From brain research to artificial cognitive systems

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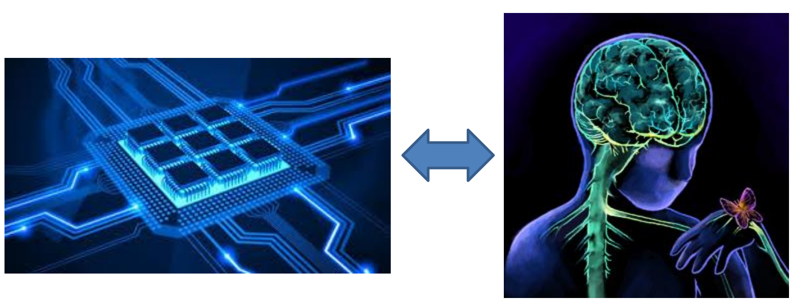
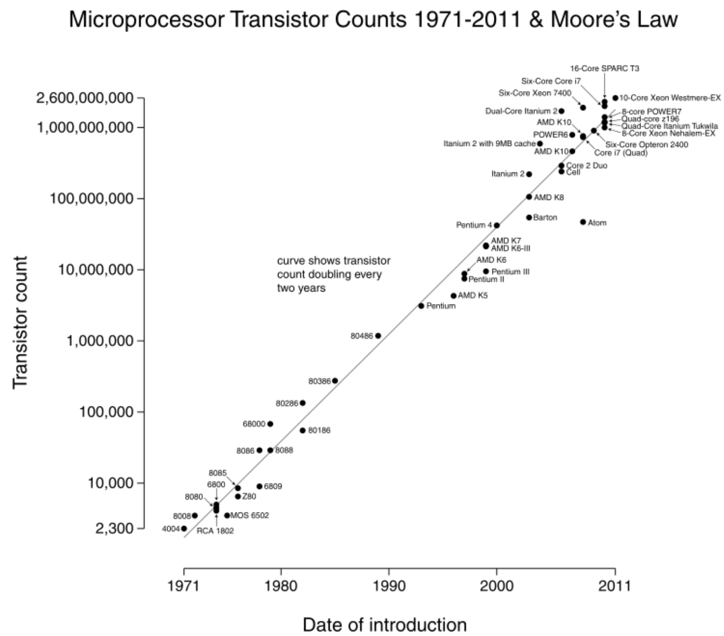
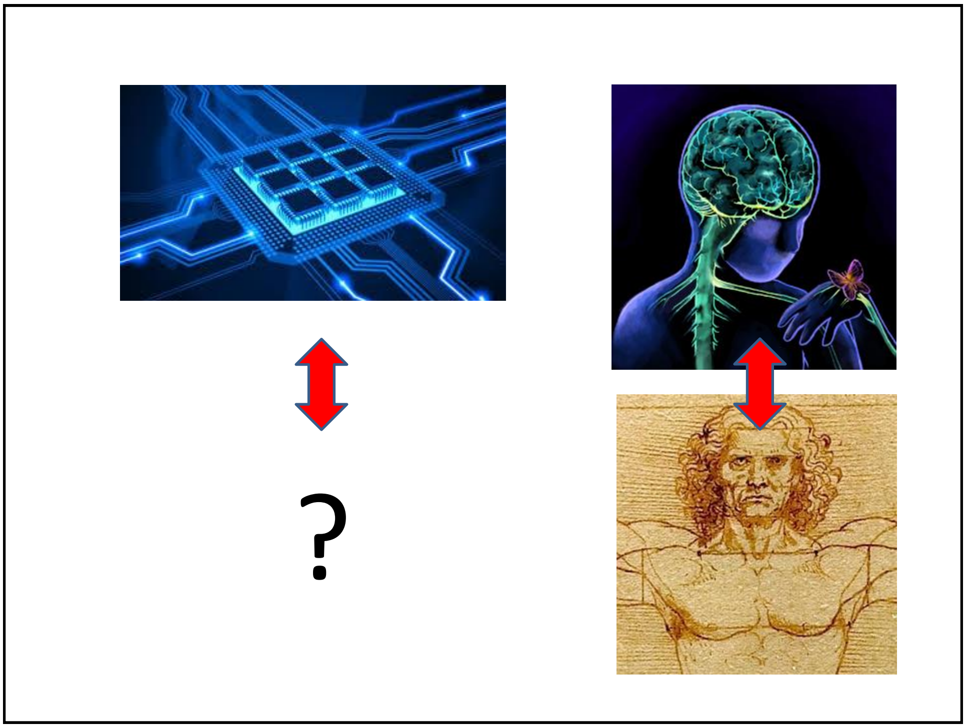
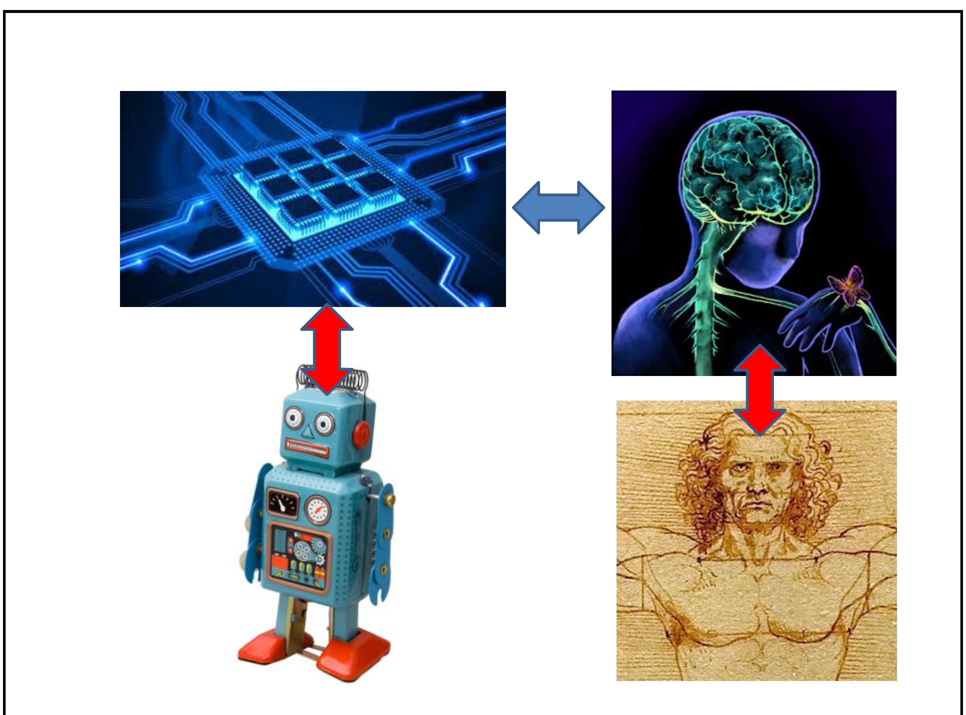
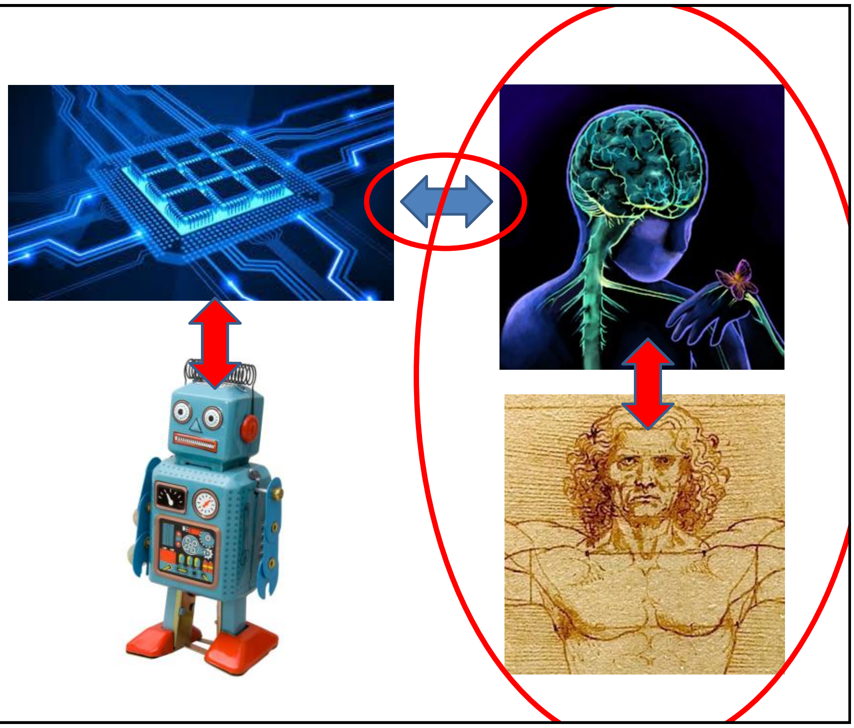
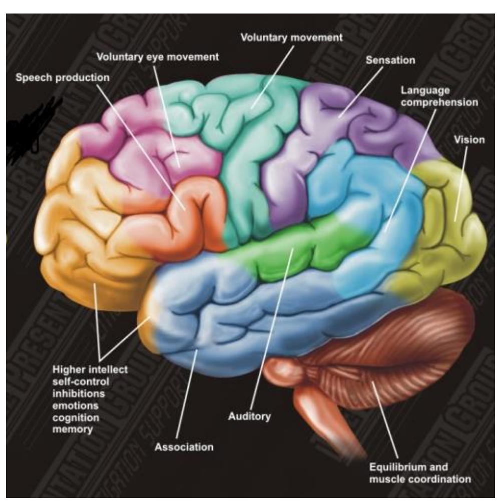


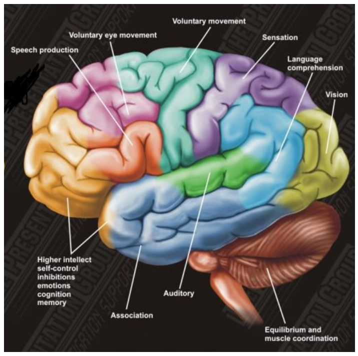

Microprocessor Transistor Counts 1971-2011 & Moore's Law
Transistor count
2,600,000,000
1,000,000,000
100,000,000
10,000,000
1,000,000
100,000
10,000
2,300
Date of introduction
1971
1980
1990
2000
2011
curve shows transistor count doubling every two years
16-Core SPARC T3
Six-Core Core i7
Six-Core Xeon 7400
10-Core Xeon Westmere-EX
Dual-Core Itanium 2
8-core POWER7
Quad-core z196
Quad-Core Itanium Tukwila
8-Core Xeon Nehalem-EX
AMD K10
POWER6
Itanium 2 with 9MB cache
Six-Core Opteron 2400
AMD K10
Core i7 (Quad)
Core 2 Duo
Cell
Itanium 2
AMD K8
Barton
Atom
Pentium 4
AMD K7
AMD K6-III
AMD K6
Pentium III
Pentium II
AMD K5
Pentium
80486
80386
80286
68000
80186
8086
8088
8085
6800
6809
8080
Z80
8008
MOS 6502
4004
RCA 1802

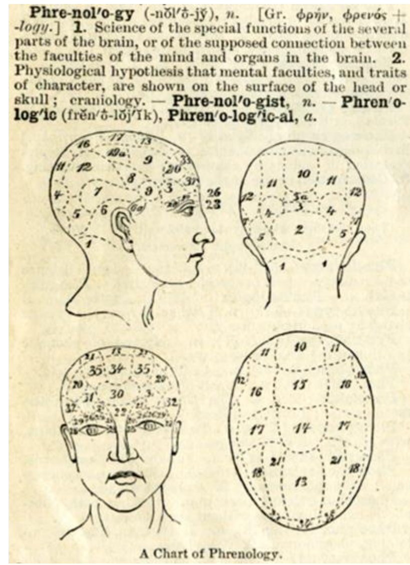







Voluntary movement
Voluntary eye movement
Sensation
Speech production
Language comprehension
Vision
Higher intellect
self-control
inhibitions
emotions
cognition
memory
Auditory
Association
Equilibrium and muscle coordination





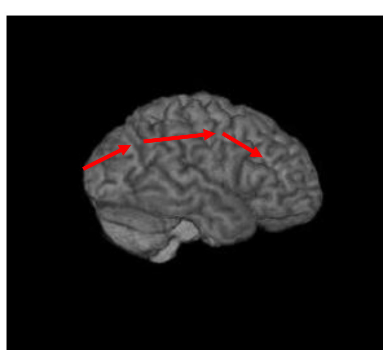
Phre-nol'o-gy (-nŏl'ō-jȳ), *n.* [Gr. φρήν, φρενός + *-logy.*] **1.** Science of the special functions of the several parts of the brain, or of the supposed connection between the faculties of the mind and organs in the brain. **2.** Physiological hypothesis that mental faculties, and traits of character, are shown on the surface of the head or skull; craniology. — **Phre-nol'o-gist**, *n.* — **Phren'o-log'ic** (frĕn'ō-lŏj'ĭk), **Phren'o-log'ic-al**, *a.*

A Chart of Phrenology.

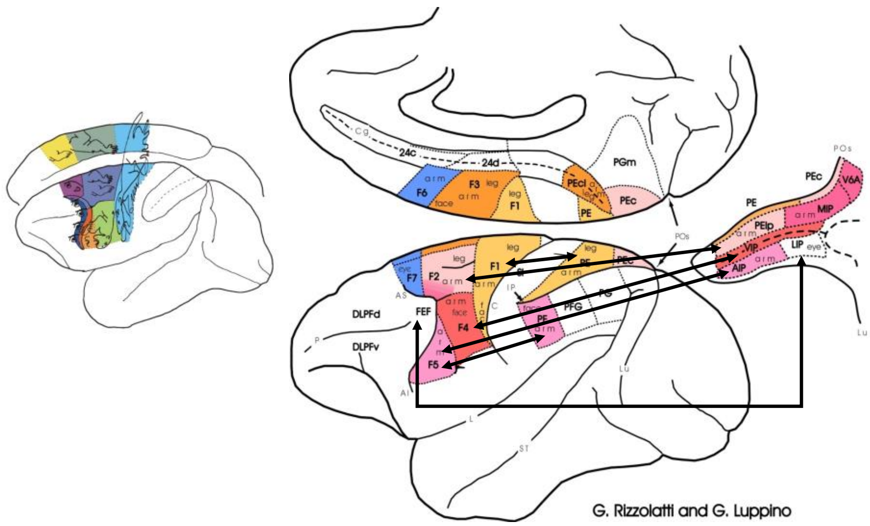
WORLD

STIMULUS ↓ RESPONSE ↑

SENSATION → PERCEPTION → DECISION → MOVEMENT

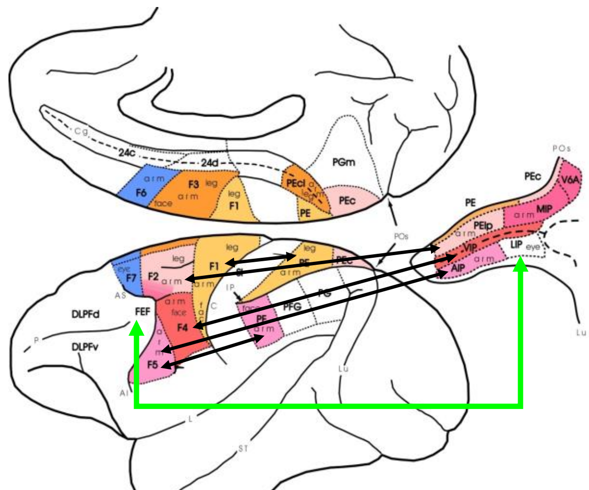


multiple sensorimotor representations in multiple parieto-frontal modules

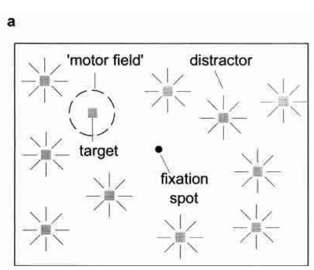


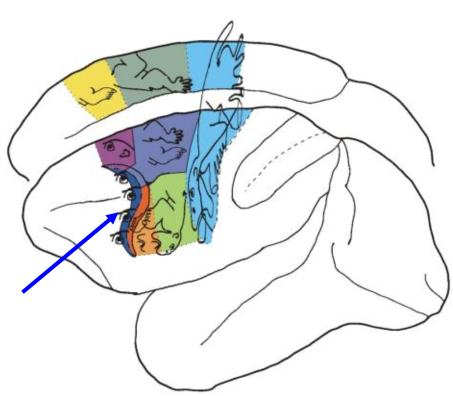
Sensorimotor neurons challenge the traditional view on the motor system:

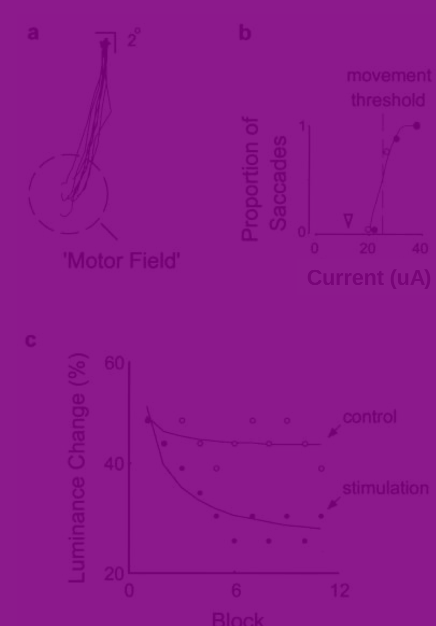
The LIP-FEF circuit



G. Rizzolatti and G. Luppino







Moore & Fallah (2001) PNAS

4228 • The Journal of Neuroscience, April 19, 2006 • 26(16):4228–4235

Behavioral/Systems/Cognitive

Contribution of the Monkey Frontal Eye Field to Covert Visual Attention

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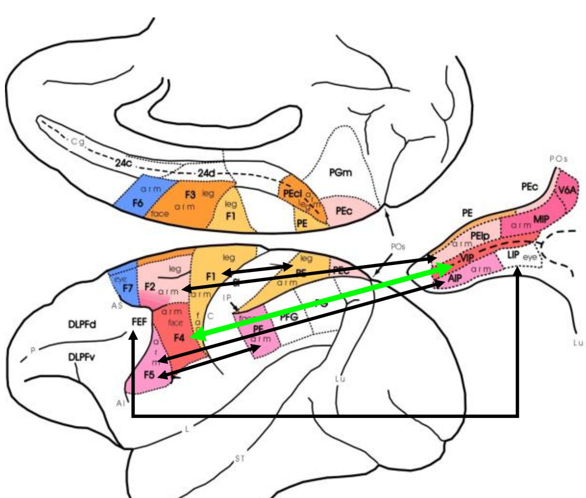
The frontal eye field (FEF) has long been regarded as a cortical area critically involved in the execution of voluntary saccadic eye movements. However, recent studies have suggested that the FEF may also play a role in orienting attention. To address this issue, we reversibly inactivated the FEF using multiple microinjections of muscimol, a $GABA_A$ agonist, in two macaque monkeys performing visually guided saccades to a single target. The effects of FEF inactivation were also studied in a covert visual search task that required monkeys to search for a target presented among several distractors without making any eye movements.

As expected, inactivating the FEF caused spatially selective deficits in executing visually guided saccades, but it also altered the ability to detect a visual target presented among distractors when no eye movements were permitted. These results allow us to conclude definitively to an involvement of the FEF in both oculomotor and attentional functions. Comparison of the present results with a similar experiment conducted in the lateral intraparietal cortex area revealed qualitatively different deficits, suggesting that the two areas may make distinct contributions to selective attention processes.

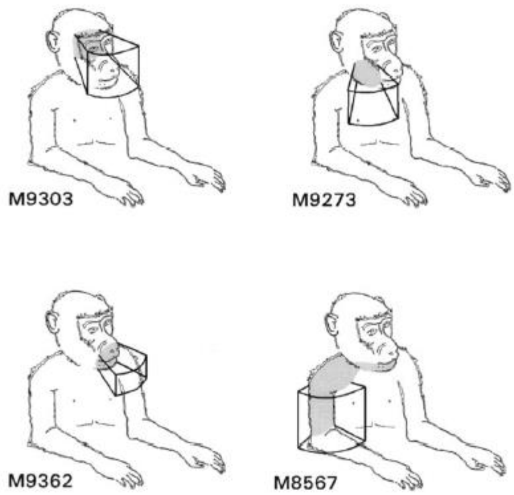
Key words: saccades; target selection; monkey; FEF; inactivation; visual salience

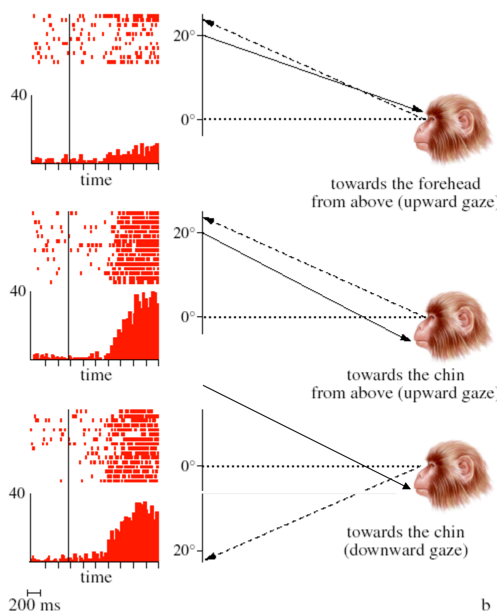
The VIP-F4 circuit

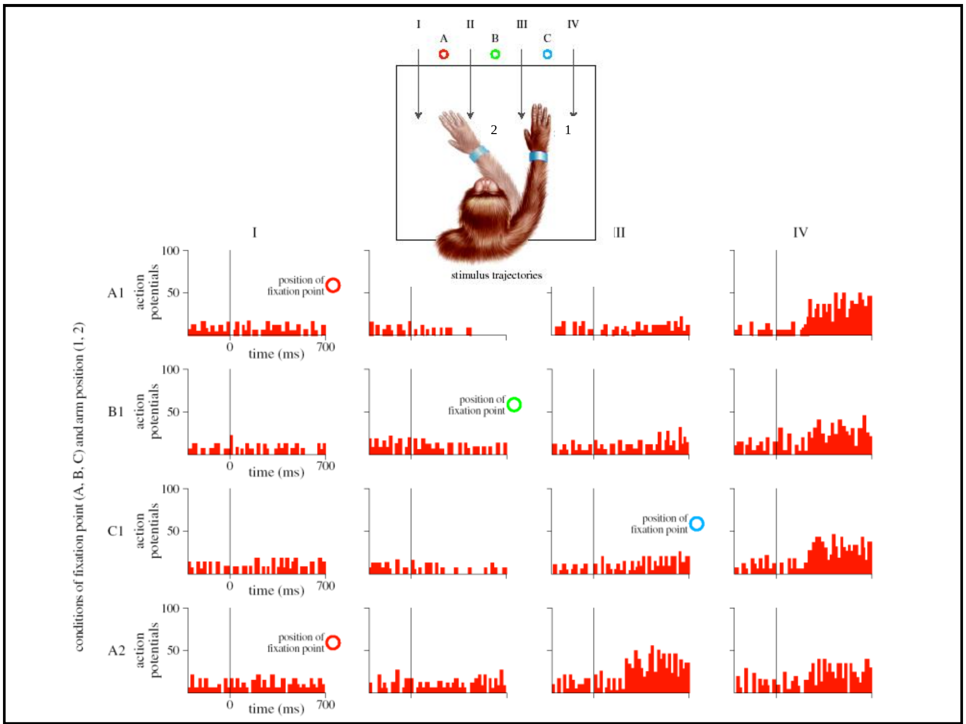


G. Rizzolatti and G. Luppino

F4: bimodal **visuomotor** neurons



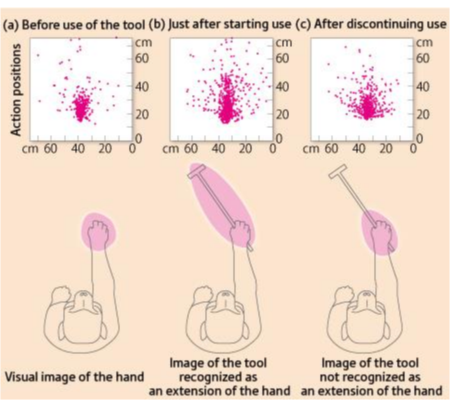




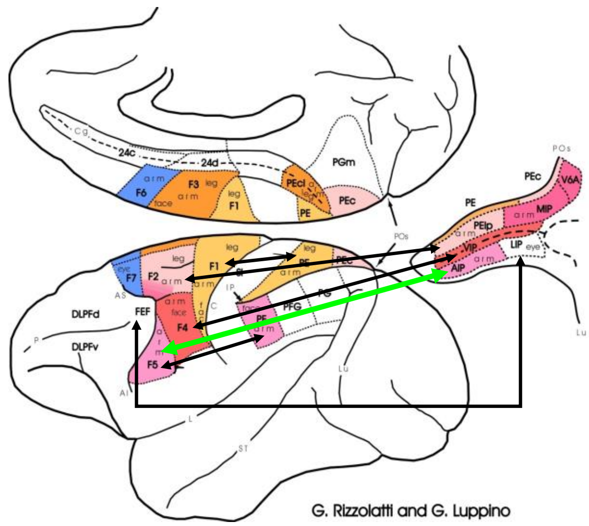
Using tools: the moment when mind, language, and humanity emerged

Atsushi Iriki

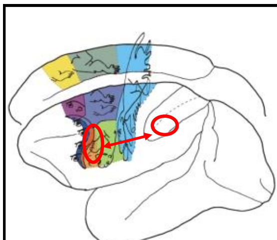
Laboratory Head
Laboratory for Symbolic Cognitive Development
Intellectual Brain Function Research Group
Brain Science Institute

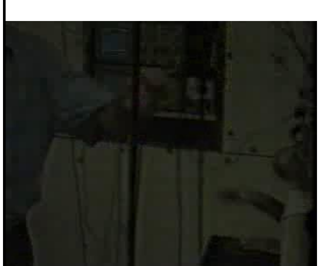


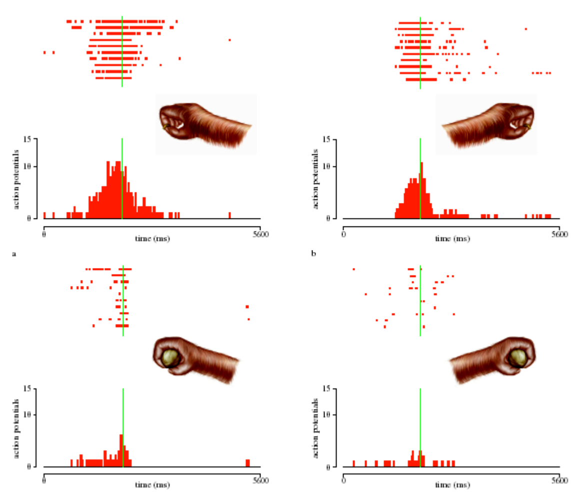
The AIP-F5 circuit

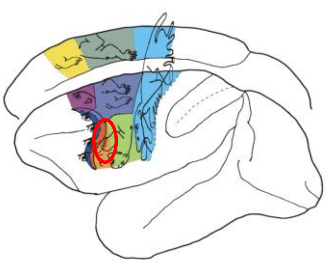


AIP-F5 a circuit for grasping objects

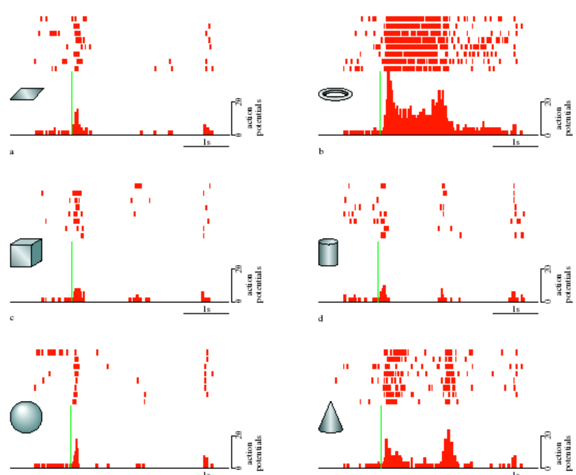


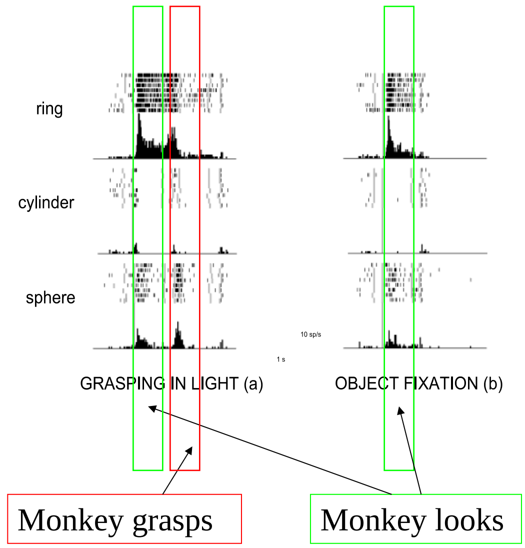




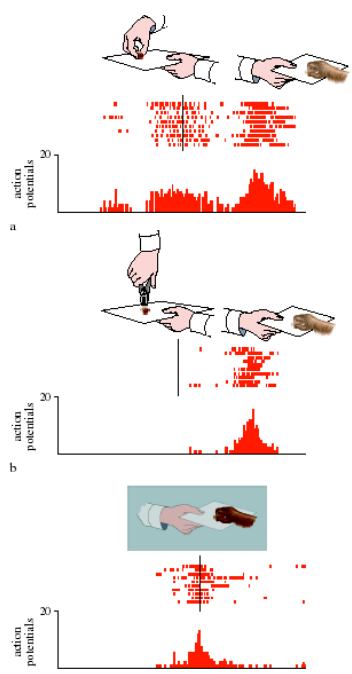


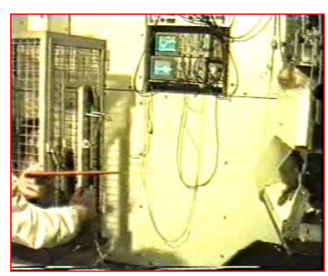
F5: canonical **visuomotor** neurons

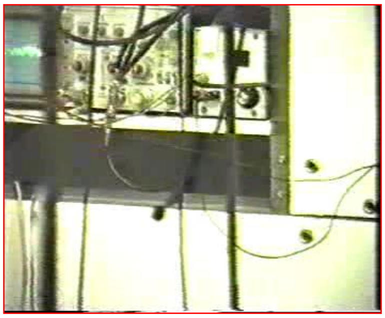


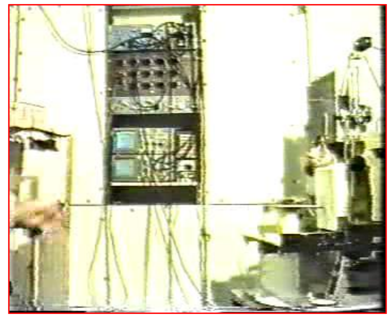


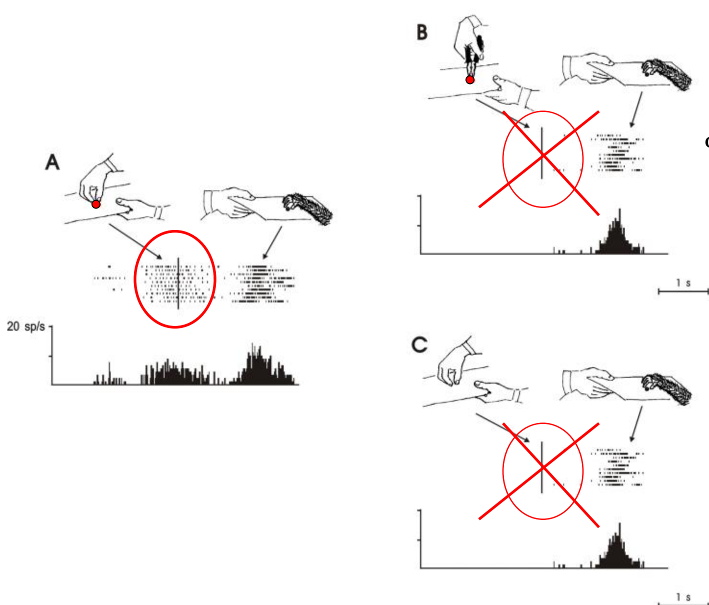
F5: mirror visuomotor neurons











GRASPING USING A TOOL
(same GOAL)

MIMIKING
(same MOVEMENT)

Mirror neurons represent a particular case, within the more general category of the visuomotor neurons

- The visuomotor properties of the premotor cortex suggest that, according to the “economy rule” common in Biology, motor representations are located in those same areas that play a role in action programming and execution.
- The **coexistence** in the **same** neuron of visual **and** motor discharges, although at first glance paradoxical, is a strong argument in favour of the existence of motor representations. Plausibly, these discharges, are neither pure visual nor pure motor…
- …they might represent ‘potential motor acts’. These motor **ideas** are evoked during execution (obviously) but also when a visual stimulus, related to a given action, is shown.

Example 1: Object perception

NEUROIMAGE 6, 231–236 (1997)
ARTICLE NO. NI970293

Premotor Cortex Activation during Observation and Naming of Familiar Tools

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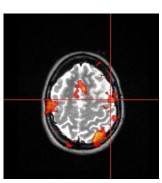
*Department of Neurology, Emory University, Atlanta, Georgia 30322; †Istituto di Fisiologia Umana, Università di Parma, Parma, Italy; and ‡Center for Neural Engineering, University of Southern California, Los Angeles, California 90089



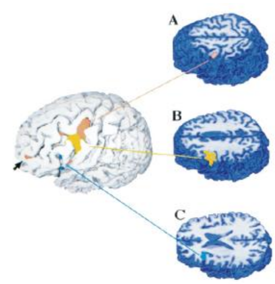
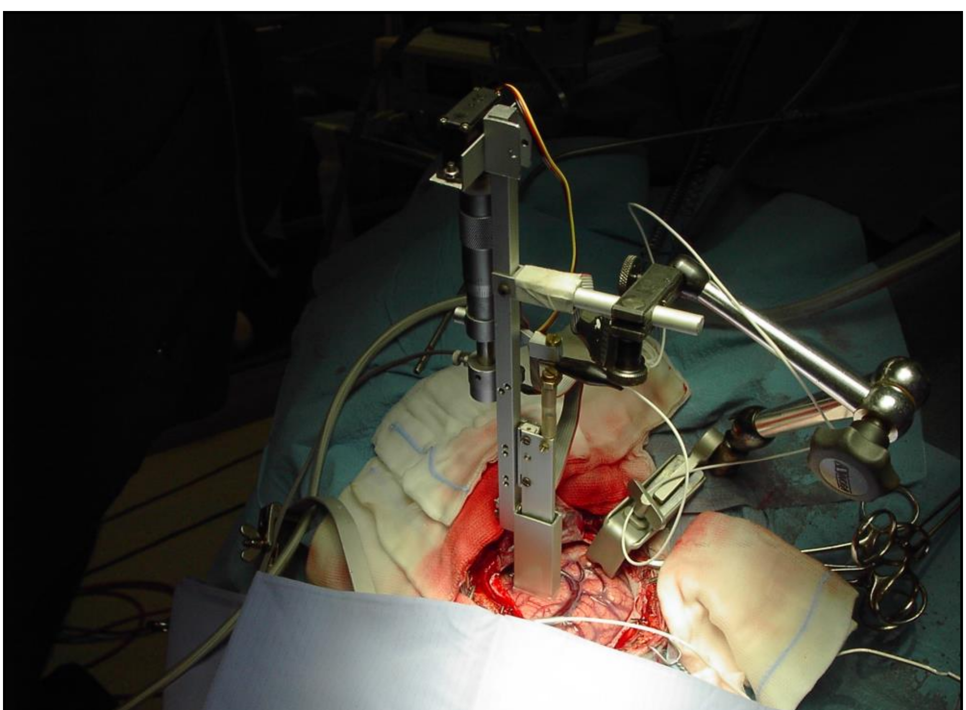


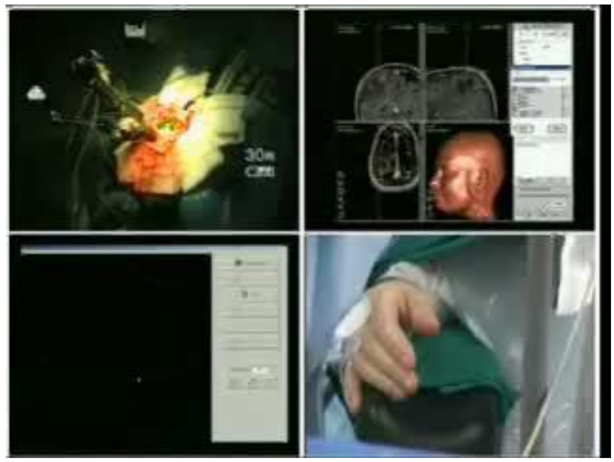
TABLE 1

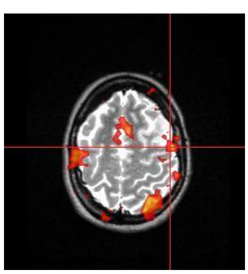
Location and Significance of Frontal Lobe Task Differences

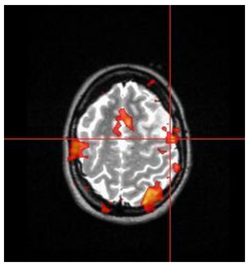
Region	Talairach coordinates (mm) x	y	z	Object versus Fractal	Naming versus Fractal	Naming versus Object	Use versus Fractal	Use versus Object	Use versus Name
Left medial frontal gyrus (6)	−3	3	63		3.724				
Left medial frontal gyrus (6)	−6	3	48				5.242	4.847	
Left dorsal precentral sulcus (6) dorsal premotor cortex	−39	−6	51	3.954	4.759		5.862	4.414	3.793
Left inferior precentral sulcus (6/44) ventral premotor cortex	−48	−2	29				4.736	5.448	5.346
Left inferior frontal sulcus (Trans. 45/46)	−32	44	17	3.218	3.839		3.977		
Left inferior frontal gyrus (46)	−35	44	11		4.092				
Left frontal operculum (44)	−38	17	17		4.437	4.598	5.862	5.862	
Right superior frontal gyrus (9)	23	47	30			3.517			
Right anterior cingulate (32)	17	26	27		4.230	4.185			

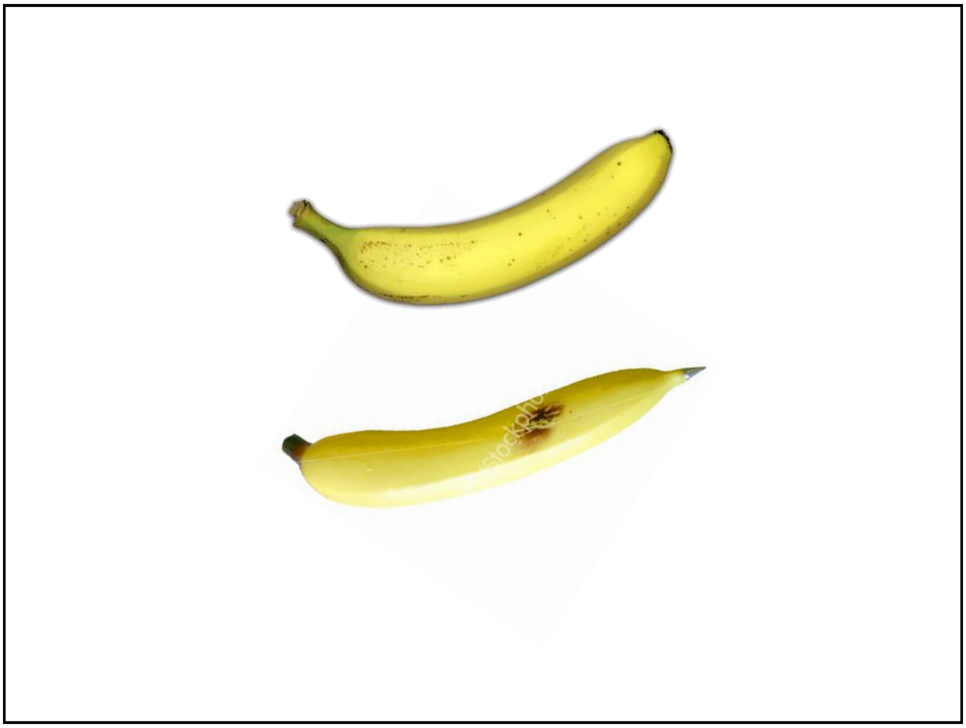
Note. Locations are relative to the anterior commissure (Talairach and Tourneaux, 1988). Significance was determined by two-way ANOVA with repeated measures and planned comparison of task means, with a threshold of $P < 0.005$ and a cluster size of >500 to account for multiple comparisons. Peak t values at each location are shown. Corresponding Brodmann's areas, as defined in Talairch and Tourneaux (1988) and Rajkowska and Goldman-Rakic (1995), are given in parentheses. Trans., transitional area.



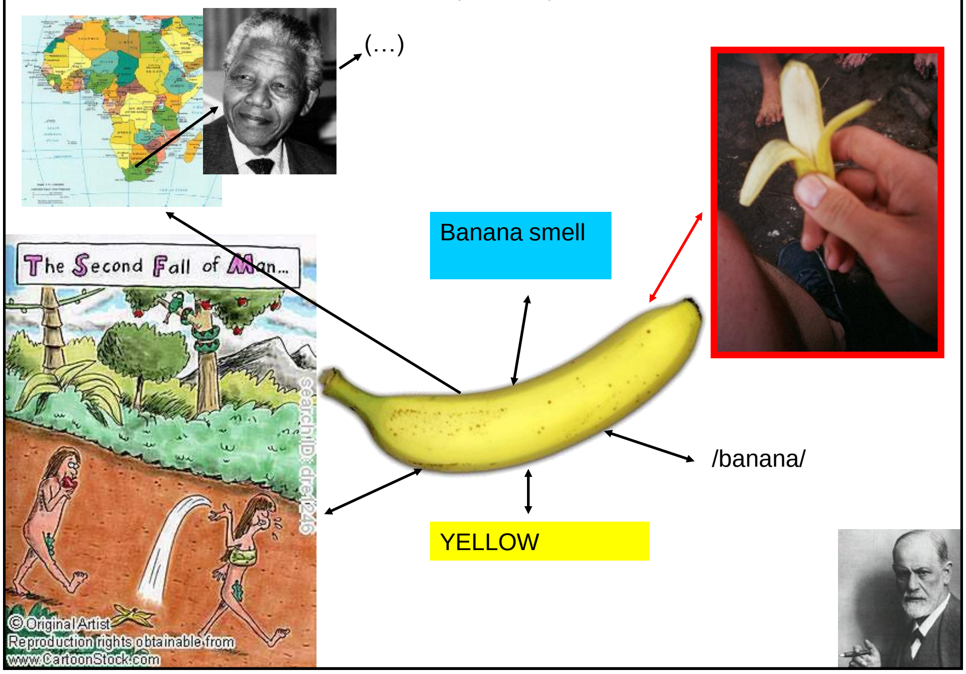






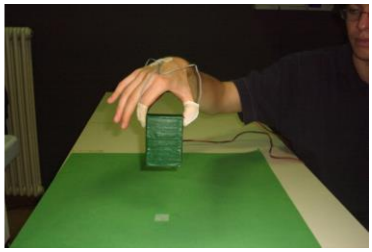


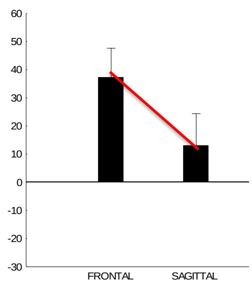
Multimodality of Representations

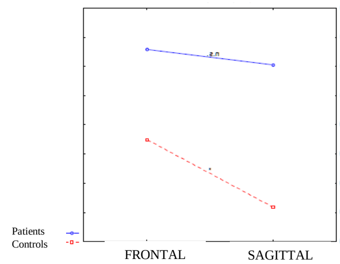


Example 2: Others’ action prediction

Prediction of grasping by observation







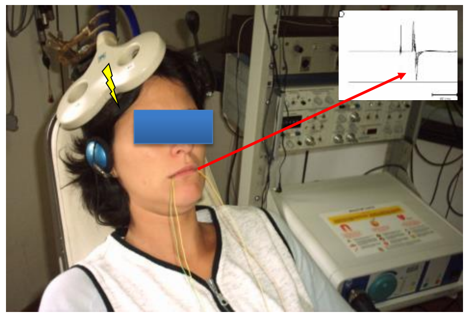
Craighero et al., Brain Res Bull, 2008

Example 3: Speech perception

Are listener's motor centers active during speech processing?

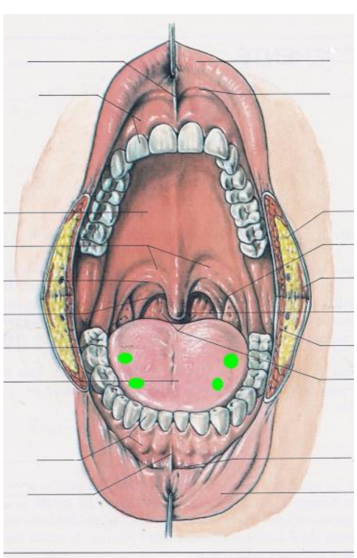
Transcranial Magnetic Stimulation

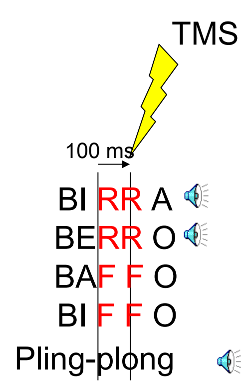
Experimental setup:



Fadiga et al., EJN 2002

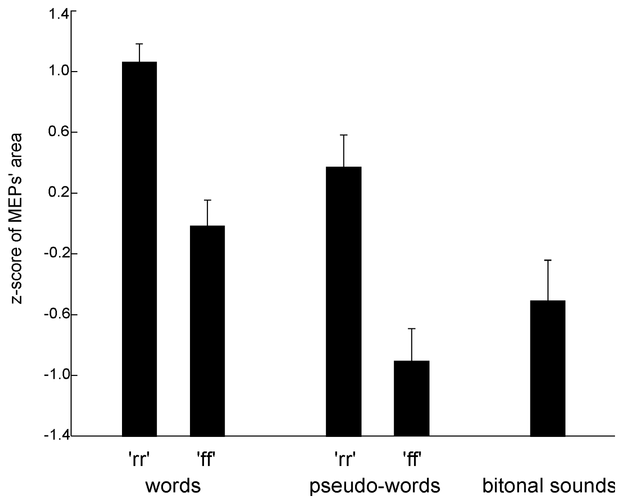
Are listener's motor centers active during speech processing?





Fadiga et al., EJN 2002

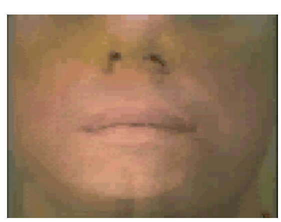
Are listener's motor centers active during speech processing?



Fadiga et al., EJN 2002

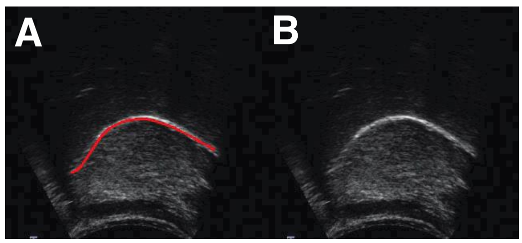
…other evidence in favor of sensorimotor facilitation during speech processing:

The McGurk effect



A McGurk-like effect: Ultrasound images of tongue profile bias auditory speech perception

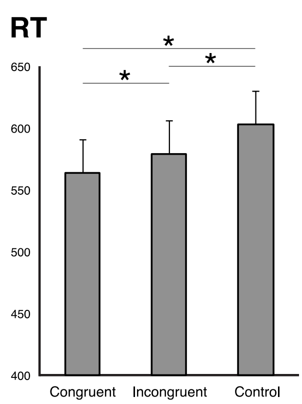
A. D'Ausilio, E. Bartoli, J. Berry, L. Maffongelli, L. Fadiga (Neuropsychologia, in press)



VISUAL:
/ba/
/ga/
/pa/
/ka/

AUDITORY:
/ba/
/pa/

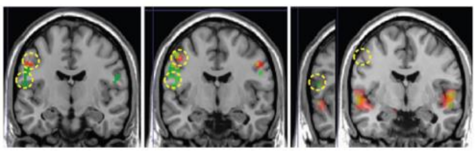
Ultrasound images of tongue profile bias auditory speech perception



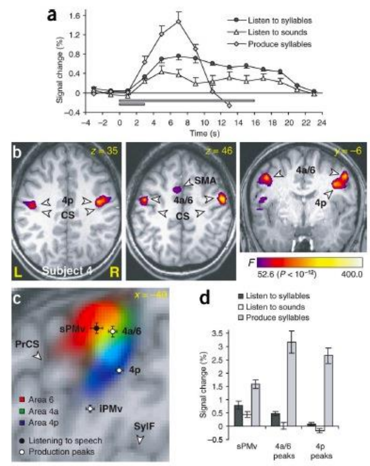
The observation of tongue movements for which one has no visual experience bias the perception of auditorily presented speech: Internal visuomotor maps may be tuned by motor primitives even in absence of specific visual learning.

Brain Imaging

Pulvermüller et al., *PNAS* 2006



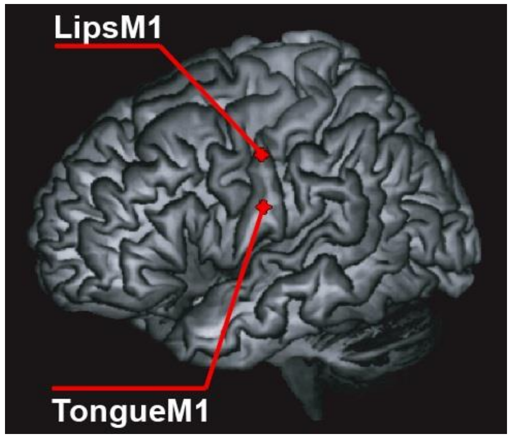
Wilson at al., *Nat Neurosci* 2004



These experiments suggest, but do not prove, a role of the motor system in speech perception…

EXP1

TMS on Tongue and Lip motor areas during a perceptual (syllable discrimination) task



Current Biology *19*, 1–5, March 10, 2009 ©2009 Elsevier Ltd All rights reserve

The Motor Somatotopy of Speech Perception

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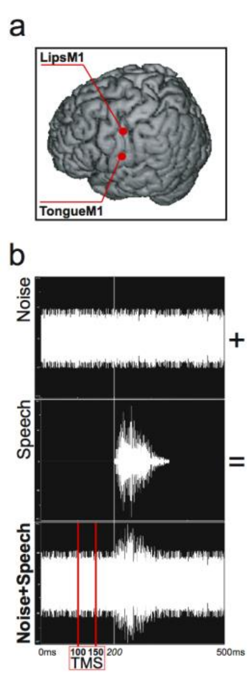
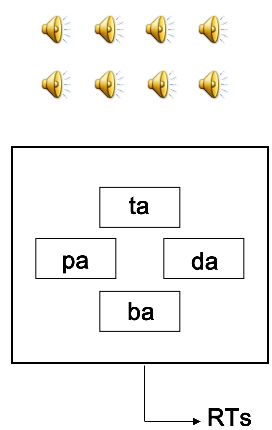
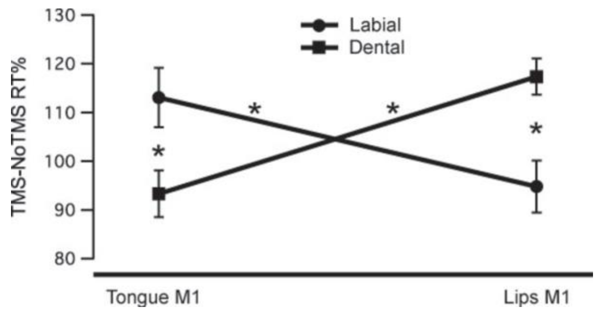
Italy

Summary

Listening to speech recruits a network of fronto-temporo-parietal cortical areas [1]. Classical models consider anterior (motor) sites to be involved in speech production whereas posterior sites are considered to be involved in comprehension [2]. This functional segregation is challenged by action-perception theories suggesting that brain circuits for speech articulation and speech perception are functionally dependent [3, 4]. Although recent data show that speech listening elicits motor activities analogous to production [5, 9], it's still debated whether motor circuits play a causal contribution to the perception of speech [10]. Here we administered transcranial magnetic stimulation (TMS) to motor cortex controlling lips and tongue during the discrimination of lip- and tongue-articulated phonemes. We found a neurofunctional double dissociation in speech sound discrimination, supporting the idea that motor structures provide a specific functional contribution to the perception of speech sounds. Moreover, our findings show a fine-grained motor somatotopy for speech comprehension. We discuss our results in light of a modified "motor theory of speech perception" according to which speech comprehension is grounded in motor circuits not exclusively involved in speech production [8].



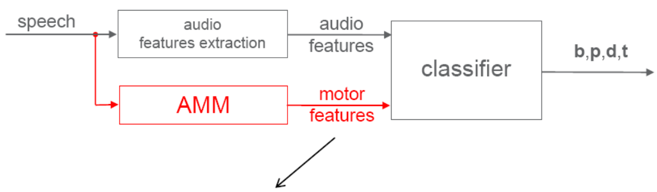


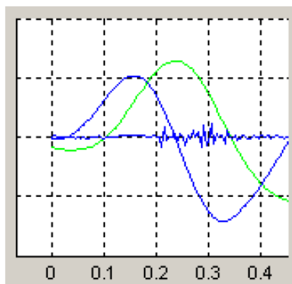


"A possible explanation for this facilitation is that the *synchronous excitation of several M1 neurons induced by TMS* may have exerted a facilitation of neurons located in premotor areas, somatotopically connected with M1, through bidirectional cortico-cortical links"

Is this computationally plausible?

Motor feature based recognition



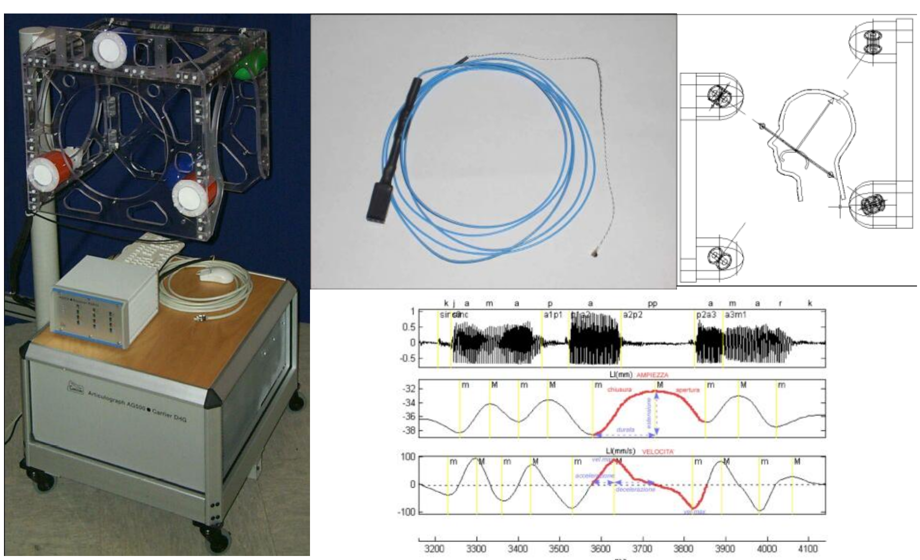


green: lips opening velocity

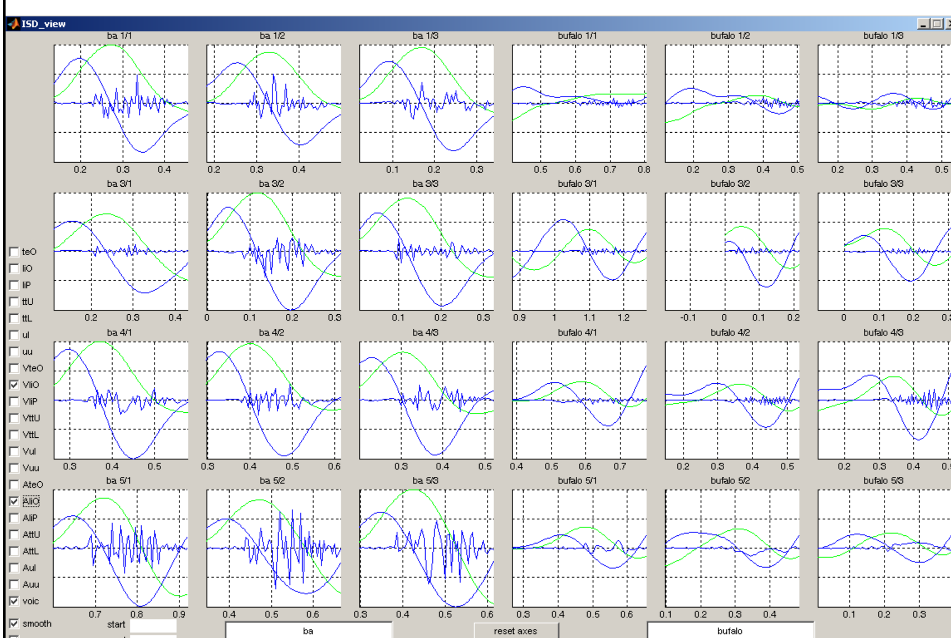
blue: lips opening acceleration

grey zone: the identified motor invariant for **b**

Articulography – AG500 - II

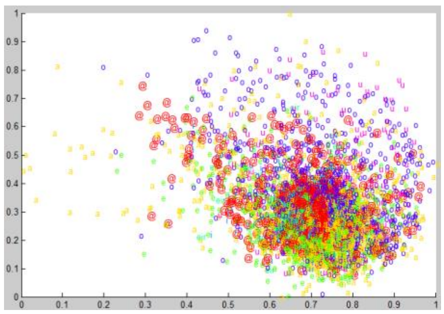


- 9 speakers, 74 (pseudo)words and syllables
- magnetic tracking of tongue, lips and teeth
- ultrasound imaging of tongue
- video of face
- laryngography of vocal folds

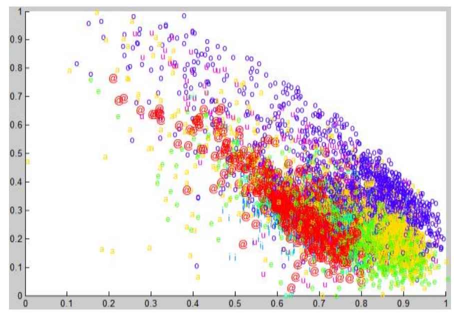


An Example of the potential utility of using an Articulatory (+Acoustic) Domain

Seven British English vowels from the MOCHA-TIMIT corpus plotted on 2D domains extracted using Deep Neural Network Auto-Encoders

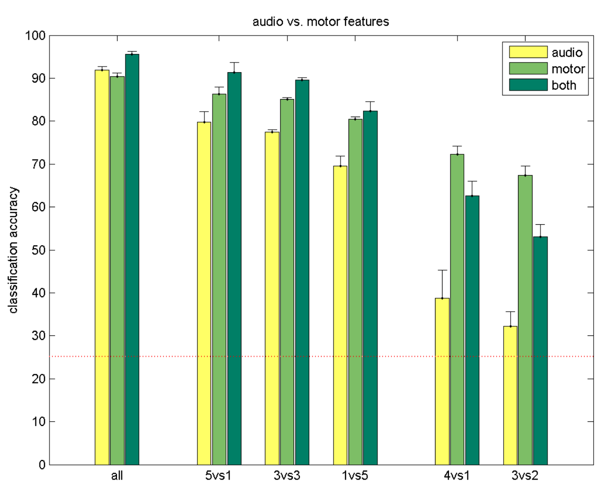


2D acoustic domain



2D (actual) articulatory+acoustic domain

motor invariants and classification



Castellini et al., *2012*