Primary motor and sensory areas

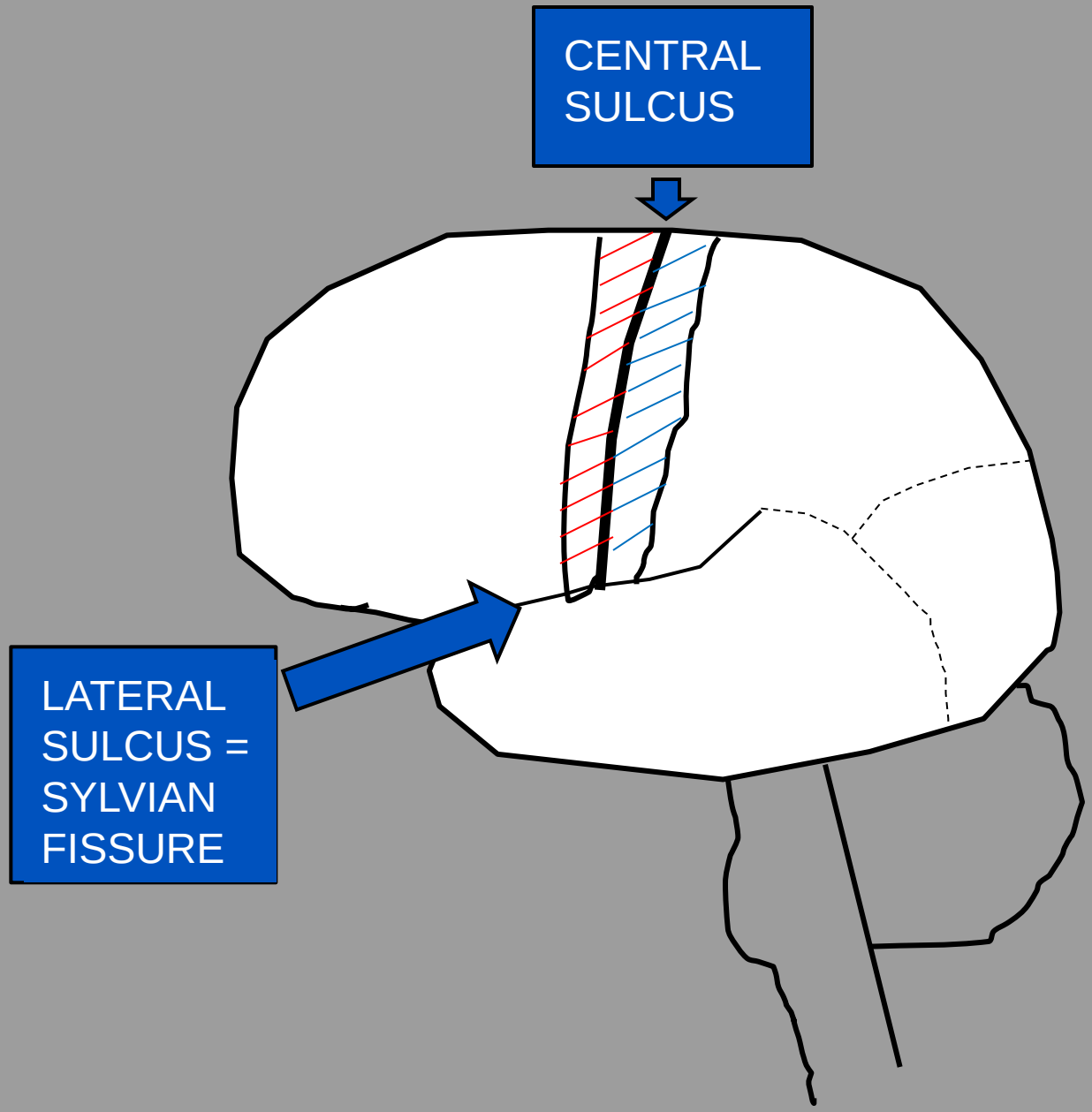
"Motor maps"

"Somatosensory maps"

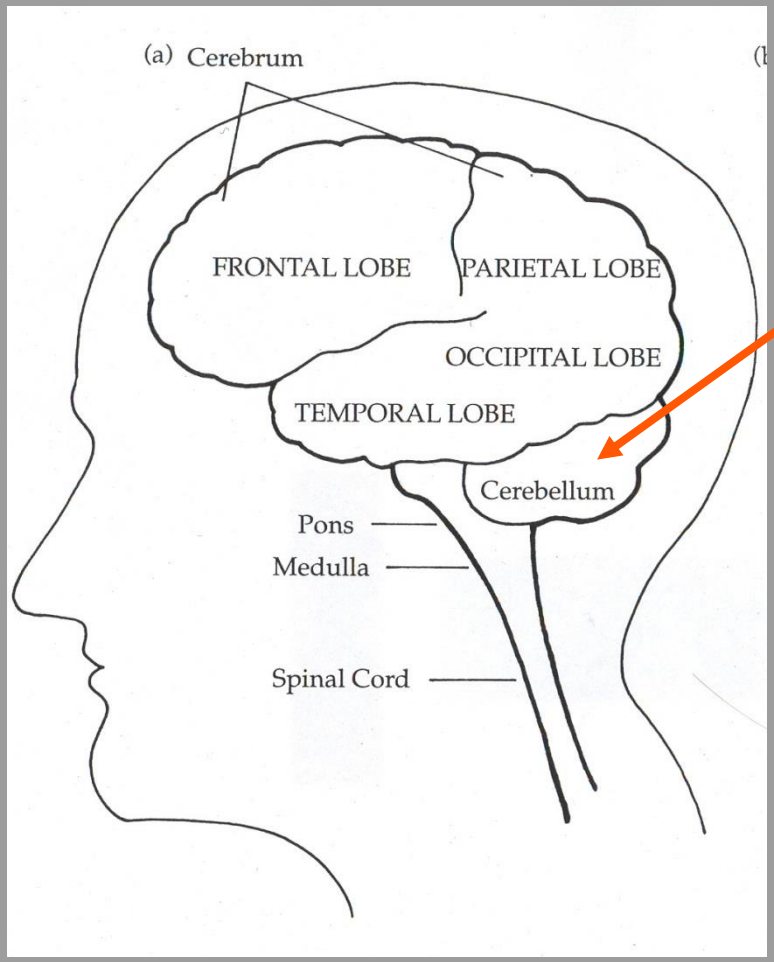




Primary auditory cortex: "tonotopic maps"


CENTRAL SULCUS
LATERAL SULCUS = SYLVIAN FISSURE

Other important areas



Source: Kent and Tjaden (1997)

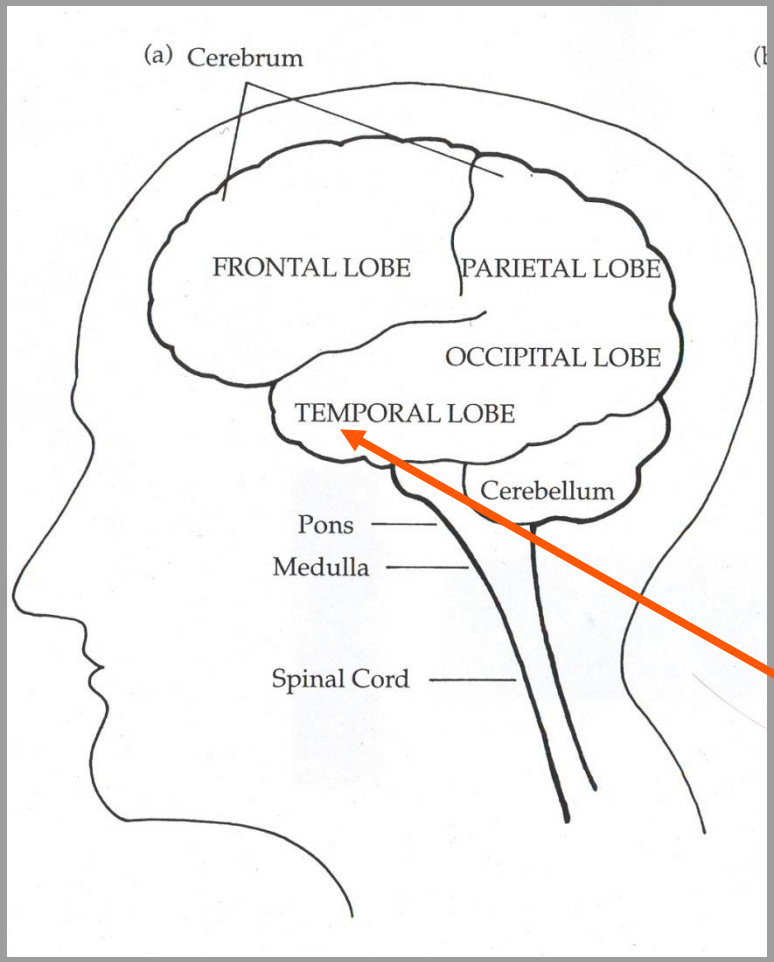
cerebellum
'little brain'

movement, stability, coordination

rhythm, timing, learning

processes information from CNS and PNS

Other important areas

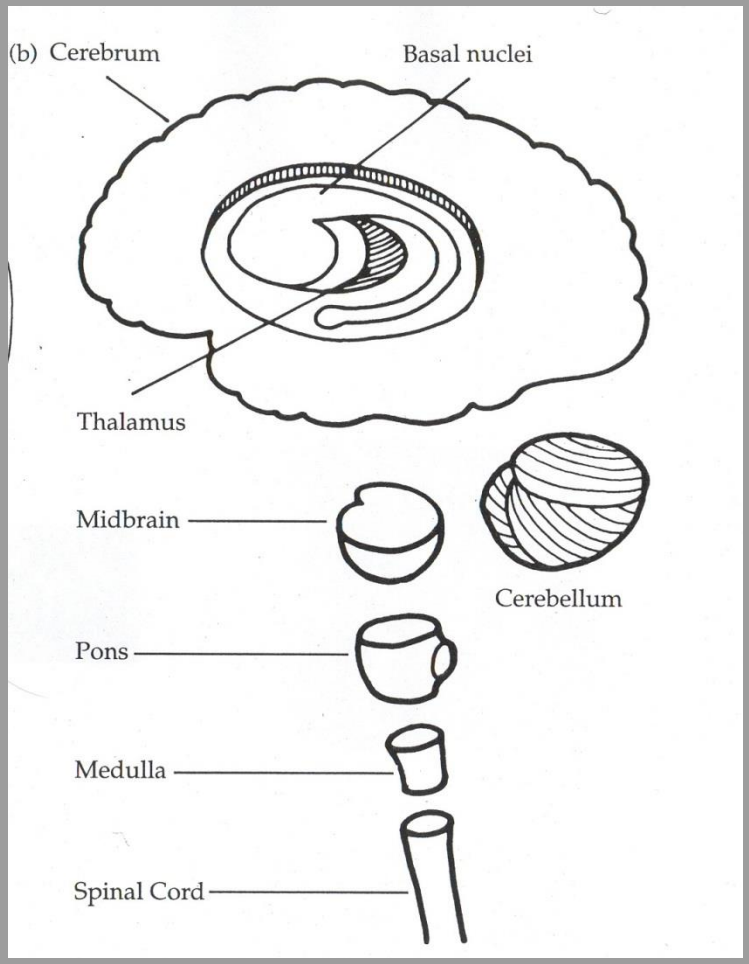


Source: Kent and Tjaden (1997)

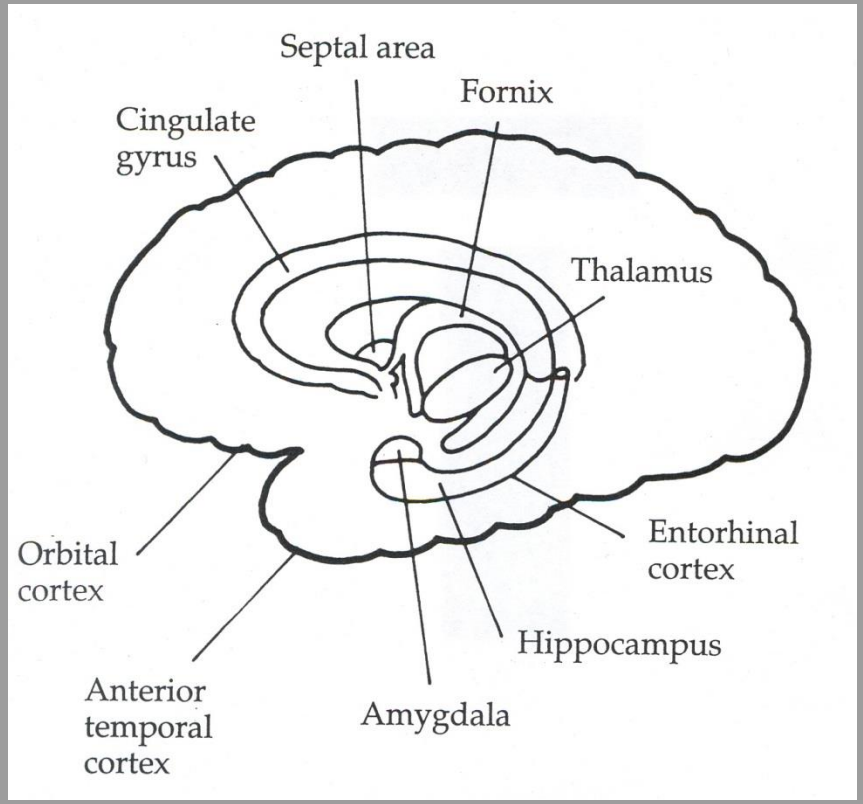
Inside temporal lobe:

- **basal ganglia, thalamus**: speaking…
- **limbic system,** including **hippocampus**: memory/learning, emotion, understanding …

Basal nuclei



Limbic system



Within the cerebrum

Cortex (cerebrum surface) = grey matter (nerve cell bodies)

Subcortical areas:

grey matter & white matter (nerve cell fibres)

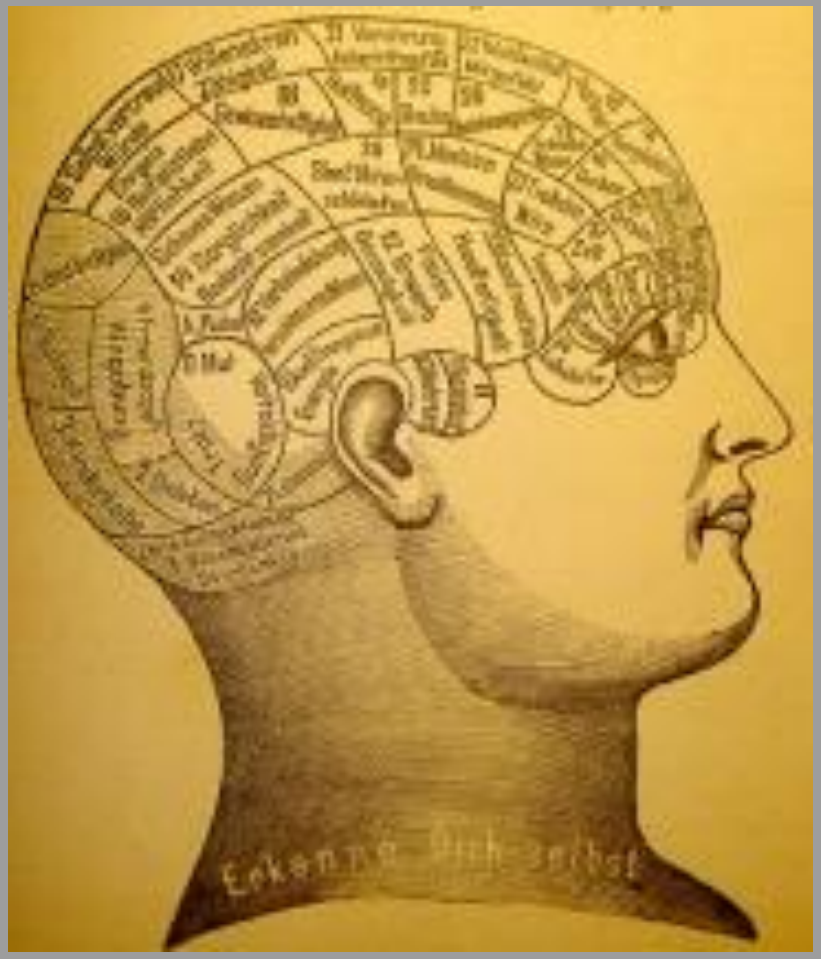
fibres: **corpus callosum** (connects right and left hemispheres), **arcuate fasciculus** (connects motor and sensory cortices)

Localisation of brain functions

Functional localisation

- Certain areas of the brain relate to certain functions (though ongoing questions about defining areas in great detail)
- Tension between
  - “the fact that language is rooted in a huge network across the entire brain” and
  - “the focal nature and high specificity of certain brain areas as shown in brain imaging studies as well as in clinical linguistics and phonetics” (Hertrich & Ackermann, 2012)

Historical aside: Phrenology



Assessing character from bodily features

Franz Joseph Gall (late 18th C)

Pseudoscience

First idea of cortical areas relating to different functions

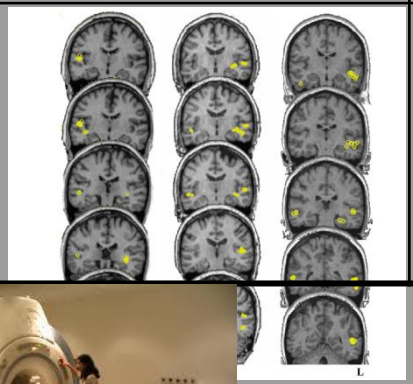
Techniques for investigation

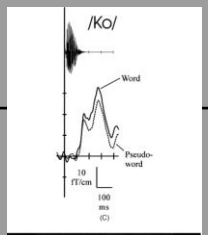
- Lesion studies, neurodegeneration
- Neurosurgery
- Dichotic listening
- Neuroimaging techniques
- Direct stimulation (TMS)

(in combination with observation of behaviour e.g. articulatory/acoustic/perceptual methods)

Neuroimaging techniques

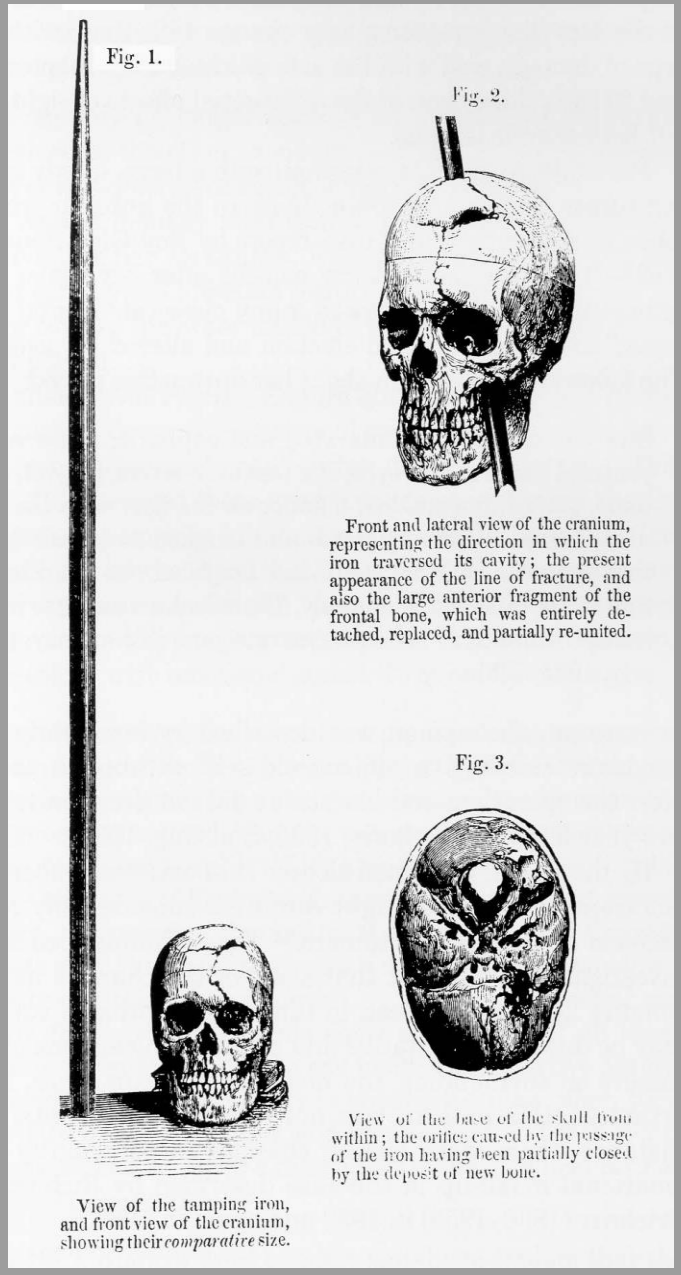
	"Haemodynamic" *Haemo* – blood *Dynamic* – flow	"Neurophysiological"
Examples	PET (positron emission tomography), fMRI (functional magnetic resonance imaging)	EEG (electro-encephalography), MEG (magneto-encephalography)
Measures	Indirect: blood supply (PET) or ratio of oxygenated to deoxygenated blood (fMRI)	Direct: activity of nerve cells
Resolution in space in time	millimetres seconds	centimetres milliseconds





Functionality and disorder

Phineas Gage
(1823-1861, accident in 1848)

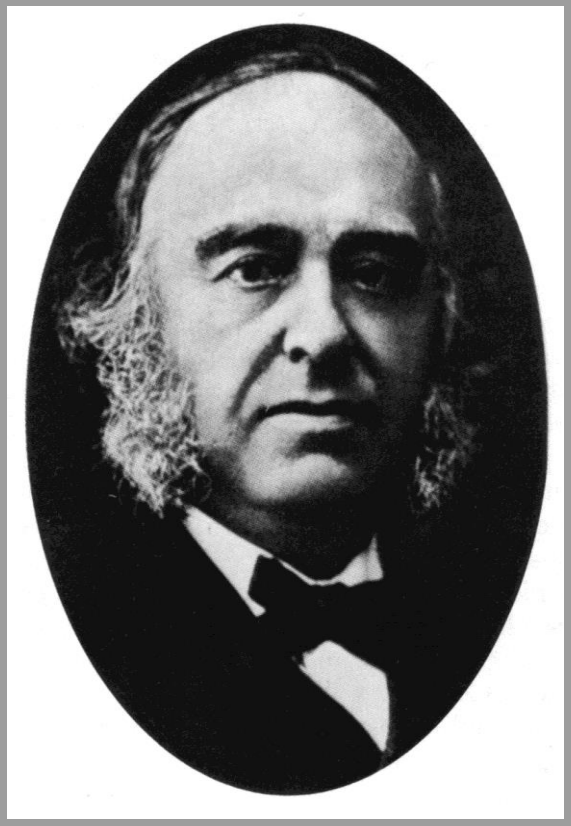


- Phineas Gage (1848): trauma to frontal lobe
  - Resulted in personality changes
  - One of first cases which highlighted role of pre-frontal lobe (area in front of motor cortex)
    - Pre-frontal lobe: personality/decision-making/social behaviour
- Pre-frontal cortex lesions found to result in:
  - Lowered attention/concentration/initiative/spontaneity
  - More carefree, euphoric

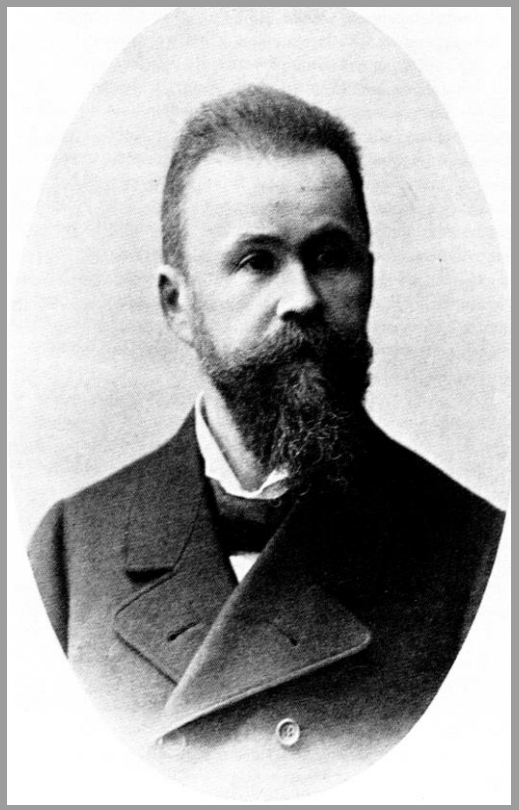
case studies by Oliver Sacks

- Various problems related to areas of damage
- E.g. ‘the man who mistook his wife for a hat’
  - Dr. P (Musician), could not recognise faces but recognised voices
  - Saw faces where there were not any (parking meters etc)
  - Visual area of brain? Eyes fine

Language Disorder and functionality



Paul Broca (1824-1880)



Karl Wernicke (1848-1905)

Brain pathology and language

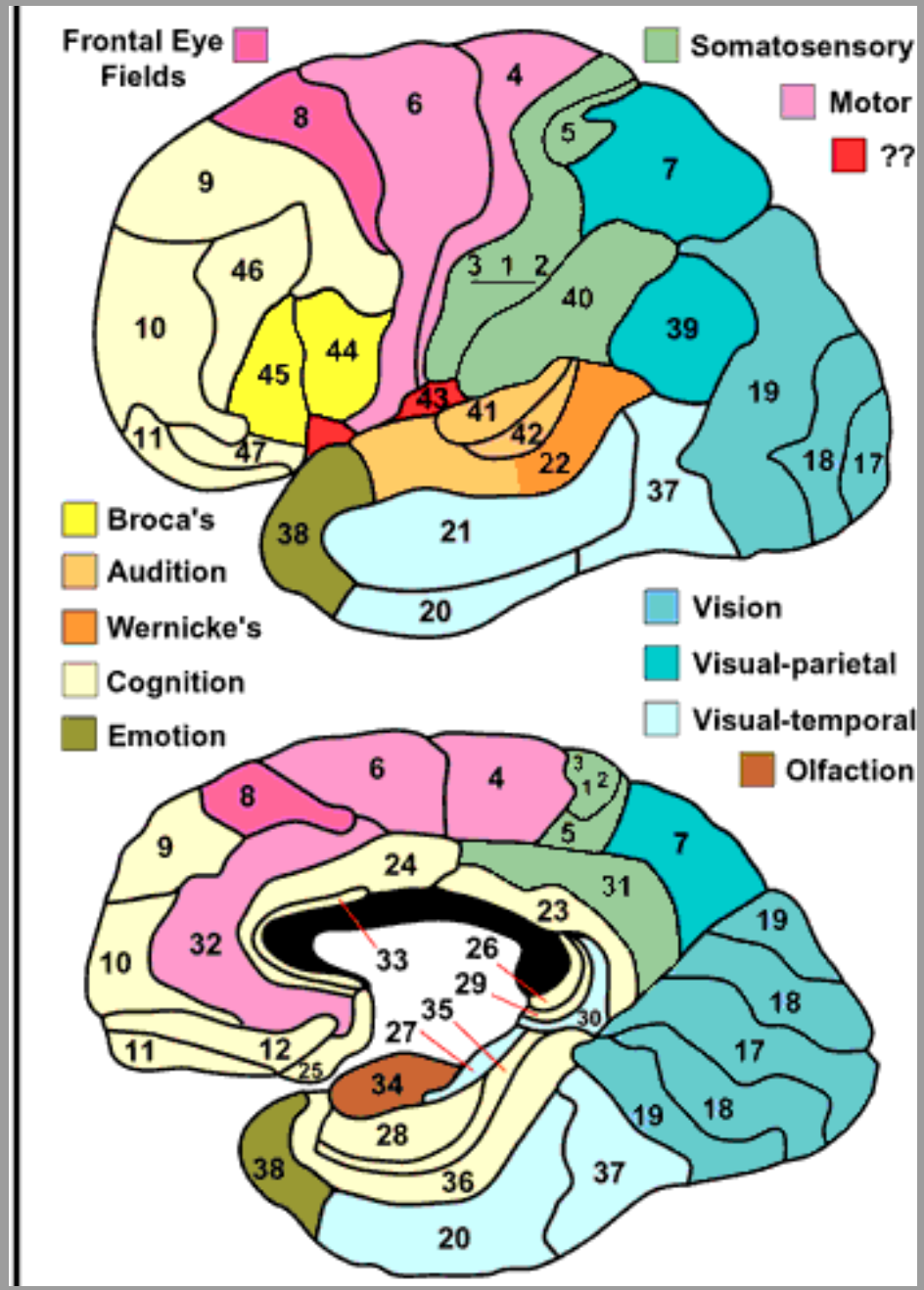
- Aphasias: the loss or impairment of the ability to produce or comprehend language, due to brain damage.
- Various types: global; Broca's/motor; Wernicke's/jargon/anomic

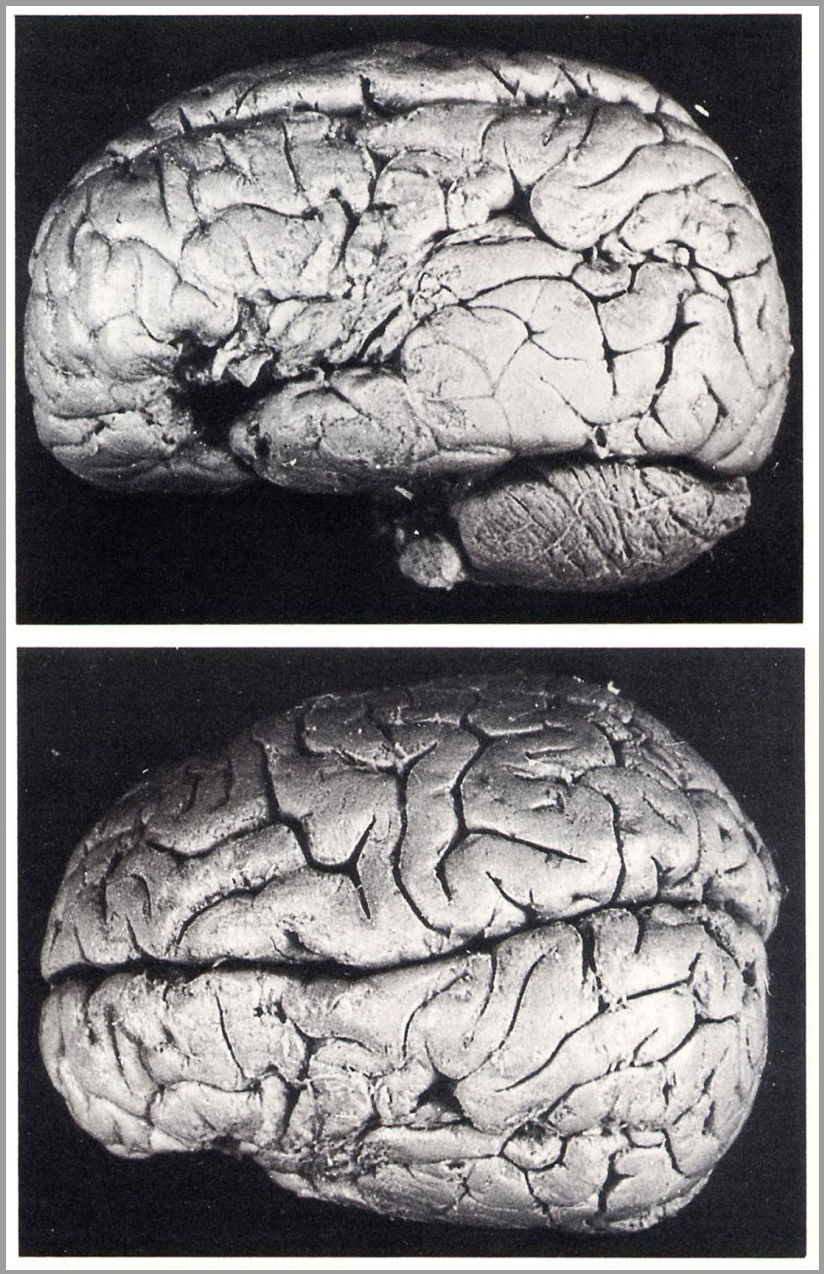
Broca and Wernicke

- Paul Broca and ‘Tan’ 1861
  - Problem with production (only one syllable ‘tan’)
  - Large cyst in the left hemisphere – “mushy and deformed” – in region above sylvian fissure.

- Karl Wernicke - 1874
  - Patient who could speak but couldn’t comprehend language
  - Lesion at the crossroads of 3 lobes of the brain

Brodmann's areas



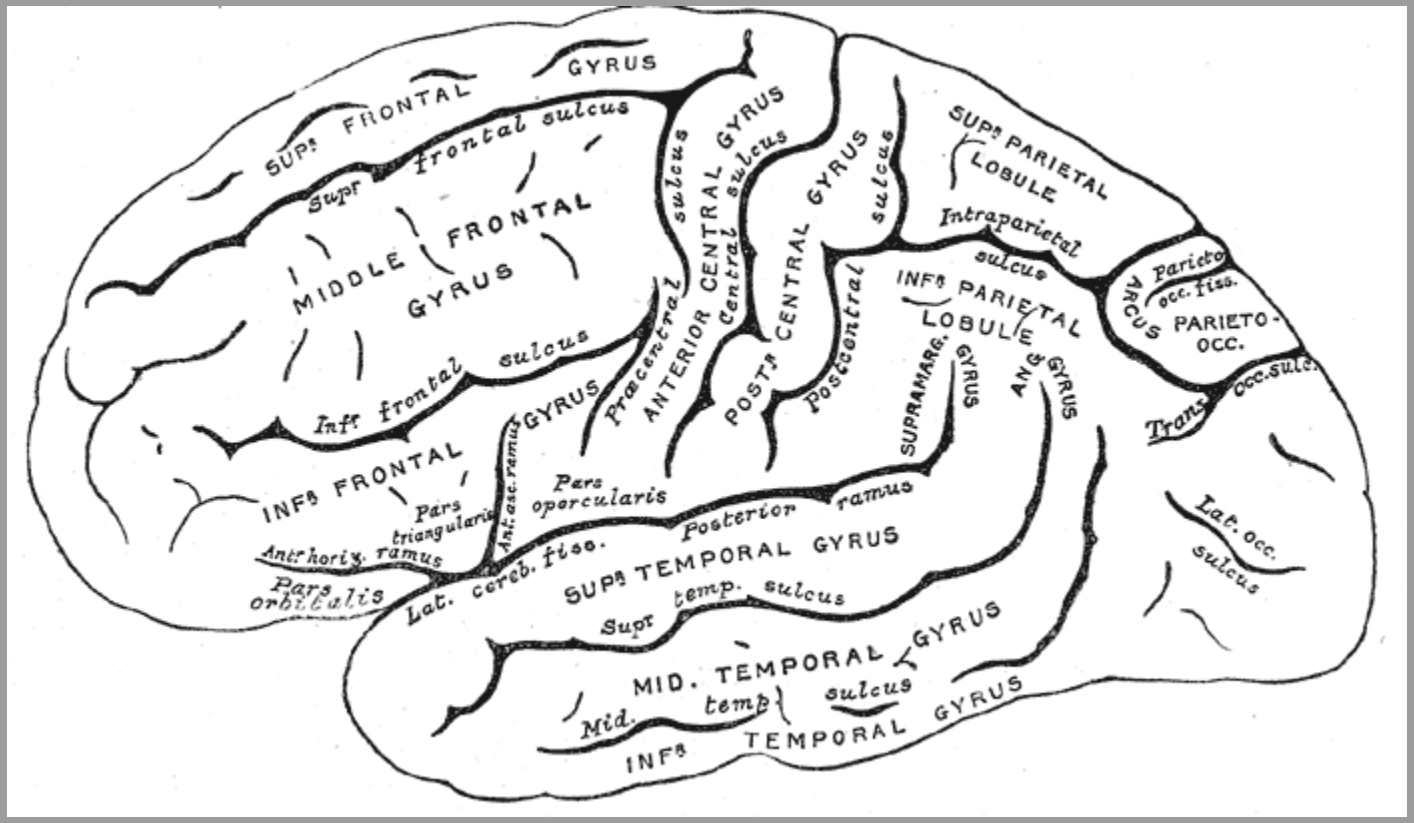


Broca's Area

Photograph of the brain of Paul Broca's patient called "Tan" (real name is Leborgne).

Broca's area

- Frontal lobe
  - Inferior frontal gyrus
  - 2 parts:
    - Pars opercularis
    - Pars triangularis


SUPR FRONTAL GYRUS
Supr frontal sulcus
MIDDLE FRONTAL GYRUS
Infr frontal sulcus
INFR FRONTAL GYRUS
Pars orbitalis
Pars triangularis
Pars opercularis
Ant. horiz. ramus
Ant. asc. ramus
Lat. cereb. fiss.
Præcentral sulcus
ANTERIOR CENTRAL GYRUS
Central sulcus
POSTR CENTRAL GYRUS
Postcentral sulcus
SUPR PARIETAL LOBULE
Intraparietal sulcus
INFR PARIETAL LOBULE
SUPRAMARG. GYRUS
ANG. GYRUS
Parieto occ. fiss.
ARCUS PARIETO-OCC.
Trans. occ. sulc.
Lat. occ. sulcus
SUPR TEMPORAL GYRUS
Posterior ramus
Supr temp. sulcus
MID. TEMPORAL GYRUS
Mid. temp. sulcus
INFR TEMPORAL GYRUS

Broca's area

- Function
  - Motor language area
  - Expression
- Aphasia
  - Motor / non-fluent aphasia
  - Good comprehension, no/impaired speech
  - E.G. 'boy go store' vs 'The boy has gone to the store'
  - Slow, laboured, ungrammatical speech
    - "yes…ah…Monday…ah…dad and…and…ah…hospital….and ah….Wednesday….Wednesday"

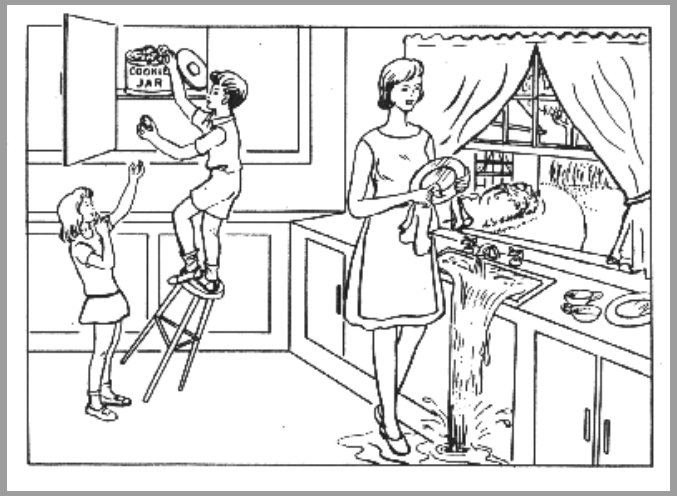
Wernicke's area

- Function
  - Sensory language area
  - Comprehension
  - 22, 39 (supramarginal gyrus), 40 (angular gyrus)

- Aphasia
  - Fluent / Receptive (cortical sensory) aphasia
  - defect in comprehension, good spontaneous speech
    - Anomic aphasia - word finding difficulty
    - Jargon aphasia - fluent, but unintelligible jargon

Wernicke’s aphasia

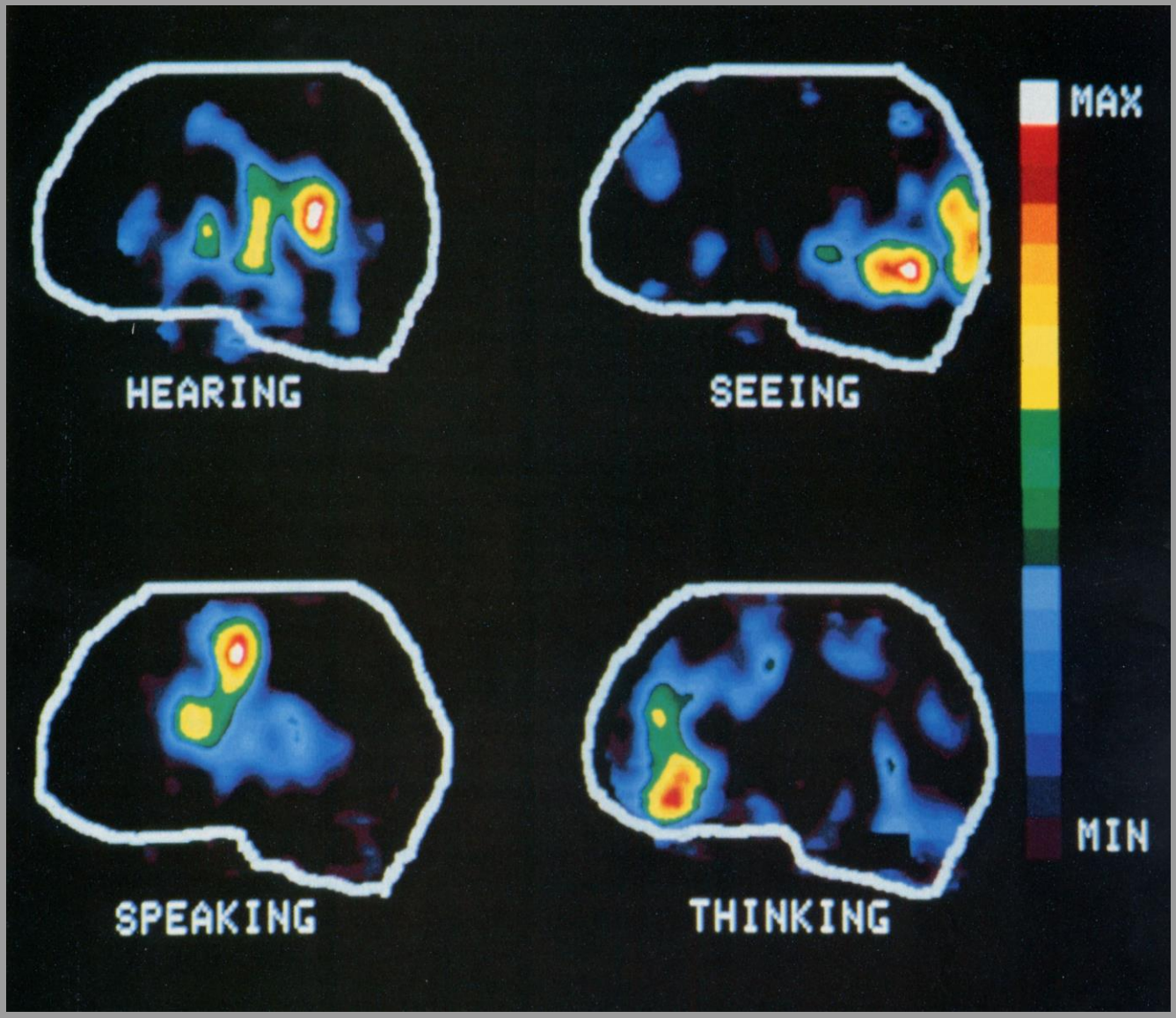
- Her normal corrucation would be a dot
- Well this is .... mother is away here working her work out o'here to get her better, but when she's looking, the two boys looking in other part. One their small tile into her time here. She's working another time because she's getting, too. So two boys work together and one is sneakin' around here, making his work an' his further funnas his time he had.



Arcuate Fasciculus

- Connection between Broca's and Wernicke's
  - Conduction Aphasia
  - good comprehension, good spontaneous speech
  - poor repetition, poor response

Neuroimaging evidence about language processing



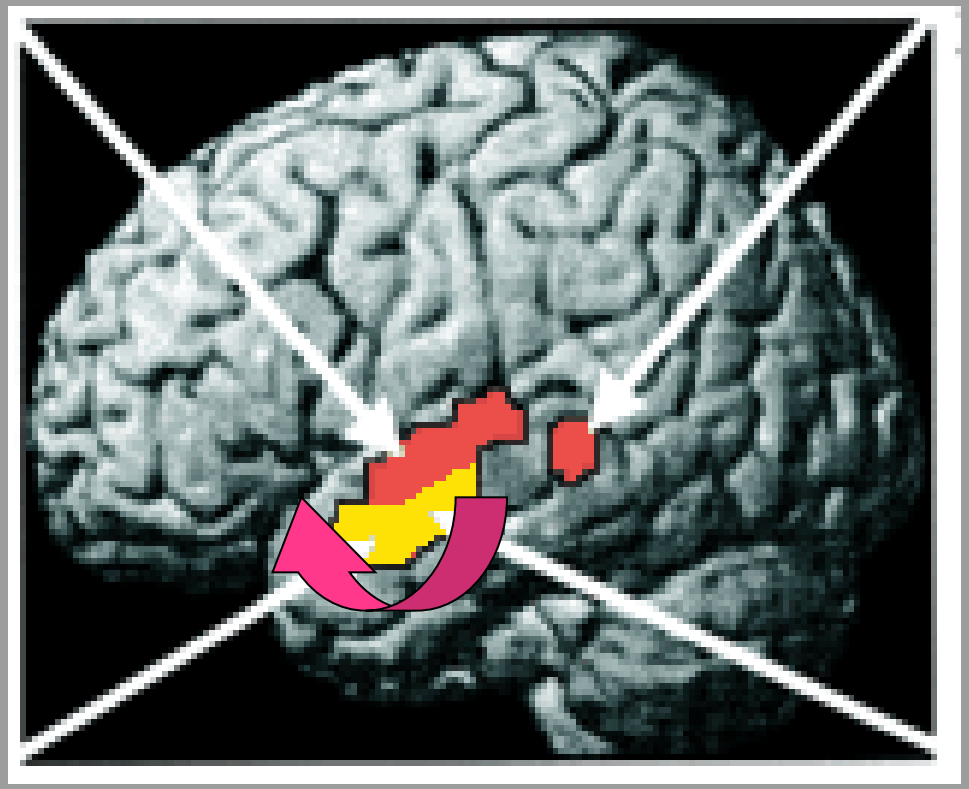
PET (positron emission tomography) scan

Neural pathways for intelligible speech

- Scott et al (2000):
- Red: responses to sounds with phonetic information

  spectrally rotated speech

- Yellow: responses to sounds that are intelligible



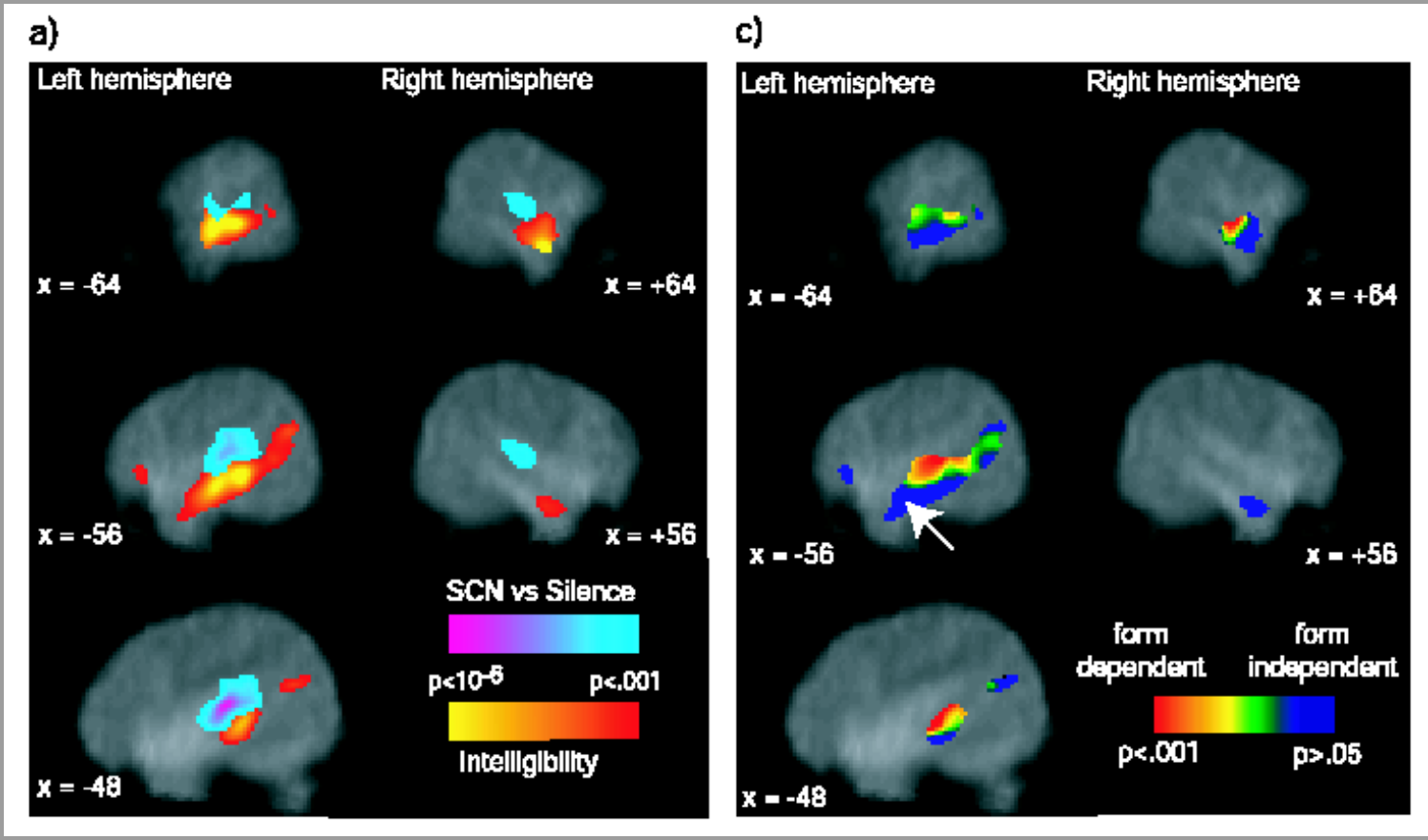
http://www.phon.ucl.ac.uk/home/brain/

Neural pathways for intelligible speech

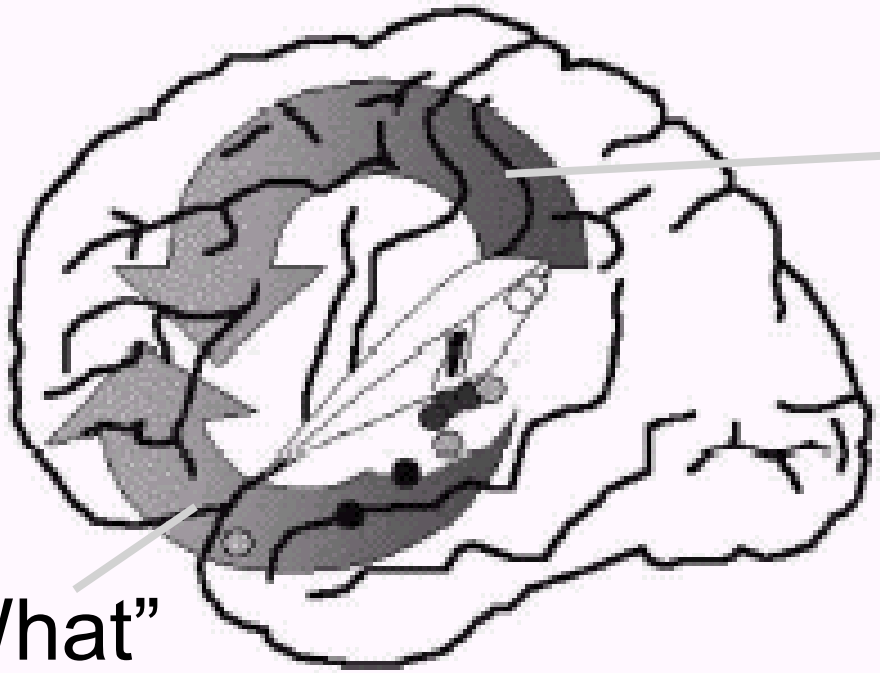
- Davis and Johnsrude (2003): English sentences, distorted in a variety of ways. Looked for correlations between blood flow and intelligibility of speech sounds

Left: intelligible speech vs noise

Right: responses to different forms of distortion



Scott and Johnsrude (2003)



- Articulation (Wise et al. 2001)
- Increasing numbers of channels of noise vocoded speech (Scott et al.)
- Phonological (versus acoustic) change (Jacquemot et al.)
- Speech and noise vocoded speech (vs. spectrally rotated equivalents) (Scott et al. 2000)

Lateralisation of language functions

Left hemisphere

- Traditionally thought to be dominant for language processing
- Pinker (1994)

  > "normal people recognise words more accurately when the words are flashed to the right side of the visual field than when flashed to the left"

- similar findings for ears
- Preference for *intelligible* speech (Scott et al.)

Right hemisphere

- Damage to RH may spare production and comprehension, but lead to problems with
  - pragmatic ability
  - prosody
  - speaker characteristics (phonagnosia)
  - recognition of music, environmental sounds

Hemispheric differences: *form*

- RH has been argued to analyse sounds with better frequency resolution and poorer time resolution than LH (Zatorre, Belin, & Penhune, 2002), but evidence is limited (Scott, McGettigan & Eisner, 2009)

Hemispheric differences: *function*

- "Same" property may be processed dominantly by one or other hemisphere, according to function

  e.g. VOT as a cue to

  - segment identity (/pa/ vs /ba/) – LH
  - speaker identity – RH

  (Francis & Driscoll, 2006)

- Spoken word recognition test, which is used to establish cerebral dominance
- large groups of native speakers of Mandarin Chinese/English/Spanish
- coronal MRI slices, data for 3 Ss, >200 ms post-stimulus onset
- Lateralisation (%Ss):

  Spanish 100% left

  English 80% left

  Chinese 79% bilateral (**tone lang**.)

Valaki et al. (2004) *Neuropsychologia* 42, 967–979

Neural correlates of phonetic skill

“Born with an ear for dialects?”

- In naïve (English) listeners, an individual’s brain structure in left auditory cortex, parietal cortex, and left inferior frontal cortex partly predicts their ability to discriminate a difficult contrast (Hindi dental vs. retroflex) (Golestani et al., 2002, 2007)
- In phoneticians, years of transcription experience correlate with size of left pars opercularis (Golestani et al., 2011)
- Phoneticians are also more likely to have multiple or split left transverse gyri in auditory cortex (thought to develop *in utero*)

Distributed, multimodal memory networks for words

Distributed, multimodal memory networks for words

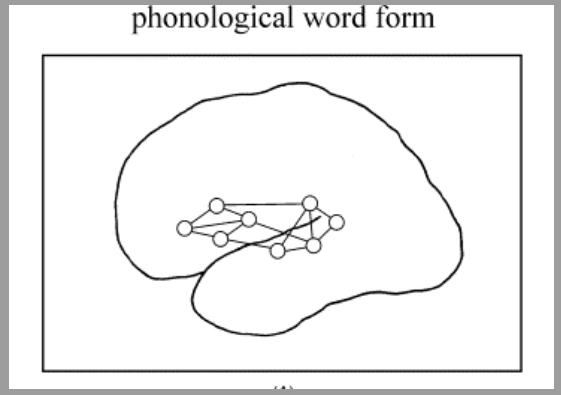
- Hebbian learning (Hebb 1949): “cells that fire together, wire together”

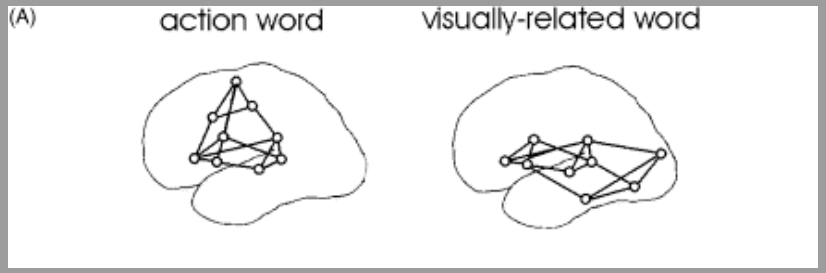
  $\rightarrow$ synchronously activated neurons link into *cell assemblies: functional webs/networks*

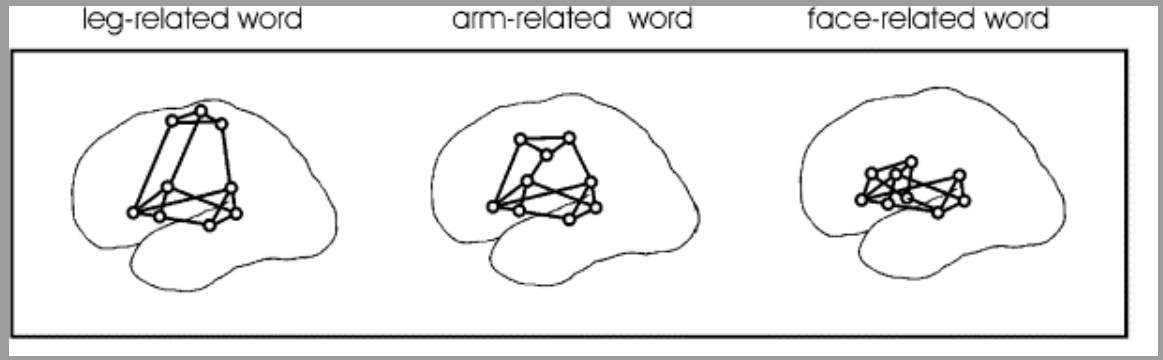
Functional webs for words

Pulvermuller, 1999 *Behavioral and Brain Sciences;*
2003 book *The Neuroscience of Language*

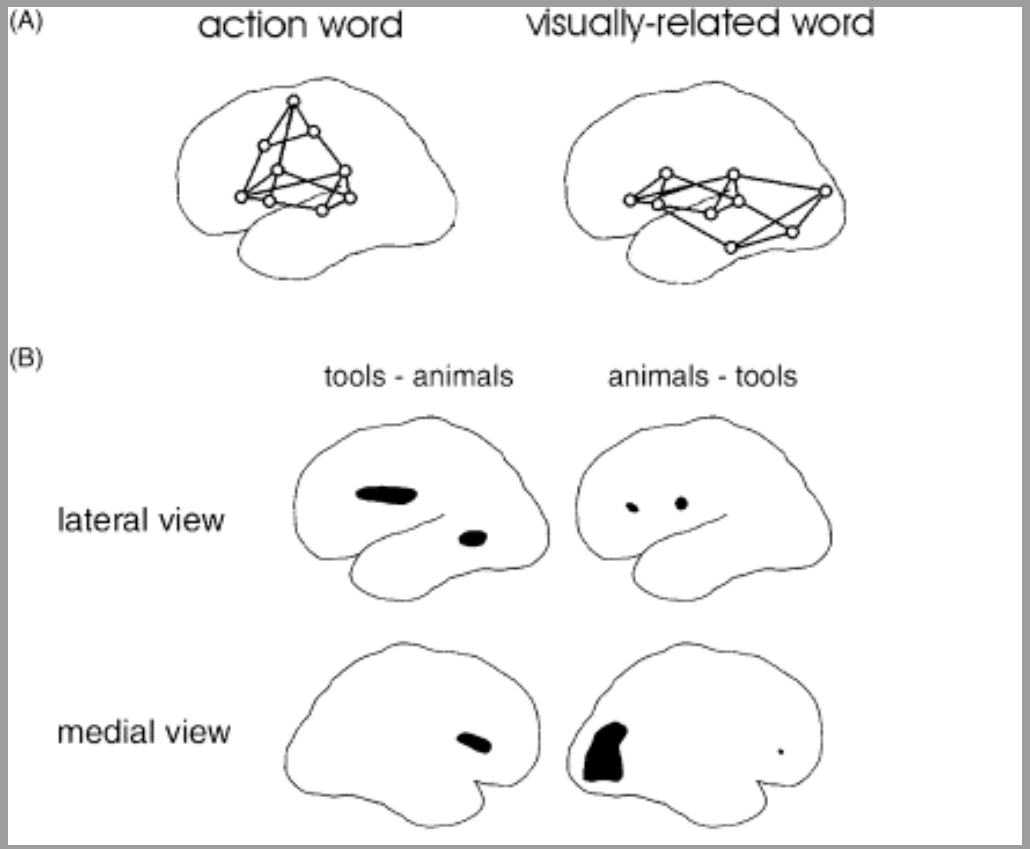
- Cell assemblies connect all neurons involved in the processes triggered by an object or action
- These assemblies "are" the cortical representation of this object or action







Action vs vision words



Source: Pulvermuller (2002), *Progress in Neurobiology* ***67***

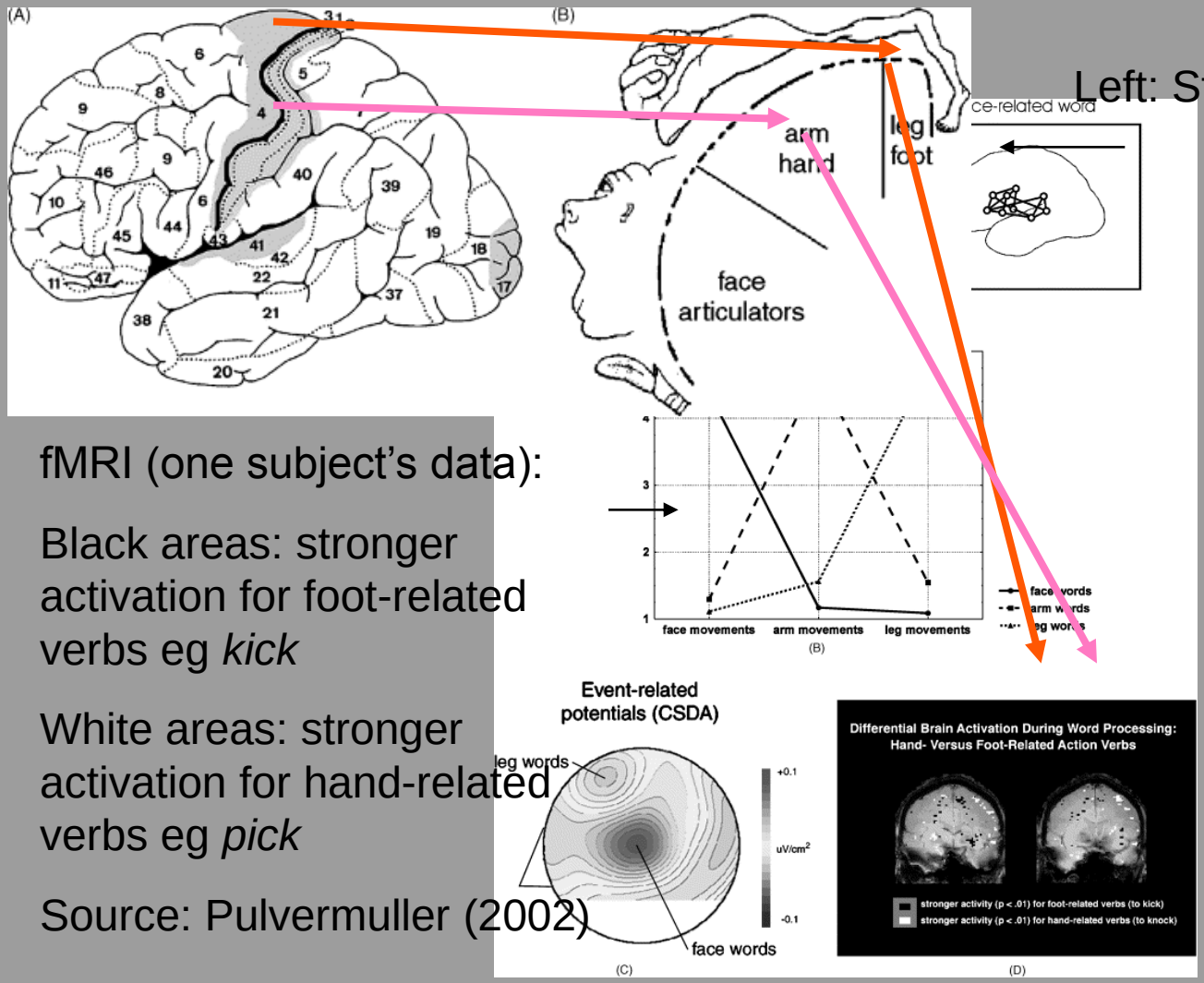
Top: schematic predictions

Bottom: fMRI data

Left panels: a **pre-motor** area and a **middle temporal** area are more strongly excited by words for tools than words for animals

Right panels: an **occipital** area is more strongly excited by words for animals than words for tools

Face vs arm vs leg words



Left: Structure of somatotopic maps in motor cortex

fMRI (one subject's data):

Black areas: stronger activation for foot-related verbs eg *kick*

White areas: stronger activation for hand-related verbs eg *pick*

Source: Pulvermuller (2002)

Language processing beyond the cortex

Cerebellum

- Co-ordination of the various muscle groups to produce a smooth flow of speech & swallowing
- important role in the integration of sensory perception and motor output.
- attention, language, music…

Damage $\rightarrow$ slurring of speech

Basal Ganglia/nuclei

- Basal Ganglia (control of muscles of face, larynx, tongue and pharynx)
  - Damage → lack of coordination and facial expression (as found in Parkinson's disease); disruption to rhythm and temporal processing
  - Role in processing:
    - Parallel (information from cortex processed independently through BG) vs funnelling (information converges in BG)
    - Relay between Broca's and Wernicke's areas?

Parkinson's speech sample
courtesy of Dr Anja Lowit (Strathclyde)

Thalamus

- Inner chamber
- determines which sensory information to forward to cortex

- Damage $\rightarrow$ deficits in memory, attention, reduced spontaneous speech

Hippocampus

- Long-term memory, language comprehension, word-generation

- DAMAGE (severe in Alzheimers) = word-finding difficulties (relating to memory)

“it takes a whole brain to produce a voice, and it takes a whole brain to recognize a voice”

(Kreiman & Sidtis 2011)

References

Kent, R. and Tjaden, (1997) Brain Functions underlying speech. In W. Hardcastle & J. Laver (eds) *The Handbook of Phonetic Sciences,* Wiley-Blackwell

(Ackermann & Ziegler 2010, in 2nd edition of *Handbook of Phonetic Sci.*, is more up-to-date, but not as accessible.)

Ziegler, W. (2008) Neurophonetics. In M. Ball, M. Perkins, N. Mueller & S. Howard (eds) *The Handbook of Clinical Linguistics,* Wiley-Blackwell

Resources

Wellcome Trust exhibition:
http://wellcometrust.wordpress.com/2012/03/29/brains-on-the-brain/

UCL Speech Communication Lab
https://sites.google.com/site/speechskscott/home

Reference guide: Dimensions and terms