

## Grounded cognition

### Mirror neurons

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- Mirror neurons (MNs) = sub-populations of motor neurons that discharge both when the individual executes and observes an action
- Motor neuron – fires during action (self-)execution
- Concepts: movement, motor act, motor action
- MNs facilitate (mediate) understanding of
  - actions “from the inside”
  - empathy, mind-reading
  - evolution of manual gestural system (→ language) (?)
- originally discovered in macaques, birds, recently in humans

(Rizzolatti & Sinigaglia, 2010)

## Mirror neurons in macaque

Discovered in ventral premotor cortex (area F5)  
(Di Pellegrino et al, 1992; Rizzolatti et al, 1996)

later in inferior parietal lobule (IPL) – PFG  
(Gallese et al, 2002, Fogassi et al, 2005)

and Anterior IntraParietal area – AIP  
(Belmalih et al, 2009)

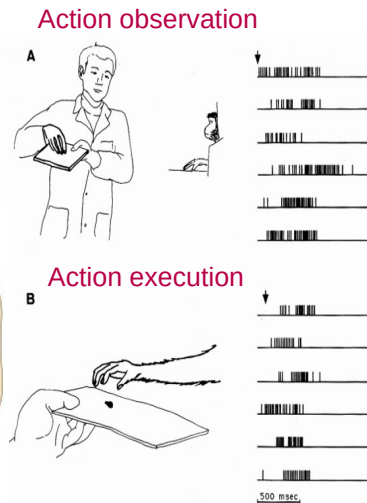
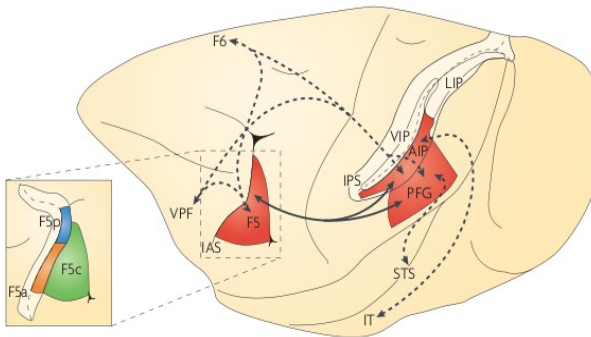
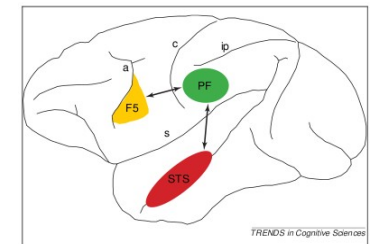


Fig.: single F5 neuron poked, 6 trials

## Two hypotheses of action understanding

- Action = intentional (goal directed) motor behavior (that produces reward)
- Two contrasting accounts
- **Visual hypothesis**
  - no motor involvement required
  - analysis of visual properties in extrastriate visual areas: IT and STS
- **Direct matching hypothesis**
  - employs motor knowledge to understand the action
  - motor areas “resonate”

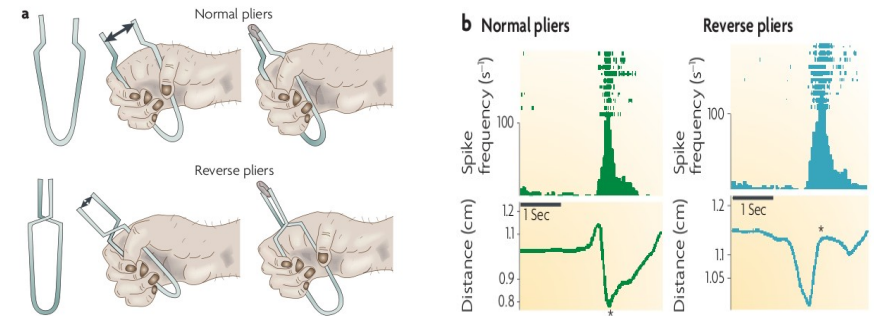


# Mirror system behavior in primates

- **Cortical motor system in primates** = a set of fronto-parietal circuits encoding different types of motor behavior (hand grasping, mouth and head movements, arm reaching and various types of eye movements)
  - activated by specific sensory inputs (somatosensory, visual, auditory)
- Additional MN systems found in parietal area:
  - LIP ~ visual cells, saliency detect., sharing of attention (Shepherd et al, 2009)
  - VIP ~ recognition of peripersonal space of self and others (tactile and visual stimuli) (Ishida et al, 2009)
- Reaching/grasping movements: presence of the target required (may have become occluded, though) => **motor acts rather than motor movements**
- MNs in F5 and IPL are similar w.r.t. their functional properties (goal encoding)

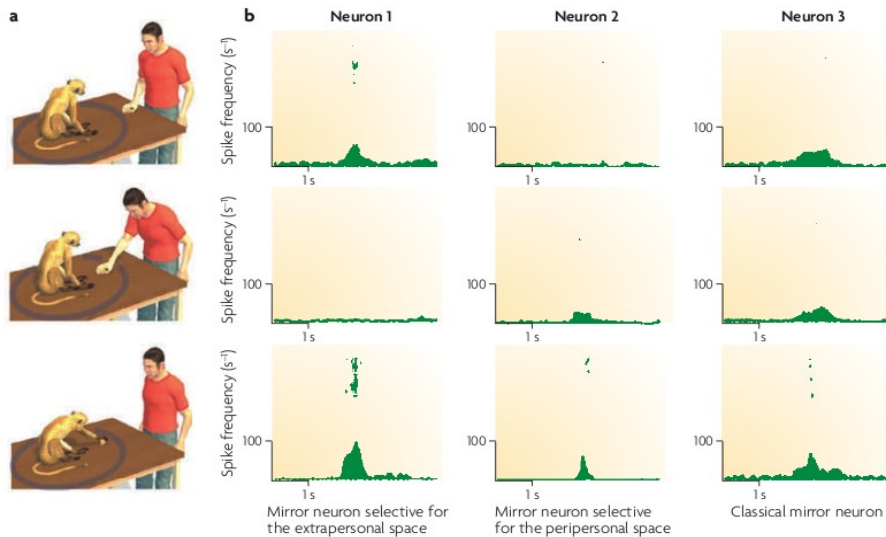
# Evidence for goal encoding

- Monkey trained to grasp object using two types of pliers (Umiltà et al, 2008)
- F5 neurons discharged at the same phase of grasping, regardless of the type



- fMRI study with aplasic individuals who observed actions performed by hands, feet, and mouth (Gazzola et al., 2007)
- mirroring occurred also for hand-actions, whose goals they were able to accomplish by mouth or feet

# Encoding peri- & extra-personal space



=> observer-centered (egocentric) spatial framework may be used

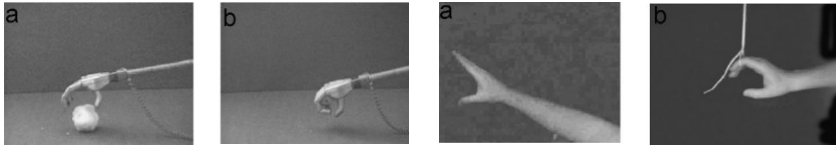
(Caggiano et al, 2009)

# MN types in primates

- Degrees of generality observed (in goal coding):
  - **strictly** congruent MNs – fire to the **same** observed/executed motor acts
    - Same action
  - **weakly** congruent MNs – fire to **similar** observed/executed motor acts
    - Different ways (actions) of achieving the same goal
- Neurons in F5:
  - **mirror** - acting or observing, but not for own affordances
  - **canonical** - acting or own affordances, not when observing
- MN in action understanding “**from inside**” (as opposed to “from outside”)

## Mirror neuron system in humans

- Indirect evidence from brain imaging, TMS, EEG and MEG (Grezes et al, 2003; Buccino et al, 2004)
- First direct evidence from patients (Mukamel et al, 2010)
- Location: parts of frontal gyrus (Broca's area) + inferior parietal lobule
- MNS is **more general/abstract** compared to primates - MNS fire also in case of
  - robotic arm – mu rhythm suppression (Gazzola et al, 2007, Oberman et al, 2007)
  - missing target (a movement, not necessarily a motor act) (Fui et al, 2008)
  - MNS can be evoked by mere imaging an action



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## Understanding actions of others

- Observer understands directly the goal of the actions of others
  - without needing inferential processing
  - two studies with monkeys to support this
  - Criticism, the role of STS highlighted
- TMS adaptation paradigm in support
- understanding from inside
  - How to understand actions that are not in observer's own repertoire?

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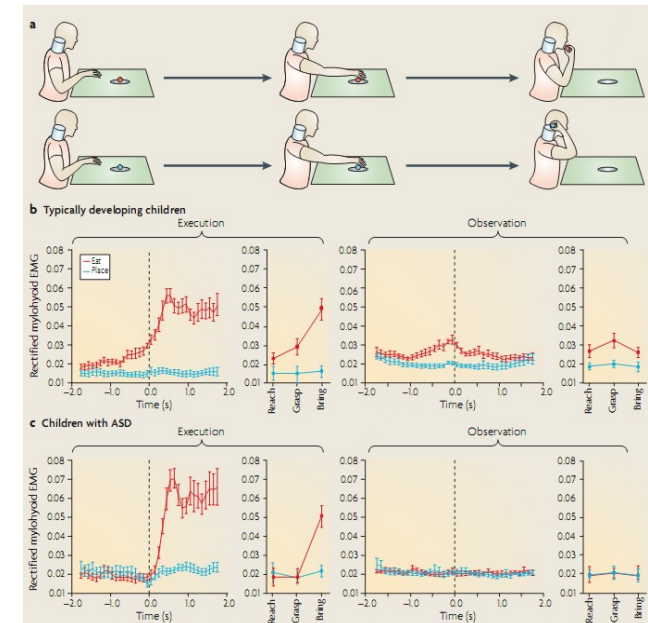
## Understanding motor intentions of others

- Evidence in monkeys: parietal and frontal mirror neurons are involved in encoding not only the observed motor acts but also the entire action of which the observed motor act is part (Fogassi et al, 2005), mouth-container experiment
- => IPL contains chains of act-encoding neurons
- many action-constrained neurons had mirror properties (!)
- Action-constrained neurons also found in F5 (Bonini et al, 2009)
- Evidence also in humans using fMRI (Iacoboni et al, 2005)
- Understanding the reasons behind an agent's motor intention requires additional inferential processes (Rizzolatti & Sinigaglia, 2007)
  - Seems localized in cortical areas (temporal parietal junction and a part of ACG) that have not yet been shown to have mirror properties.
- “Mentalizing network” proposed (de Lange et al, 2008)

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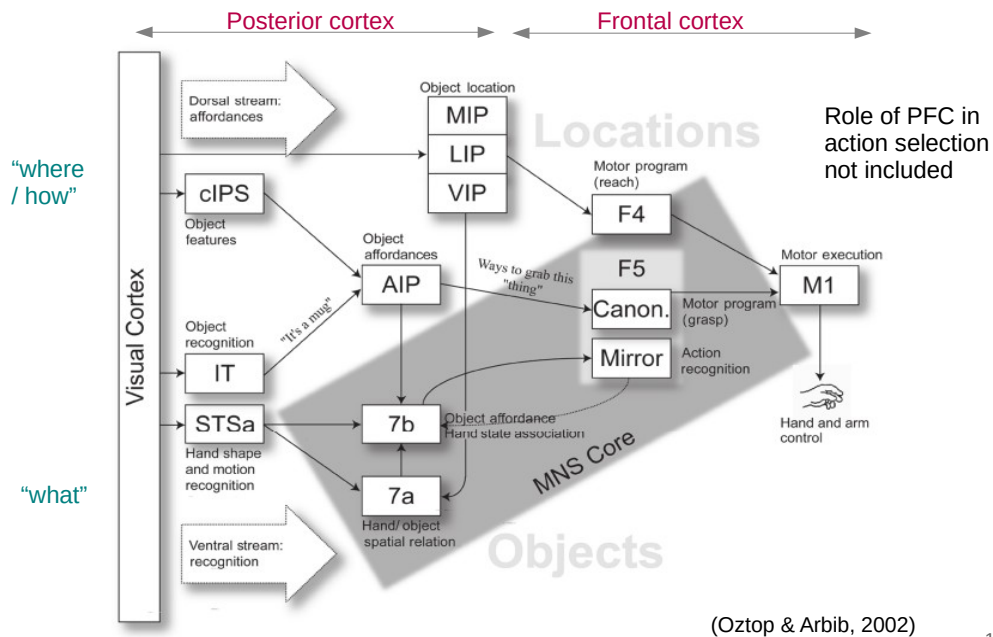
## Mirror mechanism and autism

Children with ASD have a severe impairment in motor organization that includes a deficit in chaining motor acts into intentional actions. (Cattaneo et al, 2007)



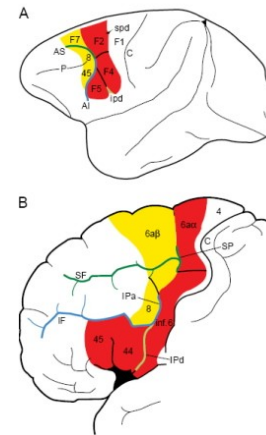
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## Schematic view of the MNS1 model



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## Mirror neurons and language



- "Missing link" between animal communication and human language (Arbib, 2005)
- Area F5 and Broca's area are anatomical homologues and share functional properties crucial for development, production and understanding of communication gestures.
- Hypothesis: Evolution of manual gestural system, facilitated by **action-execution–action-observation matching property** of neurons in Broca's area paved the way to the evolution of the open vocalization system present in humans (speech) (Rizzolatti & Arbib, 1998).

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## Origin of mirror neurons

- Rizzolatti, Arbib, Ramachandran, etc. – **adaptation hypo**
  - MNs favored by evolution, they became genetically universal through natural selection
  - capacity to "mirror" is inherent
- Heyes – **association hypo**
  - MNs are merely a byproduct of associative learning (Pavlovian conditioning)
  - Motor resonance during action observation occurs due to memory retrieval of the execution of observed action (of memory formed during the *execution* of the particular action *with visual guidance*)

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## Summary

- Mirror neurons – unify action execution and action observation
- Neurophysiological basis
- Understanding actions of others from "inside"
- In various animal species
- Provides the motor component to semantic knowledge
- Probably crucial for social cognition
- Reasonable hype?

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