Behavioral Neuroscience:

The NeuroPsychological approach

Rony Paz

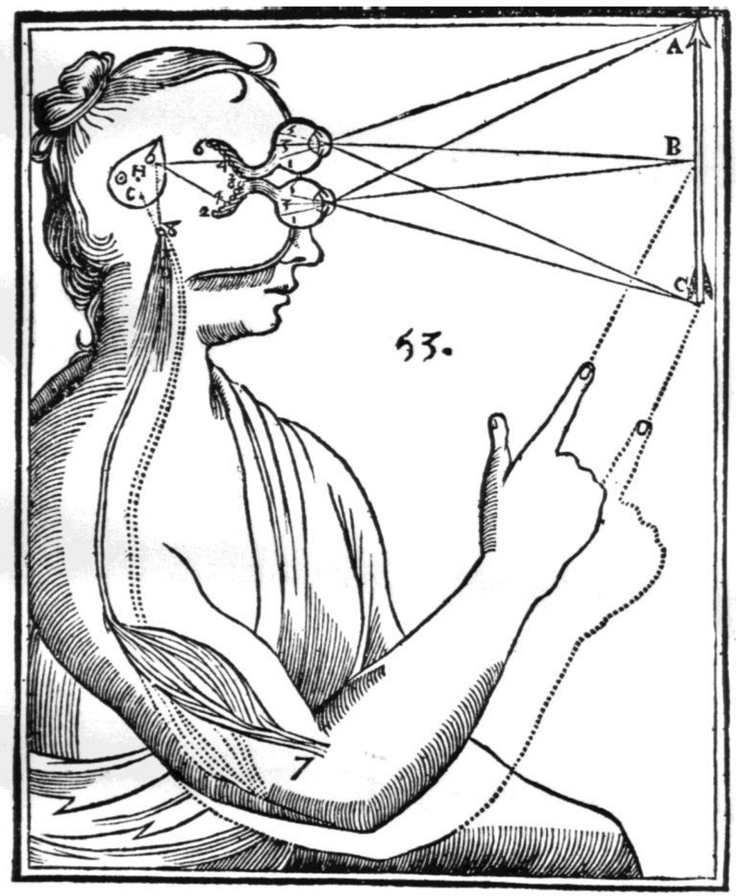
What is the NeuroPsychological approach?

- **Neuropsychology** is the basic scientific discipline that studies the structure and function of the brain related to specific psychological processes and overt behaviors.
- The use of *artificial* well-controlled tasks.
- Why?
  - Well-controlled
  - Pre-planned quantification
  - We observed something, now lets do it properly
  - Target Human behavior
- For example:
  - Sensation and perception
  - **Control of movement**
  - **Learning** and memory
  - Decision making
  - Emotions
  - Consciousness

A bad example?

Descartes, 1662 :

The pineal body controls
the flow of animal spirits
in the ventricles



Active and Passive approaches

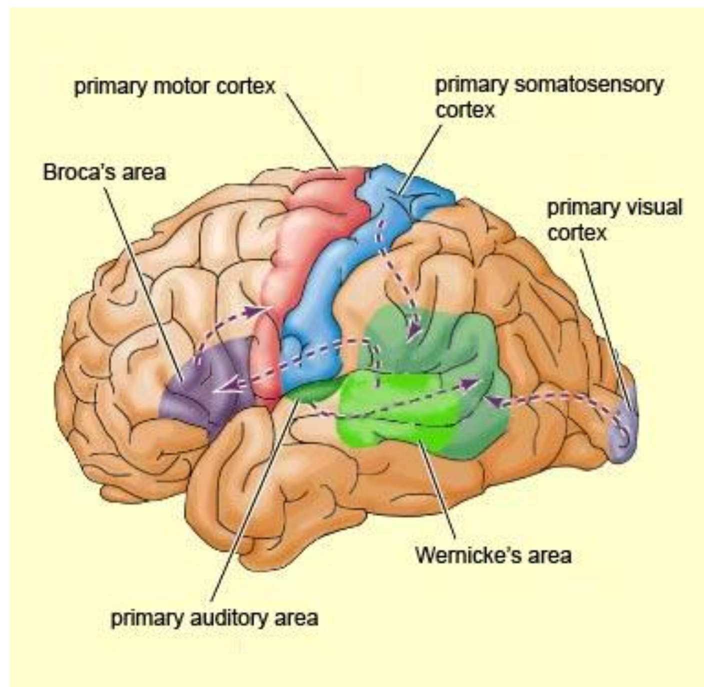
- The active approach manipulates the brain and observes behavior.
  - Stimulation
  - Lesions
  - Pharmacological intervention
  - Genetic manipulations

- The passive approach manipulates behavior and observes the brain.
  - Trained behaviors
  - Observing patients

Speech and language

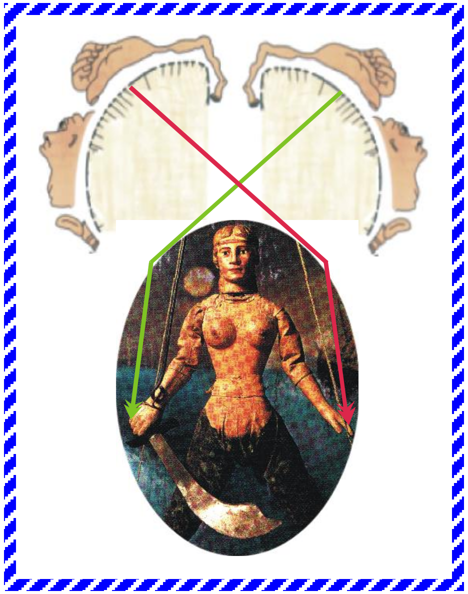
- Paul Broca (French physician, 1824-1880), discovered, by post-mortem operations, that a brain area in the **left hemisphere** causes deficits in speech production ("Tan", Syphilis).

- Karl Wernicke (German physician, 1848-1905), discovered another brain area that causes deficits in language comprehension.

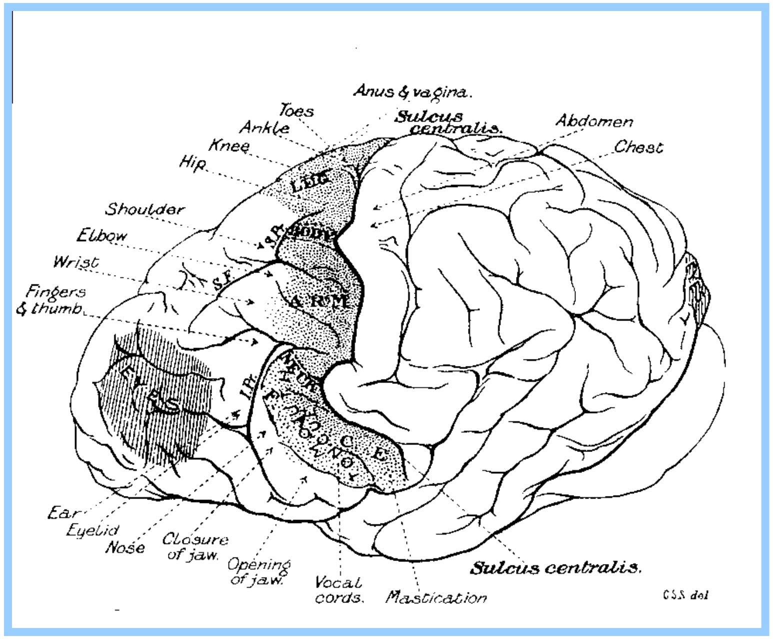


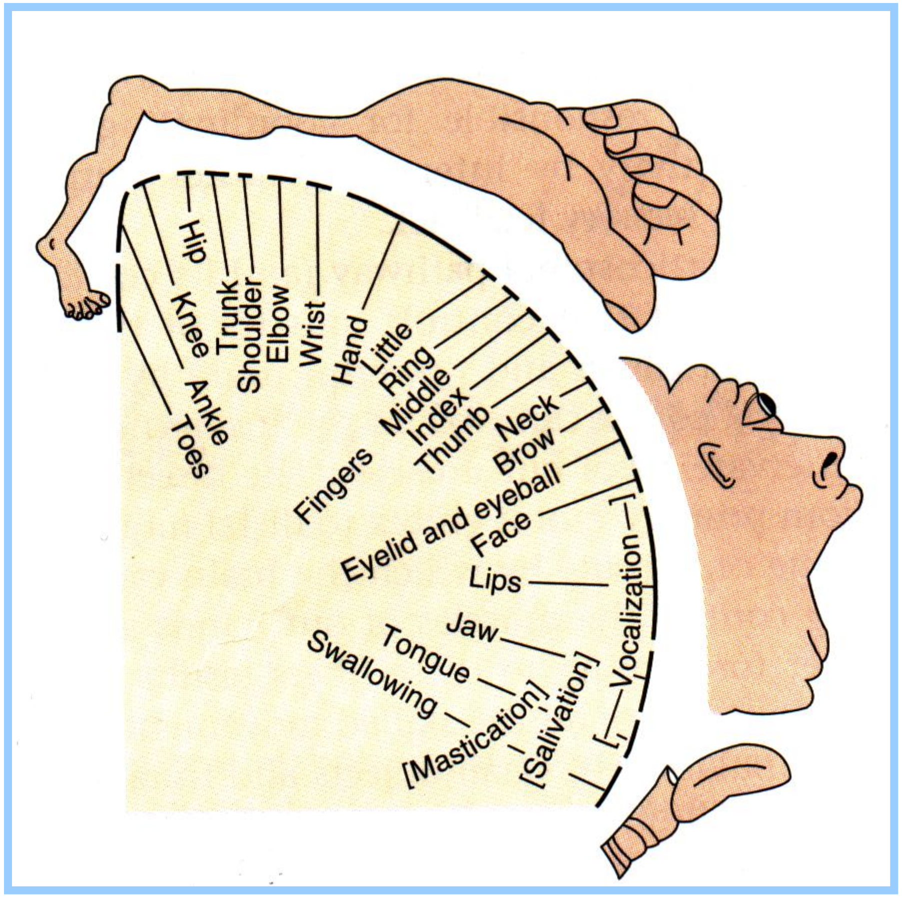
Lateralization

- Wilder G. Penfield, the "*greatest living Canadian*", a Neurosurgeon.
- Together with Herbert Jasper, treated epileptic patients by destroying neurons.
- Before that, he applied stimulation to different brain areas to probe the epileptic loci.
- One main finding was that each hemisphere controls (efferent nerves) and gets sensory inputs (afferent nerves) from the ***contralateral*** side of the body.
- How is it linked to language?



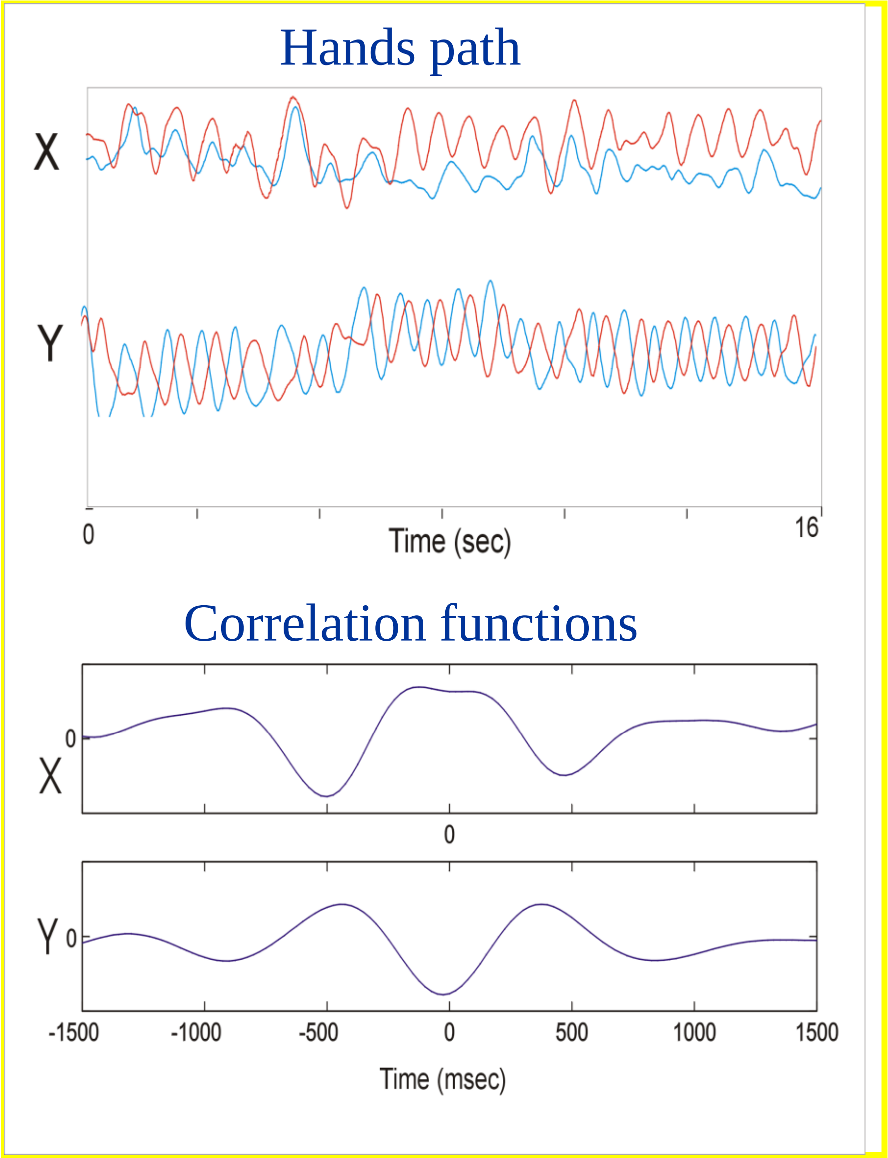
Somatotopic representation: Homunculus?

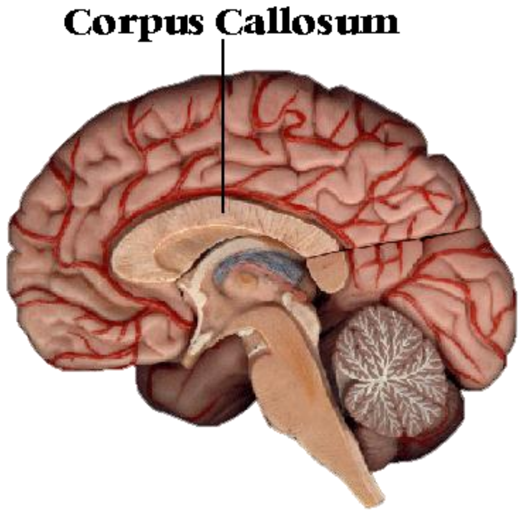




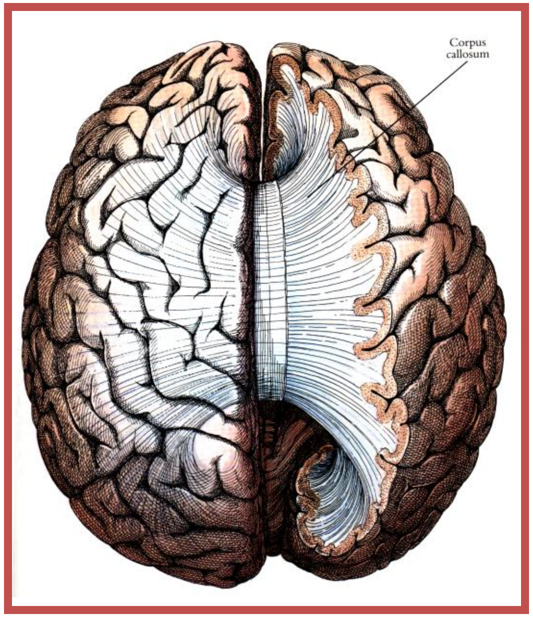
- A mosaic broadly overlapping muscle representations, with each part repeated

Natural movements are coupled

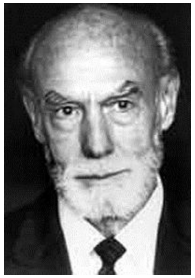




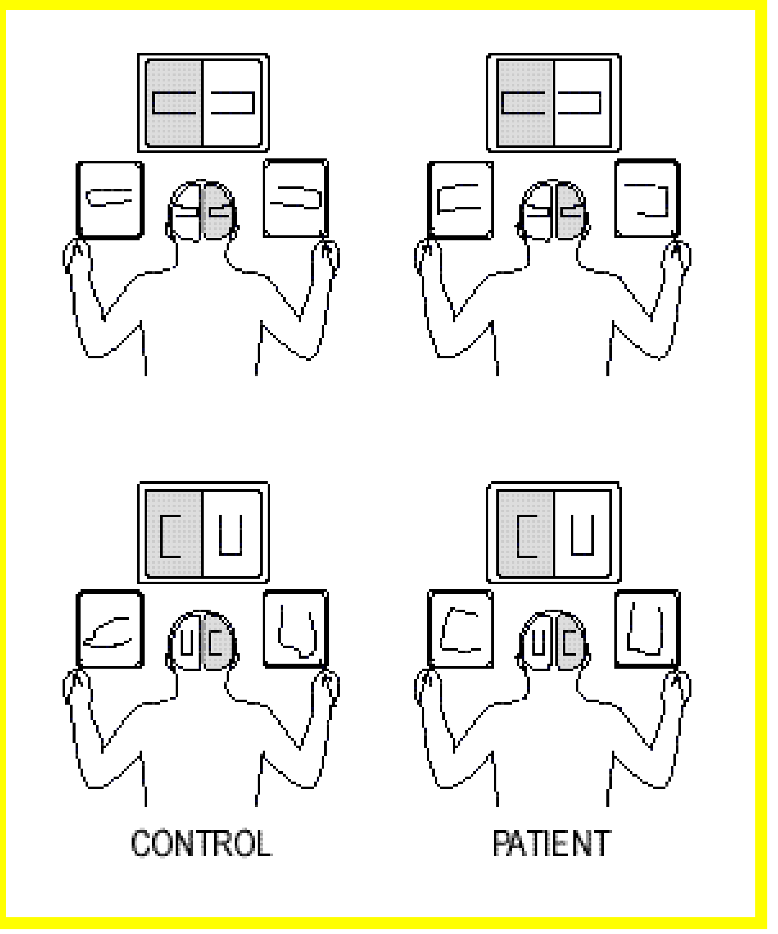
Coupled oscillators



Decoupling can help, sometimes



- Roger W. Sperry (1913-94, Nobel), **Athlete scholarship,** died from Kuru.
- & Michael S. Gazzaniga
- Observed split-brain patients (removed corpus-callosum) and found that each hemisphere is a conscious system in its own right, even in conflicting mental processes.
- Object in the left visual field, will not be vocally named, but can be handled with the ______ hand.
- Reasoning and calculation with the left hemisphere



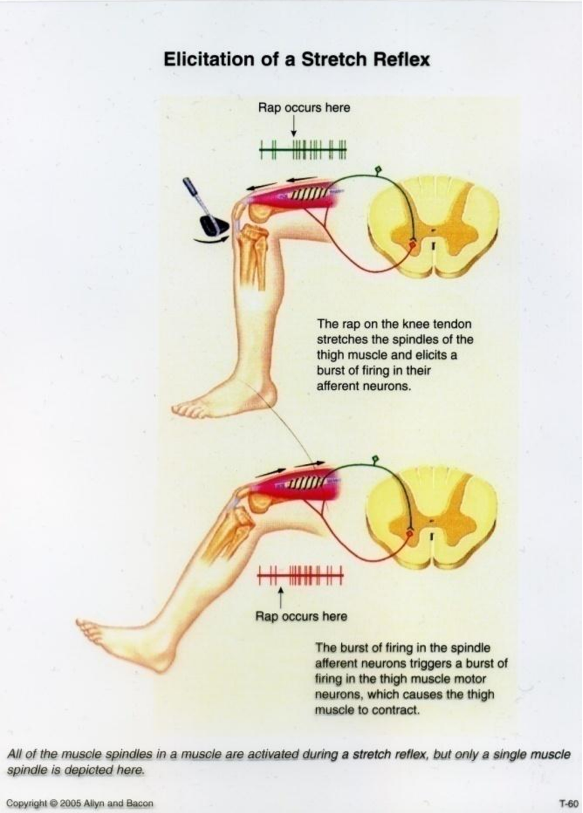
Franz et al. (1996), Psychol. Sci. 7:306-310

Reflexes and actions

- Charles S. Sherrington (1857-1952, Nobel, English Neurophysiologist)
- Together with John Langley, supported the "*localization of function*" theory for the brain.
- Mapped dorsal and ventral roots; opposing muscles, reciprocal innervations.
- "reflexes are the simplest expressions of the interactive action of the nervous system"

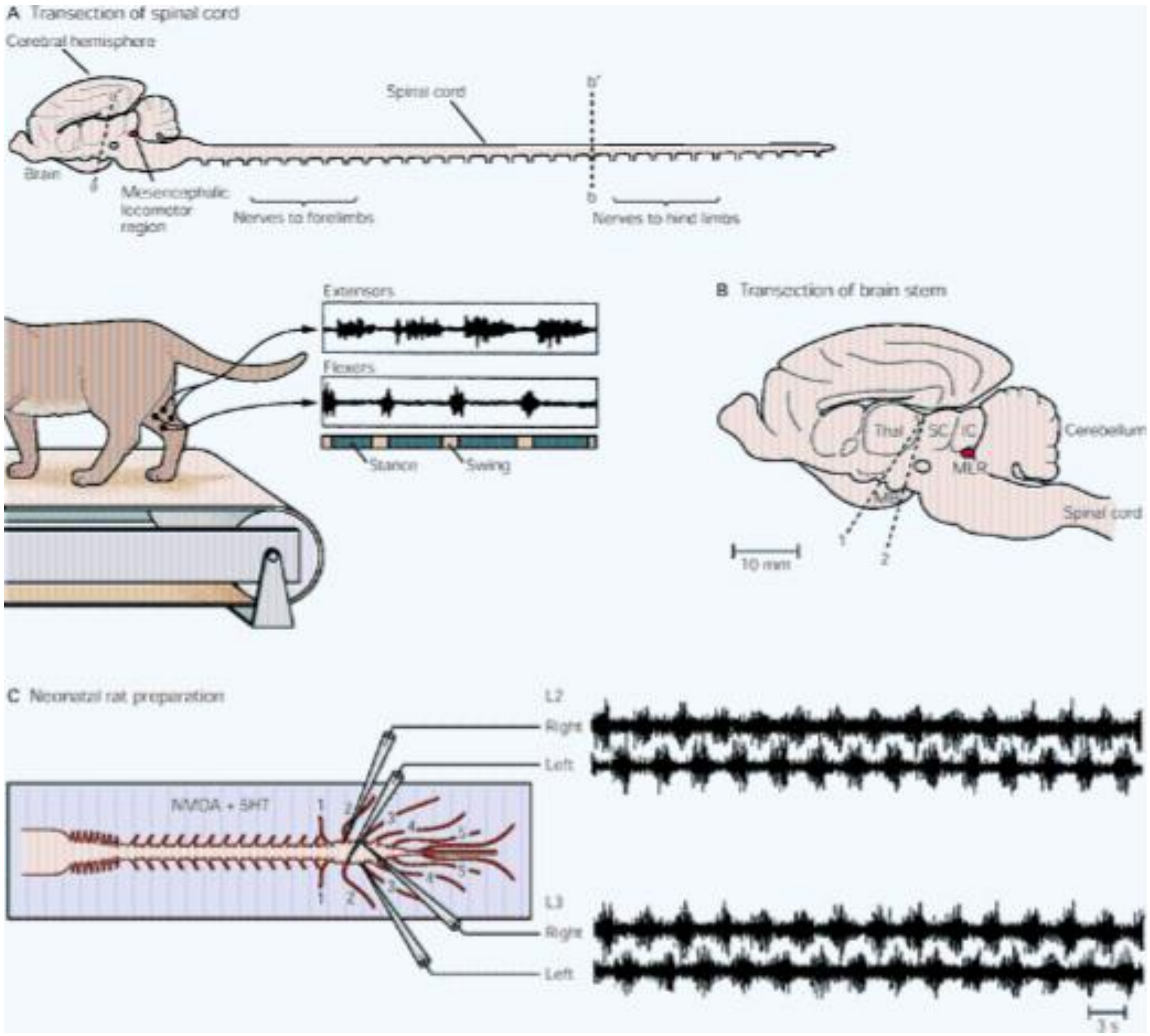
- John C. Eccles (1902-1997, Nobel, Australian Nueorphysiologist): using the stretch reflex as a model, he studied synaptic excitation and inhibition.
- Consists of only two neurons: a sensory neuron (the muscle spindle fiber) and the motor neuron. The sensory neuron synapses onto the motor neuron in the spinal cord. When Eccles passed a current into the sensory neuron in the quadriceps, the motor neuron innervating the quadriceps produced a small excitatory postsynaptic potential (EPSP). When he passed the same current through the hamstring, the opposing muscle to the quadriceps, he saw an inhibitory postsynaptic potential (IPSP) in the quadriceps motor neuron.

- Bernard Katz (1911-2003, Nobel): neurotransmitter release in synapses is quantal (Ach in motor nerve -> muscles)

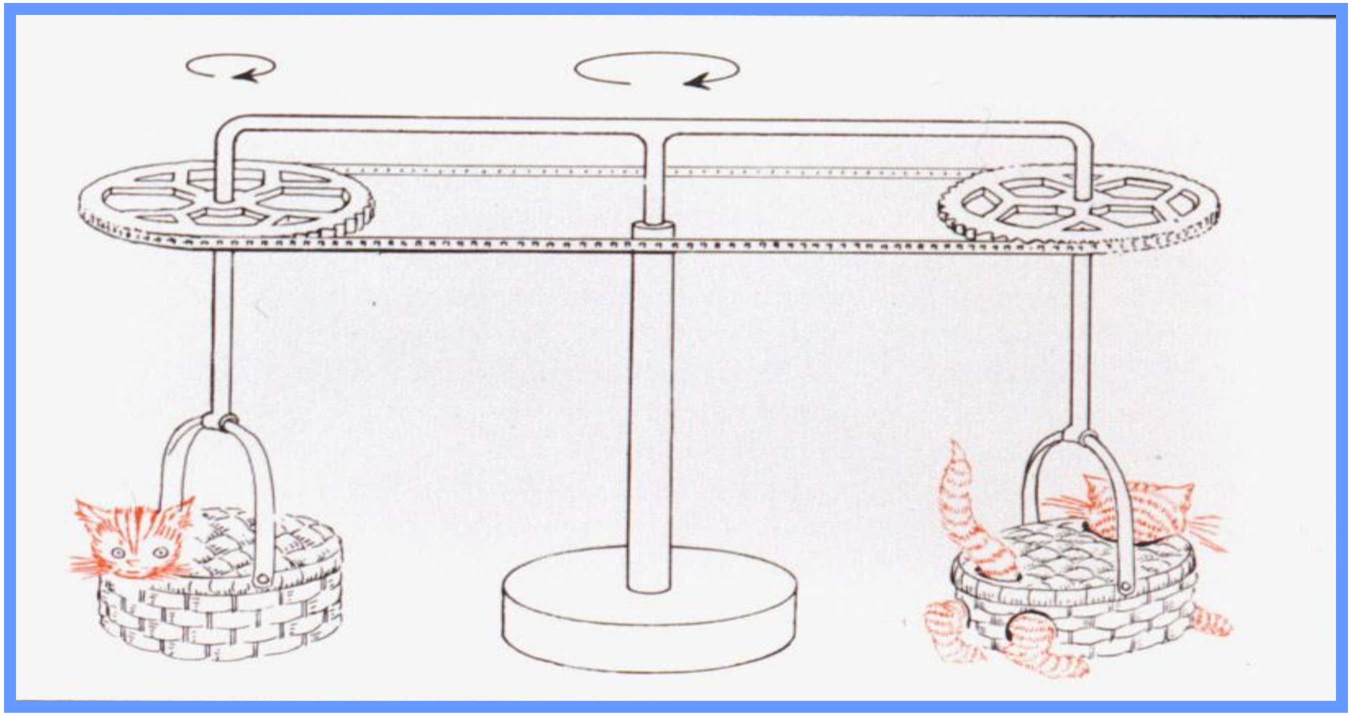


CPG: central pattern generators

Decerebration



Sensory-motor coupling



- Held and Hine (1963).
- Only the self-propelling kitten had normal 3D Vision

Control of movement: **Evolution**

- The motor system evolved for swimming, eating, reproduction, and homeostasis, some >500 mya, with vertebrates

- **The rest are just compromised adaptations**

- We had eyes and brains before skeleton, and therefore before limbs. Bones evolved from soft structures

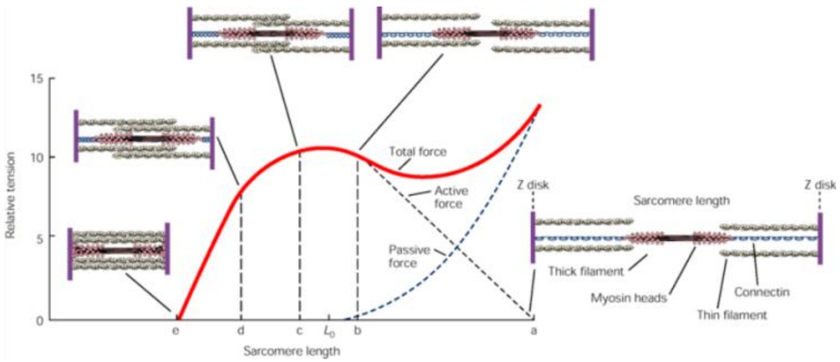
  – Vertebrates got the spinal cord and CPG; and invented the olfactory bulb, basal ganglia, primitive cortex, mobile predatory life

  – Jawed vertebrates (gnathostomes) invented the jaws, the cerebellum, paired appendages

  – Mammals invented the neocortex.

The good, The bad, and the motor system: burdens of history

- Muscles are springs
  - The bad: force varies with muscle length, the results of a motor command depends on the state of the muscle
  - The good: tough>stiff, promote stability via stable balanced states (equilibrium point)



- Multi-joint bones
  - The bad: degrees of freedom, overcompletness
  - The good: degrees of freedom: many ways for each target
- Slow muscles, Slow noisy nerves
  - The bad: slow commands, slow responses
  - The good: ?
- Stiff >tough endoskeleton (bones)
  - The bad: breakable, not flexible enough
  - The good: protection

Voluntary movement: Reaching

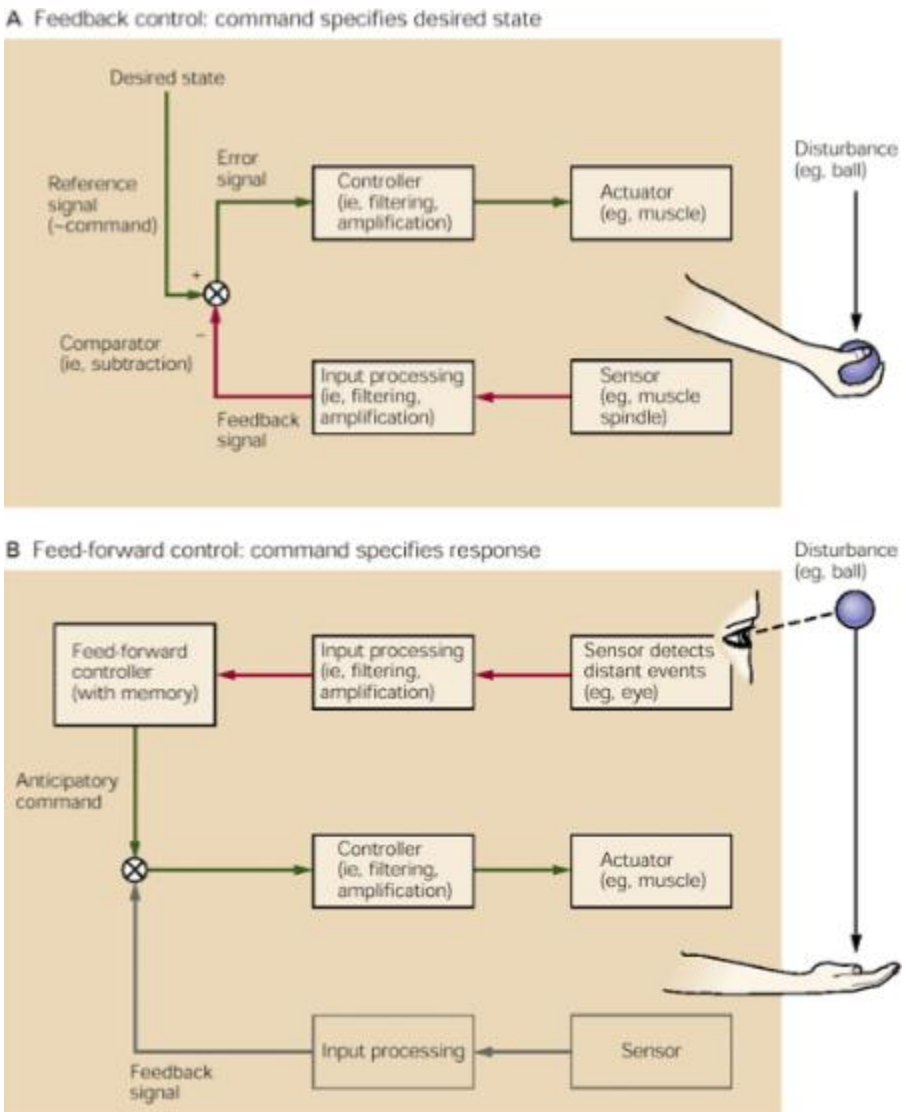
Why reaching?

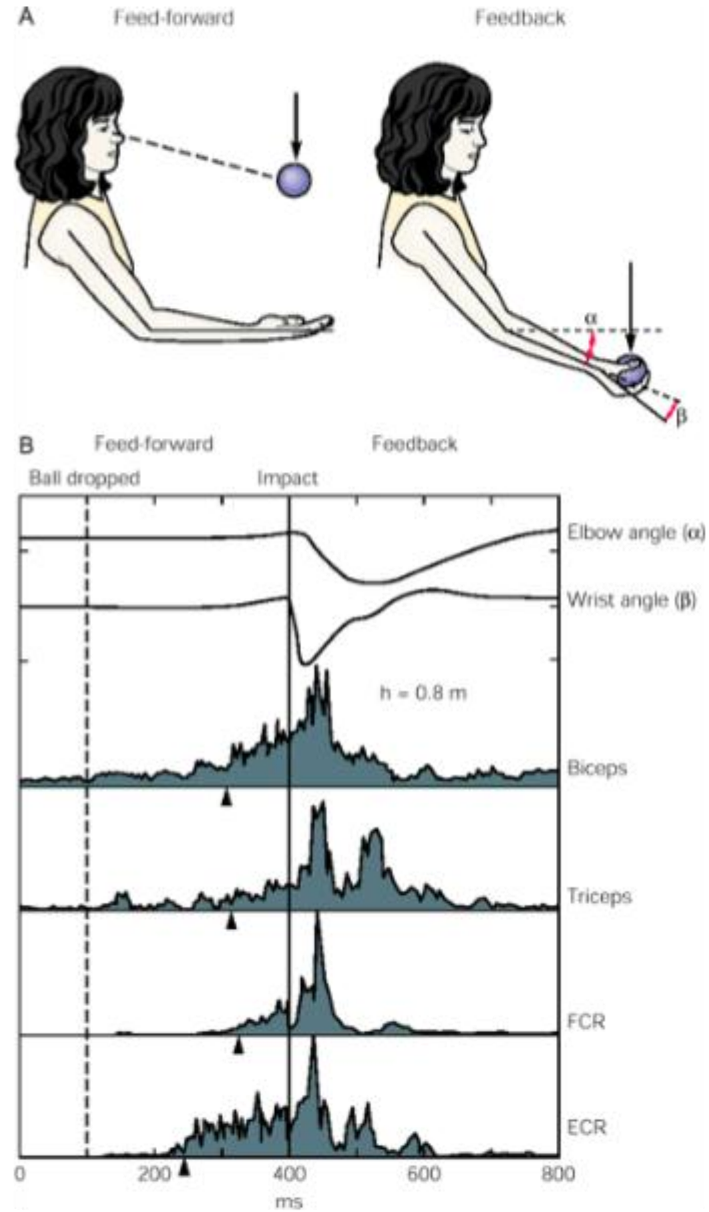
- Daily
- Fast movements (120ms)
- Specific to mammals and mainly to primates
- A crucial advantage of our ancestors
- Easy to study in a lab

Some brain engineering solutions

- Feedforward and feedback control
- Equilibrium points
- A central program
- Internal models of the apparatus and environment: Forward and inverse models
- Optimization approaches: minimum jerk, minimum noise, optimal control

Feedforward and feedback control



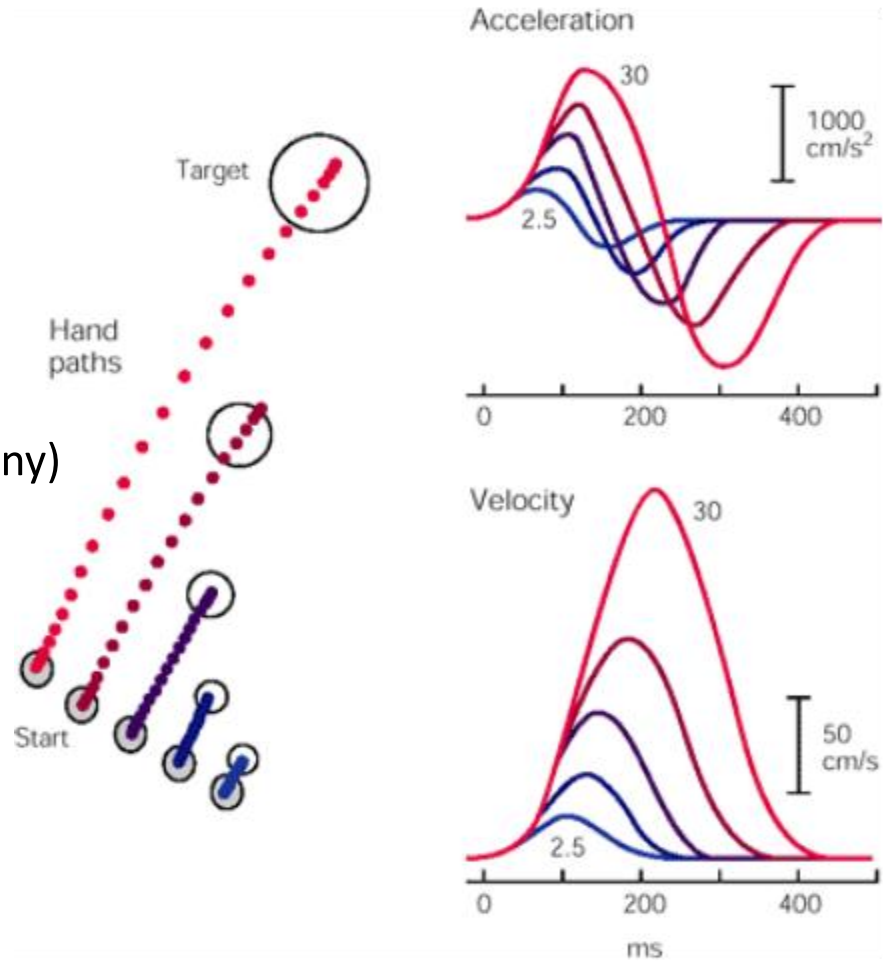


The motor program- trajectories and kinematics

Straight with bell-shaped velocity profile

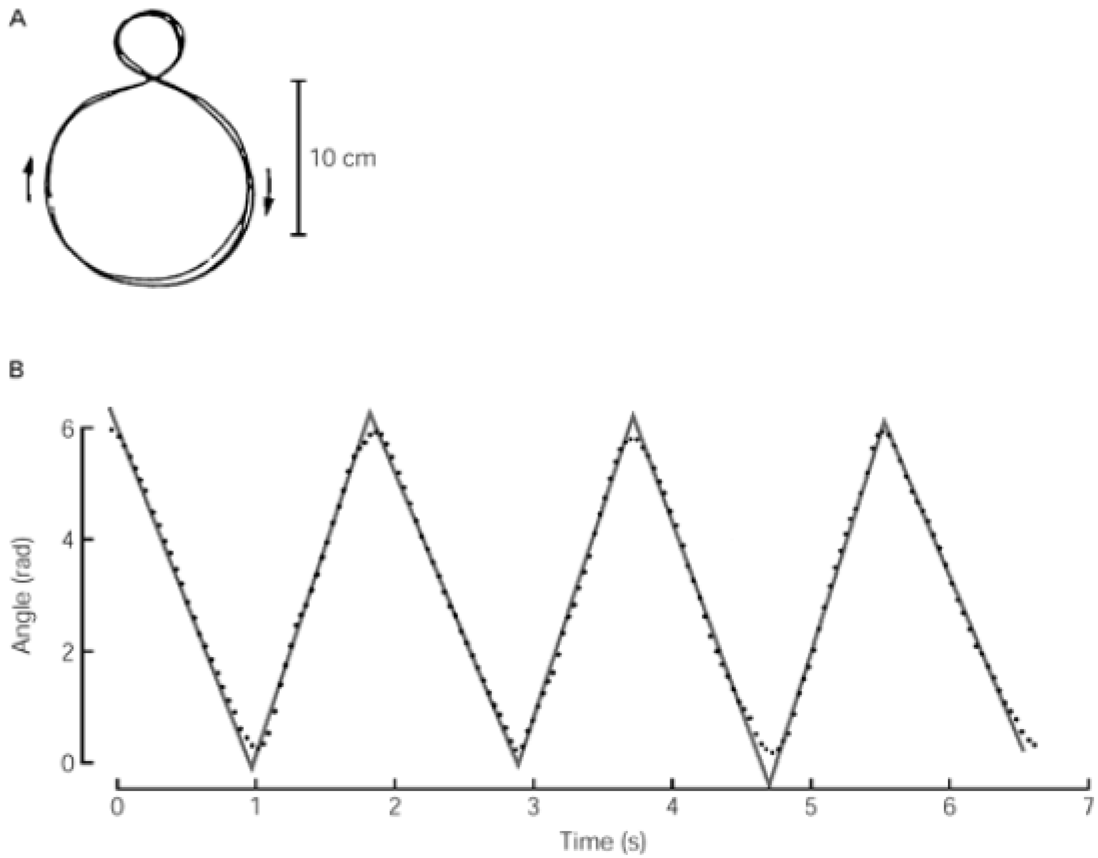
Is there online visual feedback?
No - scaling of acceleration and speed

Invariant time for each components (Isochrony)



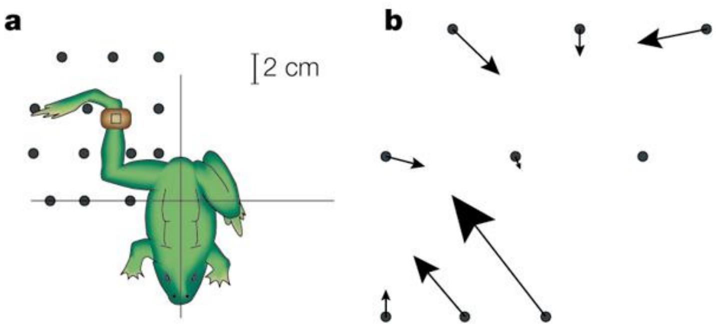
Building blocks – segmentation into primitives

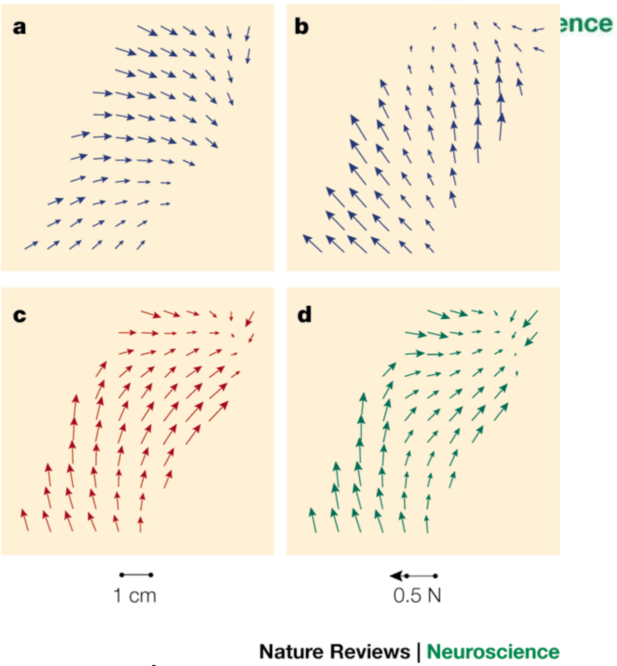
Isogony (equal angles)
Isochrony (duration independent of length)
2/3 power law: speed as a function of curvature



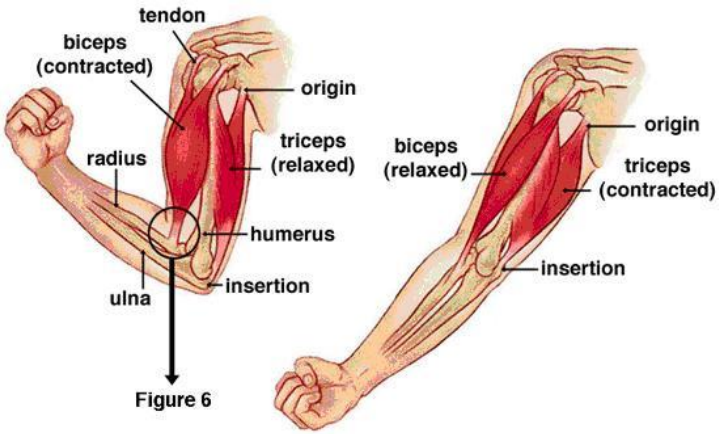
Designing a complex trajectory with limitations

- Antagonistic muscles
- Muscle-group Synergy (magnitude & temporal activation)
- Vector field
- Building blocks (functional units)
- Equilibrium point trajectory

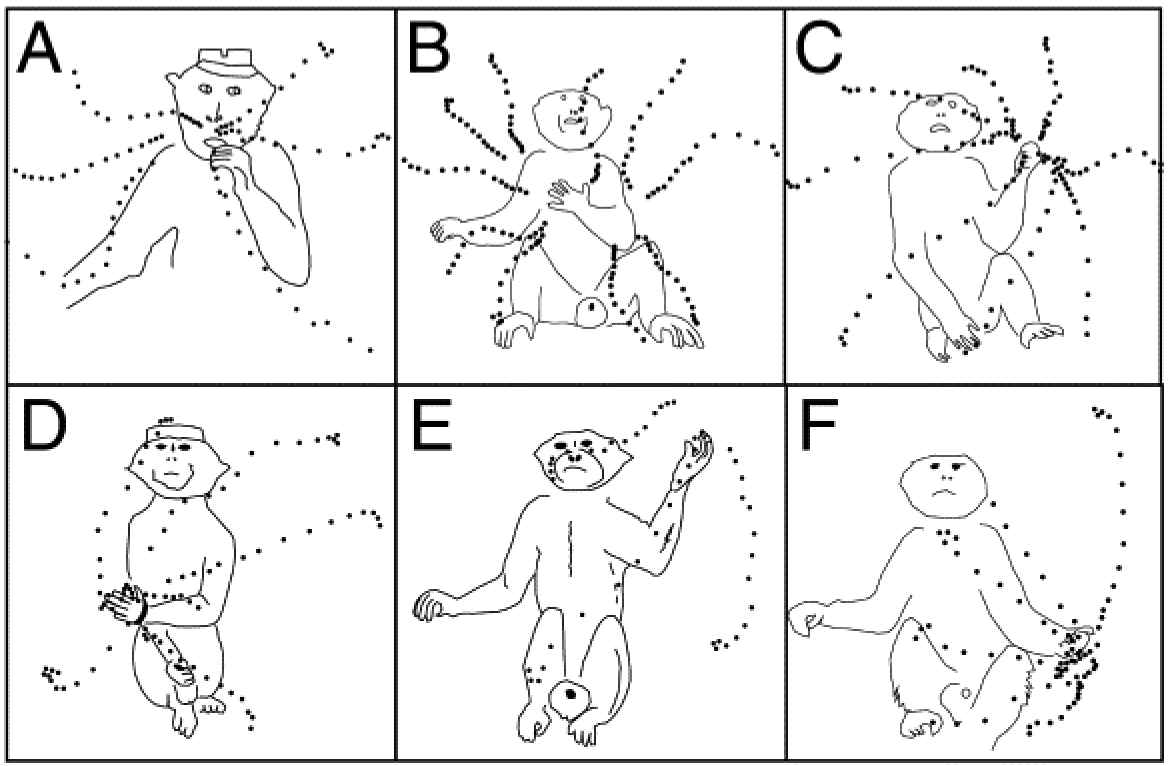




Emilio Bizzi



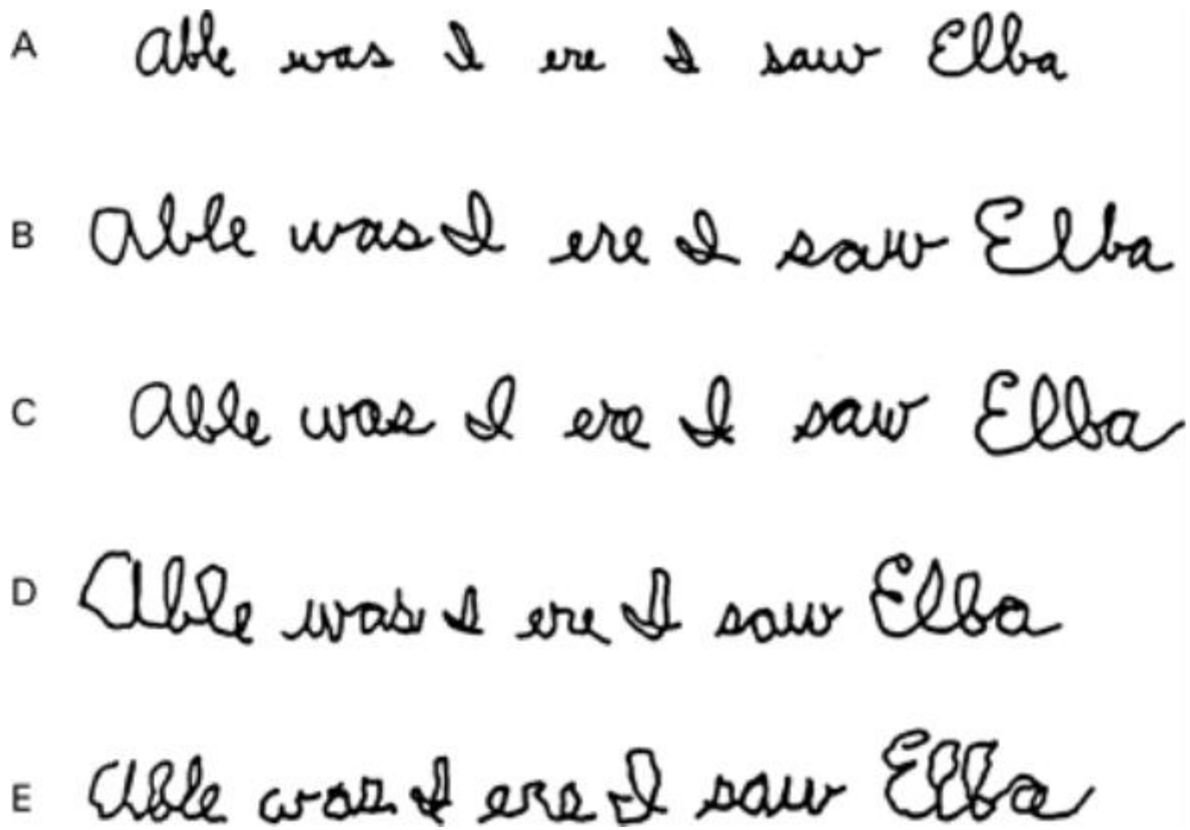
Stable behavioral gestures



Graziano MS

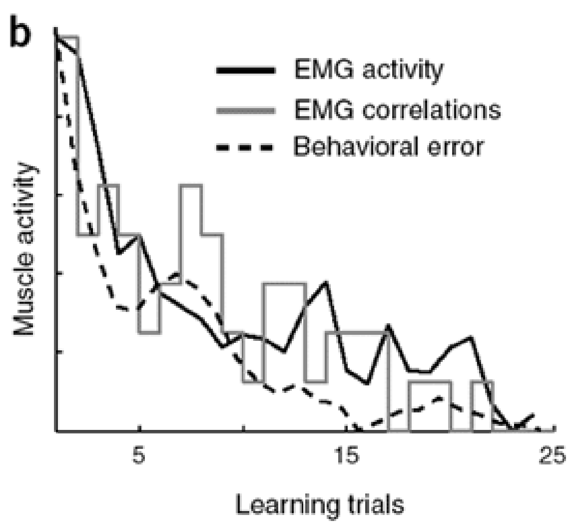
Motor programs and Invariants

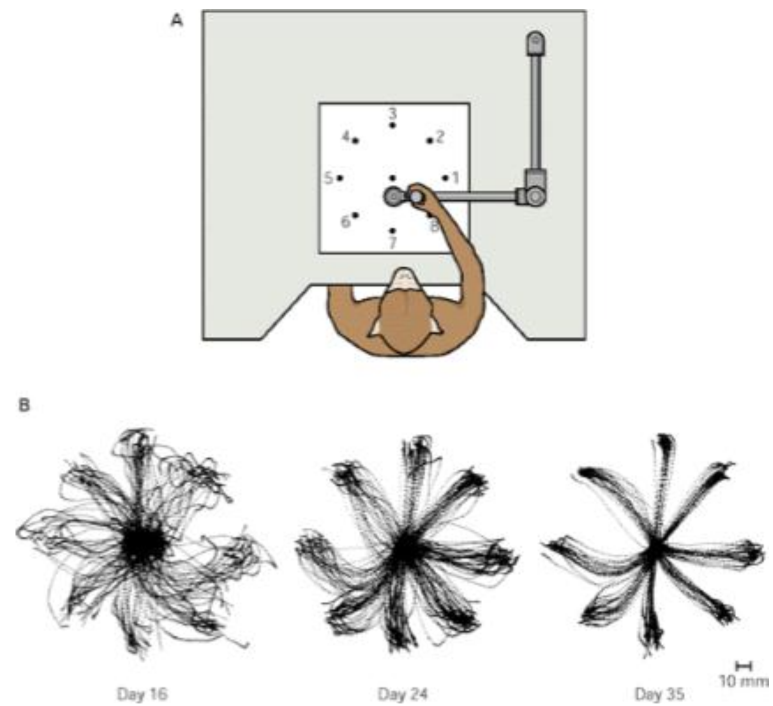
Motor equivalence
(Donald Hebb,
1904-85)



Improve with practice

- Co-contraction of muscles
- **Internal models**: a neural representation of the relationship between the hand and the environment (how the arm would respond to the neural command).



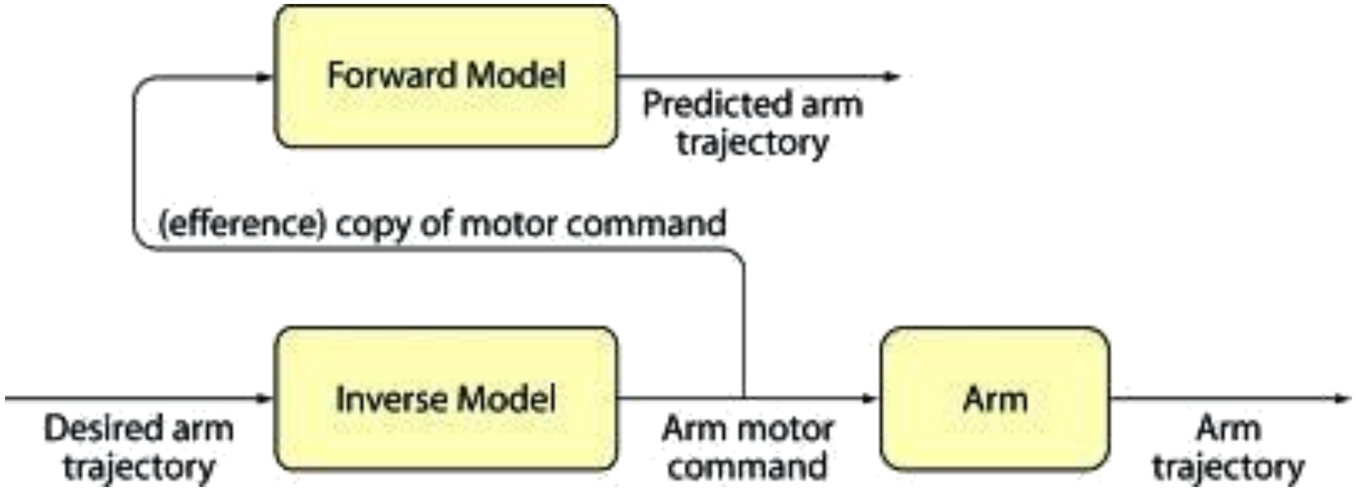


Inverse and forward internal models

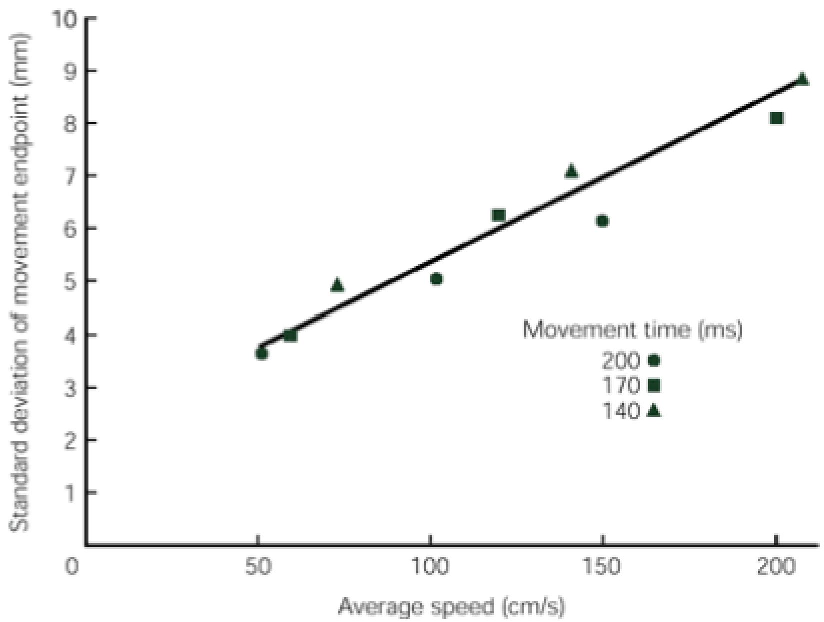
An **internal model** is used either:

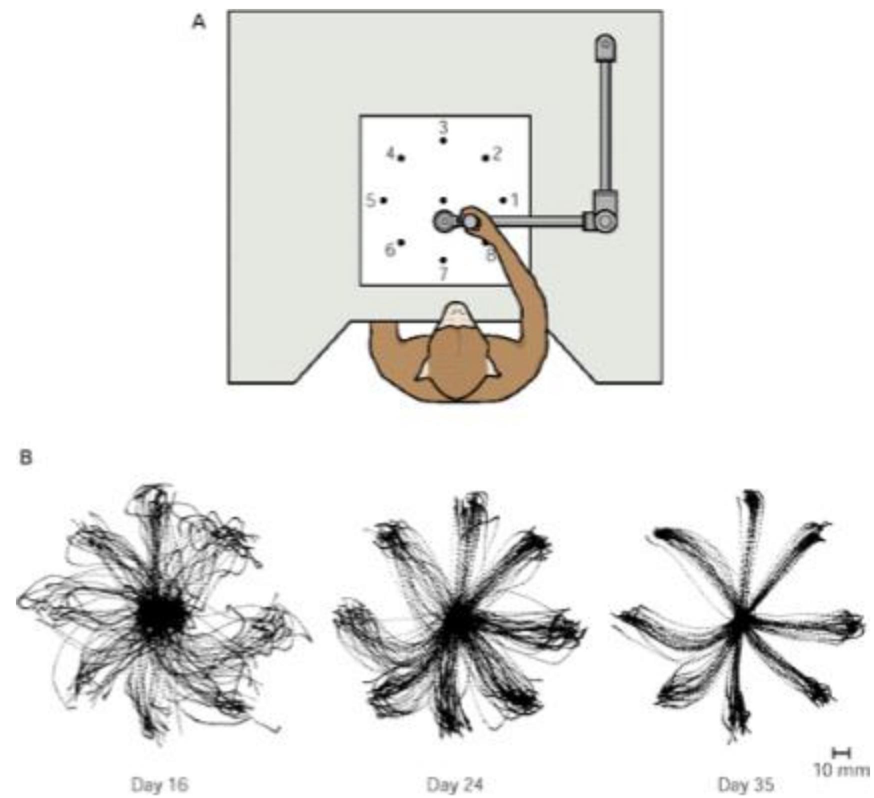
- to predict the movement consequences of a motor commands (*forward model*);

- to determine the motor commands needed to achieve a desired movement trajectory (*inverse model*).



Speed – accuracy tradeoff

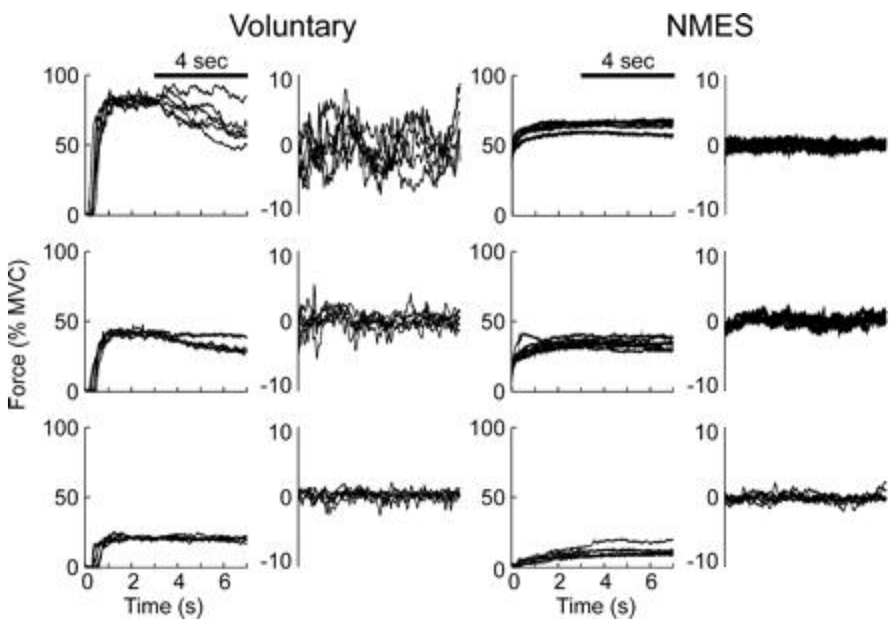


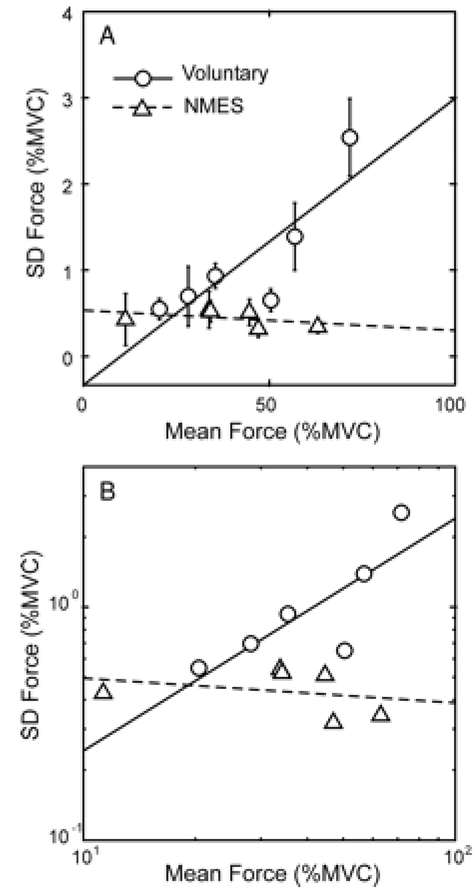


- Less time for feedback corrections?
- No, even without sensory feedback
- Why then?

Variability of the components
But which?

Neurons are noisy channels, not muscles





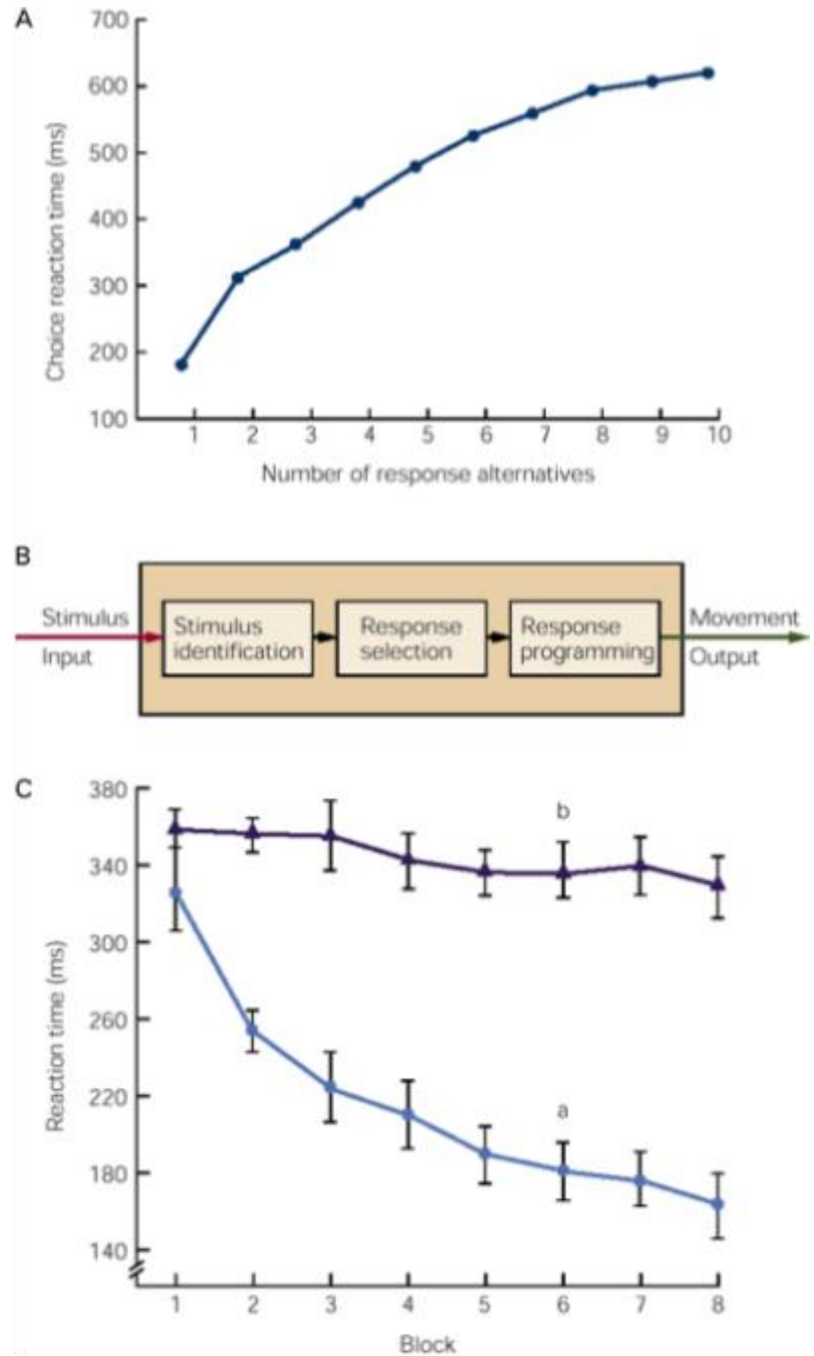
Jones & Wolpert, 2002

Overcoming noise: optimization principles

- Minimum jerk (smooth acceleration)
- Minimum signal-dependent noise
- Optimal control: minimize only what is relevant, and ignore other variables.

Reaction time and information

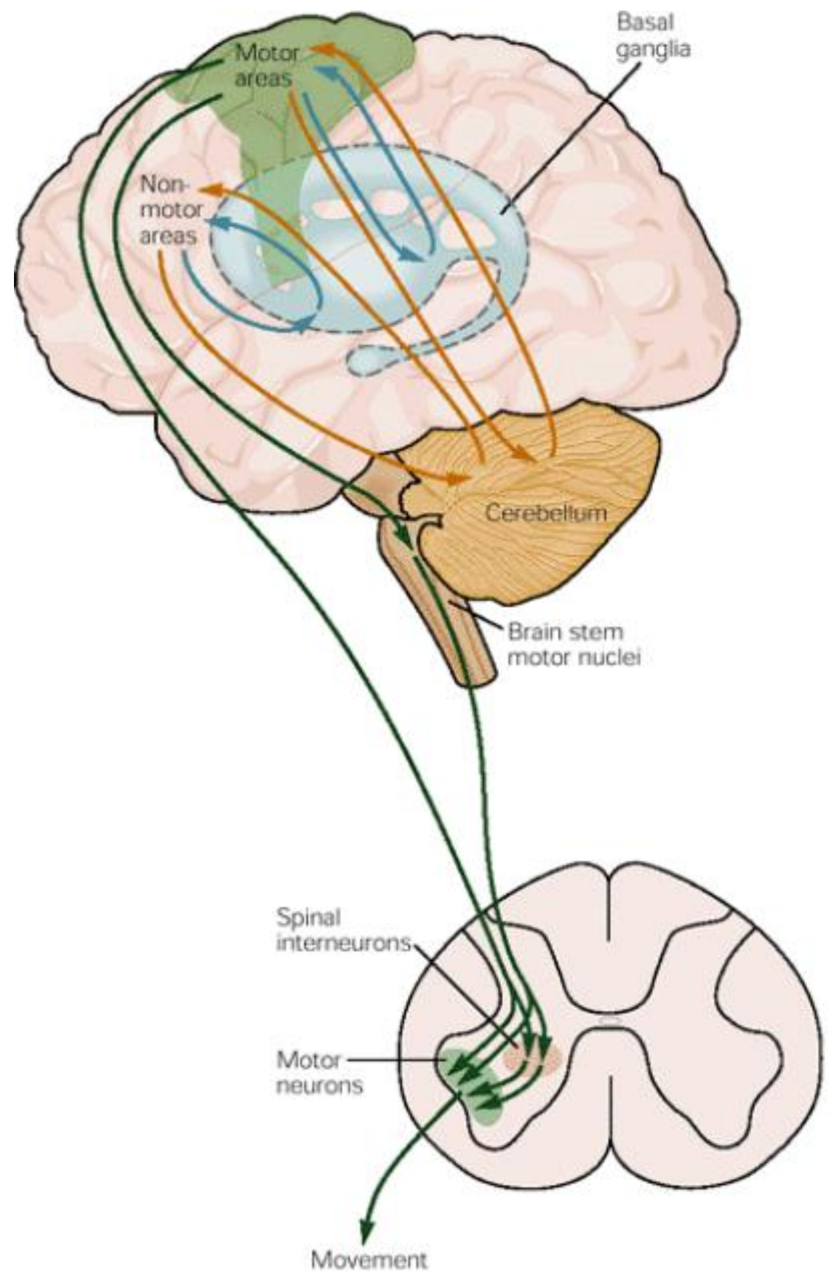
>=40ms for reflex
>=120ms for voluntary



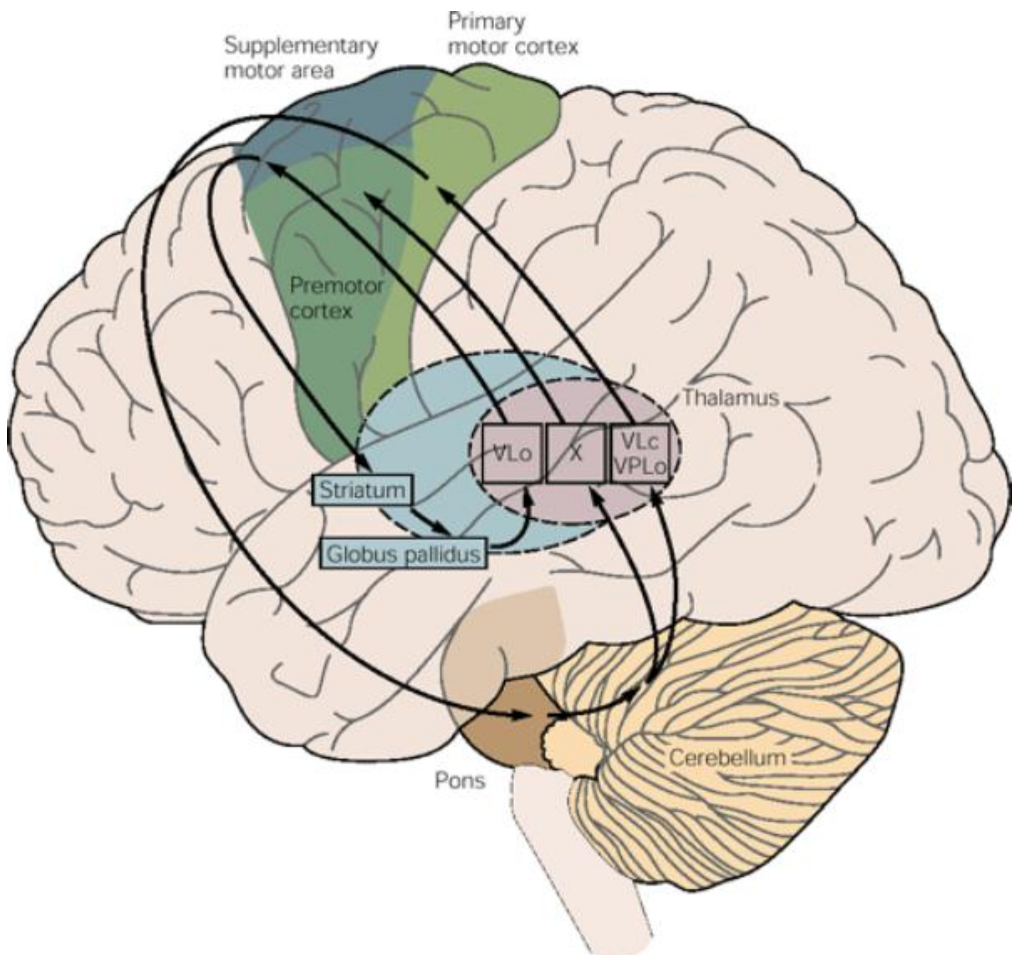
Components of the motor system

Hierarchical organization

- Cortex
- Cerebellum
- Basal-ganglia
- Brain stem
- Spinal cord
- Muscles



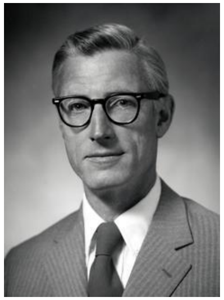
Cortex : control of voluntary movement

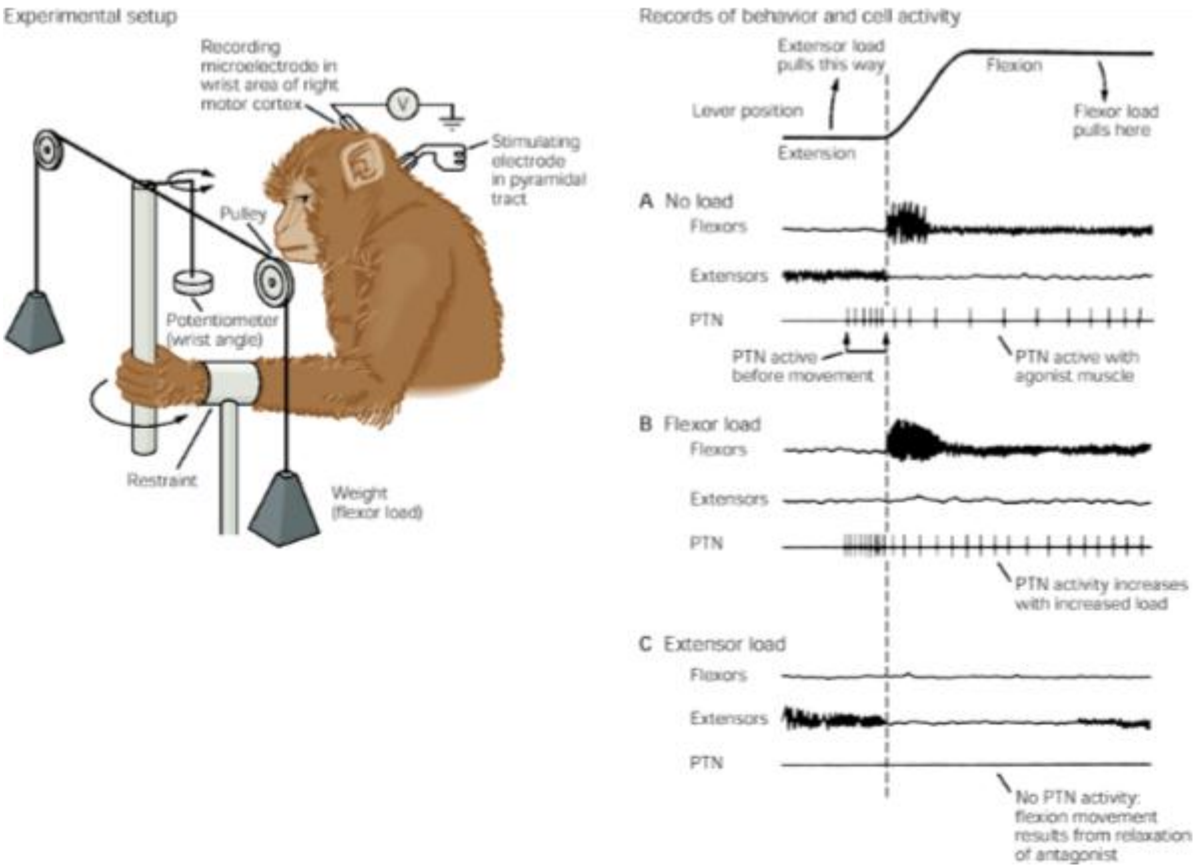


Primary motor cortex was the first cortical area to be functionally examined in the history of neuroscience

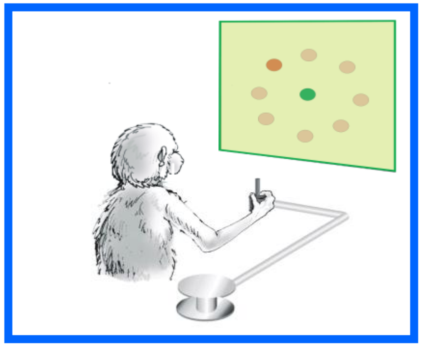
Coding of force

Edward V. Evarts (1926-85), pioneered single-unit recordings during behavior



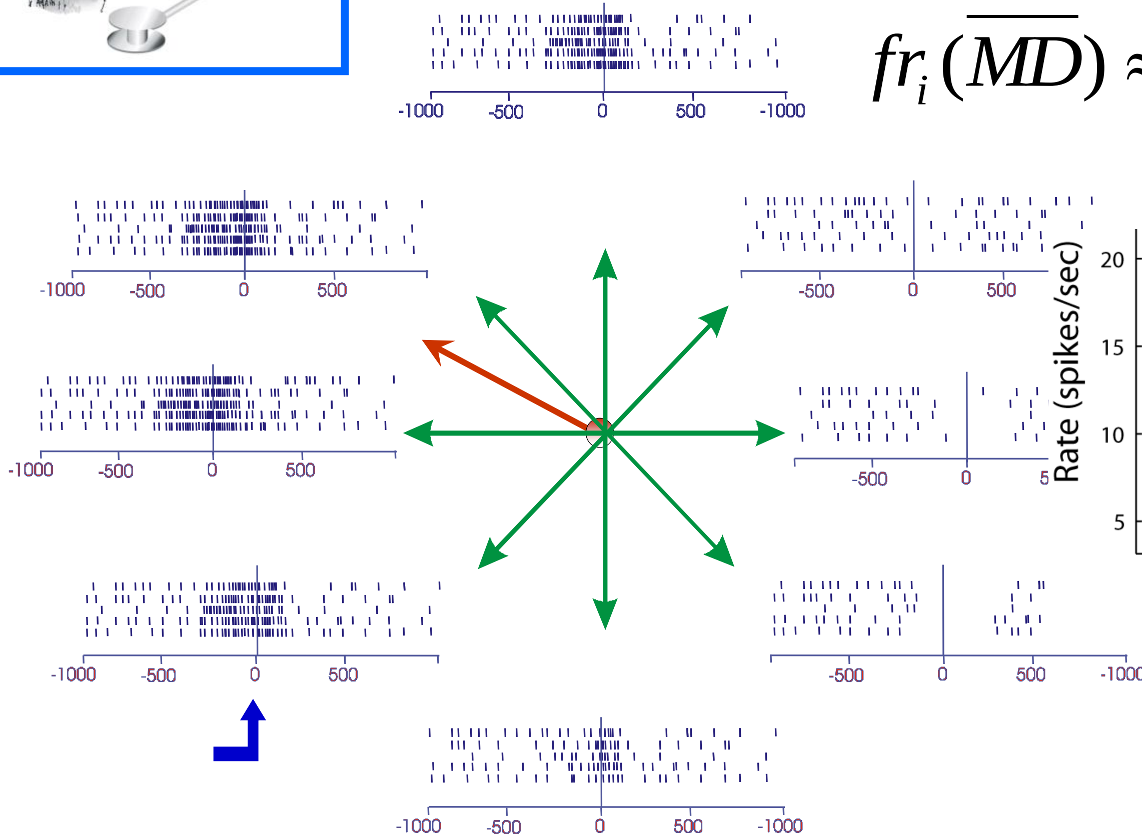


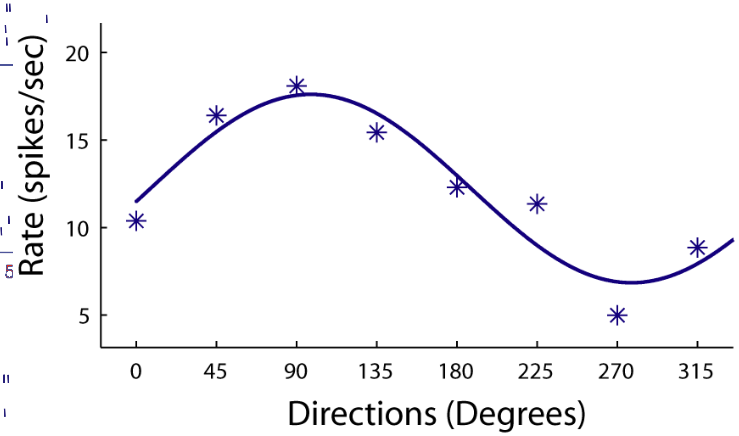
Coding of direction



Apostolos Georgopoulos , 1982

$$fr_i(\overline{MD}) \approx b_i + k_i \cos(\theta_i - \theta_{MD})$$



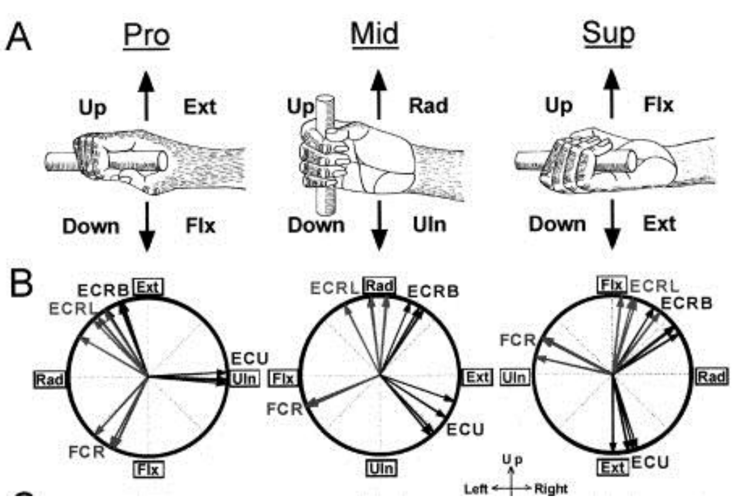


So, does M1 code for kinematics or dynamics?

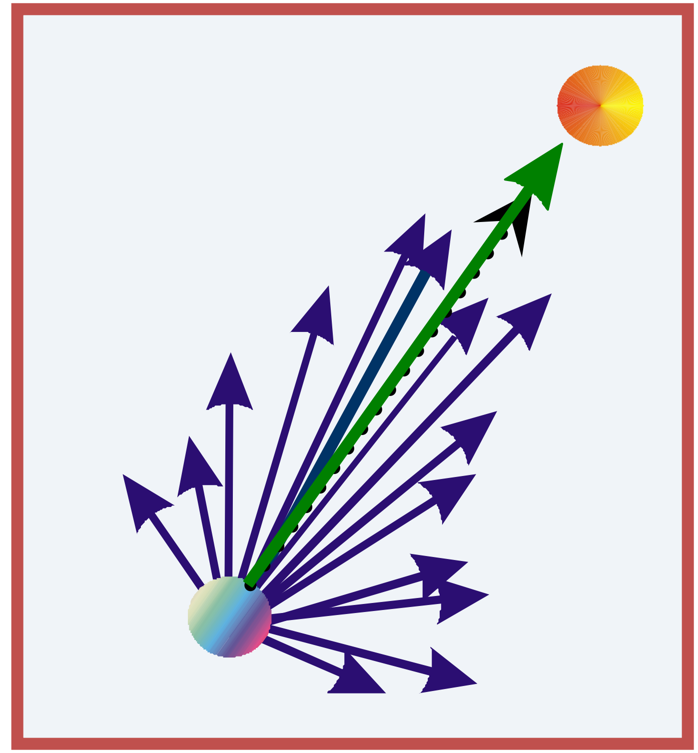
Kinematic transformation: to transform a target position into a command to the skeletal system to move the hand i.e. to convert between coordinate systems;

Dynamic transformation: relate motor commands to the motion of the system; in the reaching task here considered, the forces applied changed the system without changing the kinematics.

How can we test this?



From neurons to something useful: the population vector



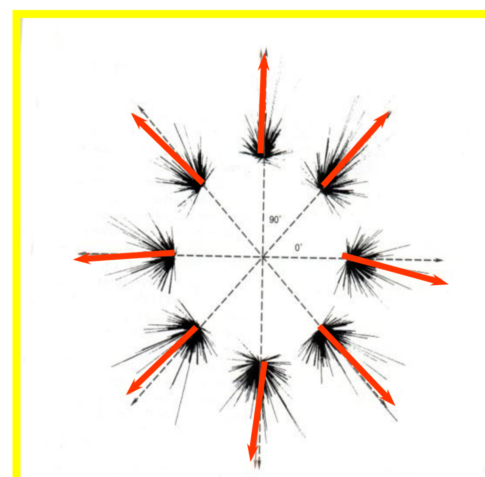
If:

- Many cells "care" about direction of movement
- Cells are tuned "cosine like" with a preferred direction
- Preferred directions are uniformly distributed

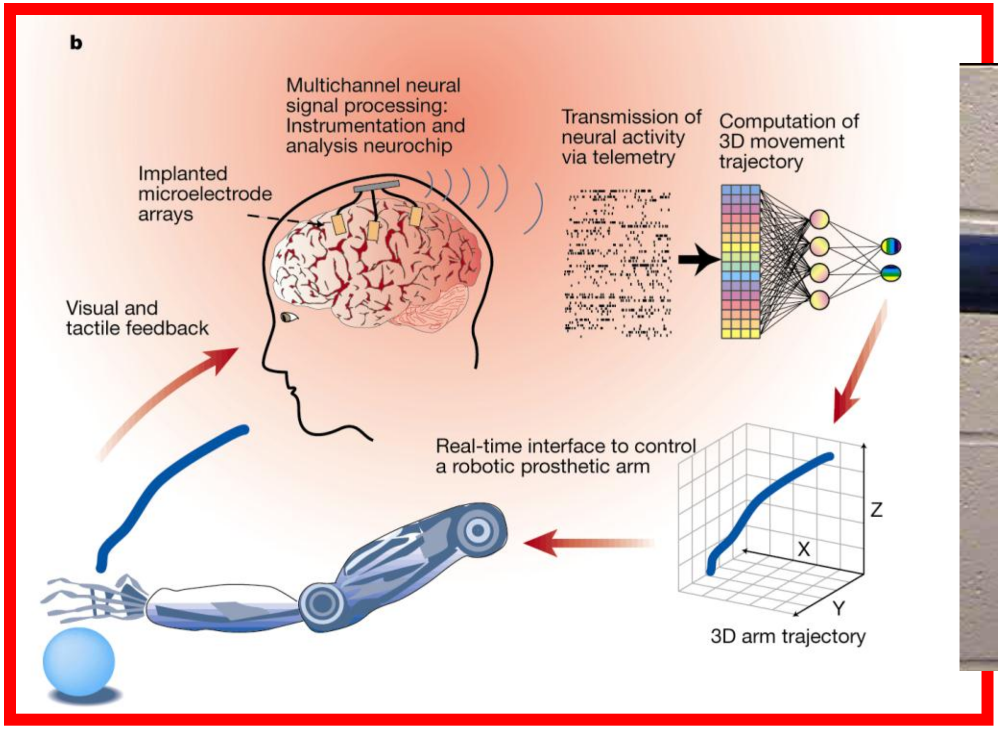
$$\overline{MD} \approx PV = \sum_{i=1}^{N} w_i \overline{C}_i$$

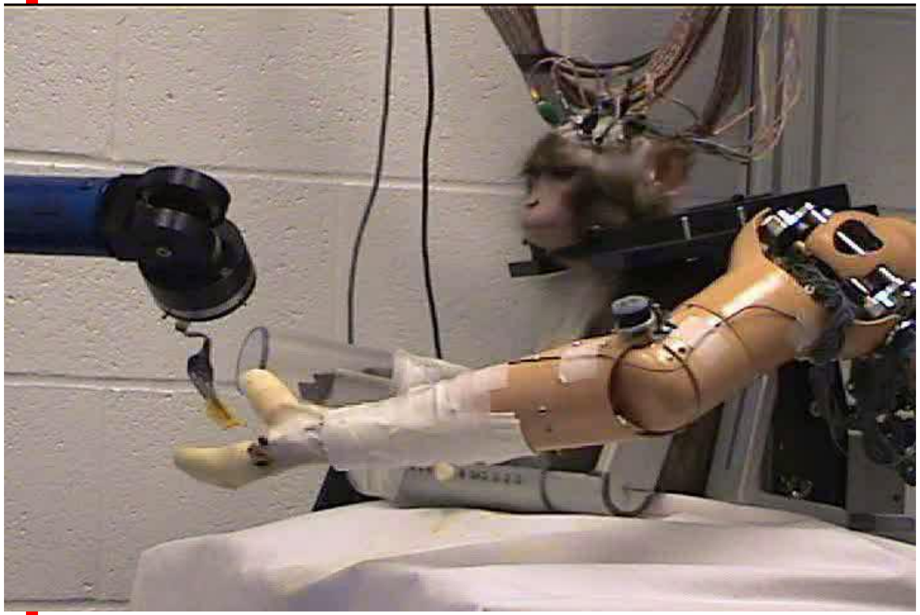
Then:

The actual movement can be estimated in Cartesian coordinates by a linear combination of weighting the preferred directions with the actual firing rate



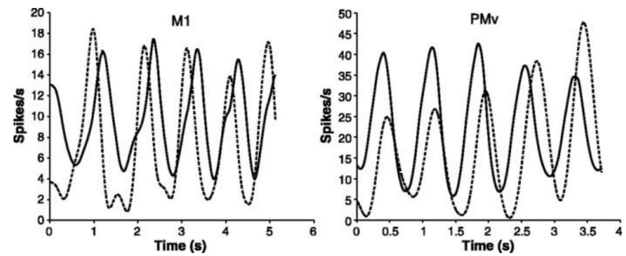
Brain-machine interfaces: Neural prostheses

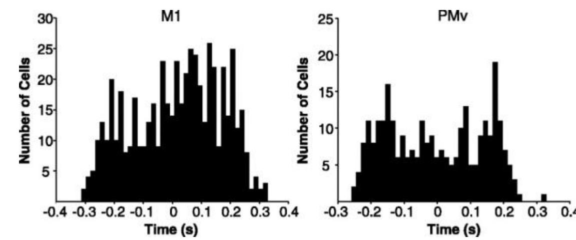


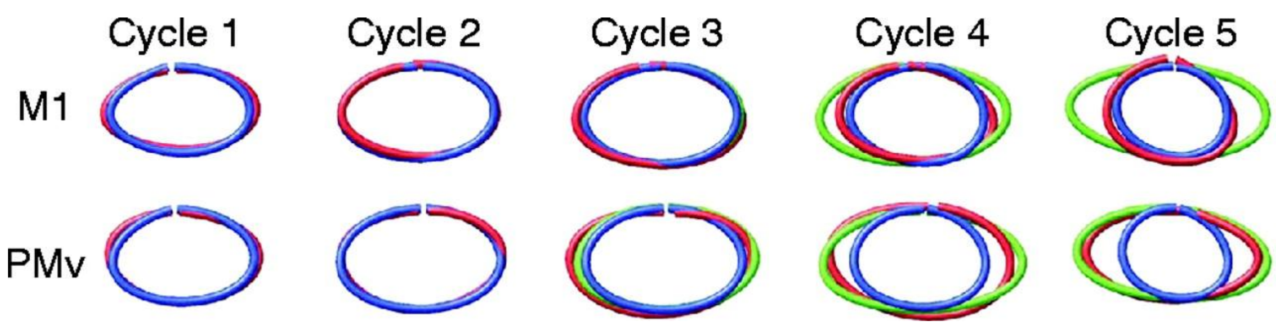


Andy Schwartz

Representation of plan and execution



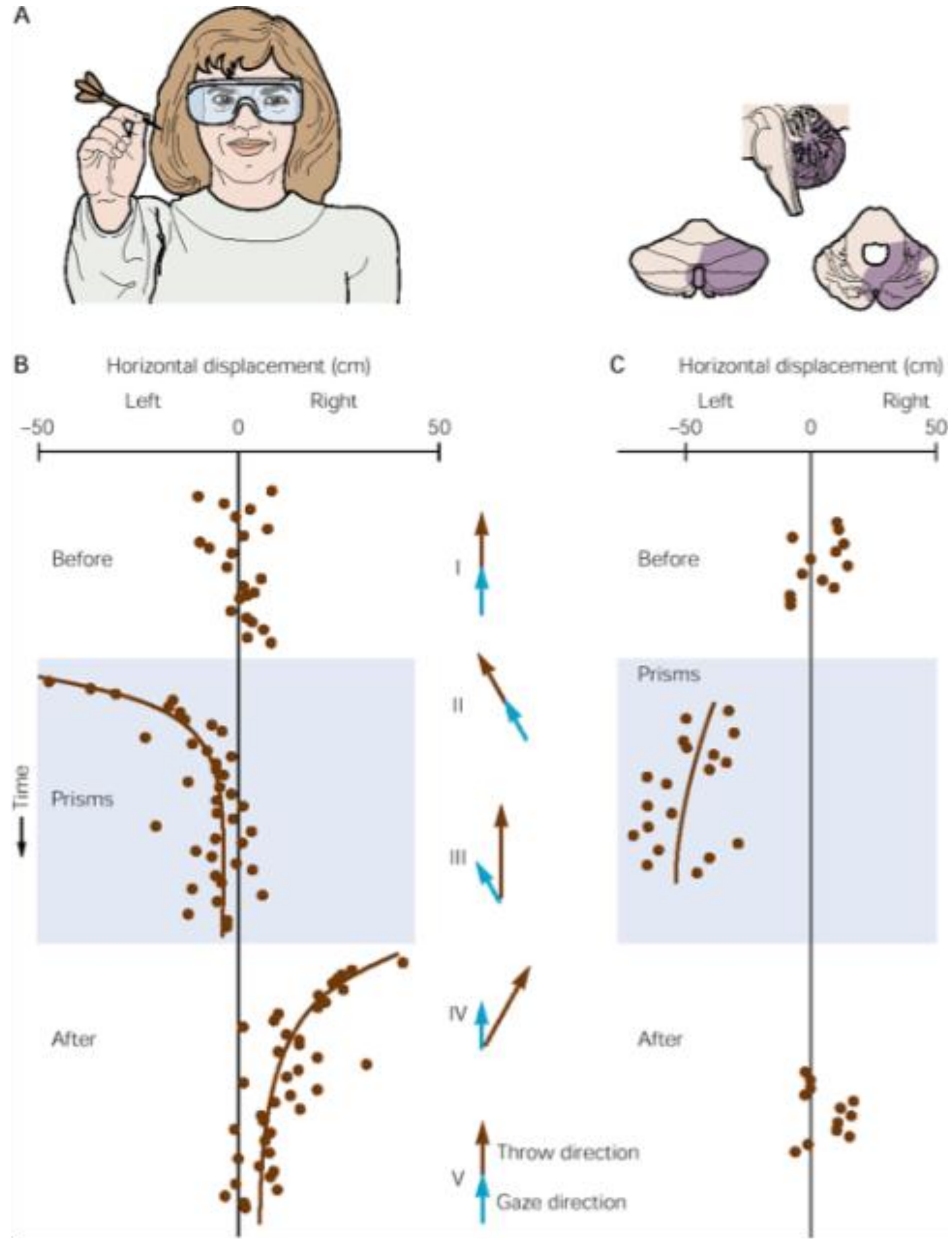




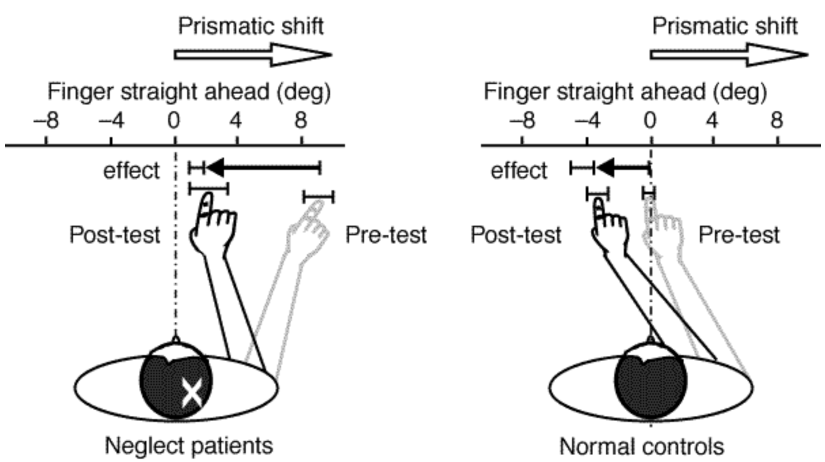
Illusion task trajectories. Top row is five cycles from M1 units. Bottom row is from the PMv. The hand trajectory is blue, cursor trajectory is green, and neural trajectory is red. Each displayed trajectory is the mean across five repetitions

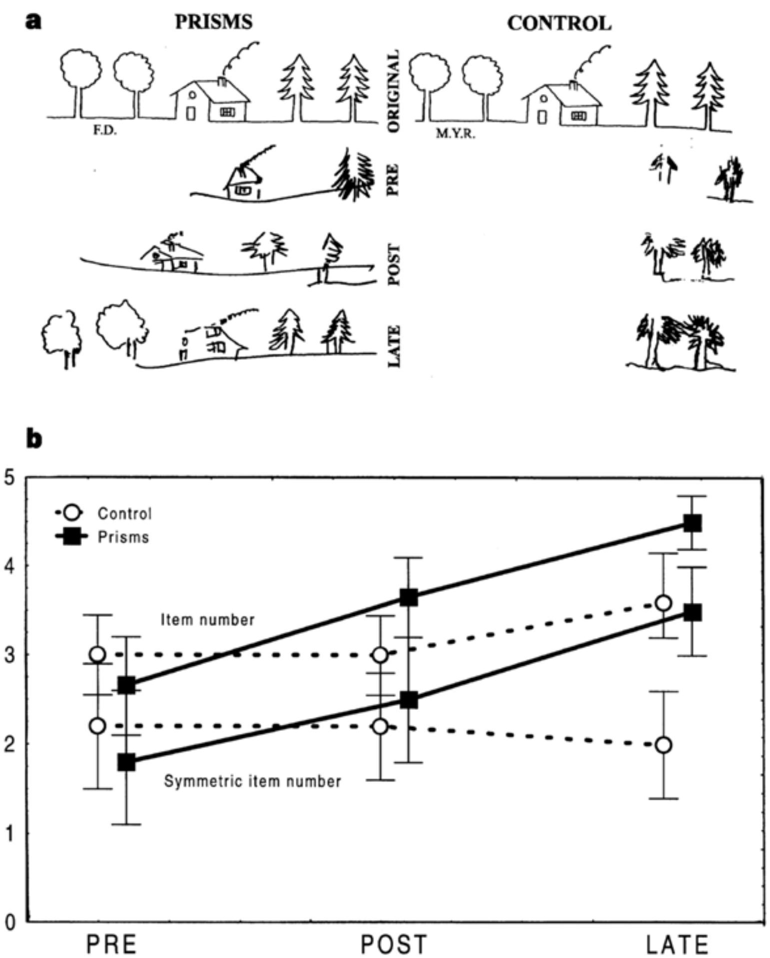
Andy Schwartz

Adaptation and motor learning via sensory feedback



Prisms for neglect

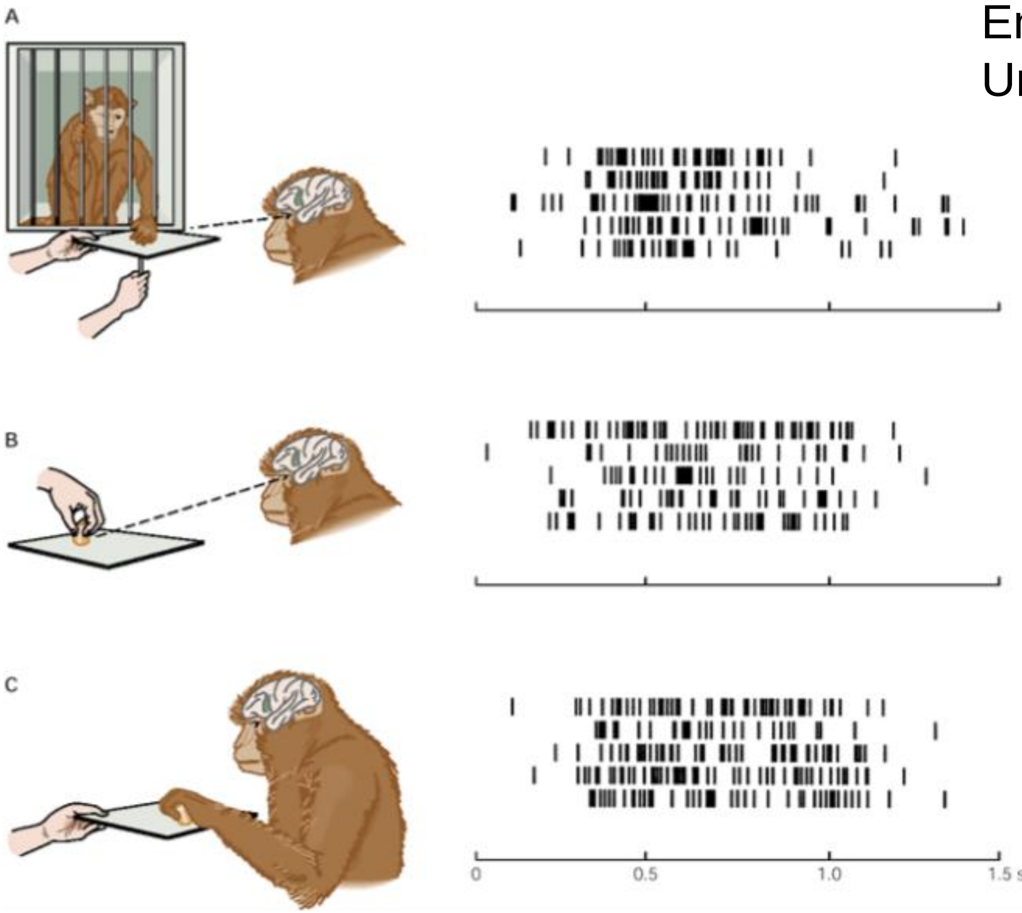


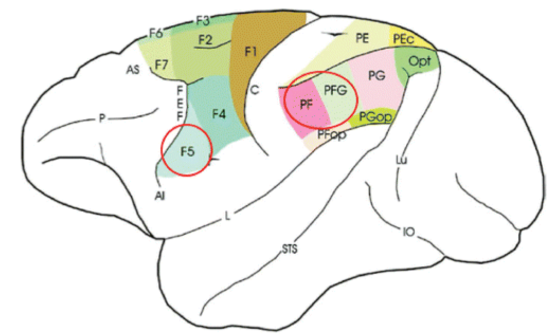


Rossetti & pisalla, 98

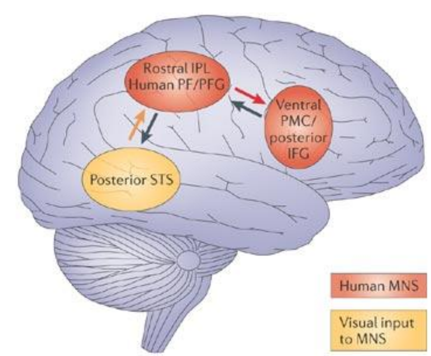
Mirror neurons

Learning by observation/imitation
Theory of mind
Language
Autism
Empathy
Understanding intentions



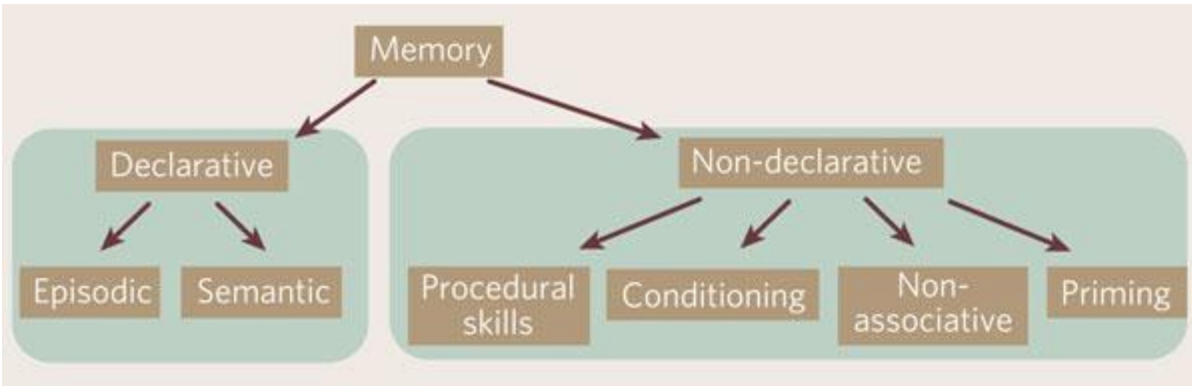


Iacoboni M. 2009.
Annu. Rev. Psychol. 60:653–70

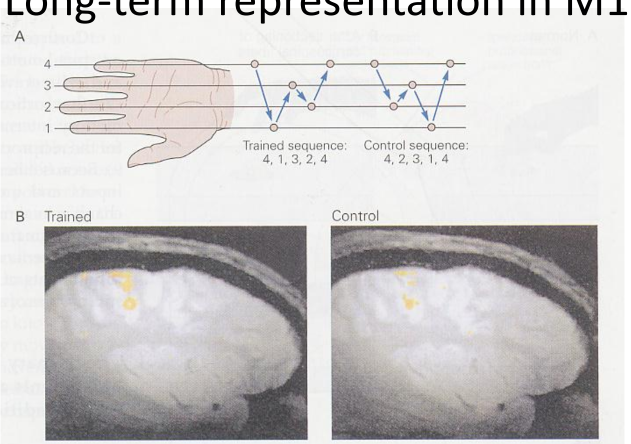


Rizzolatti G

Motor memories

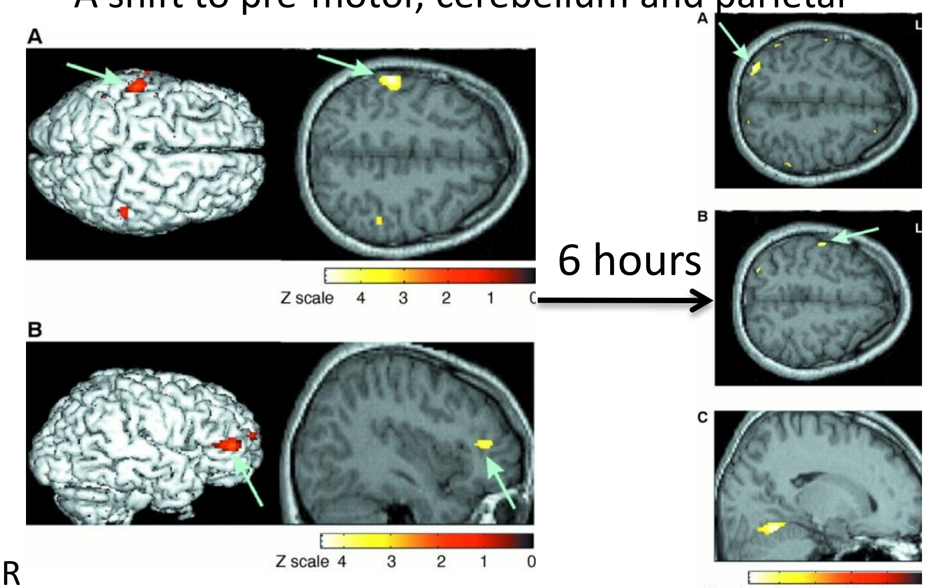


Long-term representation in M1



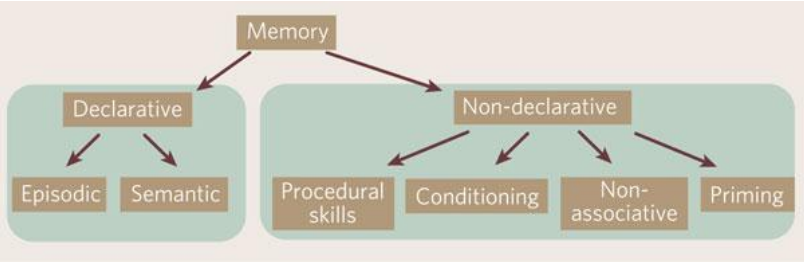
Karni A.

A shift to pre-motor, cerebellum and parietal

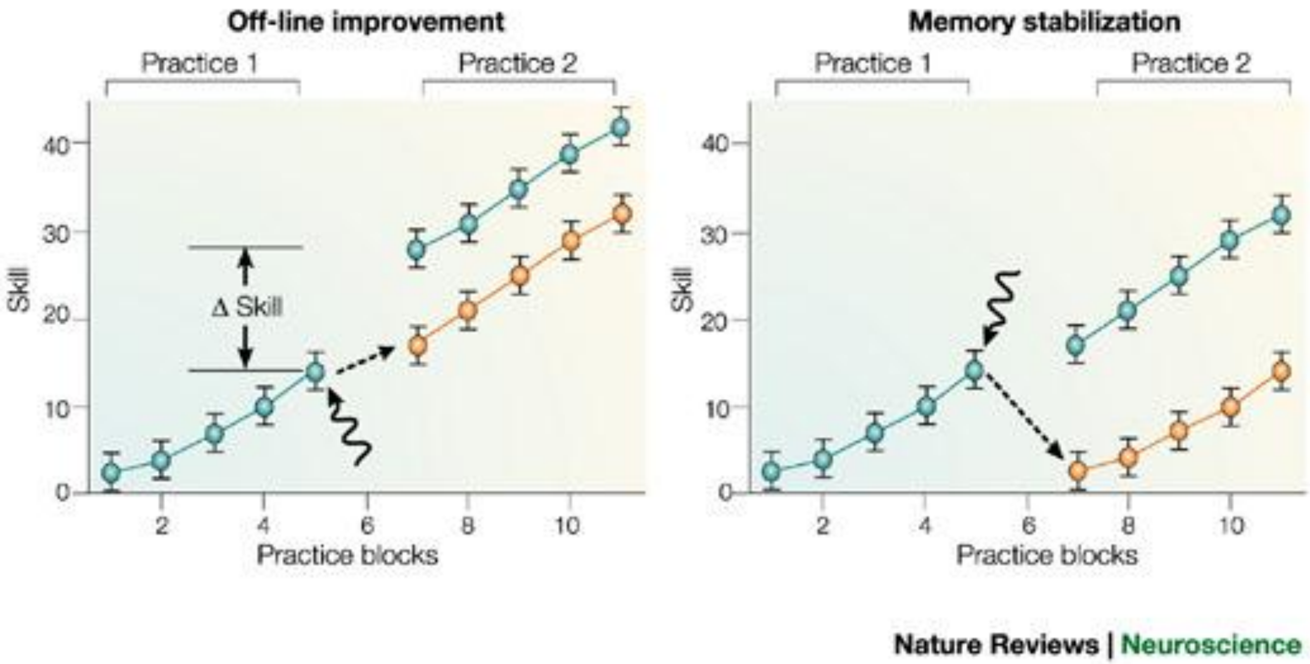


Shadmehr R

Motor consolidation



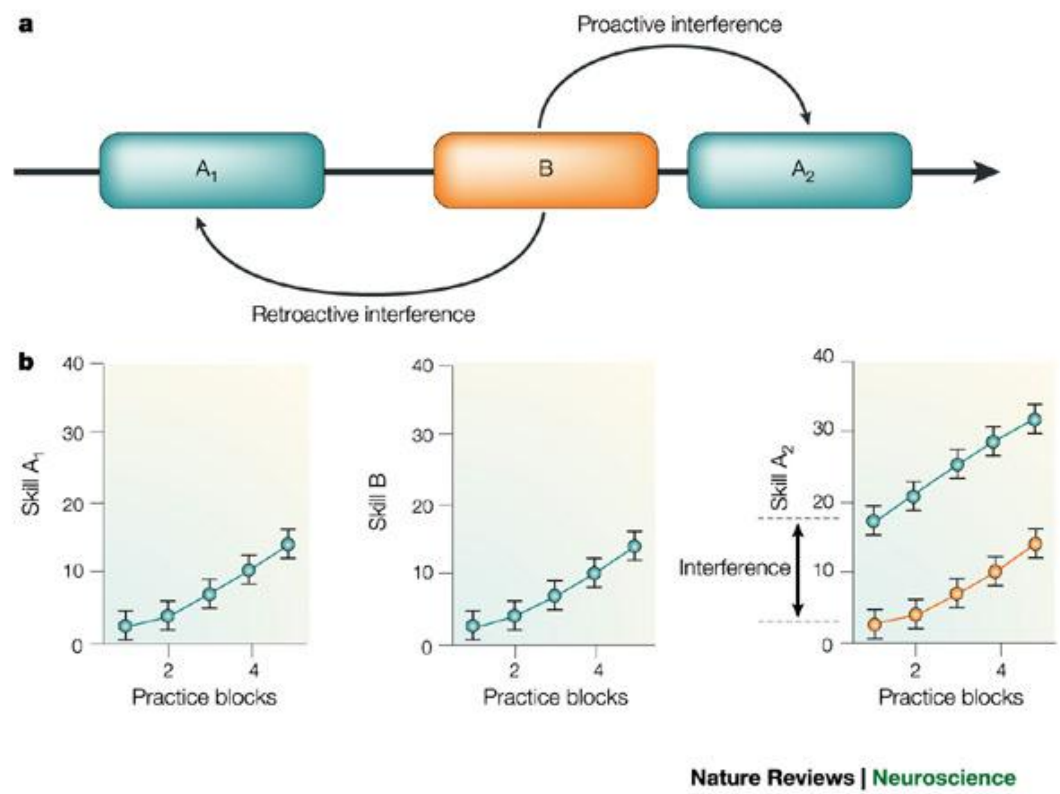
- The transfer of a memory from short-term into long-term
- Consolidation has two behavioral characteristics



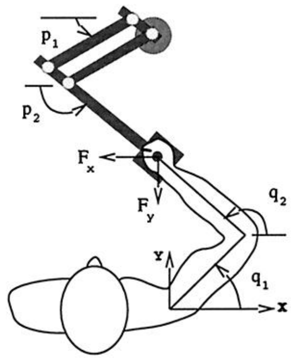
Robertson EM et al, 04

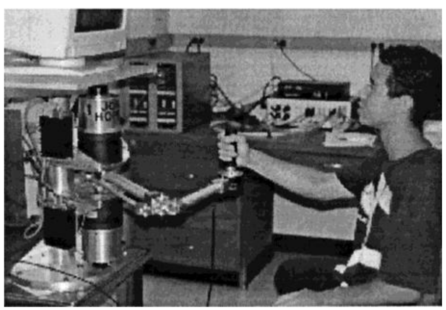
Interrupting consolidation

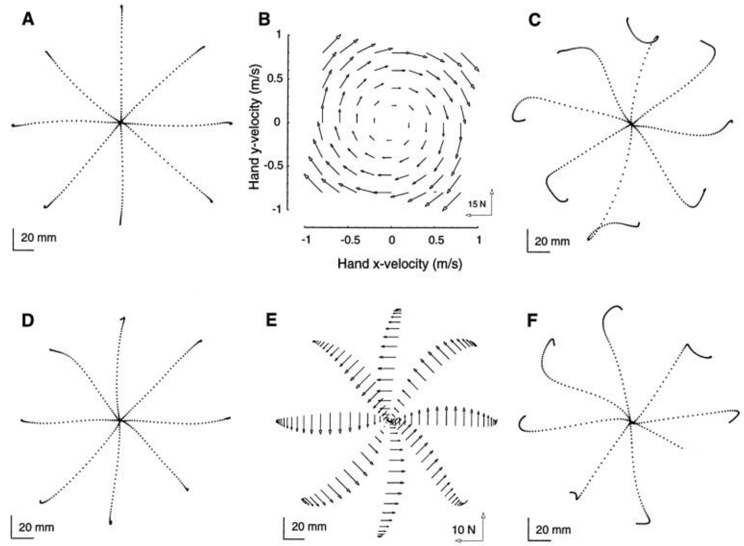
- Types of interrupt: proactive and retroactive
- What can interrupt consolidation?
  - Behavior
  - stimulation
  - Protein synthesis
- What can help consolidation?
  - Sleep
  - Multiple sessions

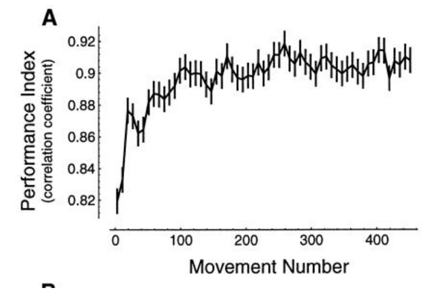


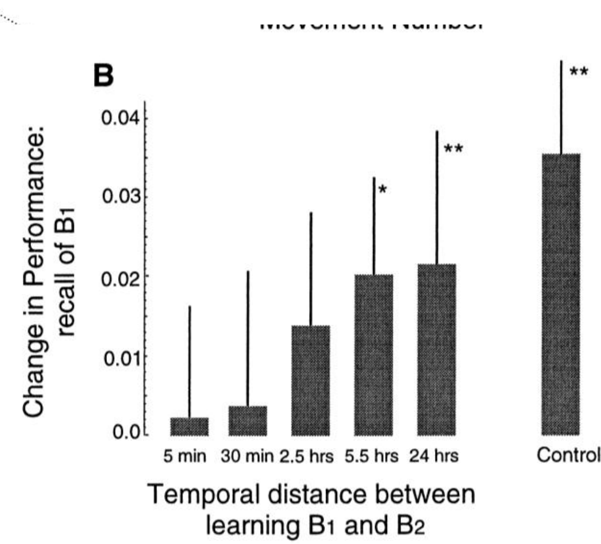
Testing motor consolidation

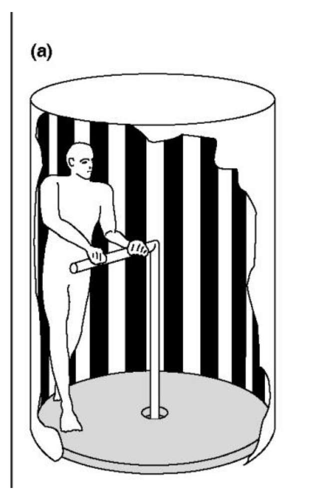






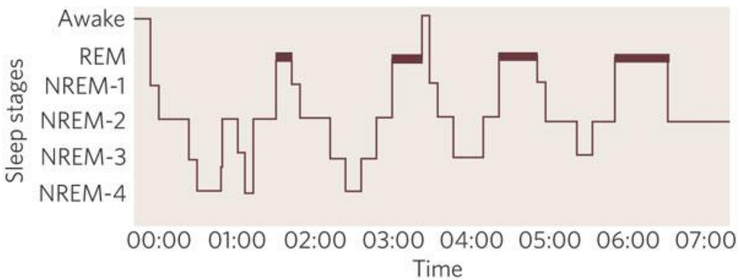


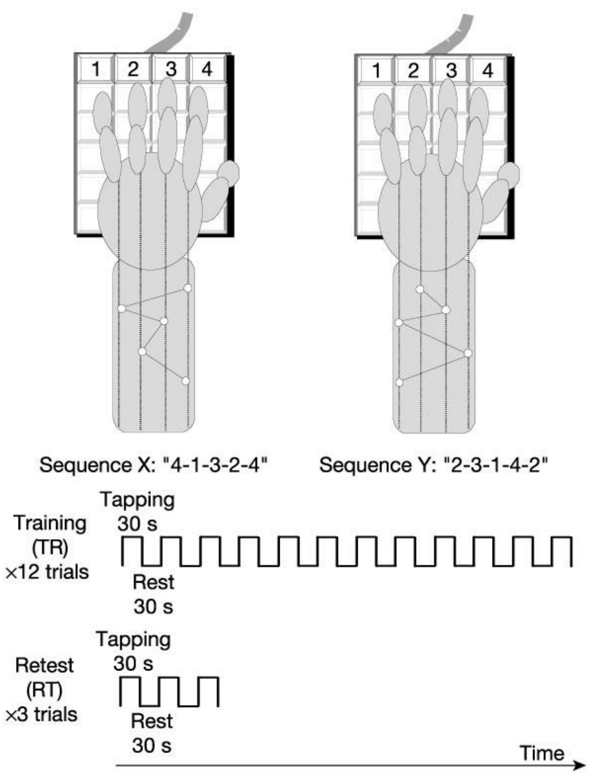


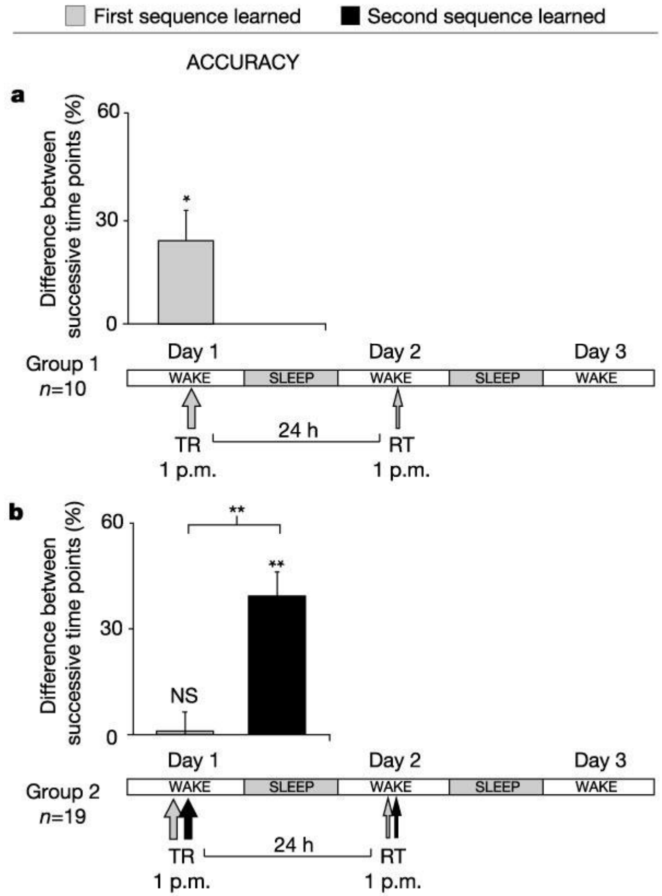


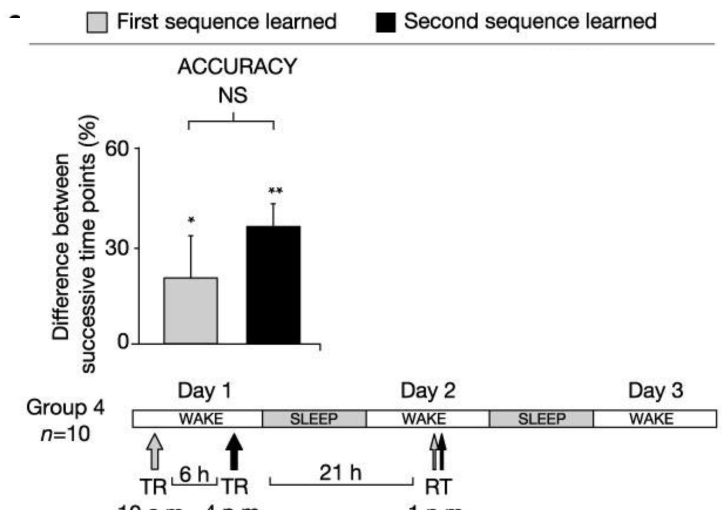
R. Shadmehr

Sleep on it







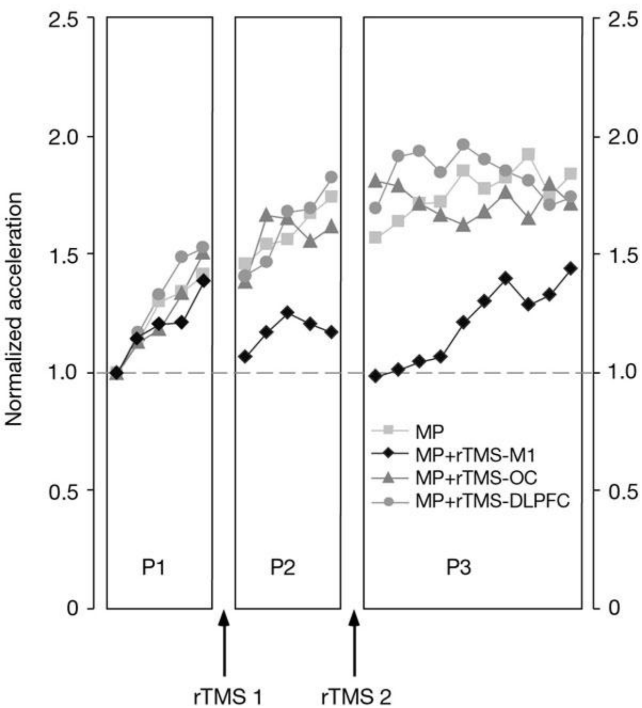


Stickgold R, Walker MP, Nature, 03

Where are motor memories stored?

Long-term representation in M1

Using TMS



Muellbacher W, Hallett, Nature, 02

Karni A, Nature, 95

A shift to pre-motor, cerebellum and parietal

6 hours

Enjoy your motor system and use it carefully

Next time: Reinforcement learning and more

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