Agentúra Ministerstva školstva, vedy, výskumu a športu SR pre štrukturálne fondy EÚ

Operačný program VZDELÁVANIE

ASFEU

Európska únia

Grounded cognition:
Mirror neurons

Igor Farkaš
Centre for Cognitive Science, DAI FMFI
Comenius University in Bratislava

Mirror neurons

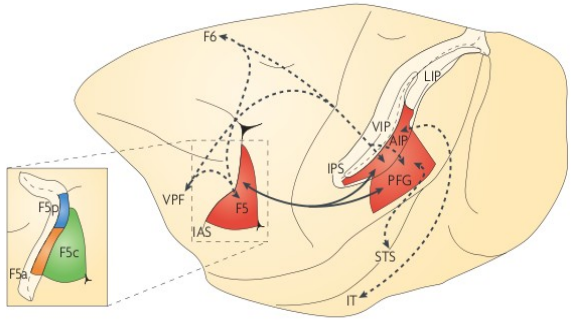
- Mirror neurons (MNs) = sub-populations of motor neurons that discharge both when the individual executes and observes an action
- Motor neuron – fires during action (self-)execution
- MNs facilitate (mediate) understanding of
  - actions “from the inside”
  - empathy, mind-reading
  - evolution of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

Mirror neurons in macaque

Discovered in ventral premotor cortex (area F5)
(Di Pelegrino 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)



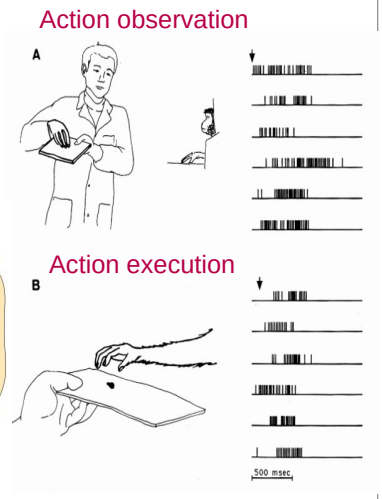


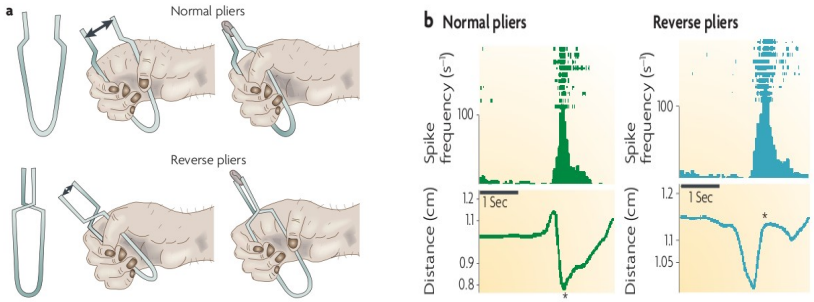
Fig.: single F5 neuron poked, 6 trials

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., shared 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 become occluded, though) => motor acts rather than motor movements
- MNs in F5 and IPL are similar w.r.t. their functional properties (goal encoding)

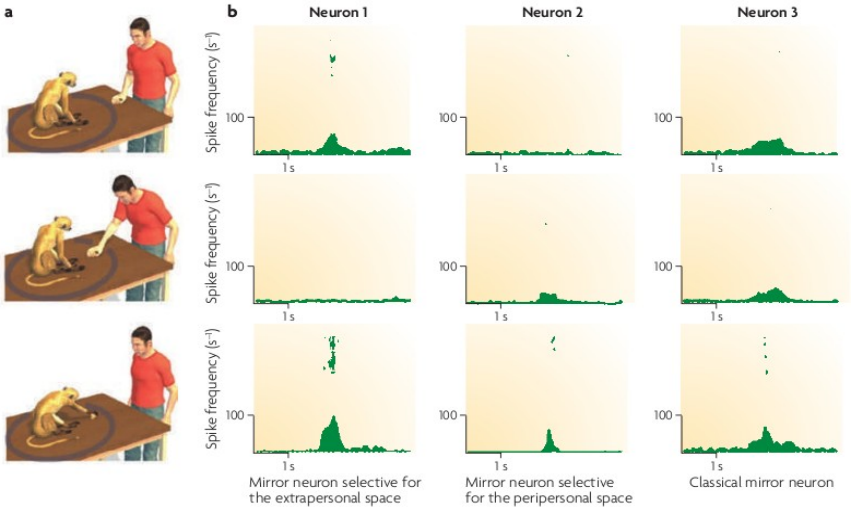
Evidence for goal encoding

- Monkey trained to grasp object using two types of pliers (Umilta 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



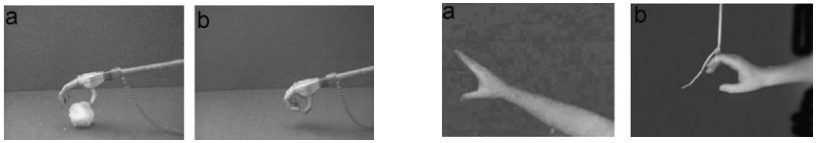
=> observer-centered (egocentric) spatial framework may be used (Caggiano et al, 2009)

MN types in primates

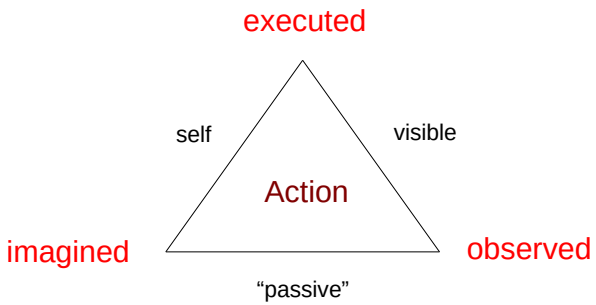
- Degrees of generality observed in MNs (in goal coding):
  - strictly congruent – fire to **same** observed/executed motor acts
    - Same action
  - weakly congruent – fire to **similar** observed/executed motor acts
    - Different ways (actions) of achieving the same goal
- Neurons in F5:
  - mirror - acting or observing, but not for own affordancies
  - canonical - acting or own affordancies, not when observing
- MNs in F5 – perspective variant or invariant (Caggiano et al, 2009)
- MN in action understanding "from inside" (versus "from outside")

Mirror neuron system in humans

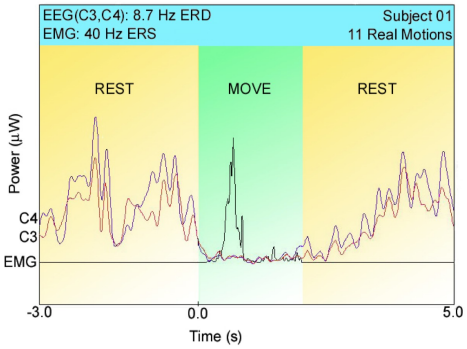
- Indirect evidence from brain imaging, TMS, EEG and MEG (Grezes et al, 2003; Buccino et al, 2004)
- First direct evidence from patients (Mukamel et al, 2010)
- Location: parts of frontal gyrus (Broca's area) + inferior parietal lobule
- MNS is more general/abstract compared to primates - MNs fire also 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 imagining an action

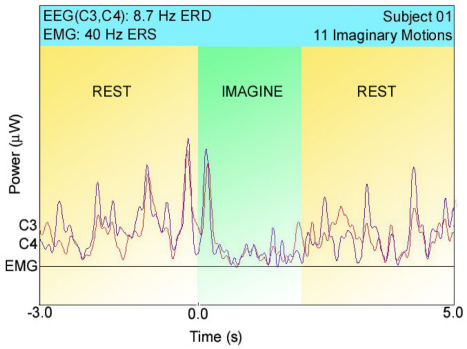


Action EIO “triangle”



Event-related desynchronization (ERD)





Executed action

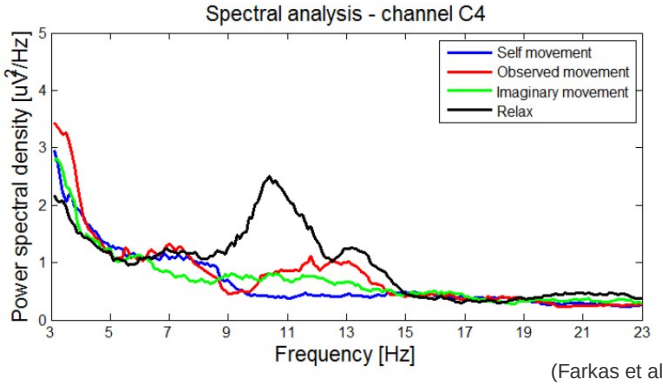
Imagined action

Motor resonance disrupted

Mu rhythms: 8-12 Hz

(Trejo, Rosipal, & Matthews, 2006)

EEG spectrum during motor actions



(Farkas et al, 2011)

Mirror neurons may down modulate motor cortex (leading to mu-rhythm desynchronization) (Oberman et al, 2007)

Mu-rhythm = brain waves (detectable by EEG, 8–13 Hz) associated with motor actions.

MNs for 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 (i.e. next to primary visual cortex): IT and STS
- Direct matching hypothesis
  - employs motor knowledge to understand the action
  - motor areas “resonate”
- How do we understand observed actions that we do not have in our repertoire?

Understanding motor intentions of others

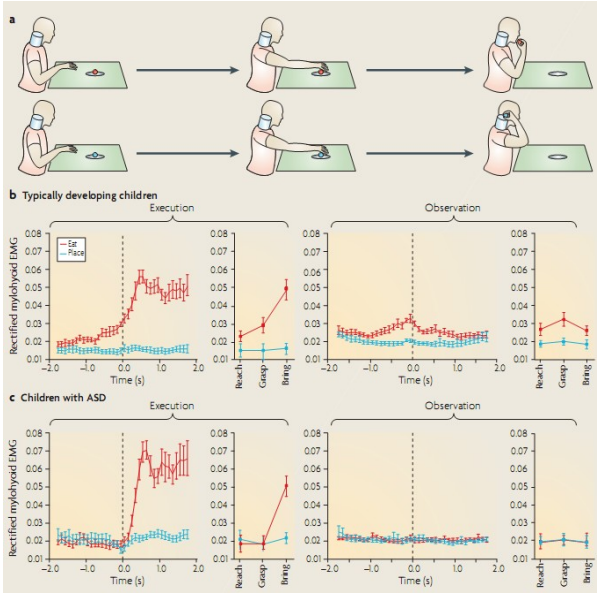
- Evidence in monkeys: parietal and frontal mirror neurons are involved in encoding not only the observed motor acts but also the entire action of which the observed motor act is part (grasp for eat/put exper.) (Fogassi et al, 2005)
- Action-constrained neurons also found in F5 (Bonini et al, 2009) and many have mirror properties
- 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)
- → "mentalizing network" proposed (de Lange et al, 2008) going beyond MNS

Mirror mechanism and autism

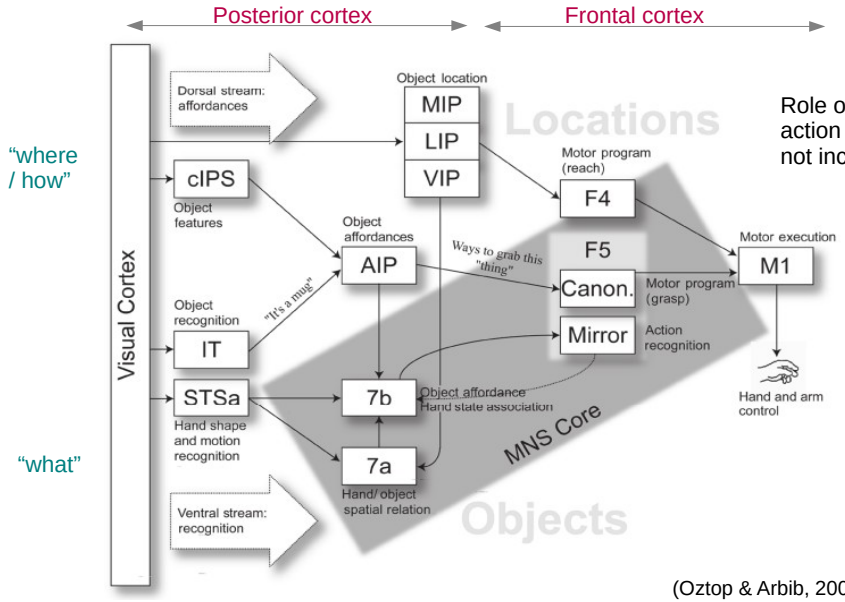
Children with ASD have a severe impairment in motor organization that includes a deficit in chaining motor acts into intentional actions. (Cattaneo et al, 2007):

During performing grasping-for-eating action, the MH muscle was activated only during the bring phase.

During observation, it did not activate at all.



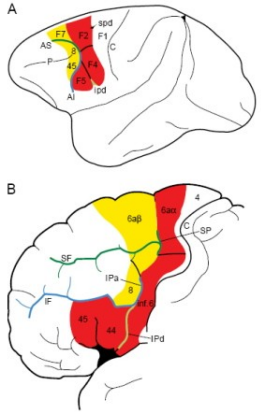
Schematic view of the MNS1 model



Role of PFC in action selection not included

(Oztop & Arbib, 2002)

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).