Language And The Brain

Preamble

- Language: is one of the few uniquely human cognitive abilities
  - Foundation of human culture and civilization
- What cognitive and neural mechanisms enable us to produce and understand language?
  - Brain regions implicated in linguistic processing: frontal, temporal, and parietal lobes of both hemispheres, as well as subcortical and cerebellar structures.
  - Characterizing the precise contributions of these different structures to linguistic processing has proven challenging.
- Research Questions:
  - to understand the representations and computations that underlie our linguistic ability,
  - to provide a detailed characterization of the brain regions that support language processing in both typical and atypical brains.

Key Research Questions

- **Language comprehension:** How do we infer others' thoughts from their utterances?
- **Language production:** How do we convert our thoughts into utterances?
- **Language and executive functions:** What role do domain-general executive resources, like attention, working memory, and cognitive control play in language comprehension/production?
- **Language and social cognition:** Given that linguistic communication is a social behavior, what is the relationship between the language system and the mechanisms that support social perception and cognition?

Key Research Questions

- **Meaning:** What is the nature of our conceptual representations, and how do they map onto linguistic forms?
- **Plasticity:** How do our minds and brains reorganize following early or late damage to the language system?
- **Individual differences:** How do individuals vary in their neural architecture, and how does this variability relate to behavioral variability in linguistic and cognitive abilities, and to differences in our genetic make-up, including in individuals with neurodevelopmental disorders?

Key Research Questions

- **Bi- and multilingualism:** How do bi- and multilingual individuals process different languages? What aspects of our experience affect neural responses to native and non-native languages?
  - **Language Acquisition**
- **Literacy and Cognition:** Are these two related? What is the cognitive architecture in illiterate brain?
  - **Learning Difficulties (LD):** What is the neural basis of developmental disorders such as LD - Dyslexia, Dysgraphia, etc?
  - **Reading and Writing**: How does reading become automatic? Are the brain mechanisms of reading acquisition similar across writing systems? And do similar brain anomalies underlie reading difficulties (Dyslexia) in alphabetic, ideographic, and Akshara-based reading systems?

Methods and Approaches of Study

- Psycholinguistics
  - Behavioral experiments
  - Including, Eye tracking
- Neuroimaging:
  - fMRI (functional magnetic resonance imaging)
  - ERP (Event related potentials using EEG)
  - MEG (magneto encephalography)
  - Intracranial recordings (ECoG, SEEG) and stimulation
- Clinical studies (aphasia, dyslexia, etc)
- Computational:
  - Corpus (Linguistics) analyses
  - Natural language processing
  - Neural network and Deep Learning modeling

Ev Federenko, MIT Lab

What is Language?

- Language
  - A flexible system of symbols that enables us to communicate our ideas, thoughts, and feelings
  - Words or symbols, and rules for combining them, which are used for thinking and communication
  - Nonhumans communicate primarily through signs
  - Human language is *semantic*, or meaningful
  - It is also characterized by *displacement* in that it is not limited to the *here-and-now*.
  - Language is often seen as a sign of intelligence
    - From information processing perspective, cognition is information processing
    - Information processing needs representations, i.e. a language

Morris & Maisto, Intro to Psych, 2005, PH

Building Blocks of Thought

- Images
  - Non-verbal mental representations of sensory experiences
- Concepts
  - Words in our language represent concepts
  - Concepts help us to parse/categorize the world and think about things
    - Mental categories for classifying people, objects, or experiences
  - Prototype
    - Mental model containing the most typical features of a concept

Morris & Maisto, Intro to Psych, 2005, PH

Structure of Language

- Phonemes
  - Basic sounds (ph, t)
  - *shortest segment of speech* that, if changed, changes the meaning of the word
- Morphemes
  - Speech sounds collected into meaningful units, like syllables or words
  - smallest meaning unit (words, prefixes)
  - For example, “dogs”, “saddle” are morphemes that stand as words, and anti, pre-, uni-, -ed, -s are also morphemes
- Surface structure
  - Phrases of sentence
- Deep structure
  - Underlying meaning of a sentence
- Grammar
  - Rules of how sounds combine

Morris & Maisto, Intro to Psych, 2005, PH

Components of Language

Phonology	**Rules about structure and sequence of speech sounds**
Semantics	**Vocabulary - words and word combinations for concepts**
Grammar	**• Syntax - rules for sentences** **• Morphology - grammatical markers**
Pragmatics	**Appropriate and effective communication**

Chapter 9: Language Development:
In Child Development, Laura E. Berk 7th edition, 2007

Universality of Language

- Deaf children invent sign language
- All cultures have a language
- Language development is similar across cultures
- Languages are “unique but the same”
  - Different words, sounds, and rules
  - All have nouns, verbs, negatives, questions, past/present tense
- Noam Chomsky (1957) Syntactic Structures
  - Human language coded in the genes
  - Underlying basis of all language is similar

Theories of Language Development

Behaviorist	**Learned through operant conditioning (reinforcement) and imitation**
Nativist	**Language Acquisition Device (LAD) biologically prepares infants to learn rules of language through universal grammar**
Interactionist	**Inner capacities and environment work together; Social context is important**

Chapter 9: Language Development:
In Child Development, Laura E. Berk 7th edition, 2007

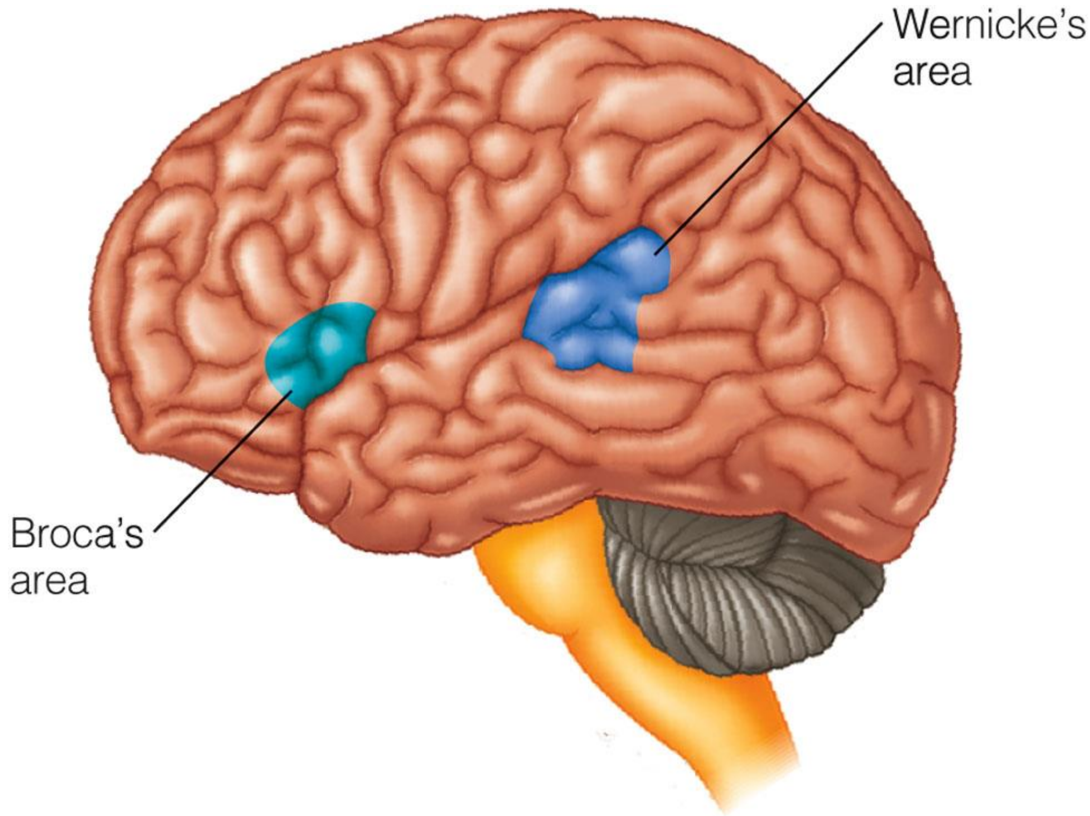
Theories of Language Development

- **All individuals within a given human society talk**: true defining human trait
- Steven Pinker's *The Language Instinct* (1994)
- **Nativist view**: Humans are genetically programmed to have:
  - a *general* innate capacity for language, including
  - capacity for *particular aspects of language*: general linguistic structures, the building blocks that go into it, and the mental process of acquiring it, etc.
  - Mental "organ" (like "wings", "breast", etc.)
- **Anti-nativist view:** Language is:
  - not genetically programmed organ
  - A magnificent aspect or by-product of our extensive cognitive abilities (including learning and memory)
  - Superlearners of animal kingdom

Language Inherited or Learned?

- Daniel Everett:
  - Language as a incredibly useful tool used in problem-solving
  - E.g., to share information; consider arrows

Brain and Language



Speaking a Written Word

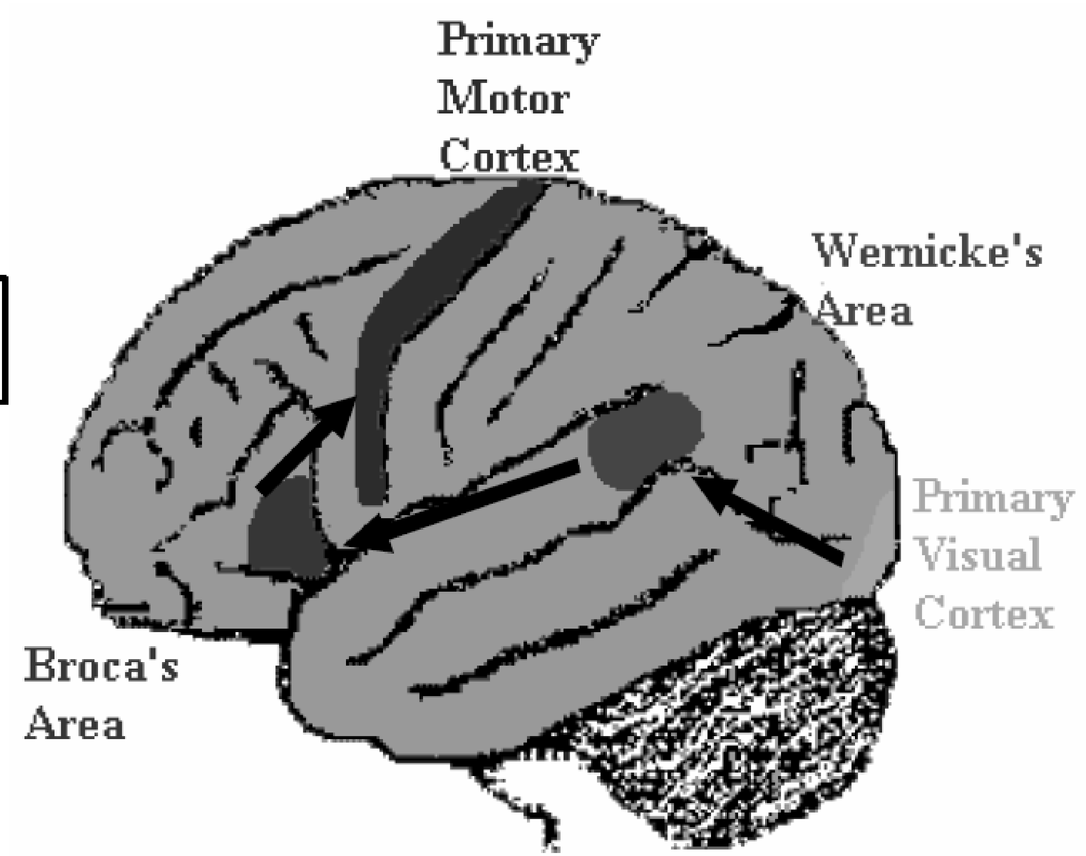
written text

primary visual cortex

Posterior speech area
(including Wernicke's area)

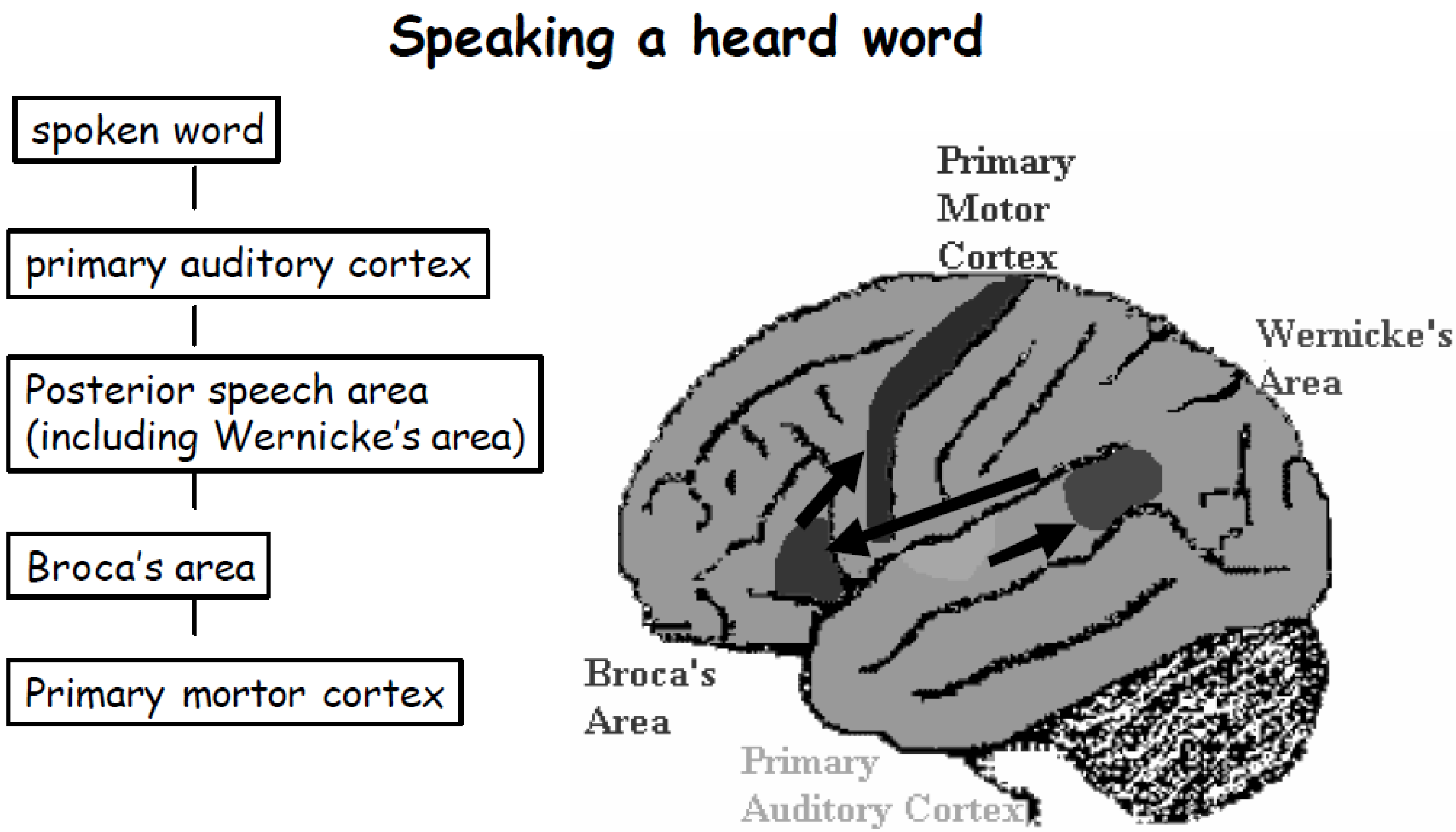
Broca's area

Primary mortor cortex



Source:http://faculty.washington.edu/chudler/lang.html#speak

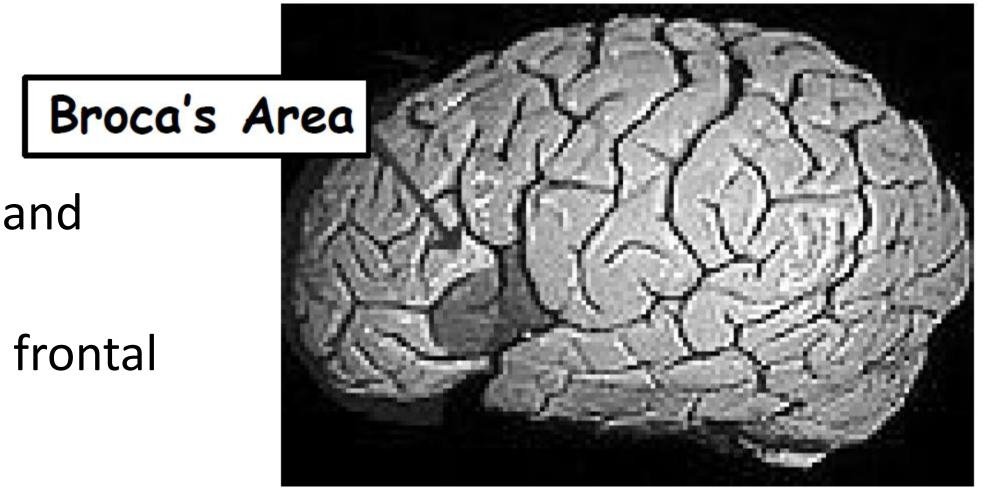
Speaking a Heard Word



Source:http://faculty.washington.edu/chudler/lang.html#speak

Broca’s Aphasia

- Broca’s Area
  - Expressive Speech Area
  - involved in speech production and syntactic analysis
  - is a region in the (usually) Left frontal lobe: Inferior Frontal Gyrus

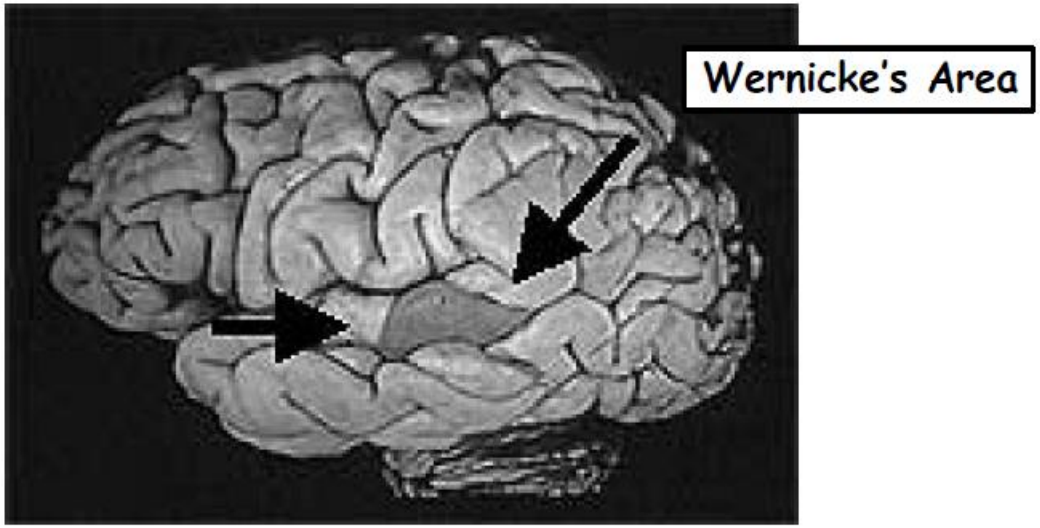


- Broca’s Aphasia
  - often referred to as *agrammatic*
  - problems with production: slow, slurred speech *(Expressive Aphasia)*
  - difficulty with syntax
  - interpretation requiring syntactic analysis can also be problematic
  - The dog chased the car. (okay)
  - The cat chased the dog. (confusing)

Source:http://faculty.washington.edu/chudler/lang.html

Wernicke's Aphasia

- Wernicke's Area
  - Receptive Speech Area
  - Language comprehension
  - posterior section of the superior temporal gyrus (STG) in the dominant cerebral hemisphere (which is the left hemisphere in about 95% of right handed individuals and 60% of left handed individuals)



- Wernicke's Aphasia
  - *Receptive* or *Fluent aphasia*
  - comprehension difficulties; characterized by verbal fluency without coherence
  - They also have difficulty understanding others

Source:http://faculty.washington.edu/chudler/lang.html

Psycholinguistic Experiments

- How do infants learn language?
  - Swimming in a sea of sound
  - Segmentation problem: beginning & end
- Tasks at hand:
  - Differentiate their native lang from other languages
  - Have a sense of how stream of sounds are carved up into words
  - Give special attention to distinctions in sounds that will be especially useful for signaling different meanings (e.g., /b/ vs. /p/)
  - Figure out how sounds can be "legally" combined into words in their language

Infant Language Acquisition

- Babies begin learning their native lang from before birth
  - 4-day French differentiated b/w French and Russian; but not b/w English and Italian
  - Babies *in utero* begin learning their native lang
  - Are human babies genetically programmed like that for bee dance or birdsong?
    - Chinese child brought up in the USA?
  - Huge linguistic flexibility as humans are powerful learning machines

HAS Paradigm

- **High-Amplitude Sucking (HAS)**
  - Pressure transducer: Magnitude & frequency
  - Baseline: with no stimulation
  - Training: reward: an appetitive stim (e.g. mother's voice)
- **Habituation & Dishabituation**
  - DV: sucking period of HAS ≈ likes the stimulation [What's IV here?]
  - Can the infant differentiate b/w two stimuli
  - HAS: for investigation of the way prenatal exposure to speech affects fetuses and newborn infants

Word Segmentation

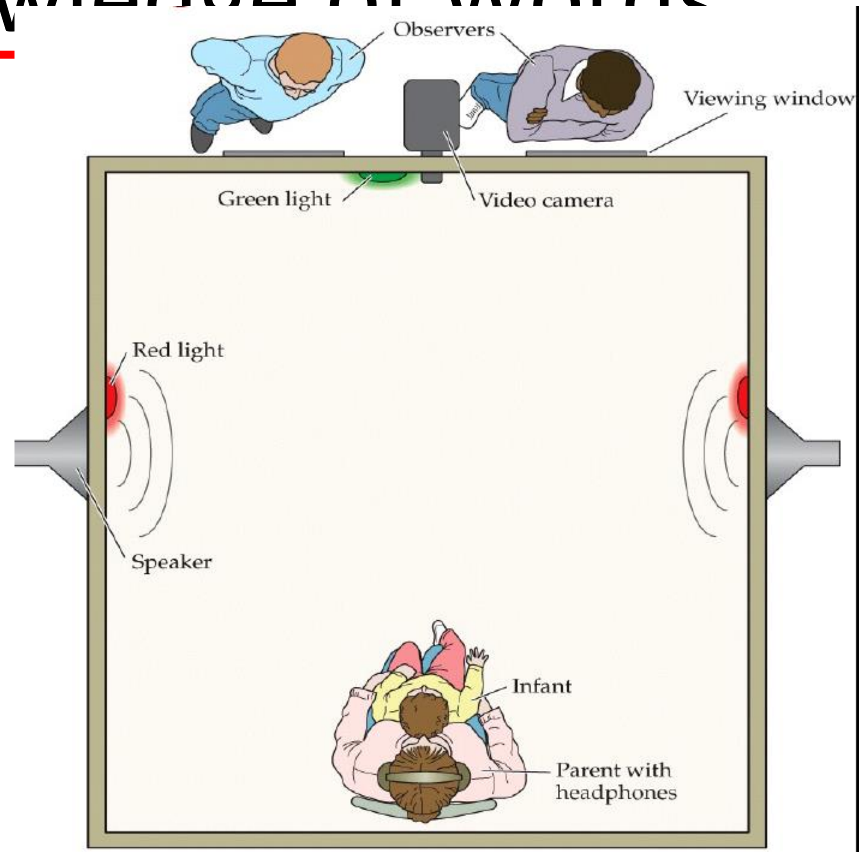
- Parent rarely speak to their children in single-word utterances: approx. 10% of the time
  - Babies confronted with speech in which multiple words are sewn seamlessly together,
  - so their boundaries need to be figured out: word segmentation problem

Head-turn Preference Paradigm

- **Familiarization phase**
  - 1. Infant becomes familiar with the sound stim (in word learning studies: the 'to be learnt' word played)
  - 2. Train infants to expect that sounds can come from the speaker on either left or the right wall
  - 3. To tightly lock together the head-turn beh to the infant's auditory attention (flash a light in the location of the speaker before each sound, making sure that sounds are played only for as long as the baby looks in the dir of the sound)
- **Testing Phase**
  - 1. Sounds of interest played either on left or right speaker
  - 2. Baby's head turn beh recorded by video camera
  - In learning experiment: is there a difference (positive or negative) in looking times between the learned and the new stimuli.

Probing Infant's Knowledge of Words

- **Jusczyk & Aslin (1995)**
- Familiarization phase:
  - Target word: "bike"
- Test phase:
  - how long listened to "bike" (cf. "dog")
- Result from : 7.5 mo-old babies spent more time turning to speaker when it played a familiar (learned) than unfamiliar (unlearned) word
  - 7.5 mo-old can do speech segmentation
  - 6-mo-olds do NOT have this ability
- How do they manage to do this?
- What info are they using in doing this?



His bike had big black wheels.
The girl rode her big bike.
Her bike could go very fast.
The bell on the bike was really loud.
The boy had a new red bike.
Your bike always stays in the garage.

Language, Perception, Cognition

- Does language affect perception and cognition?
- Does the nature of a culture’s language affect the way people think?
- Sapir-Whorf Hypothesis
  – the varying cultural concepts and categories inherent in different languages affect the cognitive classification of the experienced world in such a way that speakers of different languages think and behave differently because of it.
  – This view has been criticized and debunked, but…

Yamauchi, T, Texas A&M

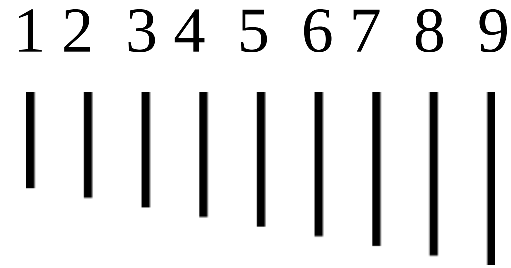
Categorical Perception Effect

- Forming categories (e.g., speech sound, color, or any other categories that group things, events, and people) modify people's perception.
- Categories create a contraction of features within a category and an expansion of features that divide between categories.

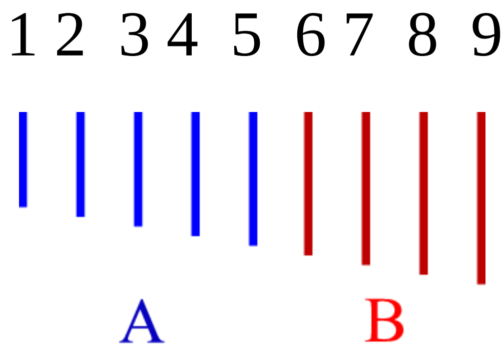
Categorical Perception Effect

- “r” and “l” distinction in Japanese
- Japanese adults cannot distinguish “r” and “l” speech sounds.
- But Japanese babies initially can. As the babies learn Japanese, the variation of “r” and “l” is lost, because the Japanese language does not distinguish them.

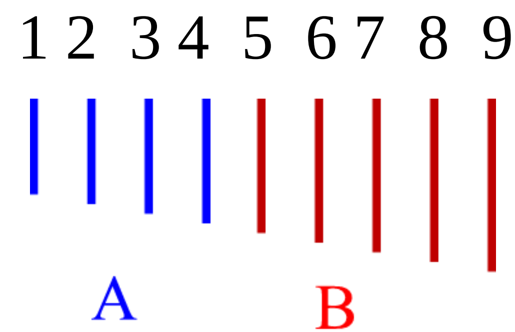
Categorical perception effect



(a)



(b)



In (a), you learn to classify 1-5 into A and 6-9 into B.

As you learn A and B categories, 1-5 and 6-9 become perceptually similar.

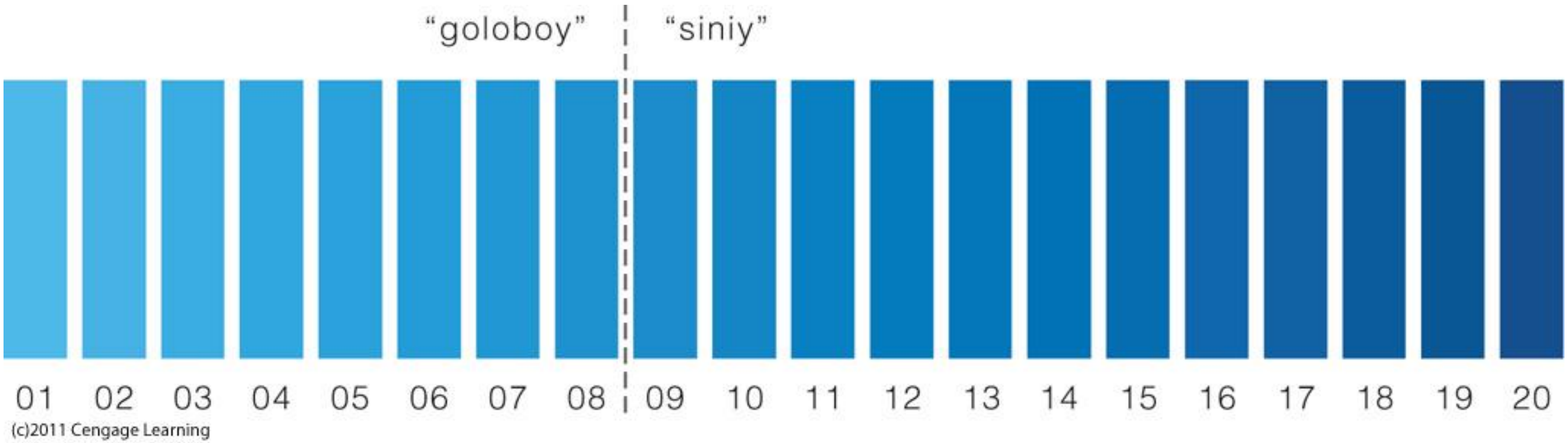
In contrast, 5-6 become perceptually distinct.

In (b), you learn to classify 1-4 into A and 5-9 into B.

As you learn A and B categories, 1-4 and 5-9 become perceptually similar.

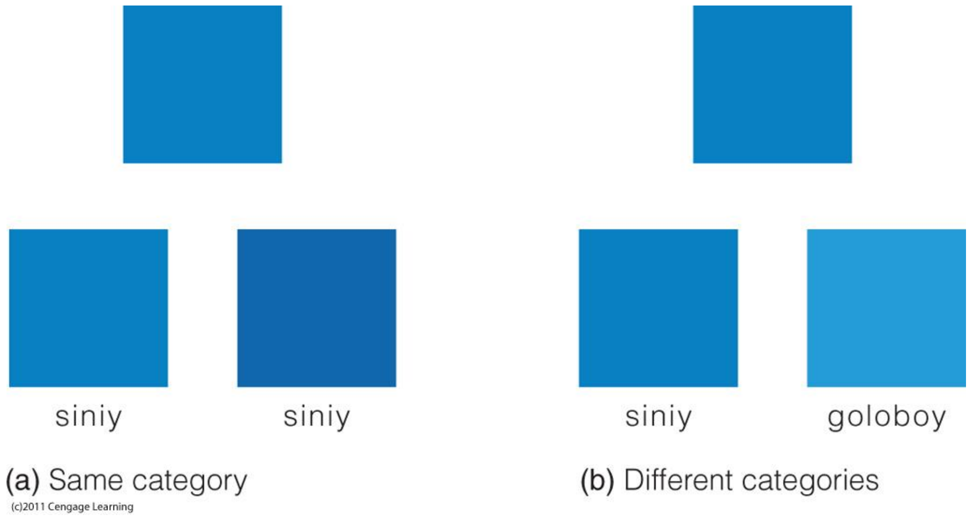
In contrast, 4-5 become perceptually distinct.

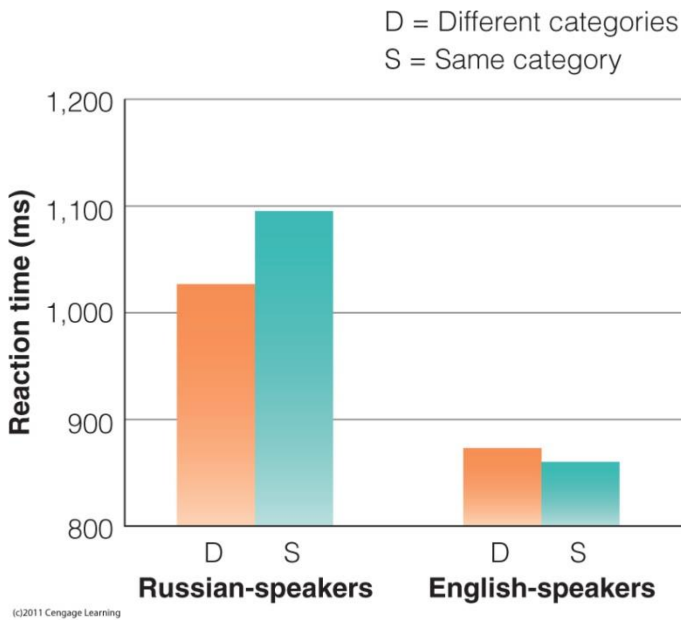
Yamauchi, T, Texas A&M



Colors ranging from light blue to dark blue. English speakers call all of them "blue" but Russian speakers call the lighter colors "goloboy" and the darker colors "siniy."

Yamauchi, T, Texas A&M





(a) The two bottom squares are from the same Russian color category (siniy, siniy); (b) the two bottom squares are from different Russian color categories (siniy, goloboy). Ss judged which of the bottom two (left or right) matched the top square. The color names were not visible to Ss. (From *Winawer, Witthoft , Frank, Wu, Wade, and Boroditsky, PNAS 2007*)

Russian subjects took longer when the bottom colors had the same color name – (a), than when they had different color names.

Influence of Language on Visual Perception

Ways of naming color may influence speed of color perception!

Yamauchi, T, Texas A&M

Stroop Interference

Name the colors as quickly as you can!

Stroop Interference

PURPLE	BLUE	GREEN	GREEN
RED	PURPLE	RED	GREEN

Name the ***colour of the ink*** used to print the words as quickly as you can!

Stroop Interference

- There are several theories used to explain the Stroop effect and are commonly known as 'race' models.
  - Competing processes 'racing' in parallel to be selected by the response system
  - Speed of processing theory
  - Selective Attention theory
  - Automation of Reading theory (automaticity hypothesis)
  - Parallel distributed processing theory

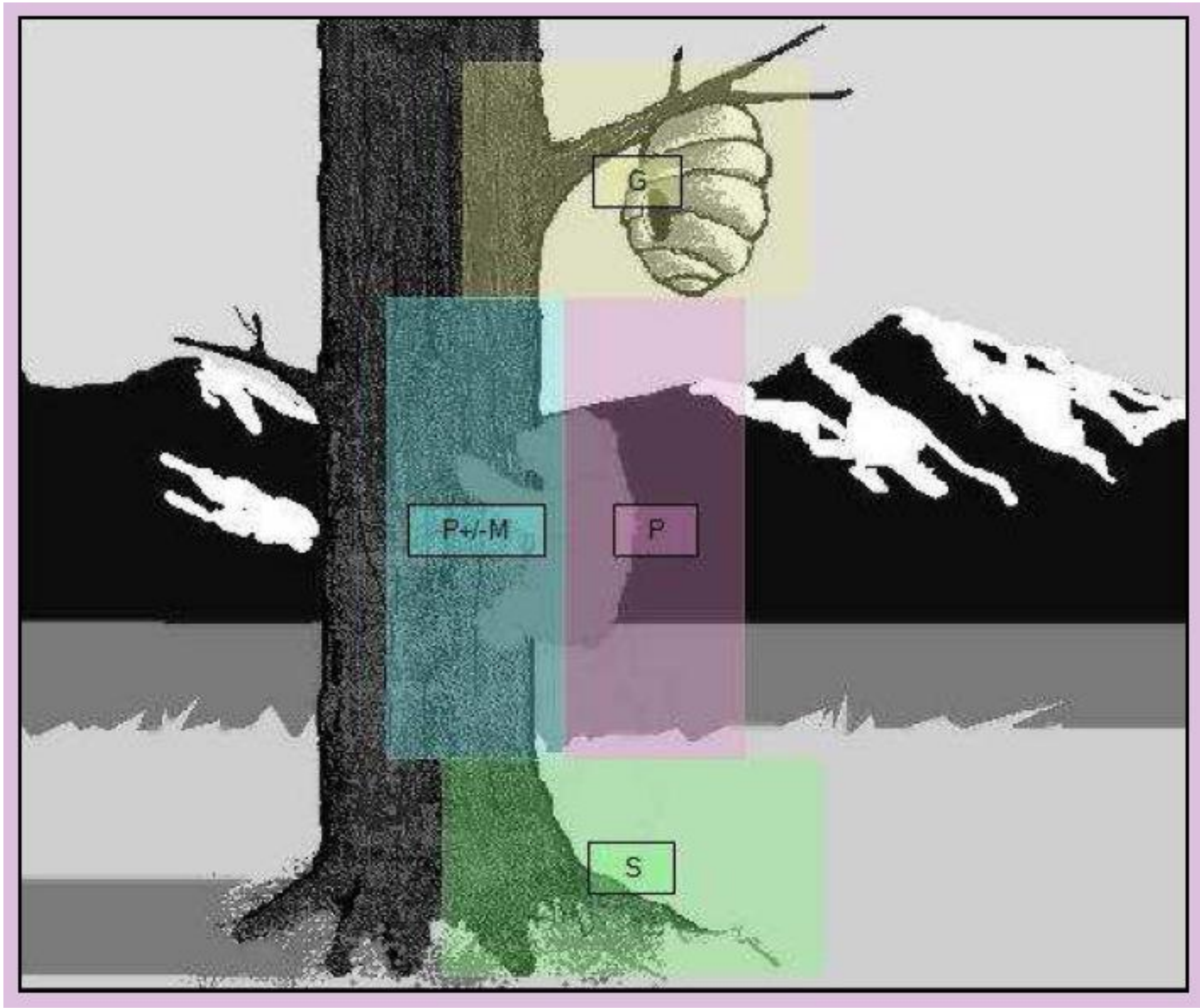
Does Language affect Thinking?

- Language seems to influence our perception
  - Our ability to perceive color (distinguish colors) seems to be influenced by the language we use.
- We tend to think that perception is independent of language, but actually it does not seem to be.
- Controversial work on Inuit (Eskimo) terms for snow:
  - Eskimos seem to have many different names for “white.”
  - This may be because they really see many different gradients of “white”?
- Recent work of Carruthers, Lera Boroditsky on perception of features of Space and Time depend on the language we use
- Language typology affects eye movements

Language Typology

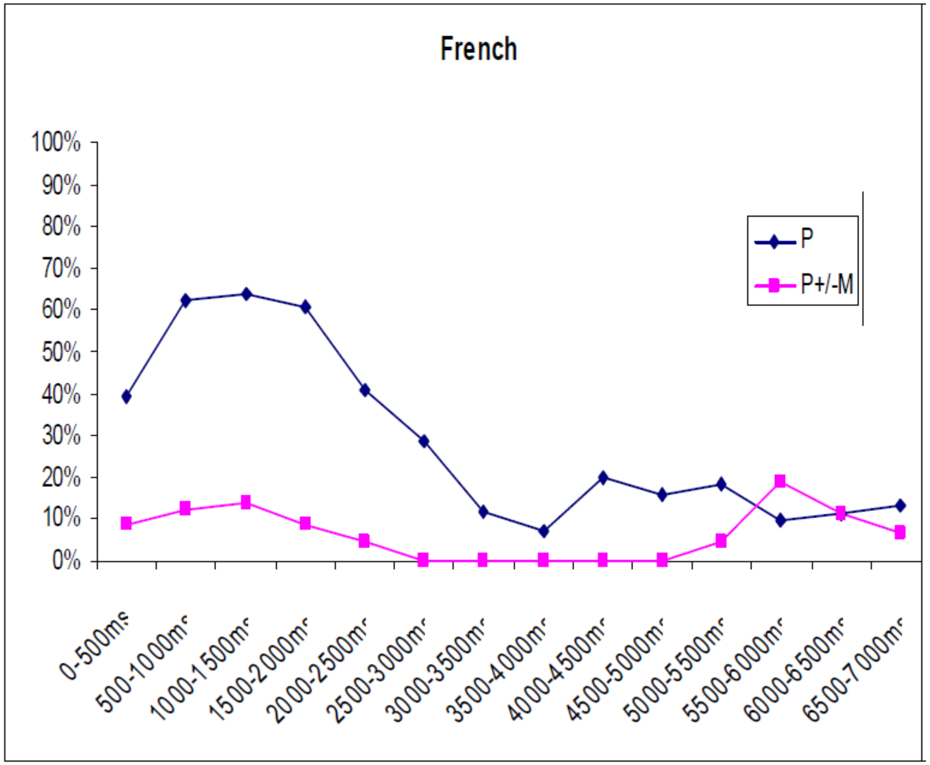
- Languages show striking differences in how they encode space and in how they represent motion events.
- They either lexicalize or grammaticalize spatial information, thereby highlighting some types of information more than others
- Talmys’ typology (1985, 2000):
- **Satellite-framed languages** (Ex. English):
  - He is running up, down, across, into, away …
  - Lexicalization of Manner of motion in verb roots and Path in Satellites (ex., particles).
  - Ex. He is running up the hill.
  - Ex. The baby is crawling across the street.
- **Verb-framed languages** (Ex. French):
  - Il monte, descend, traverse, entre, part ... en courant
  - Lexicalization of Path in Verb roots, leaving Manner implicit or peripheral.
  - Ex. *Il monte la colline en courant*.
  - Lit. ‘He is *ascending* the hill by running’.
  - Ex. *Le bébé traverse la rue à quatre pattes*.
  - Lit. ‘The baby is crossing the street on all fours’.

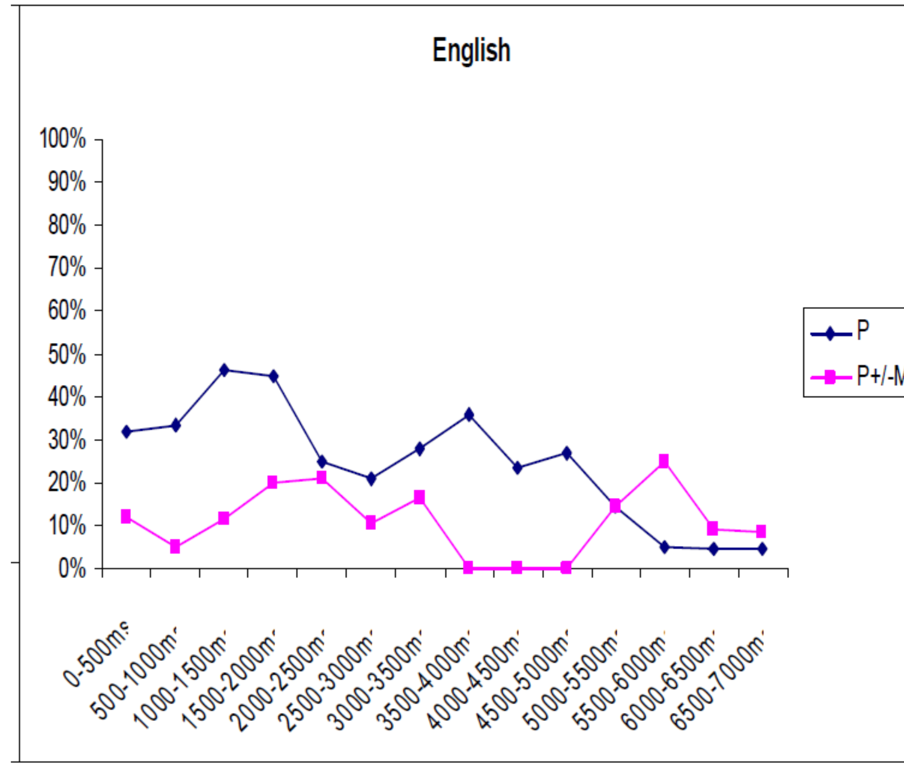
Lang. Typology & Eye movements



Areas of Interest (AoI) marked for Source, Goal, Path and Path(+with or - without Manner) in a Verbal Production task

Lang. Typology & Eye movements



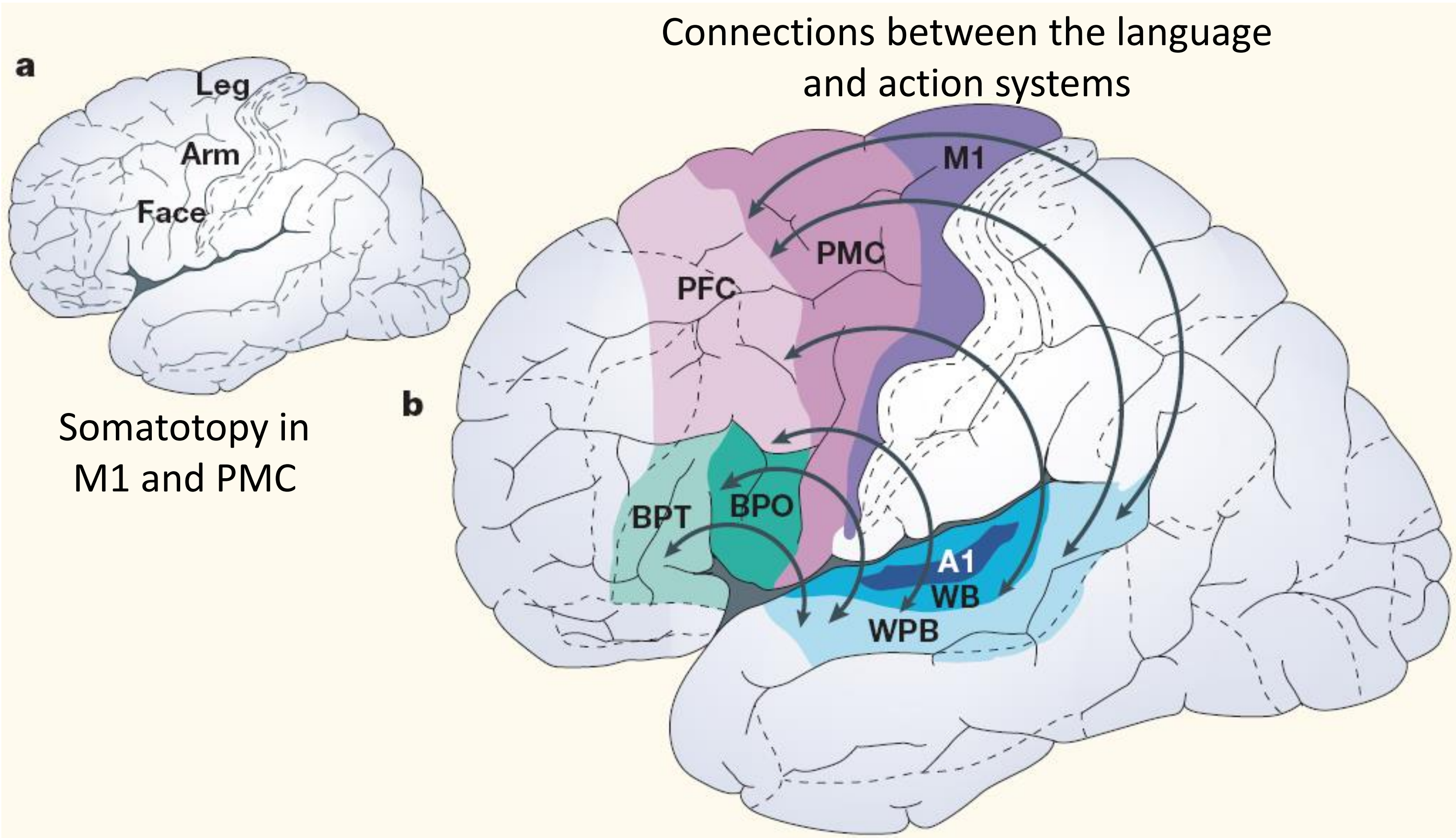


A difference in allocation of attention to different Areas of Interest (eye tracking):

French (V-framed) speakers focused their attention more on Path

English (S-framed) speakers paid as much attention to Path and to Manner,

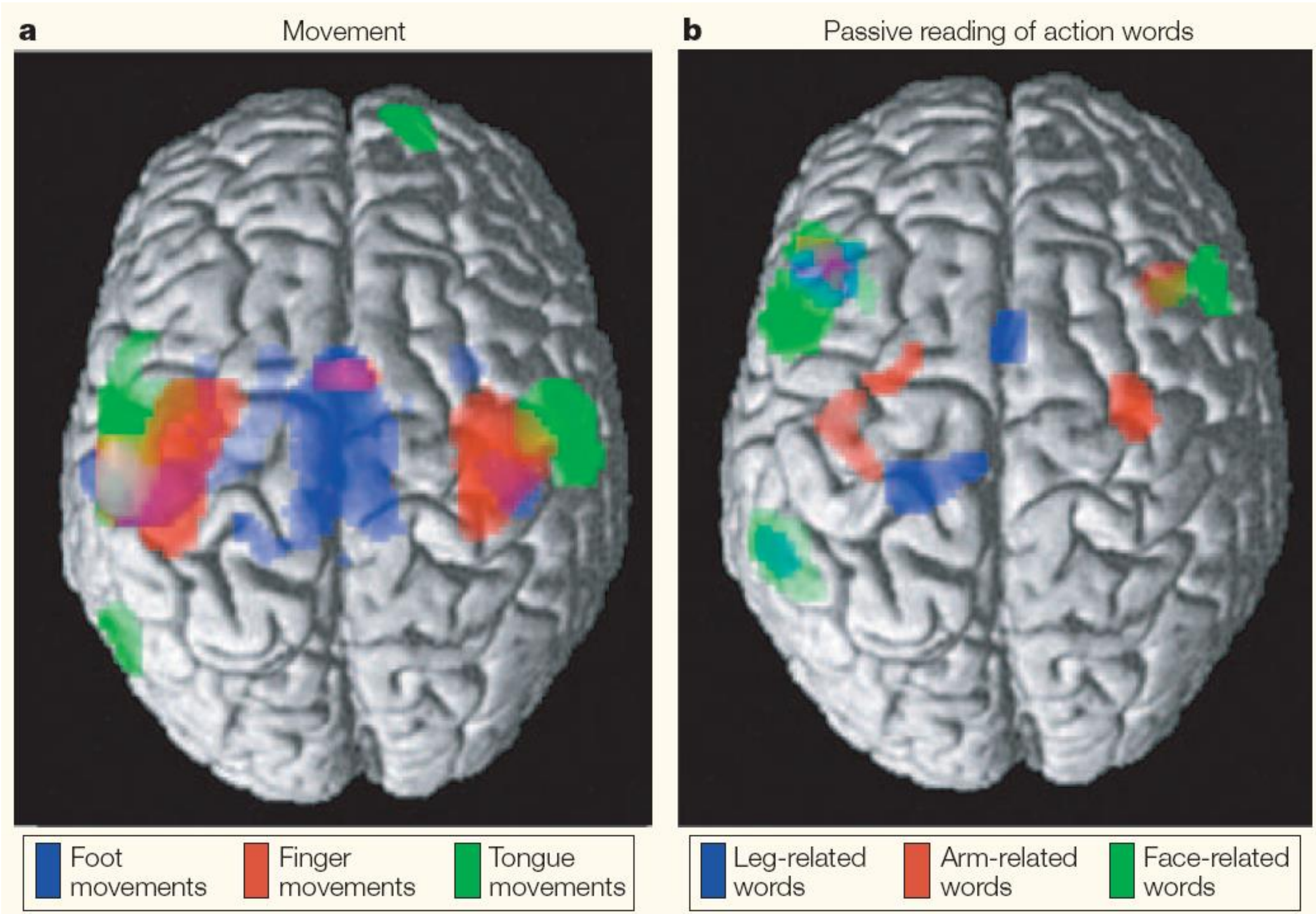
Somatotopy



Connections between the language and action systems

Somatotopy in M1 and PMC

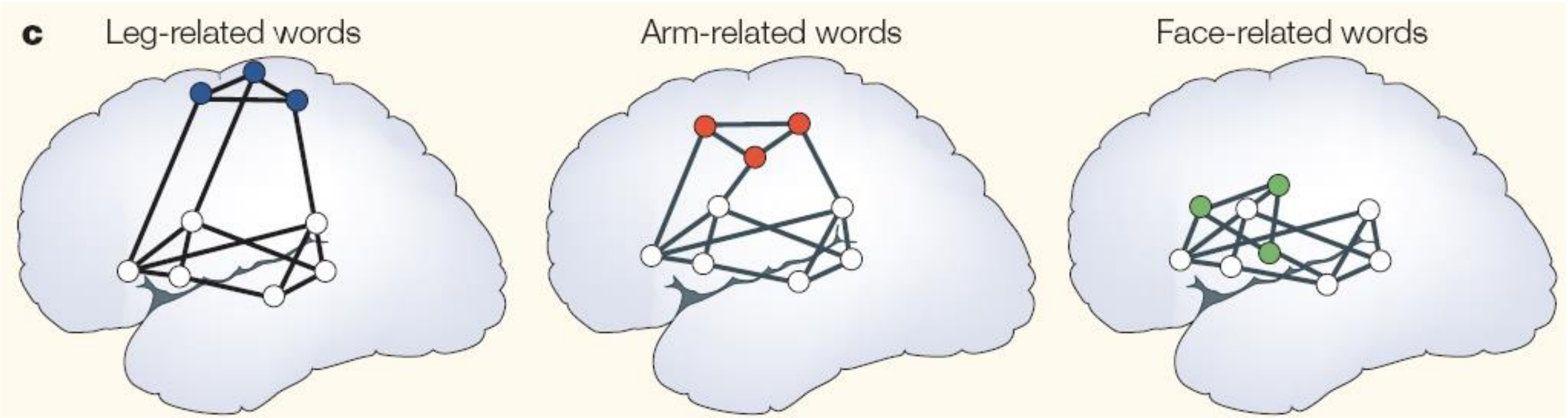
Pulvermüller (2005)



Common Neural substrate is involved in the processing of actions and the meaning of action words

Pulvermüller (2005)

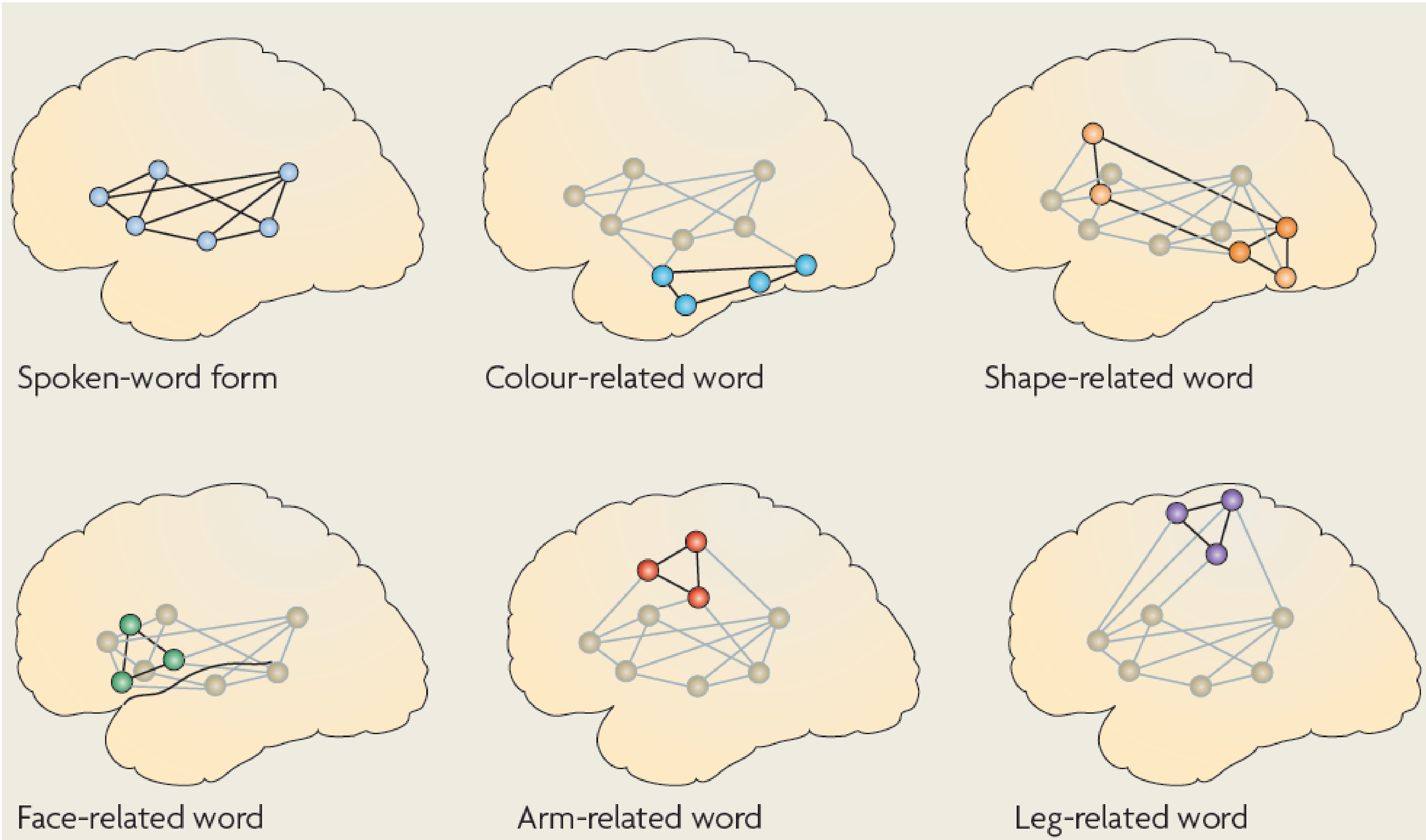
Embodied Representation



Semantic Somatotopy model of action word processing:
Distributed neuronal Assemblies bind information about
word forms and actions to which they are semantically linked

Pulvermüller (2005)

Embodied Representation



Category-specific action–perception circuits play an important role in semantic processing

Active Perception: Sensorimotor circuits as a cortical basis for language

Pulvermüller & Fadiga (2010)

Our Work

- Embodied Verbal Semantics
- Verb-Body Part Association
- Language Typology and Eye movements
- Dementia and Multilingualism (NIMHANS)
- Aphasia (LTRC)

Infant Statistician

Tracking transitional probabilities: The information is out there

- **Bidakupadotigolabubidaku**

bi-dak-upa	bid-aku-pa	bid-ak-u-pa
bi-da-kup-a	bid-ak-up-a	bidaku-pa
bid-akupa	bida-kupa	bi-dakup-a
bi-daku-pa	bid-akup-a	bidak-upa

- **Jenny Saffran and colleagues (1996)**
- Preferential head-turn paradigm
- **Artificial language**: 4 words
- Only repeated CV, no pauses, no stress patterns, no phonotactic cues; randomly combined with other syllables

Test phase
Loudspeakers present infant either a "real" word:
bidaku, golabu
or a sequence of syllables with parts of two words:
dakugo, buduta

Results

Mean looking times for 8-month-olds	
"Real" words	6.77 seconds
Part-words	7.60 seconds

- 8-mo-old
- just 2 min exposure of unfam lang is sufficient

Familiarization phase bidaku, golabu, padoti, dubata: total 180 words

Infant hears each "word" repeated 45 times in random order, in an unbroken 2-minute synthesized speech stream:

bidaku-golabu-dutaba-golabu-padoti-bidaku-dutaba-padoti-golabu-dutaba-padoti-dutaba-golabu-bidaku-dutaba-bidaku-padoti-bidaku-padoti-golabu etc.

ERPs Reveal Statistical Skills of Newborns

Tuomas Teinonen and colleagues (2009) used ERP methods to test whether newborns can pick up on the transitional probabilities of syllables in a sample of speech. Their subjects were less than 2 days old, and they listened to at least 15 minutes of running speech consisting of ten different three-syllable made-up words randomly strung together. After this 15-minute "learning" period, the researchers analyzed the electrical activity in the babies' brains. Because the ERPs of newborn babies are less wildly variable if measured during sleep, the researchers limited the analysis to brain activity that was monitored during active sleep—which turned out to represent 40%–80% of the hour-long experiment.

ERP activity was compared for each of the three syllables of the novel "words." The logic behind this comparison was that, since the first syllable for any given "word" was less predictable (having a lower transitional probability) than the second and third syllables, it should show heightened brain activity compared with the other two syllables.

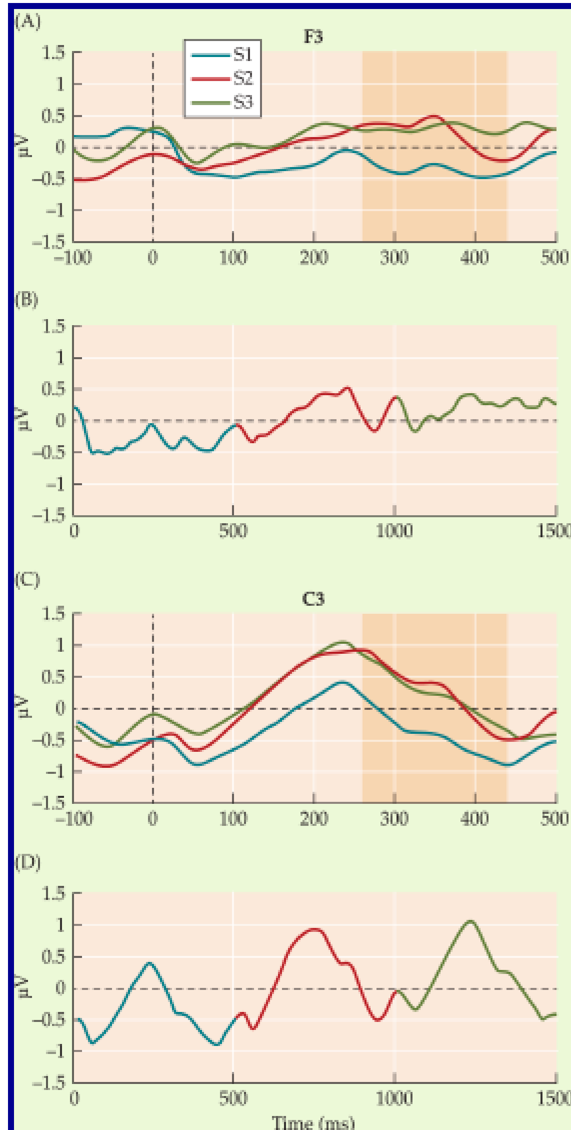


Figure 4.4 ERP activity at two recording sites (F3 and C3) shows enhanced negativity. In panels (A) and (C), the syllables are aligned so that each syllable's onset corresponds to 0. The shaded areas show the region where there is a statistically significant difference between the first syllable (S1) and the second and third syllables (S2 and S3). Panels (B) and (D) track EEG activity for the three syllables spoken in sequence. (Adapted from Teinonen et al., 2009.)