LANGUAGE AND BRAIN

2024-12-22

Minkyu Kim

Minkyu Kim 金珉圭

- **2011** IOL Pittsburgh (🥉)
- **2016** IOL Mysore, **2017** Dublin, **2018** Prague (Team Leader)
- **2019** IOL Yongin (Organizer)
- **2021** IOL Ventspils, **2022** Isle of Man, **2023** Bansko (Jury)

- 2019 B.S. in Chemistry & B.A. in Linguistics @ Seoul National University
- Currently, PhD candidate in Cognitive Neuroscience @ University of California, Irvine
- Co-chair of KLO, Chair of APLO, Problem Committee of IOL

Human Language

- Language: a distinctive trait of humanity
  - Exclusively human
  - Fundamental to our existence
  - An enigma yet to be fully understood

Image Source: Susan Kuklin / Nim Chimpsky and his trainer

Human Language

- When did human language first appear in our evolutionary history?
    - Historical linguistics can give us insights into language development dating back only as far as 10,000 years ago

PIE

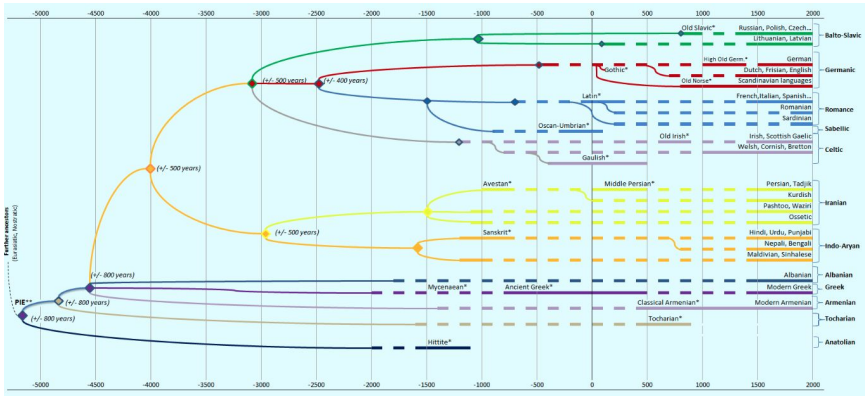


Image Source: eLinguistics.net / Evolution timeline of the Indo-European languages

Human Language

- When did human language first appear in our evolutionary history?
    - Evolutionary biology offers insight from a few million years ago
      ⋯ but things are little unclear

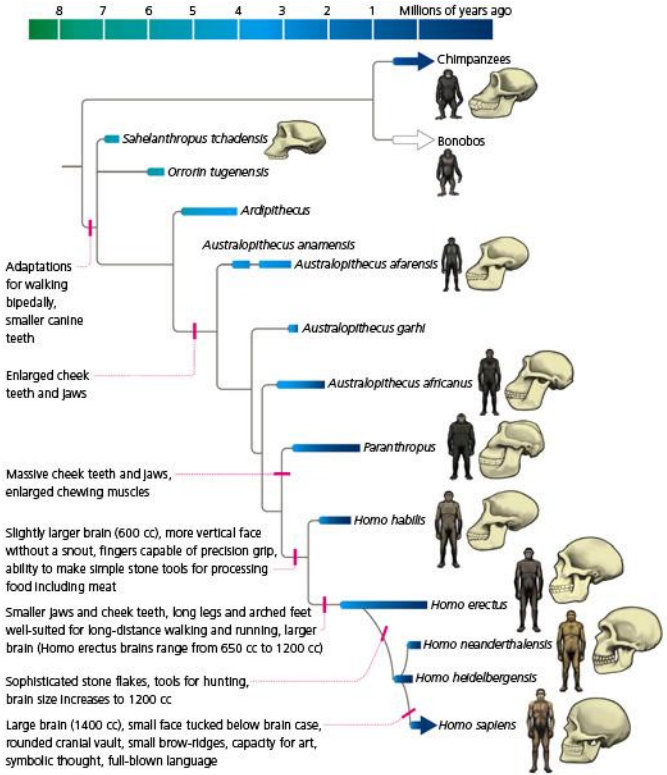


Image Source: Zimmer, C., & Kingsolver, J. G. (2010). The tangled bank: an introduction to evolution. Roberts.

Human Language

- When did human language first appear in our evolutionary history?
    - One thing for sure is that the emergence of human language coincide with a significant increase in brain size

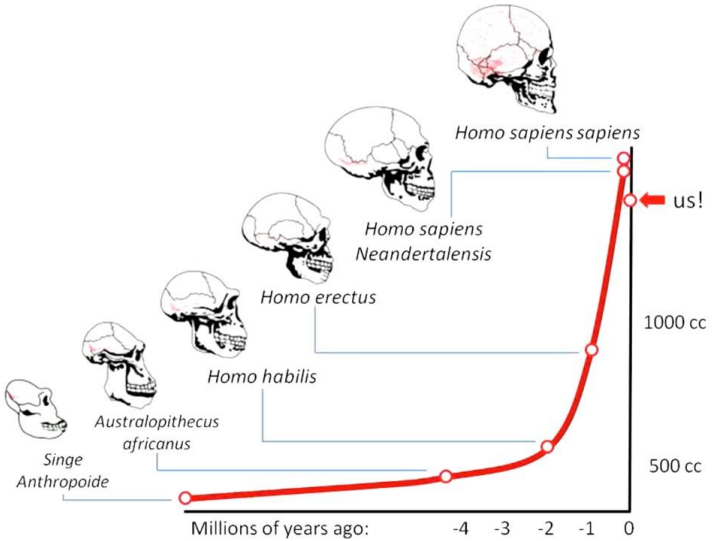


Image Source:

Through the Lens of Neuroscience

- Mechanisms of human language
  - How is language ⋯
    ⋯ produced? processed? acquired?
- Brain-based Language Disorders
  - Stuttering, Aphasia, Dyslexia ⋯
- Development of Artificial Intelligence
  - Machine translation, voice recognition, text-to-speech, chatbot ⋯

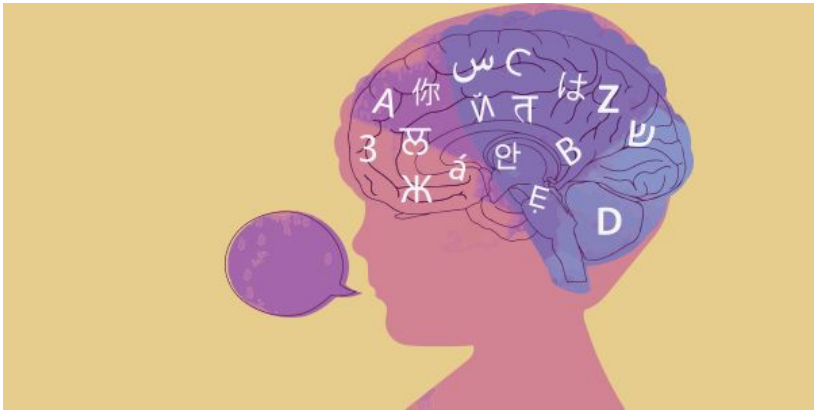


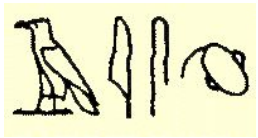
Image Source:

Dawn of Brain Science

Evidence of prehistoric brain surgery. BC 7000, Peruvian male, Brain surgery survivor.

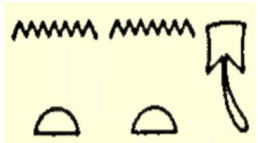
Image Source: Musée cantonal d'archéologie et d'histoire de Lausanne

Dawn of Brain Science

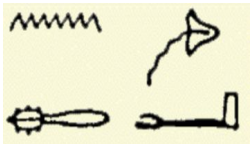


brain

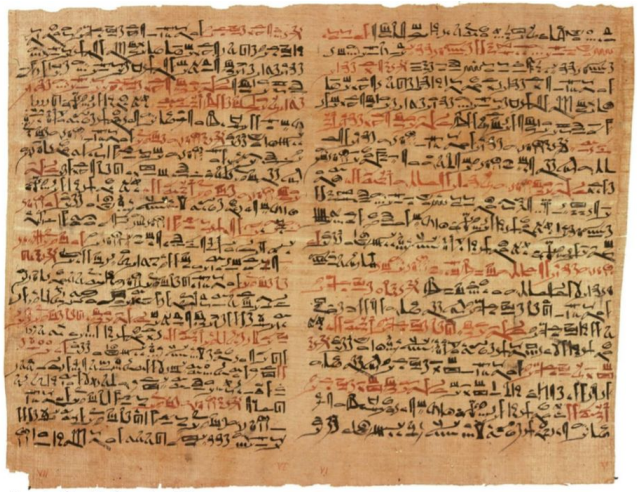
gyrus



meninges



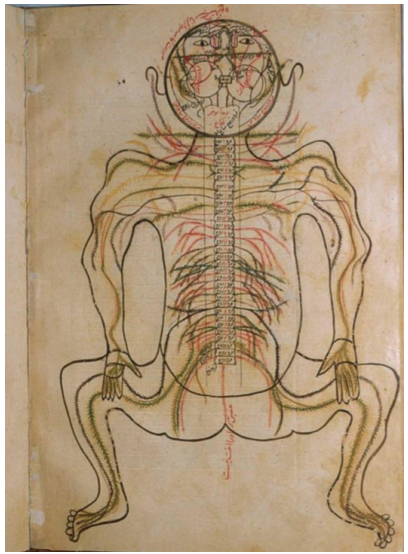
cerebrospinal fluid



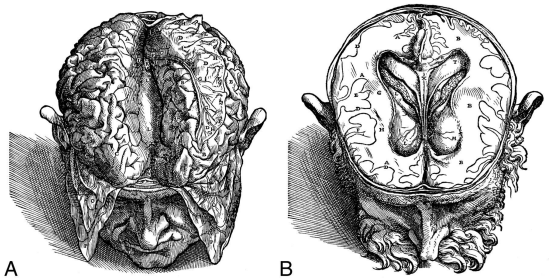
Edwin Smith Surgical Papyrus
Analysis of the writing style reveals that the papyrus is a copy made by a scribe around 1,600 BCE (17th Dynasty). The original document was written *circa* 3,000 BCE (3rd Dynasty), and has been credited to Imhotep, the real father of medicine, who lived some 2,000 years before Hippocrates. (In fact, it is believed that the ancient Greeks knew of the contents of the Edwin Smith papyrus, and used them as a basis for their writings on science and medicine.) The papyrus also contains the first descriptions of the cerebrospinal fluid, meninges and the surface of the brain, including the gyri and sulci, as well as a description of sciatica.

Image Source: Plates vi & vii of the Edwin Smith Papyrus at the Rare Book Room, New York Academy of Medicine

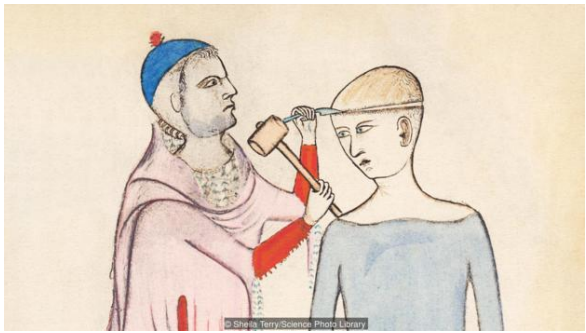
Dawn of Brain Science



Mansur ibn Ilyas, Persian anatomical illustration of the nervous system, ca. 1400



Andreas Vesalius, Professor of Surgery and Anatomy at the University of Padua, 1537-1543



A 14th-Century painting of trepanation by Guido da Vigevano

Image Source: United States National Library of Medicine / Illustrations from Vesalius ' Fabrica (1555) 7 / SHEILA TERRY, SCIENCE PHOTO LIBRARY

Brain Science Nowadays

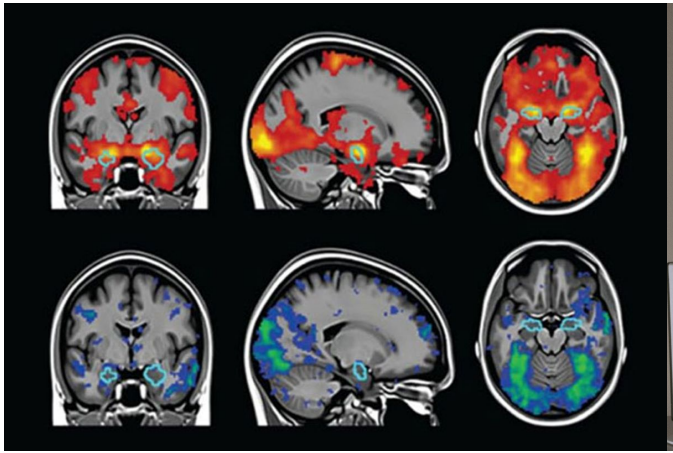
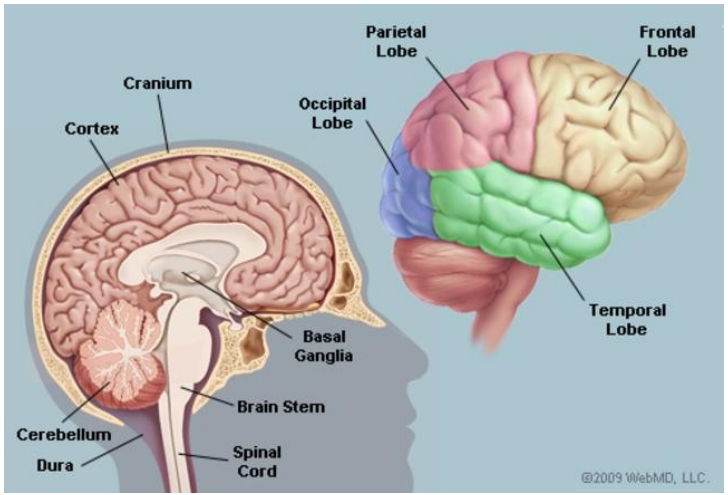


Image Source: https://www.the-scientist.com/news-opinion/how-scientists-are-tackling-brain-imaging-s-replication-problem-68942
Image Source: https://ixico.com/news-and-resources/blog/alzheimers-disease-the-role-of-cutting-edge-neuroimaging-techniques/

Language and Brain



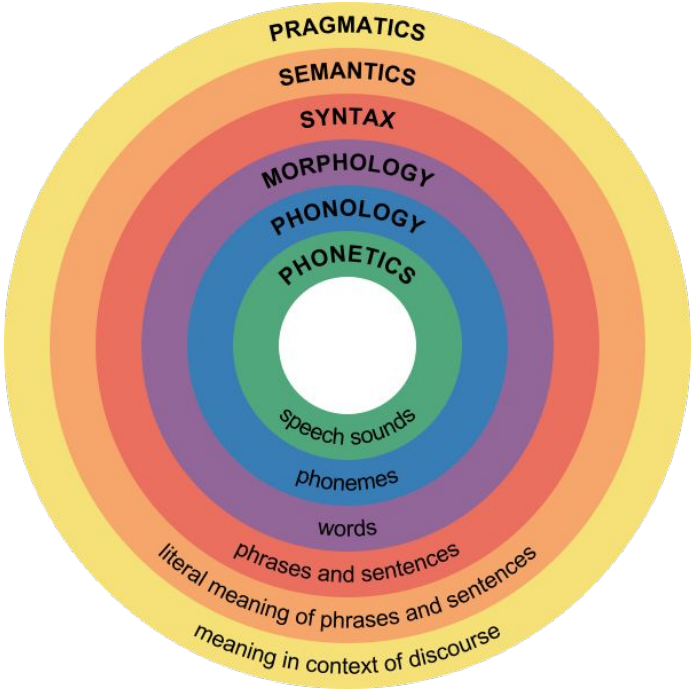


Image Source: WebMD / Thomas, James J. & Cook, Kristin A. , ed. (2005) Illuminating the Path: The Research and Development Agenda for Visual Analytics, p. 110

From the Perspective a Martian Scientist

Image Source: Kner from The Wounded Frontier by Michael D. Smith

From the Perspective a Martian Scientist

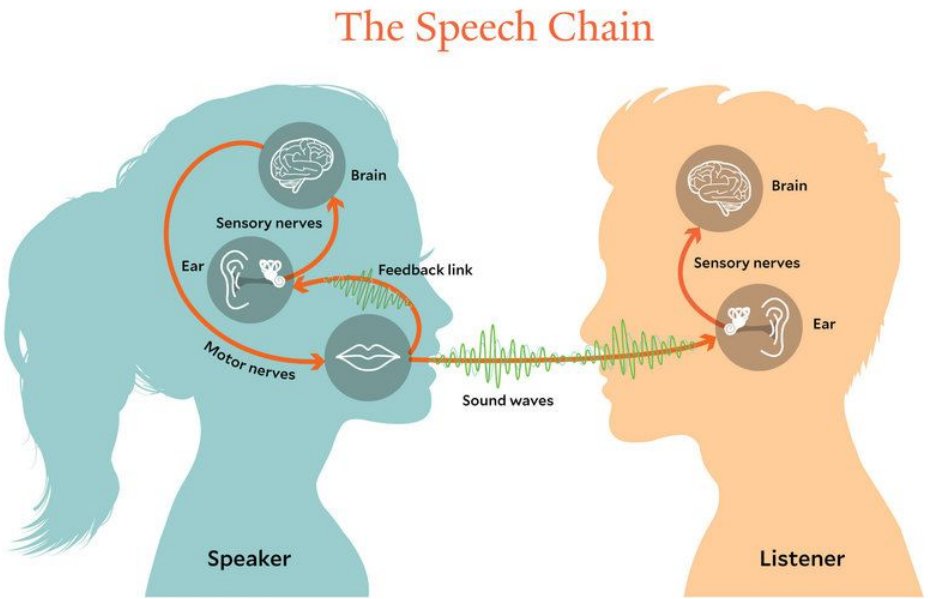


Image Source: Anne T. and Robert M. Bass Library

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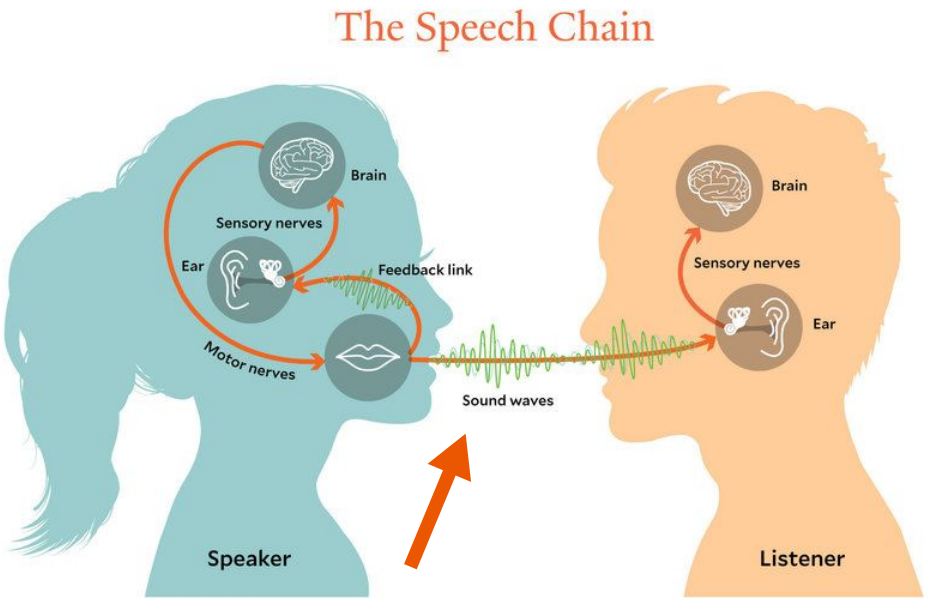

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Physics of Language

- Language is (mostly) made of sound

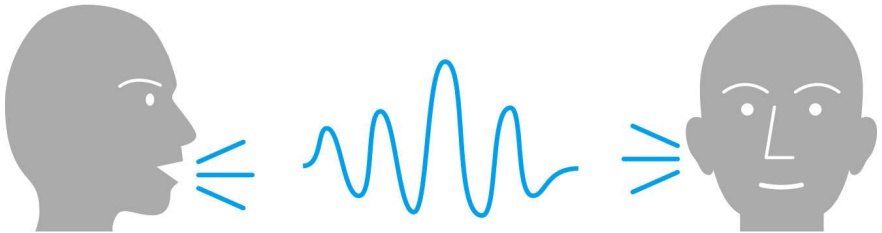
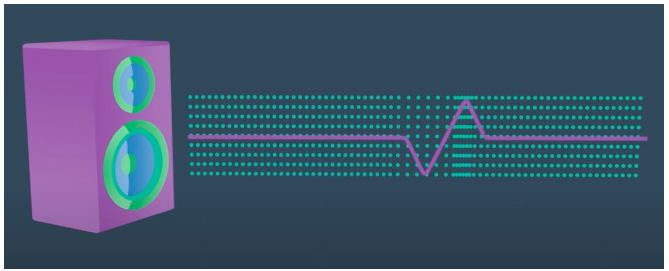


Image Source: https://www.st.keio.ac.jp/en/kyurizukai/26_sugiyama.html

Physics of Language

- Language is (mostly) made of sound
- Sound is a mechanical wave that results from the back and forth vibration of the particles of the medium



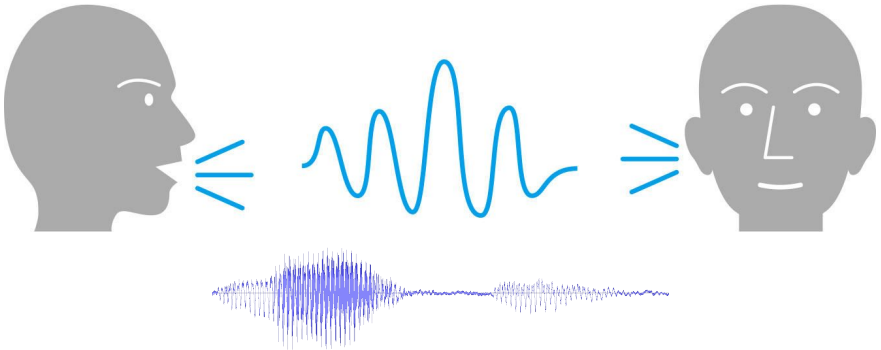


Image Source: https://www.youtube.com/watch?v=Cbr3ws4QGpc

Physics of Language

Schlieren Flow Visualization

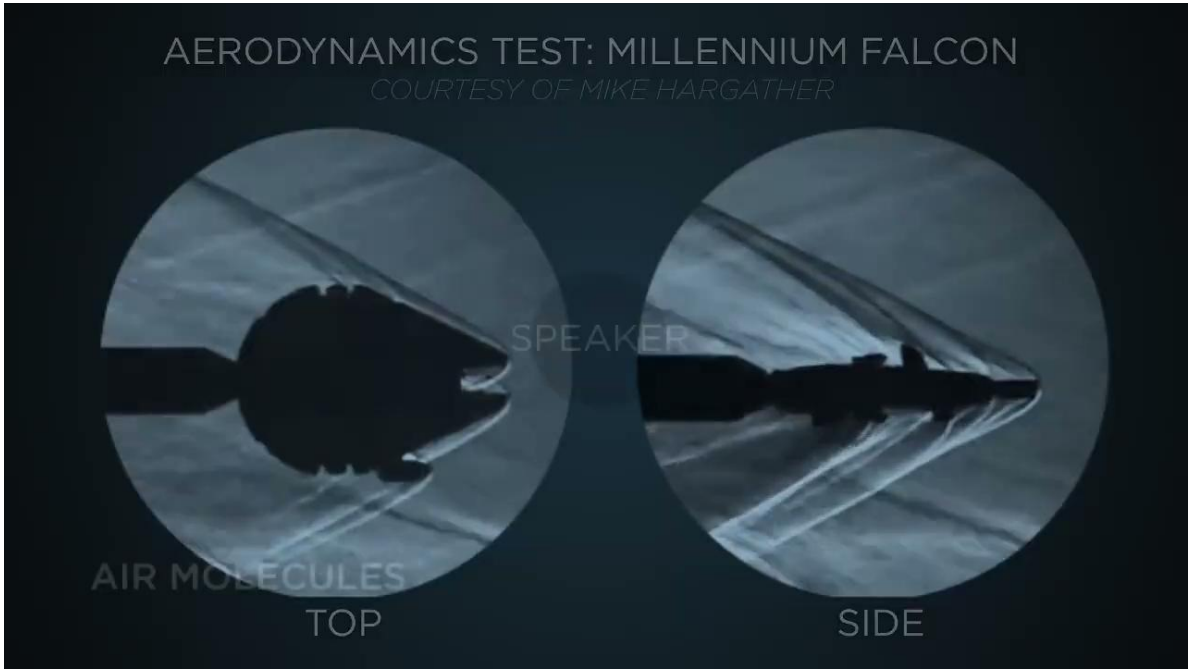


Image Source: npr

Physics of Language

- Sound wave can be represented by a **spectrogram**

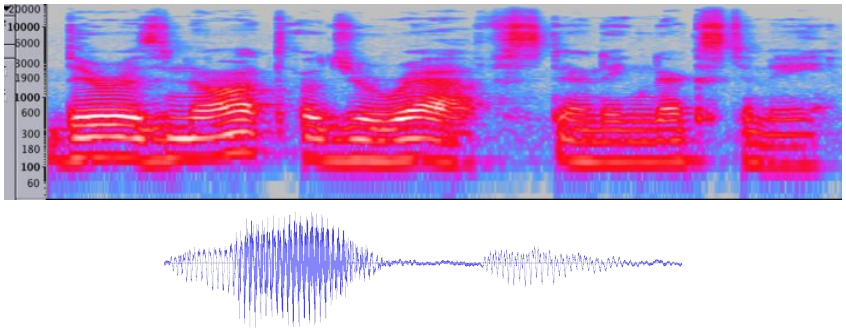
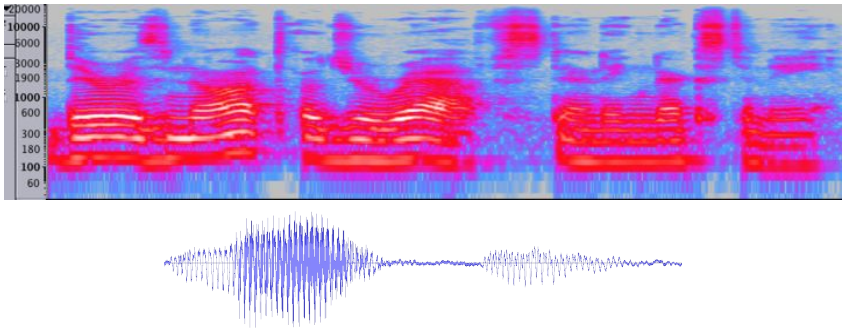


Image Source:

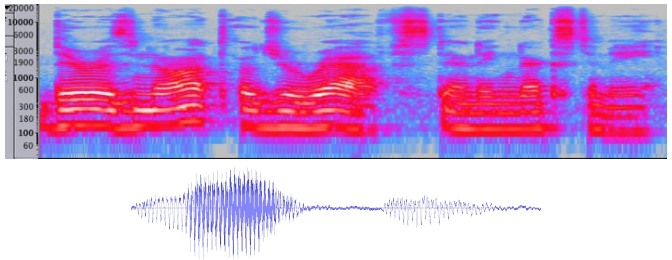
Physics of Language

- Sound wave can be represented by a **spectrogram**
    - Spectrogram is a graph of a sound wave's **component frequencies** over time



Physics of Language

- Sound wave can be represented by a **spectrogram**
  - Spectrogram is a graph of a sound wave's **component frequencies** over time
  - Fourier transform:
    time–domain → frequency–domain



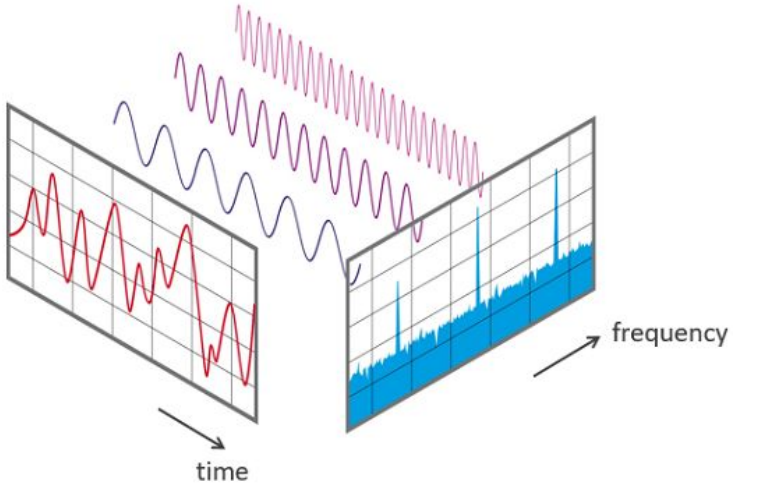


Image Source: https://www.nti-audio.com/en/support/know-how/fast-fourier-transform-fft

Formants

- The vocal resonances are altered by the articulators to form **vowel** sounds.

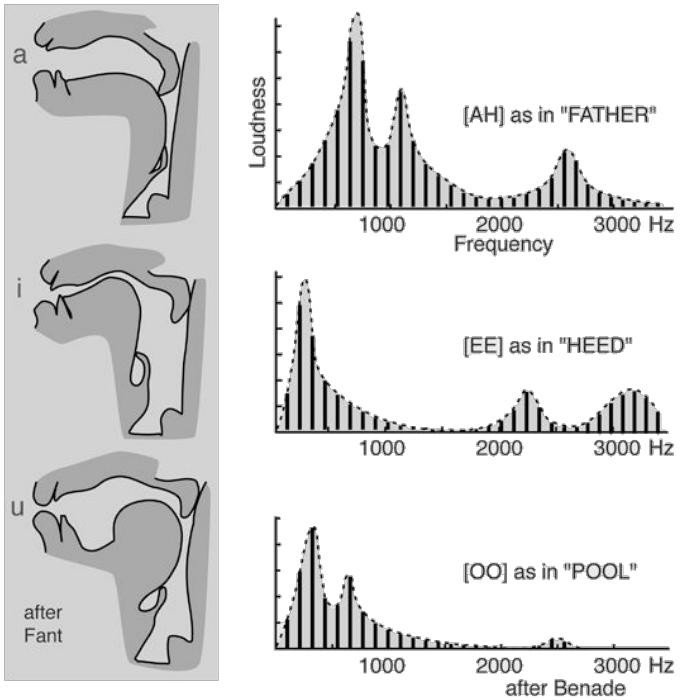
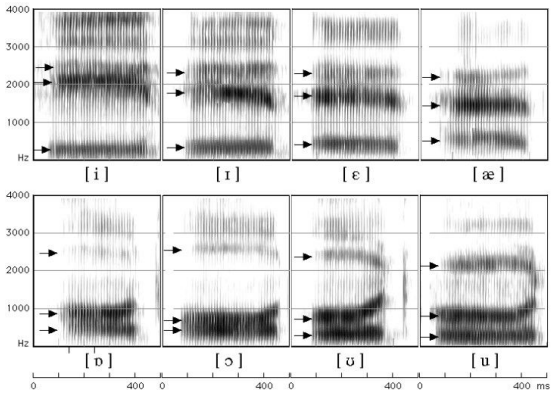


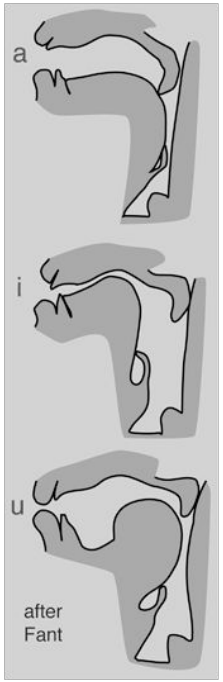
Image Source: Rod Nave, HyperPhysics / http://hyperphysics.phy-astr.gsu.edu/hbase/Music/vowel.html

Formants

- The vocal resonances are altered by the articulators to form **vowel** sounds.
- The peaks in the vowel spectra are called **formants**

spectrogram →





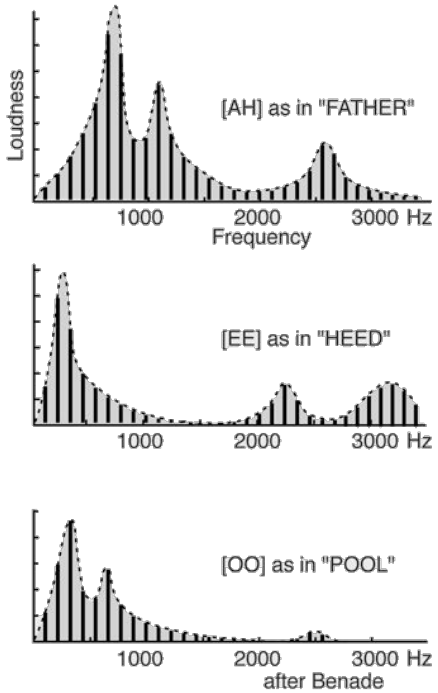


Image Source: EduHK Praat Manual

Formants

- The vocal resonances are altered by the articulators to form **vowel** sounds.
- The peaks in the vowel spectra are called **formants**
- Vowels can be distinguished by their first 2–3 formants (F1 F2 ⋯)
- Two Formants

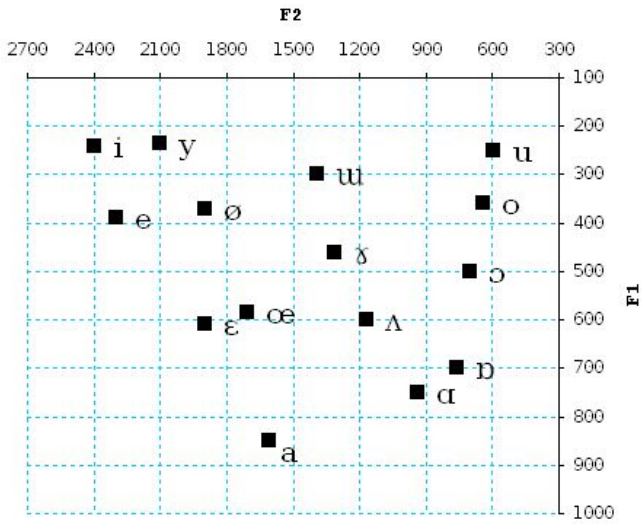


Image Source: Wikimedia. Любослов Езыкин. File:Average vowel formants F1 F2.png

From the Perspective a Martian Scientist

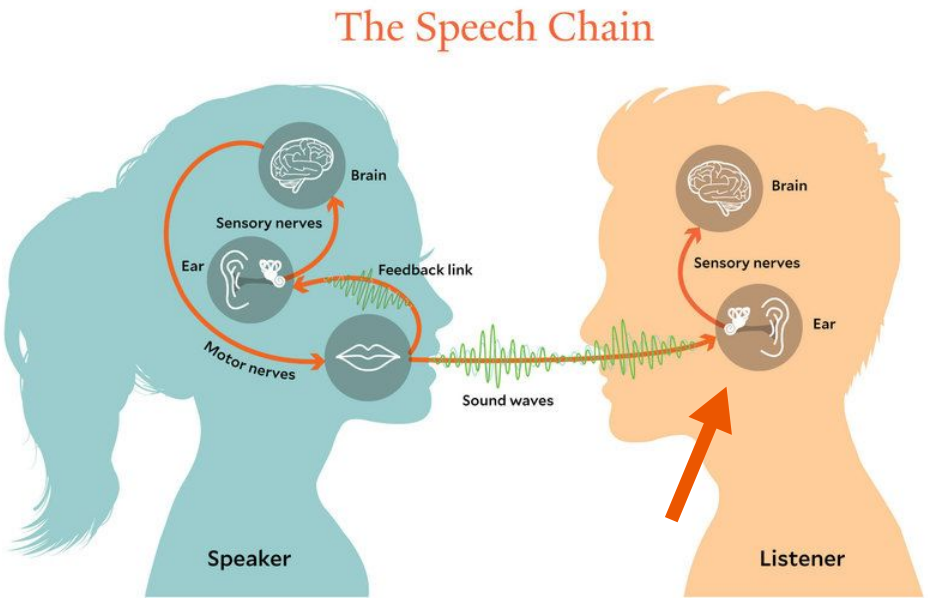


Image Source: Anne T. and Robert M. Bass Library

Hearing

- First step of language comprehension

Hearing

- First step of language comprehension
- Cochlear Tonotopy
  - Different frequencies of sound are processed and organized along the length of the **cochlea**
  - A cochlea is a spiral-shaped, fluid-filled organ in the inner ear

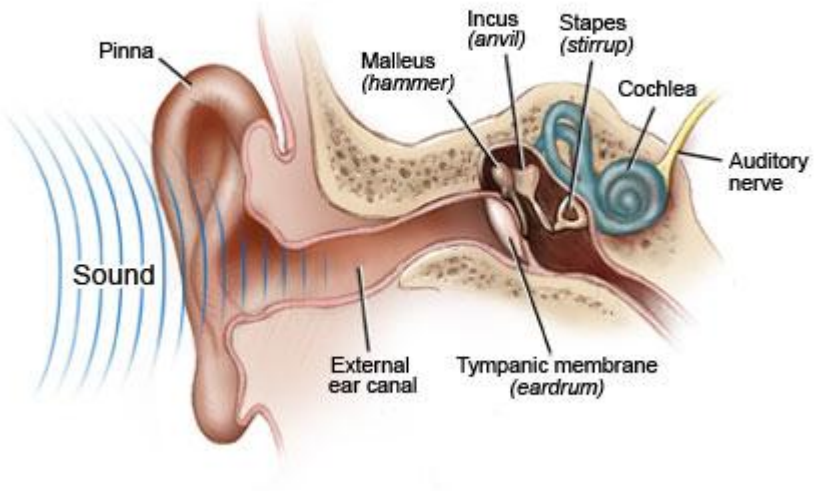


Image Source:

Hearing

- First step of language comprehension
- Cochlear Tonotopy
    - Different frequencies of sound are processed and organized along the length of the **cochlea**
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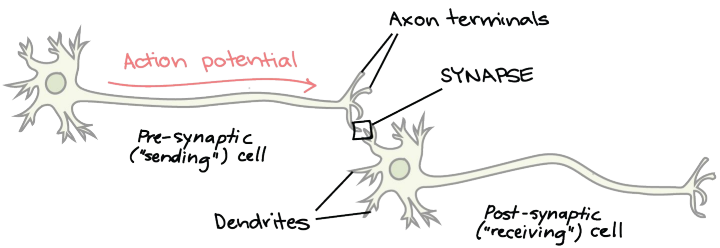
Image Source: https://www.youtube.com/watch?v=gd5nSKNaHZ8

To the Brain

- Auditory Transduction
  - conversion of sound waves into electrical signals
  - transmission of these signals to the brain



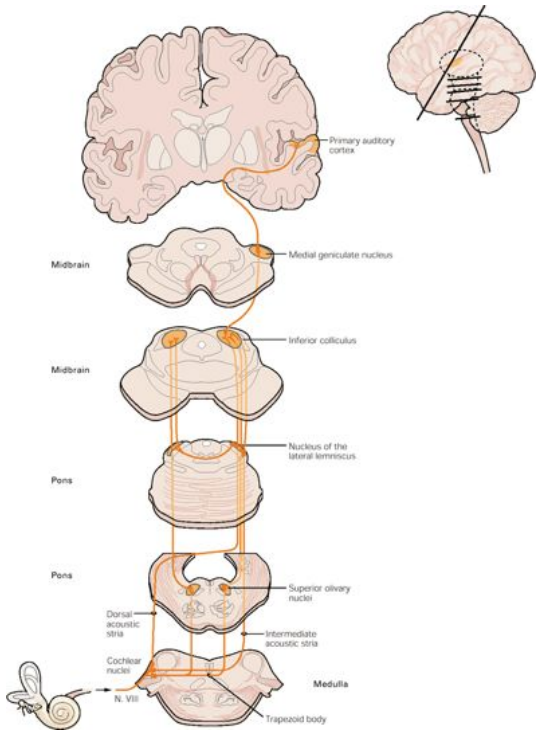


Image Source: Graven, S. N., & Browne, J. V. (2008). Auditory development in the fetus and infant. Newborn and infant nursing reviews, 8(4), 187-193.

To the Brain

- Acoustic characteristics of sound waves are finally projected to the brain (cortical area)

To the Brain

- Acoustic characteristics of sound waves are finally projected to the brain (cortical area)
    - Where? Auditory cortex

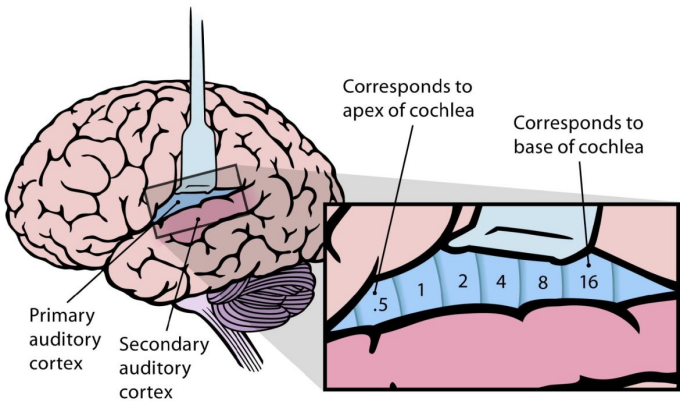
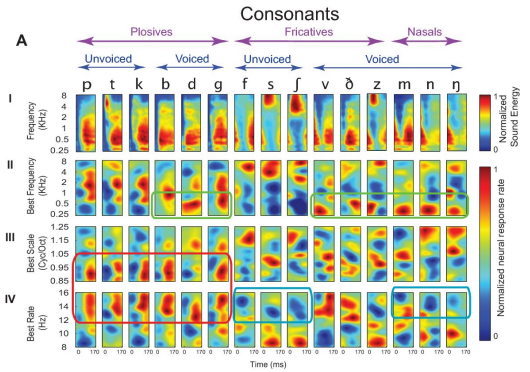


Image Source: Chittka, L., & Brockmann, A. (2005). Perception space—the final frontier. PLoS biology, 3(4), e137.

To the Brain

- Acoustic characteristics of sound waves are finally projected to the brain (cortical area)
  - Where? Auditory cortex
  - How? Yet to be known



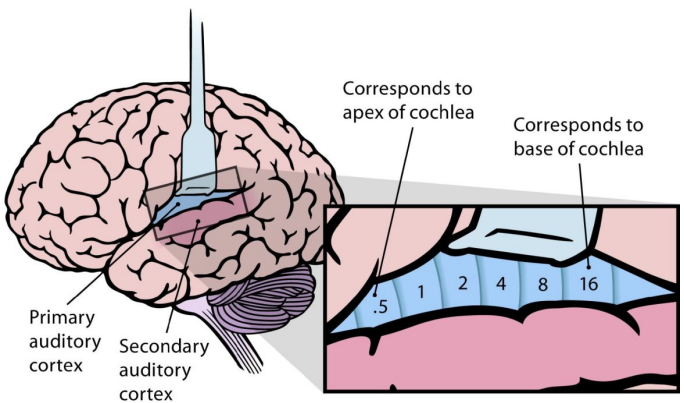


Image Source: Mesgarani, N., et al. (2008). Phoneme representation and classification in primary auditory cortex. The Journal of the Acoustical Society of America, 123(2), 899-909.

Interpreting (Understanding)

- Phonological Processing
  - Recognizing phonemes and words from continuous speech signals

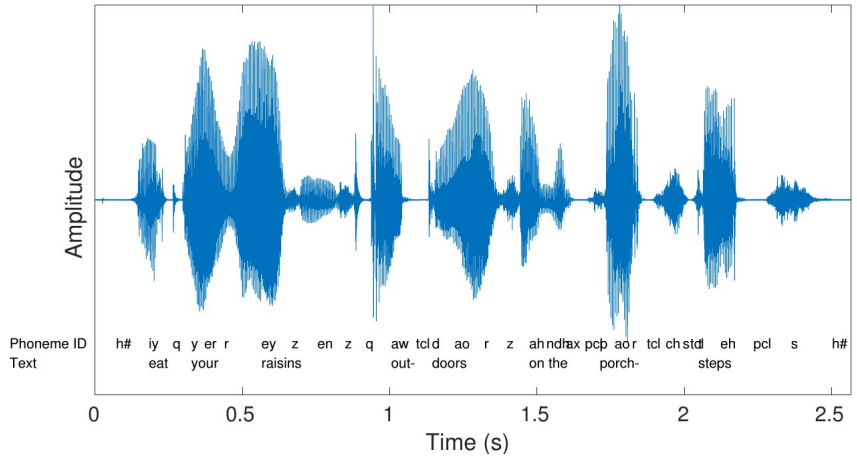
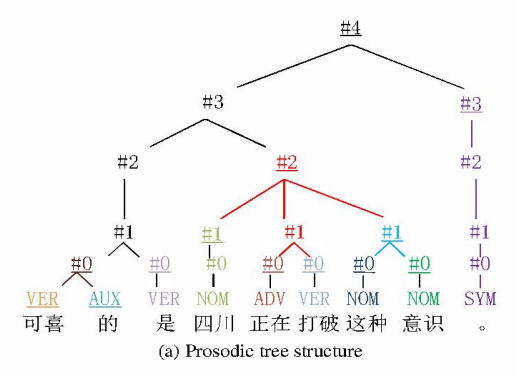


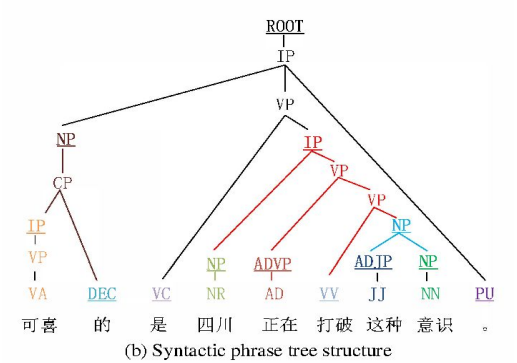
Image Source:

Interpreting (Understanding)

- Phonological Processing
  - Recognizing phonemes and words from continuous speech signals
- Morphological & Syntactic Processing
  - Understanding the grammar and structure of words, phrases and sentences



(a) Prosodic tree structure



(b) Syntactic phrase tree structure

Image Source: https://bcmi.sjtu.edu.cn/~zhangxiaotian/paper_iscslp.pdf

Interpreting (Understanding)

- Phonological Processing
  - Recognizing phonemes and words from continuous speech signals
- Morphological & Syntactic Processing
  - Understanding the grammar and structure of words, phrases and sentences
- Semantic Processing
  - Meanings of words and sentences are interpreted

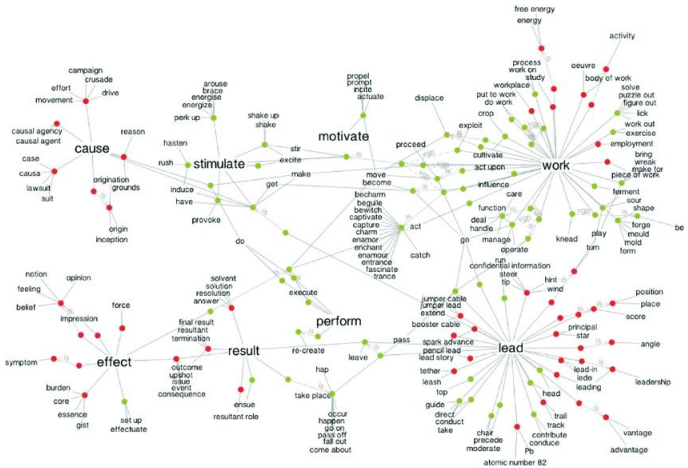


Image Source: Arnulf, J. K., et al. (2018). Semantic algorithms can detect how media language shapes survey responses in organizational behaviour. PLoS One, 13(12), e0207643.

Interpreting (Understanding)

- How? Largely unknown

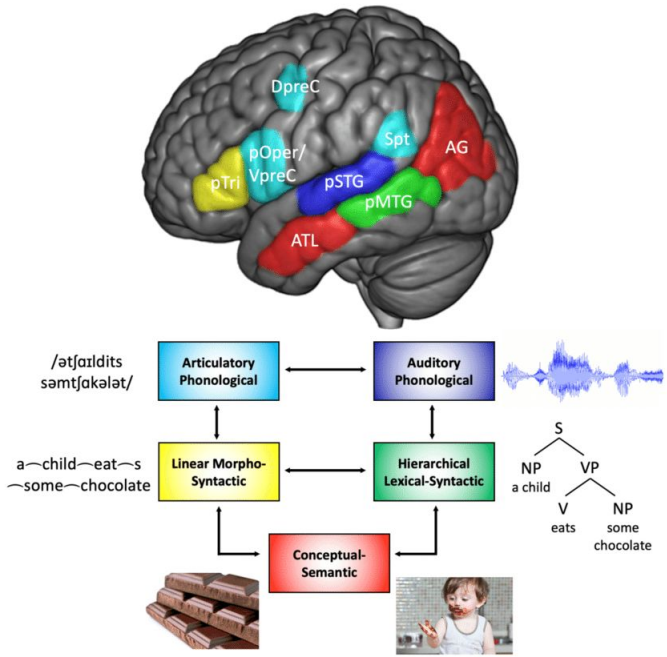


Image Source: Matchin, W., & Hickok, G. (2020). The cortical organization of syntax. Cerebral Cortex, 30(3), 1481-1498.

From the Perspective a Martian Scientist

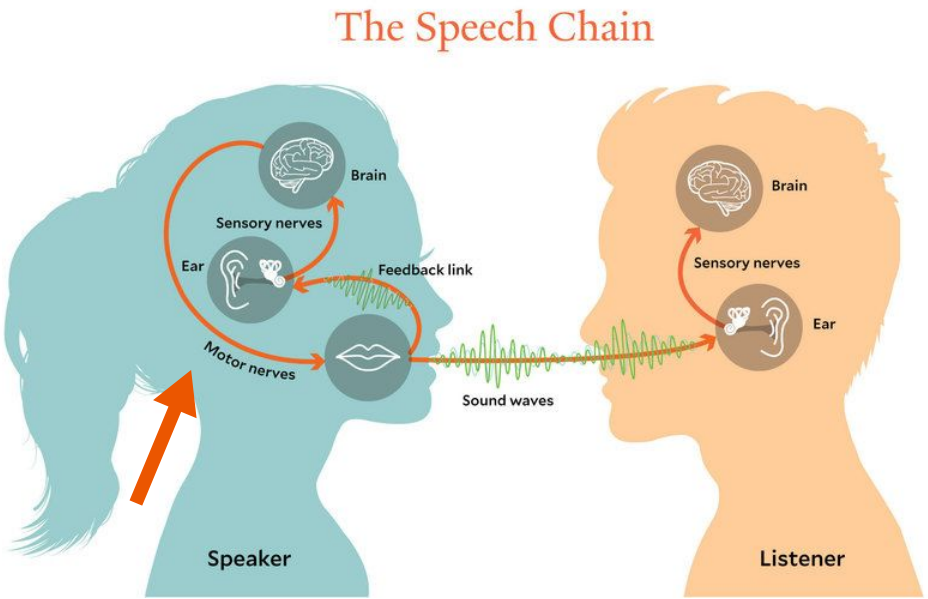


Image Source: Anne T. and Robert M. Bass Library

Language Production (Talking)

- Complexity and precision
  - Human produces 100–200 words per minute
  - Each phoneme has a duration ranging from a few tens to hundreds of milliseconds

  - Chris Brown – Look At Me Now ft. Lil Wayne, Busta Rhymes
  - USC SPAN MRI – Look at Me Now (NOT Busta cover)

Language Production

- Cranial nerves for speech

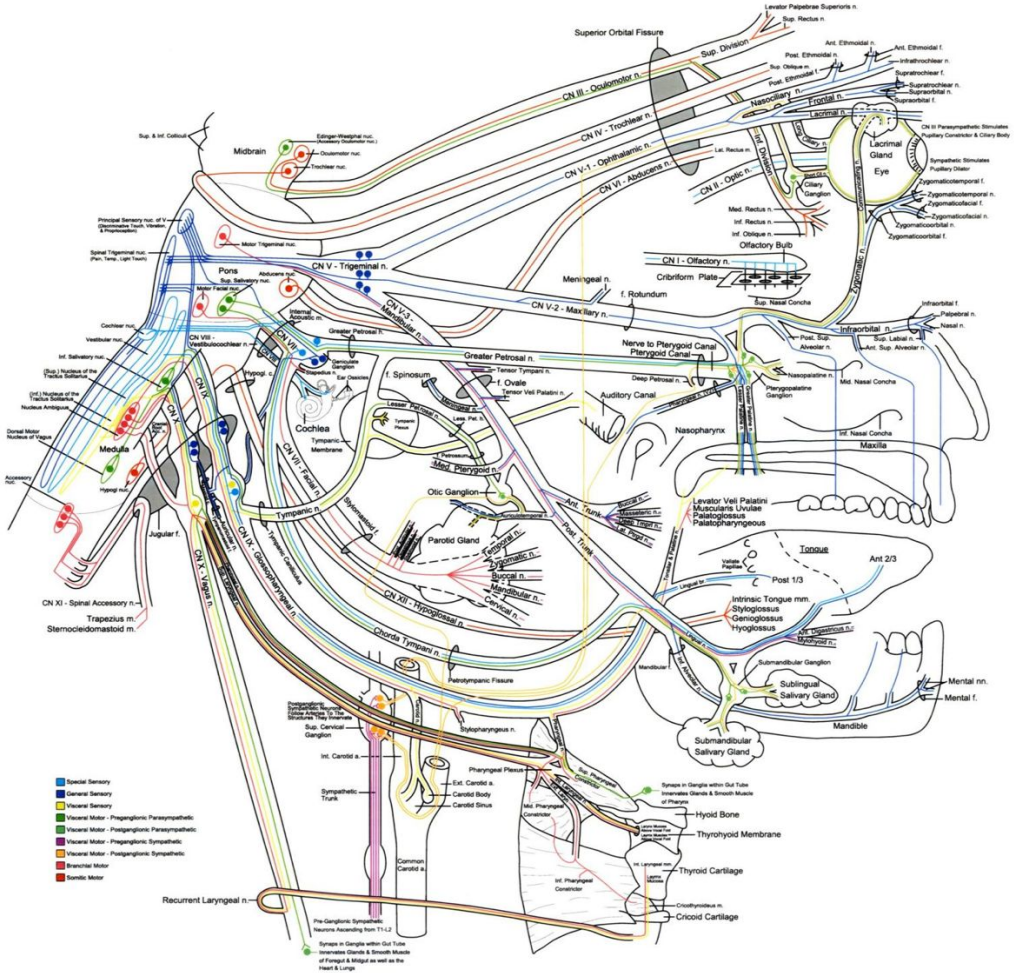


Image Source:

Language Production (Talking)

- Computational models for speech articulation

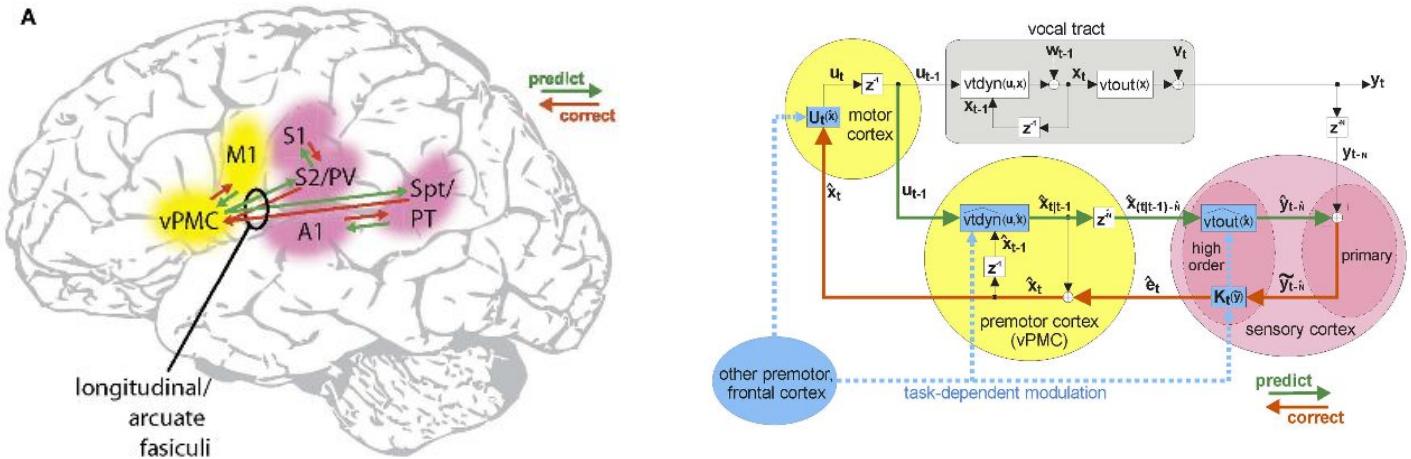


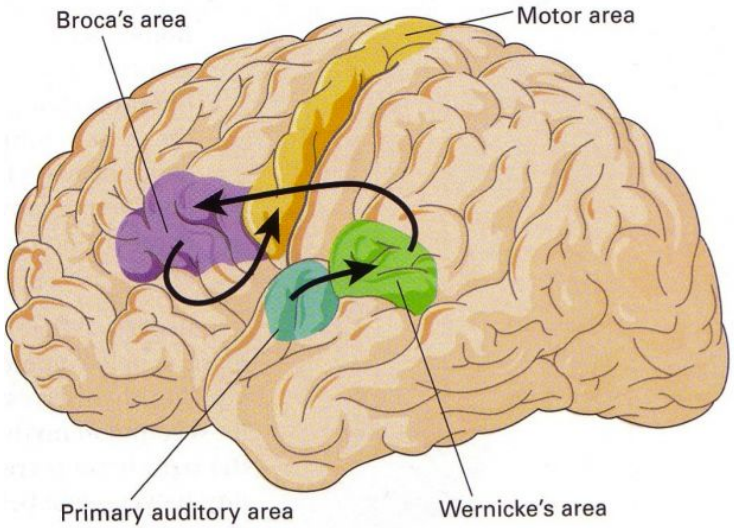
Image Source: Houde, J. F., & Nagarajan, S. S. (2011). Speech production as state feedback control. Frontiers in human neuroscience, 5, 82.

Language Production (Talking)

- Articulation isn't everything
- Generation of a sentence needs a lot of steps
  - Find information structure, pick a focus, pick the best grammatical structure
  - Pick vocabularies, morphological processes, morpho-phonological rules
  - Align words, give prosody ⋯
- And do all of this in a split second!

Aphasia

- Broca's aphasia
  - Difficulty in speech production, but relatively good comprehension. Video
- Wernicke's aphasia
  - Poor comprehension; fluent but often meaningless or nonsensical speech. Video



Language Development

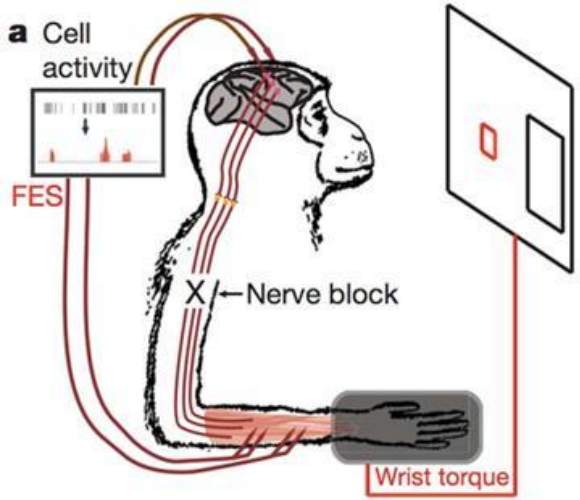
- Poverty of the stimulus
  - children are not exposed to rich enough data within their linguistic environments to acquire every feature of their language
- Bella Devyatkina

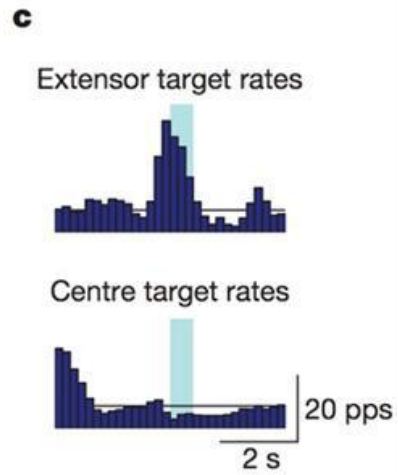
Image Source: NYTimes, Hunting One Language, Stumbling Upon Another

Cognitive Neuroscience Methods

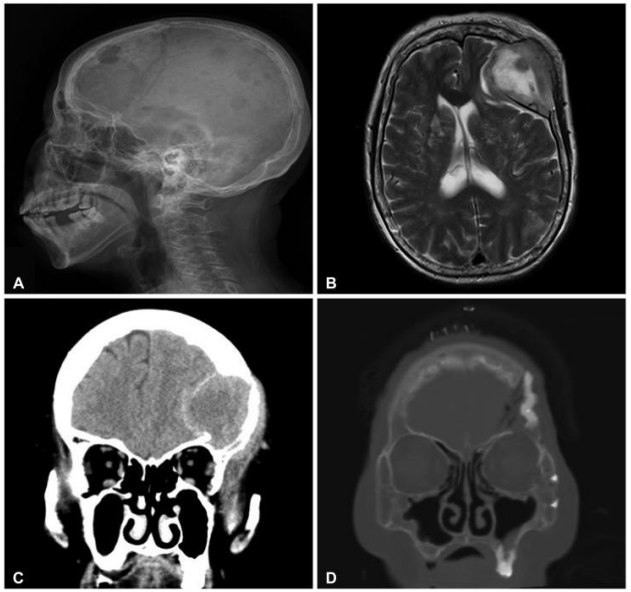
- Single cell measurement
- Lesion studies
- TMS (Transcranial magnetic stimulation)
- Neurosurgical studies
  - Direct cortical stimulation
  - Split-brain studies
- Neuroimaging (fMRI, PET, CT, MEG, EEG …)

Single Cell Measurement



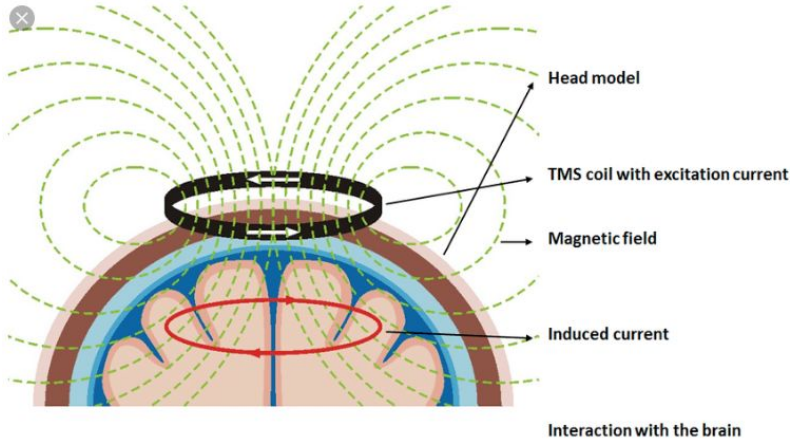


Lesion Studies



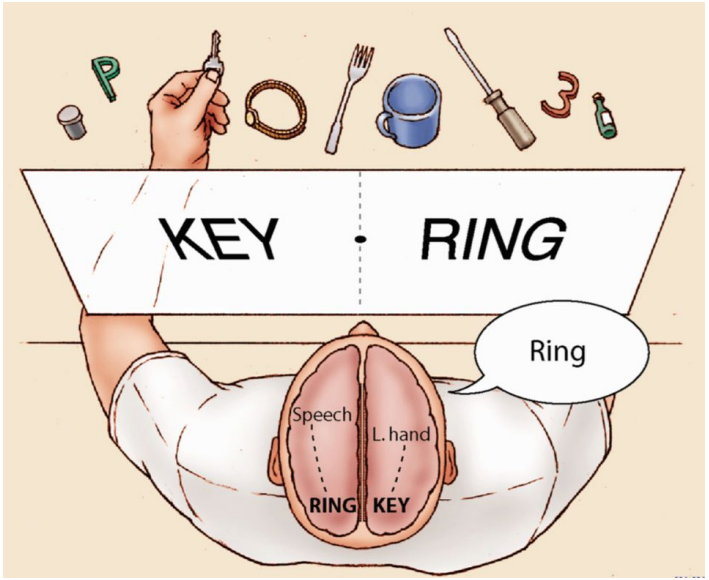
TMS(Transcranial magnetic stimulation)

- The Brain: A Secret History – BBC Four



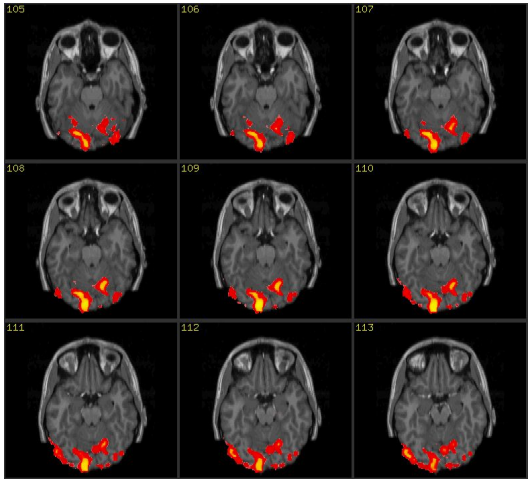
Neurosurgical Studies

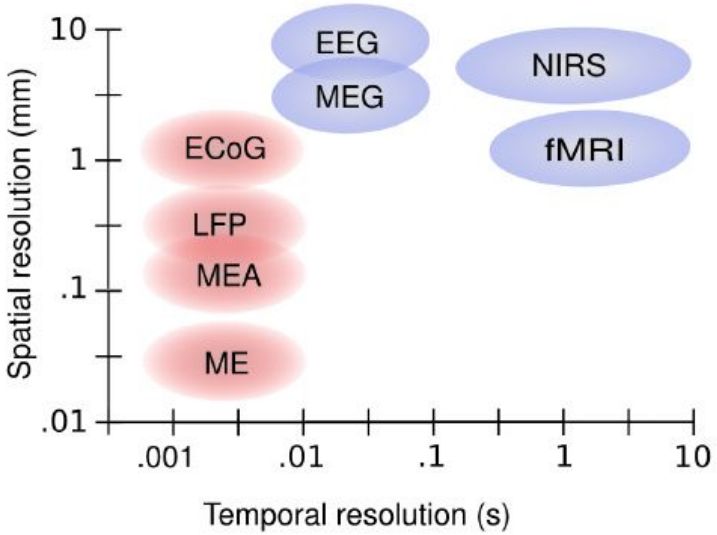
- Split brain



Neuroimaging

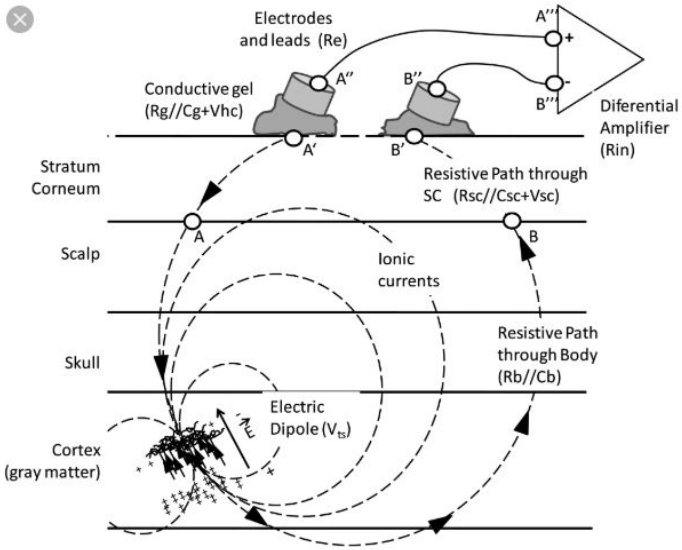
- fMRI

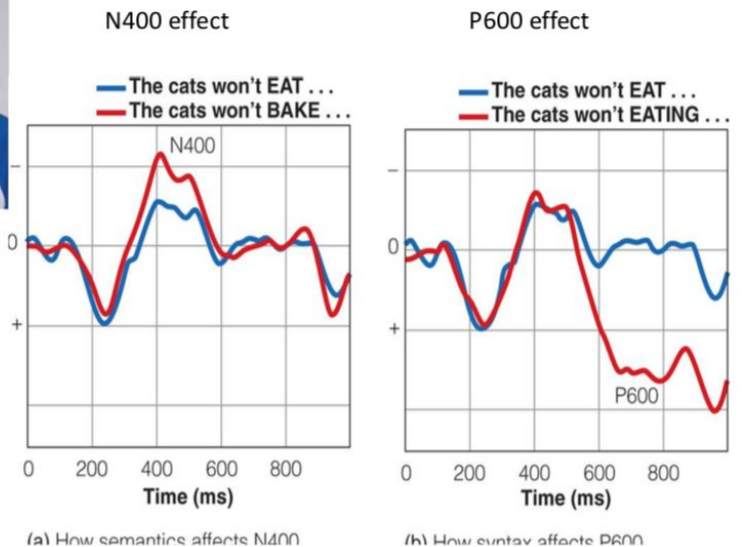




Neuroimaging

- EEG

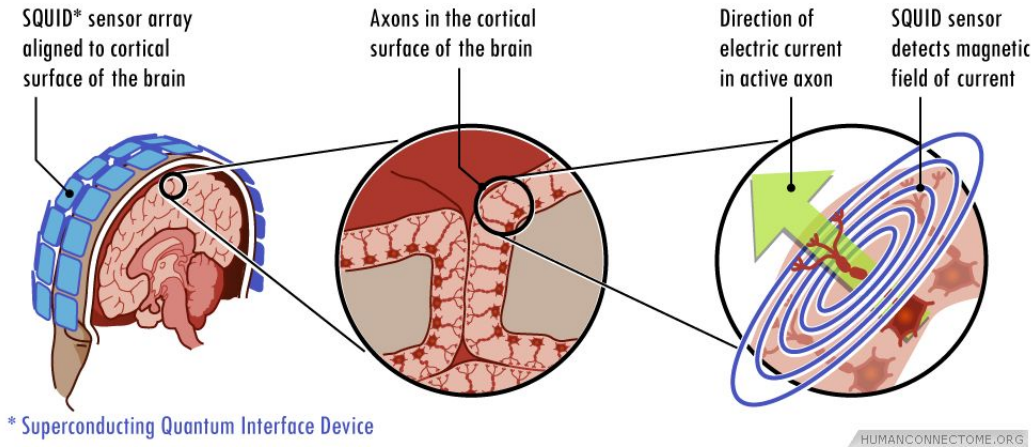




(a) How semantics affects N400 (b) How syntax affects P600

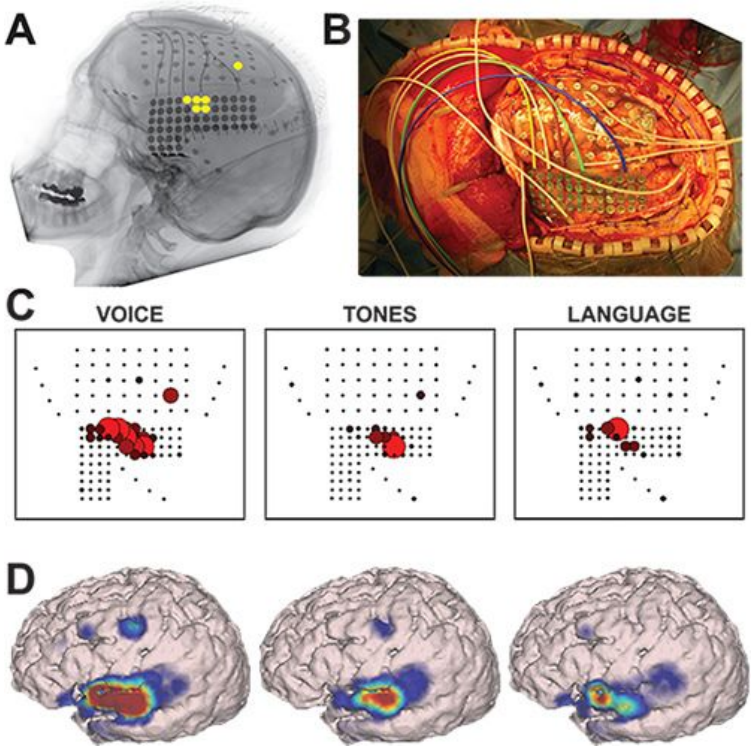
Neuroimaging

- MEG



Neuroimaging

- ECoG



KOREA LINGUISTICS OLYMPIAD

Thank you!

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