FLST:Cognitive Foundations I

Matthew W. Crocker
crocker@coli.uni-sb.de

What is Cognitive Foundations?

- Language is fundamentally a human phenomenon
  - It originates in, and is processed by the human brain
- The nature of language is shaped by ...
  - communicative pressures and goals
  - the structure of the world: objects, events, ...
  - the processing mechanisms & capacities of the brain
- Study of linguistic behaviour contributes to theories
- Experiments help us test theory predictions
- Computational models help express dynamical theories, and simulate language processes

The cognitive study of language

- The acquisition of our native language
  - General cognitive learning mechanisms, or domain specific ones?
  - How does language learning take place?
- The use of language
  - What mechanisms support language encoding and decoding
- The evolution of the human capacity for language
  - What are the distinguishing traits that enable humans alone to have language?
  - What caused the emergence of this capacity?

Nature *versus* Nurture

Nature: Innate Language
Chomsky

- UG constitutes a language specific genetic/biological endowment
- explains why languages have structural commonalities
- **Argument**: successful acquisition despite *poverty of stimulus*

Nuture: Emergentist
Elman, Bates, Karmiloff-Smith

- linguistic knowledge is derived solely from our experience
- language has adapted to be learnable
- **Argument**: makes fewer assumptions (Occam's razor)

Universal Grammar

- Domain specific knowledge of language is part of our genetic endowment
  - The structure of possible human languages is “hard-wired”
  - Domain specific innate behaviors are not unusual in animals (e.g. spider webs)
- UG is typically viewed as a “parametrized set of principles”
  - **headedness**: left/right
  - **pro-drop**: yes/no
- Learning of syntax reduces to parameter setting
- Consistent with localization of language in the brain

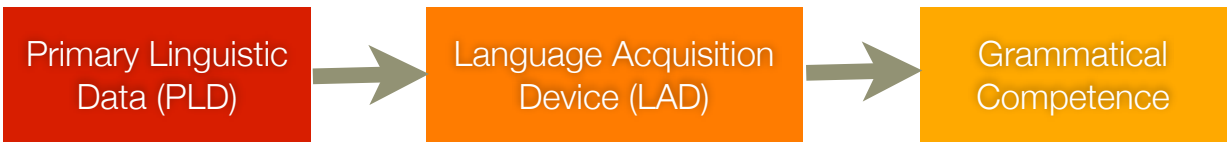
Pro Universal Grammar

- Poverty of stimulus: human language is unlearnable from evidence alone
  - E. M. Gold showed that any formal language which has hierarchical structure capable of infinite recursion is unlearnable from positive evidence alone
  - Children do not receive (and if they do, ignore) “labeled” negative evidence
  - Therefore: they must have some innate knowledge to enable acquisition
- Empirical support:
  - Creolization: Hawaiian Creole, Nicaraguan Sign Language

Nicaraguan Sign Language

- In 1977, a special centre was established to educate the deaf.
  - Spanish/lip-reading, letter signs to spell words
  - This approach largely failed, but ...
- Students developed their own “pidgin” sign language, based on their “home signs”
- This then creolized, obeying syntactic rules conforming to UG, notions of verb-agreement, etc.
- A chance to see a new language created “out of thin air”

Language Acquisition Device



- The device searches for language structure hypotheses compatible with input signals from the Primary Linguistic Data (PLD).
- The device then tests the compatibility using the knowledge of implications of each hypothesis for the sentences.
- One hypothesis or ‘grammar’ is selected as being compatible with the PLD.
- This grammar provides the device with a method of interpreting sentences

Challenging Nativism

- The Poverty of Stimuli evidence may be overstated?
- Gold's results don't take into account sophisticated probabilistic (including connectionist) learning
  - (Simpler) statistics had been previously discredited along with behaviourism
- Most researchers actually do believe in *some* degree of innateness
  - all learning algorithms possess some bias
    - influences what is learned, and how
  - disagreement is more often about the specific UG proposals
- "Logical problem of language acquisition" abstracts from the dynamics of language development

Language Learning

- Increased emphasis on what can be learned from linguistic experience:
  - Parts of speech, co-occurrences, subcategorization ...
  - Some aspects of grammar remain a challenge
- Emphasis on situated learning of meanings:
  - Co-occurrences of words and objects in the world
  - Use of other cues to disambiguate (e.g. gaze)
- Bootstrapping from what you know:
  - Infer verb meaning from objects
  - Infer object meanings from verbs

Language and thought

Linguistic Autonomy
Chomsky, Fodor, Pinker

- we are all born with knowledge of language
- separation of language and thought (*mentalese*)
- **Evidence**: commonalities among languages

Linguistic Relativity
Sapir, Whorf, Lakoff, Levinson

- the language that one speaks affects the way they think
- language adapted to the culturally relevant expression
- **Evidence**: categorisation of colour and spatial terms, expression of time

The Russian Blues

- Russian (obligatorily) distinguishes between lighter blues (“goluboy”) and darker blues (“siniy”)
- Does this influence colour discrimination?
  - no-interference condition in which there was no dual task
  - a verbal-interference condition, in which subjects silently rehearsed digit strings
  - a spatial-interference condition, in which subjects maintained a spatial pattern in memory
- Russian speakers were faster to discriminate colours from different linguistic categories
- English speakers did not show an advantage

The Russian Blues

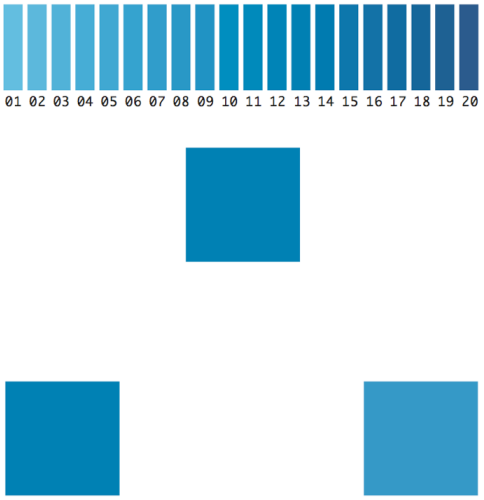


Fig. 1. The 20 blue colors used in this study are shown at the top of the figure. An example triad of color squares used in this study is shown at the bottom of the figure. Subjects were instructed to pick which one of the two bottom squares matched the color of the top square.

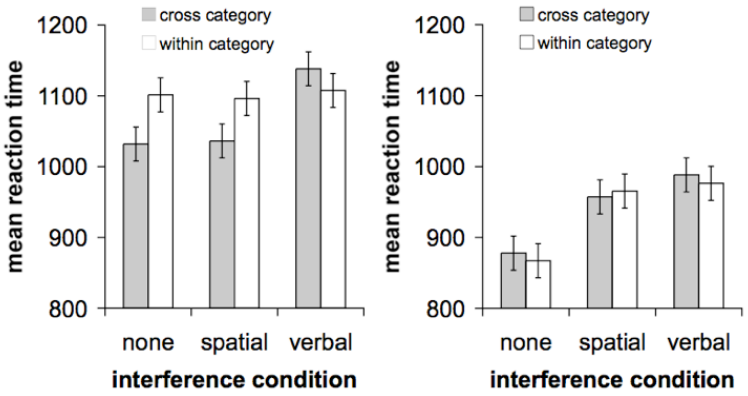


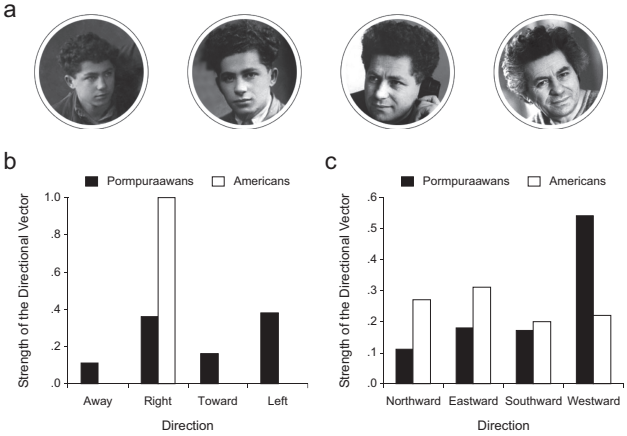
Fig. 2. Russian speakers' (*Left*) and English speakers' (*Right*) reaction times (msec) shown for the no-interference, spatial-interference, and verbal-interference conditions. Both near-color and far-color comparisons are included in these graphs. Error bars represent one SE of the estimate of the two-way interaction between category and interference condition.

Winawer et al, *PNAS*, 2006

Linguistic Relativity

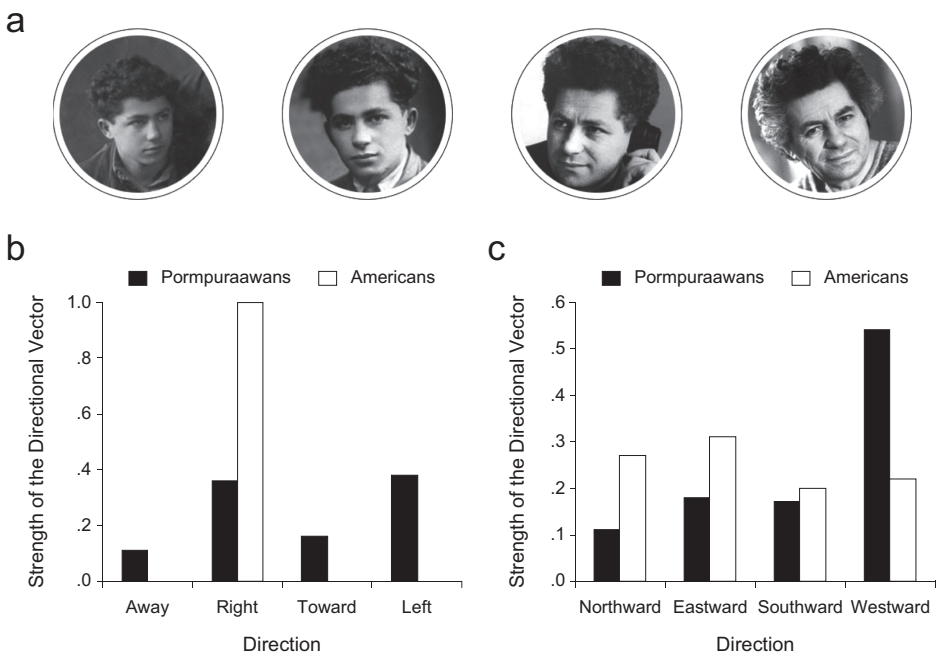
Boroditsky and Gaby, *Psych. Sci.*, 2010.

- Languages (there are about 7000) vary widely in how/ whether they encode: gender information, tense and aspect, space, time, causality ...
- Pormpuraa (Aboriginal community in Australia), "left" and "right" (body centric) are replaced by cardinal directions: "north", "east" ...
  - For Americans, time is arranged rightwards
  - For Pormpurra, time is arranged from east to west



Linguistic Relativity

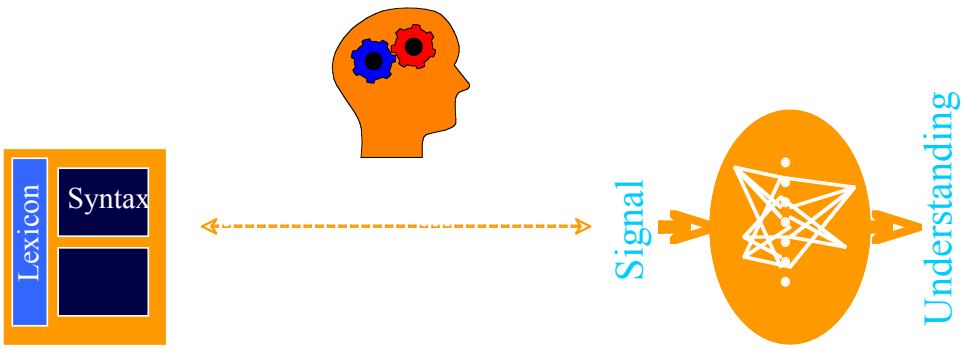
Boroditsky and Gaby, *Psych. Sci.*, 2010.



- Spatial conceptions of time vary culturally

Modularity of Language

- Is language distinct from other cognitive & perceptual processes?
  - e.g. vision, smell, reasoning ...
- Do distinct modules exist *within* the language processor?
  - e.g. word segmentation, lexical access, syntax ...
- What is a module anyway!?



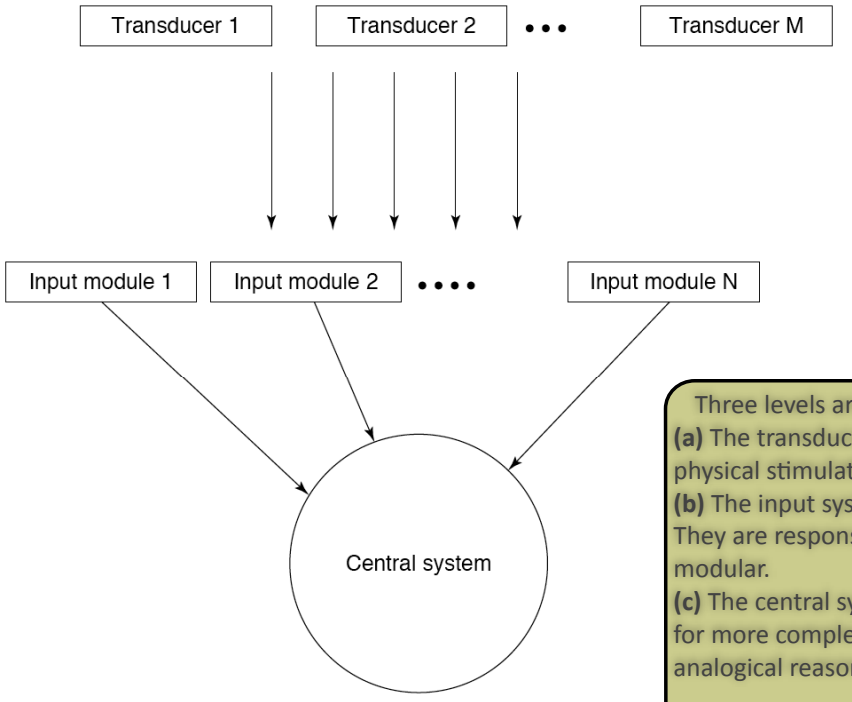
Architectures and Mechanisms

- What does "distinct" mean:
  - Representational autonomy: e.g. phonological versus syntax representations
    - Possibly interactive processes
  - Procedural autonomy: e.g. lexical access versus syntax
    - Possibly shared representations
- How is the language module organized/interact with other systems?
  - Does architecture affect possible mechanisms?
  - Theoretical, computational and empirical arguments concerning modularity?

Modularity and Computation

- The brain is the natural computer, par excellence:
  - Perception occurs in real time, and is highly strategic
- Traditional views on human perception:
  - Cognitivist – Inferential, unencapsulated: cognitive penetration of perceptual processes
  - Behaviorist – Non-inferential, encapsulated: perception reduces to conditioned reflexes
- Fodor: inferential but encapsulated
  - Perception is performed by: *"informationally encapsulated systems which may carry out complex computations"*

Fodor's Modularity

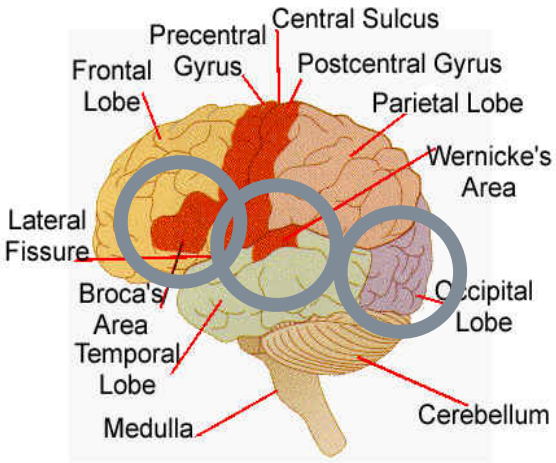


Modules are:
- domain specific
- innately specified
- informationally encapsulated
- fast
- hardwired (neurally specific)
- autonomous
- not assembled

Three levels are distinguished:
(a) The transducers, whose function is to convert physical stimulation into neural signals.
(b) The input systems, interpret transduced information. They are responsible for basic cognitive activities and are modular.
(c) The central system, is responsible for more complex cognitive activities such as analogical reasoning, and is not modular.

Reference
a Fodor, J.A. (1983) *The Modularity of Mind*, MIT Press/Bradford Books

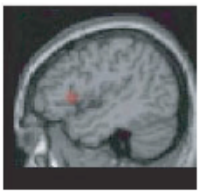
Language in the Brain

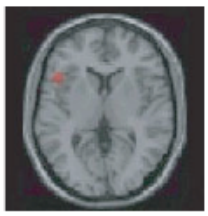


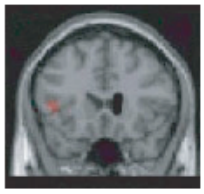
- *Frontal lobe*: **Broca's Area**
  - Damage can lead to **impaired language production** (and comprehension)
- *Temporal lobe*: **Wernicke's area**
  - Damage can result in **impaired auditory language processing**
- *Occipital lobe*: Visual processing
  - Damage can impair processing of written language

Universal Grammar in the Brain?

- German's were asked to learn a new language (Japanese, Italian)
  - instructed in the grammar, and given sentence
- Lexical items were the same, but grammar was manipulated
  - either linguistically "legal" obeying principles of UG
  - or linguistically "illegal" violating UG
- Activation of Broca's area was only found for the UG language





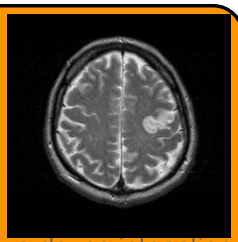


From: Musso *et al*, *Nature Neurosci.*, 2003

Proof for Modularity of Language

- The best proof of Modularity would be evidence for a "Double Dissociation":
  - #1 Damaged linguistic abilities, but intact general cognition
  - #2 Damaged cognitive abilities, but intact language

#1 Broca's aphasia
- normal IQ
- language comprehension is relatively unimpaired
- language production is non-fluent, few words, short sentences, few function words, no intonation

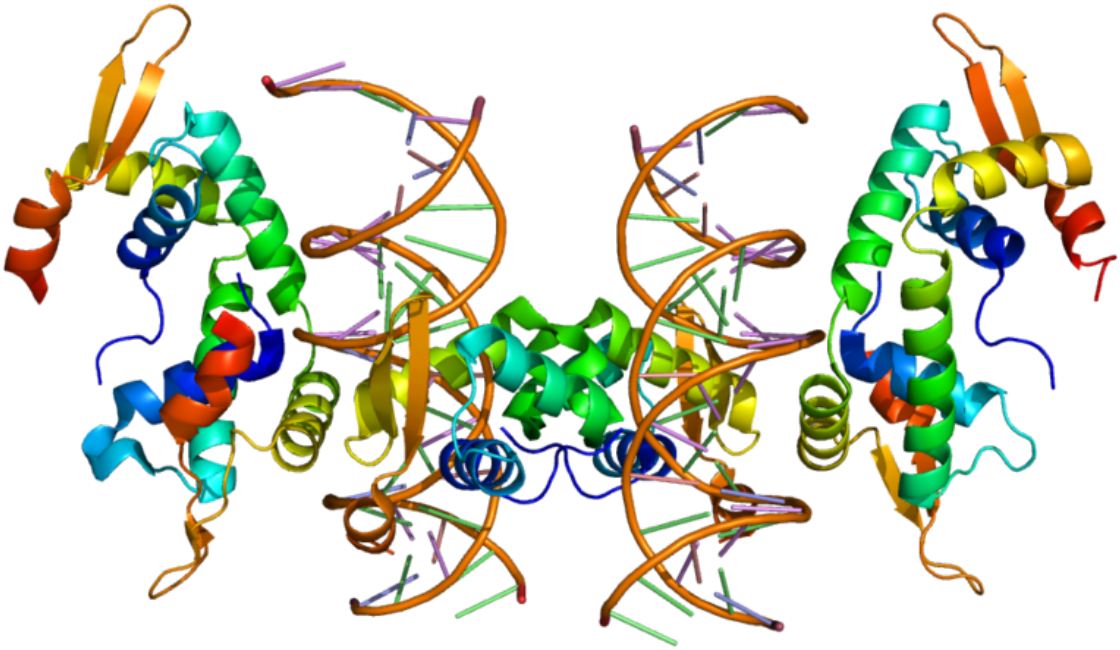


#2 Williams Syndrome
(Genetic defect in .001% births)
- low IQ, overly social, poor spatial reasoning
- good language ability, nearly age appropriate

#1 Specific Language Impairment
- normal IQ and hearing
- language is meaningful, appropriate
- problem with grammatical morphemes

#2 Senile Dementia
- poor memory and diminished general cognitive function
- language production and comprehension remain intact

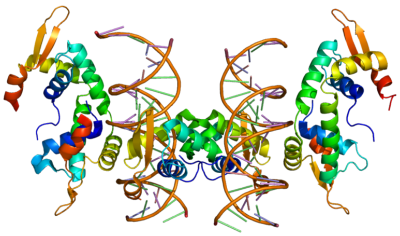
Is this Language?



The FOXP2 gene is located on human chromosome 7

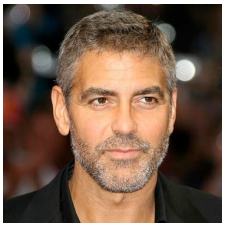
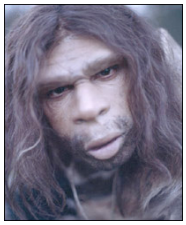
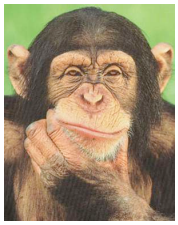
The Language Gene?

- Studies conducted on members of a large family (KE) where about 50% of family members showed
  - difficulty with comprehension of complex structures
  - speech disorder, often unintelligible
  - non-speech movement of face/mouth
  - reduced non-verbal IQ
- All affected family members showed mutation of Foxp2
- fMRI studies of patients have also shown
  - reduced Broca's area, overactivation during lexical tasks
  - functional abnormalities in language-related cortical and basal/ganglia regions



Foxp2 and Evolution

- Foxp2 in other species varies

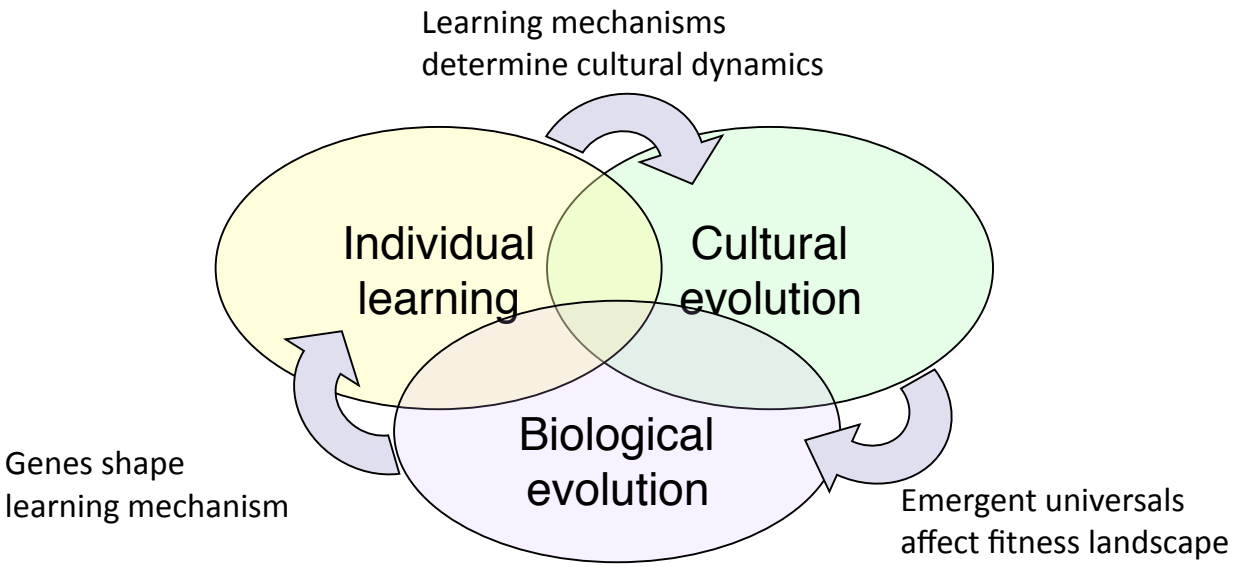



2 amino acids


3 amino acids


7 amino acids

- The gene has also been found in Neanderthals (from which humans split ~300-400K years ago).
- Foxp2 is almost certainly just one of many genes contributing to language, and may be quite periphery (correlated with brain, lung, motor development)

The Emergence of Language



From: Kirby *et al*, *PNAS*, 2007

Language & Embodiment

- How does the brain represent the meaning of words and sentences?

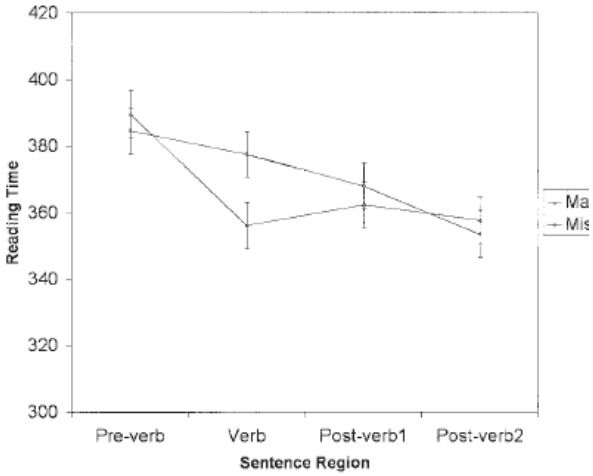
- Semantic theories typically use abstract symbols:
  - "John kicked the ball" = ball(x) & kicks(John', x)
  - Internal structure does not resemble the perceptual states from which they originate
  - Distinguish types and tokens, generalization and combinatoric representations are straightforward.
  - Symbol Grounding Problem: how are perceptual states mapped to/from amodal symbols

Perceptual Grounding

- The mental representations of words are grounded in perceptual and motor experience
  - Sentences are understood via "mental simulations"of described events
- Barsalou (1999) provides a high-level account:
  - Schematic representations of perceptual components are extracted from experience and stored in memory
  - Memories of the same component become organized around a common frame and implement a simulator
  - A simulator produces limitless simulations of the component

Action Compatibility Effect

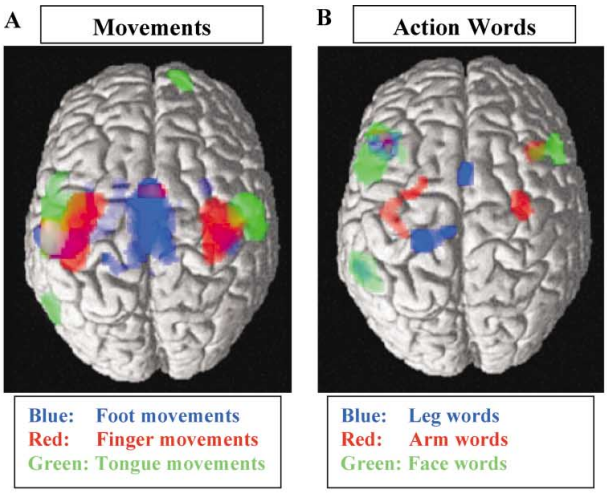
- Frame-wise presentation of a sentence
  - Each frame showed between one and three words
  - Participants rotate knob to move from one frame to the next
  - Sentences described actions involving manual rotation
  - Knob-turning action either matched direction of rotation action in the sentence or not

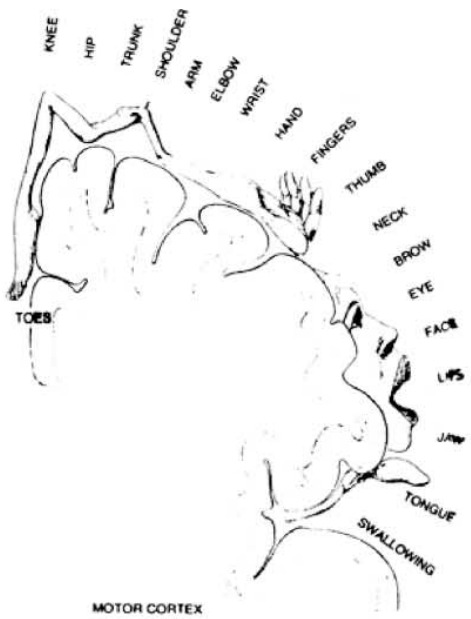


- To/quench/his/thirst/the/marathon/runner/eagerly/**opened**/the/water bottle

Action words and premotor cortex

- Participants engaged separately in motor movements, and passive listening of action words





Hauk, Johnsrude, Pulvermüller: Somatotopic Representation Of Action Words In Human Motor And Premotor Cortex *Neuron*, 41:301-307

Summary of cognitive issues

- The relation between language and thought
  - language - culture mutually constraining
  - autonomy of language vs *mentalese*
- Linguistic autonomy
  - Modularity *vs* localization in the brain (not the same thing)
  - Innate linguistic (domain specific) language “organ”
- Symbolic versus perceptually grounded meaning
  - Evidence for embodiment of mental representations
- The emergence of the capacity for human language
  - language specific versus general cognitive capacities