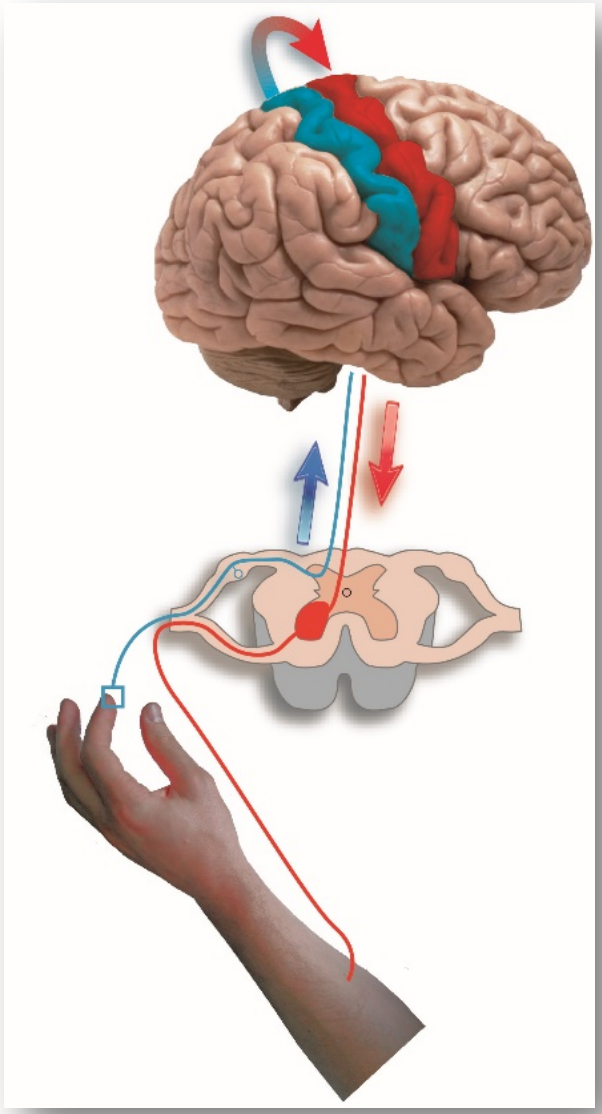
Sensations et actions en boucle fermée : le cas des interfaces cerveau-machine

Daniel Shulz (DR CNRS)
Département de Neuroscience intégratives et Computationnelles (ICN)
Institut de Neurosciences Paris-Saclay (Neuro-PSI)
CNRS-Univ. Paris-Sud, Gif sur Yvette

Boucle sensori-motrice



Toucher actif vs toucher passif

VOL. 69, NO. 6 NOVEMBER 1962

PSYCHOLOGICAL REVIEW

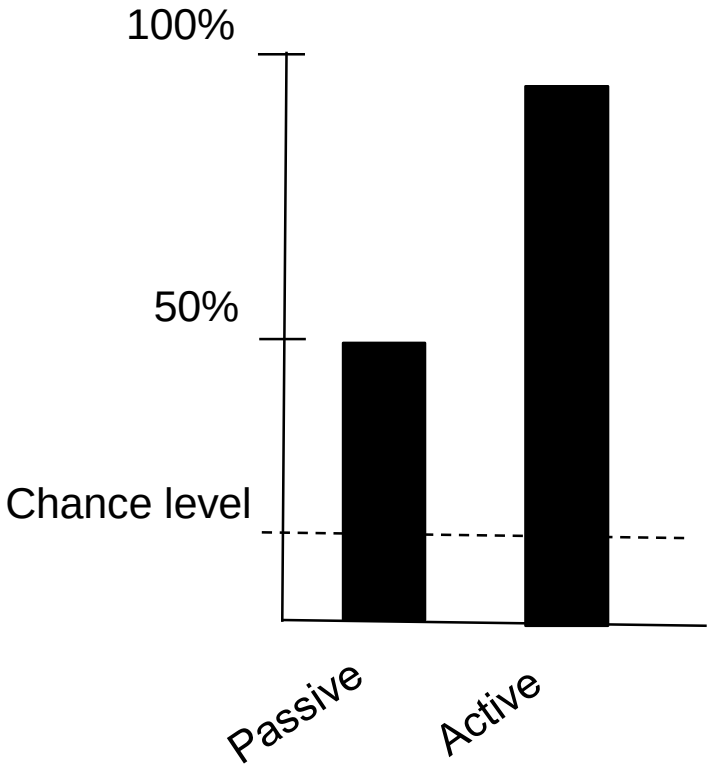
OBSERVATIONS ON ACTIVE TOUCH [1]

JAMES J. GIBSON

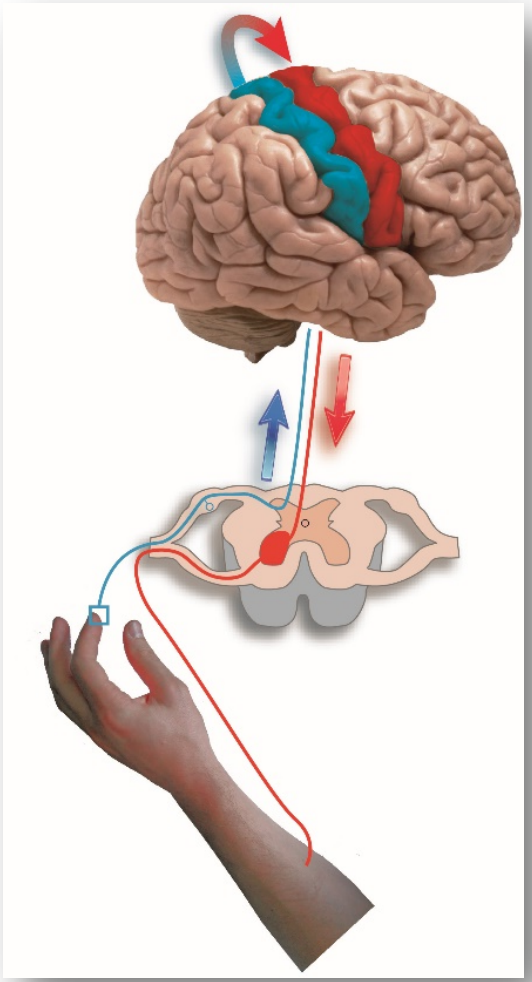
Cornell University

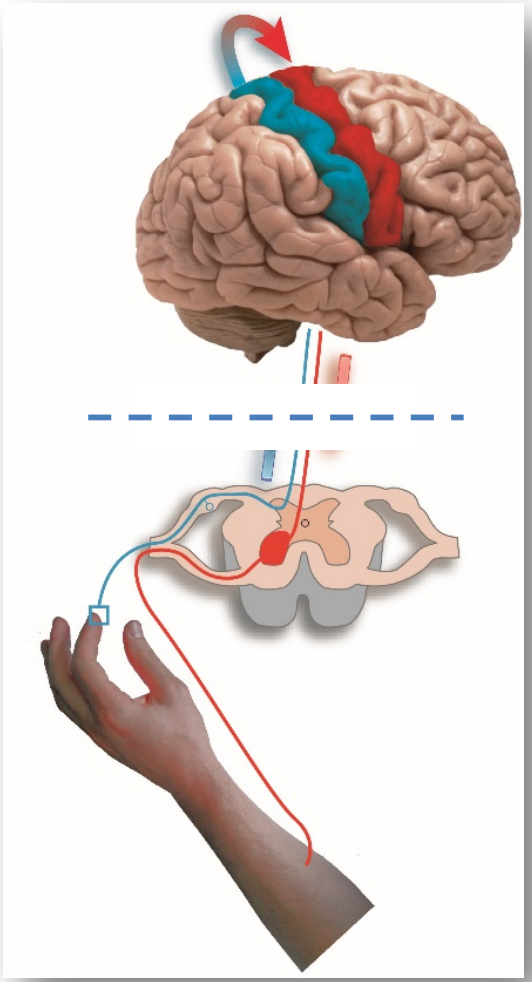
Active touch refers to what is ordinarily called *touching*. This ought to be distingushed from passive touch, or *being touched*. In one case the

these touching movements of the fingers are like the movements of the eyes. In fact, active touch can be termed *tactile scanning*, by analogy



Une lésion médullaire interrompt la boucle sensori-motrice



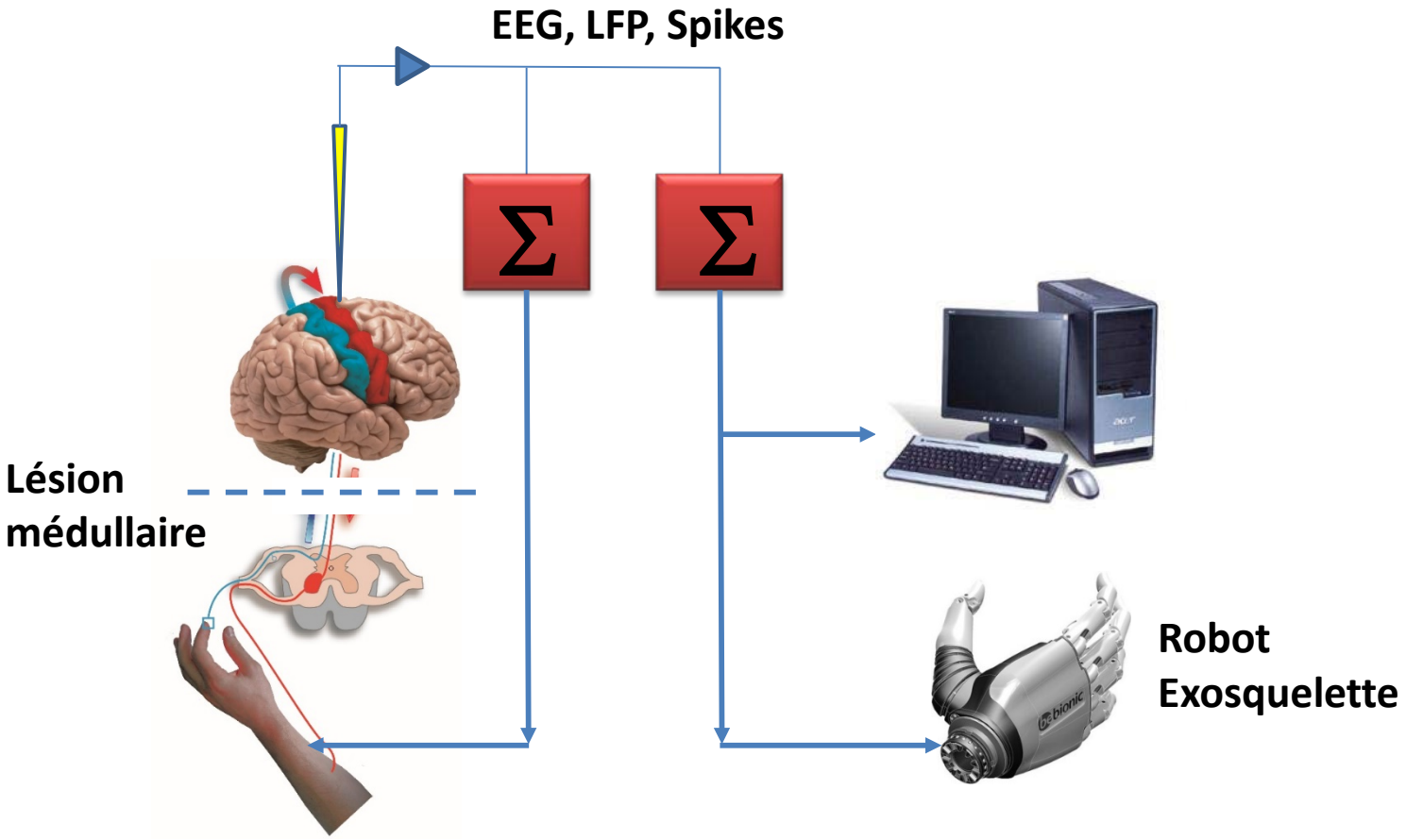


L'activité cérébrale reste intacte

Lésion médullaire

Les accidents (entre 1000 et 1500 par an en France), sont la première cause des lésions médullaires. Les estimations du nombre de personnes atteintes de para- ou tétraplégie en France sont de 25 000 à 30 000.

ICM - ICO



Brain–computer interfaces (BCI) and brain–machine interfaces (BMI) convert neural activity at the level of neuronal action potentials, ECoG, LFP, or EEG into signals that control computer cursors or external devices.

Cortex moteur et muscles

Relation of Pyramidal Tract Activity to Force Exerted During Voluntary Moveme

EDWARD V. EVARTS
Laboratory of Clinical Science, National Institute of Mental Health, National Institutes of Health, Bethesda, Maryland

1968

Edward V Evart

Activité neuronale

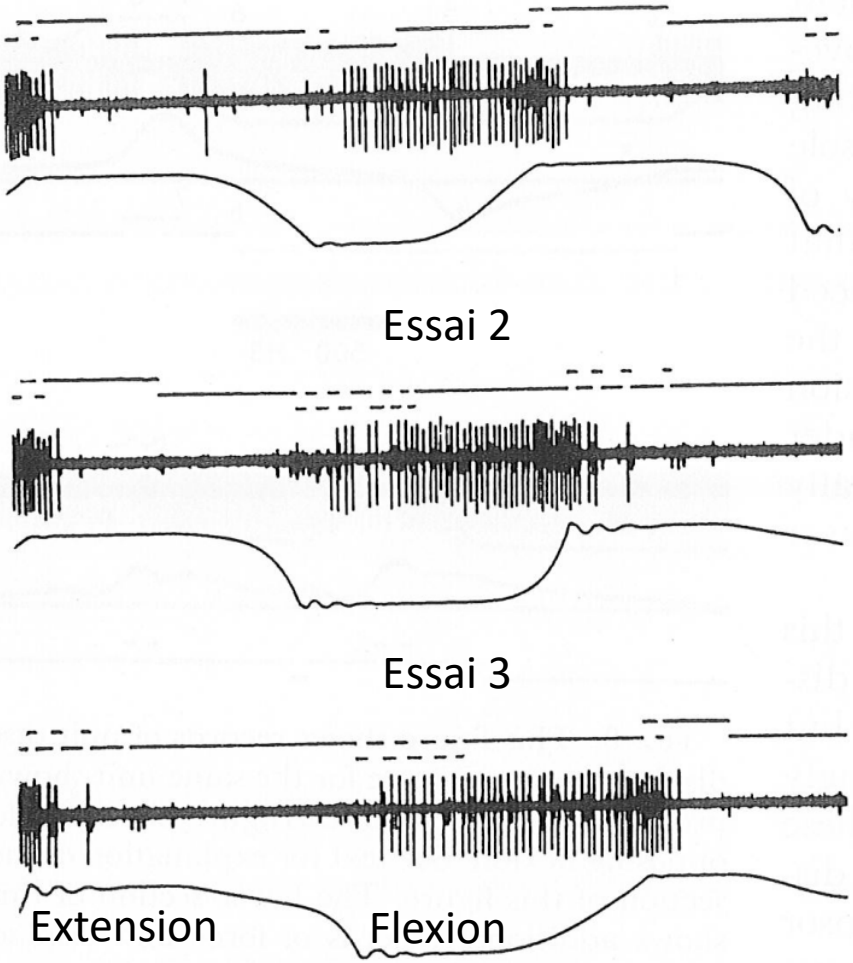
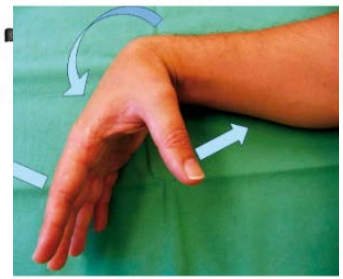
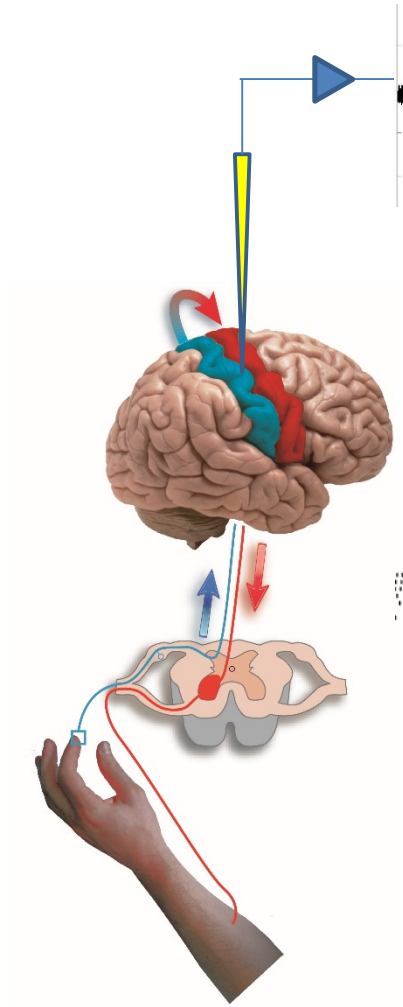
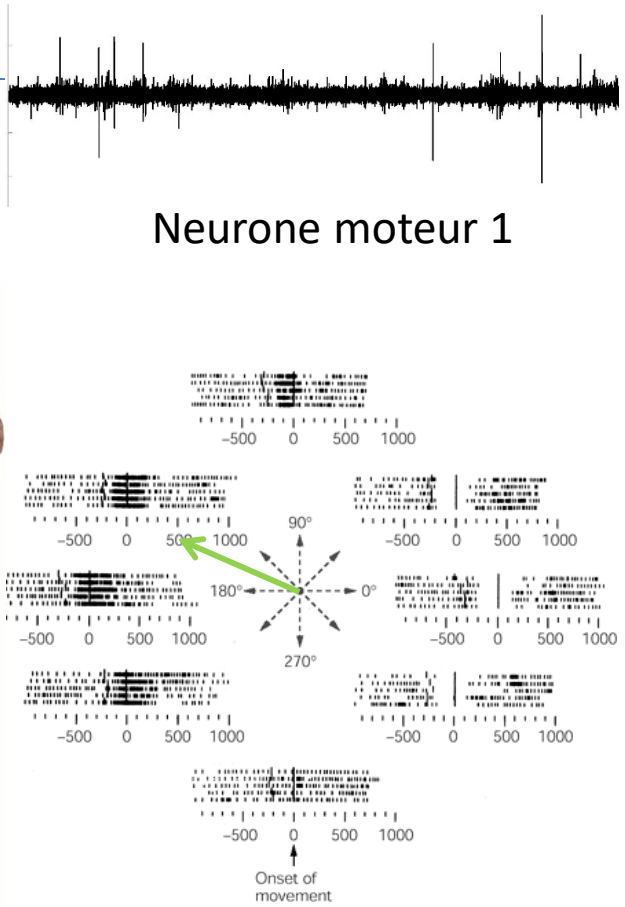


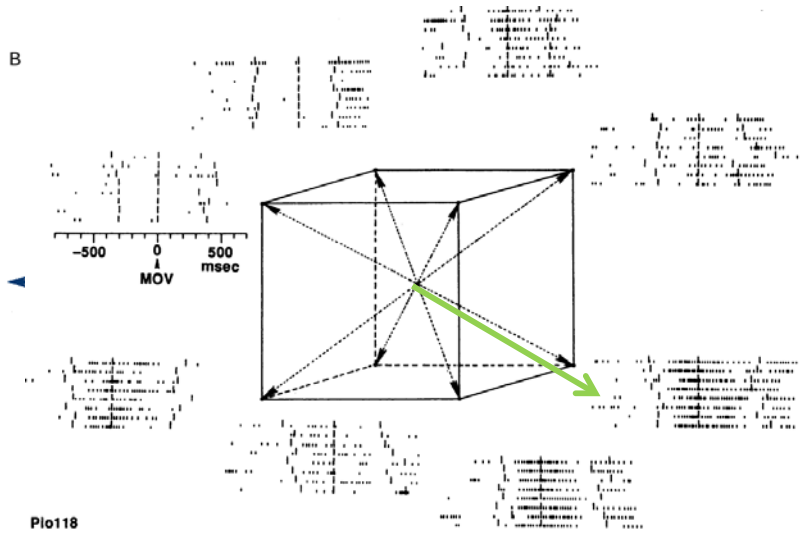
FIG. 6. This figure illustrates records of wrist displacement and unit activity on three successive cycles of the flexion-extension movement carried out with no load at all opposing the movement. The bottom line of each set of traces is the potentiometer output. When the potentiometer output is at its lowest position, the wrist is maximally extended and when the potentiometer is at its highest position, the wrist is maximally flexed. It may be seen that this unit was active during the flexion displacement and silent during the extension displacement.



Codage de la direction du mouvement par l'activité neuronale dans le cortex moteur

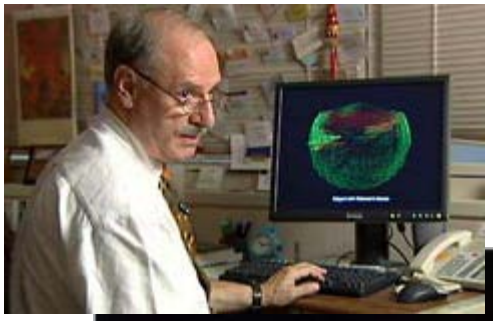




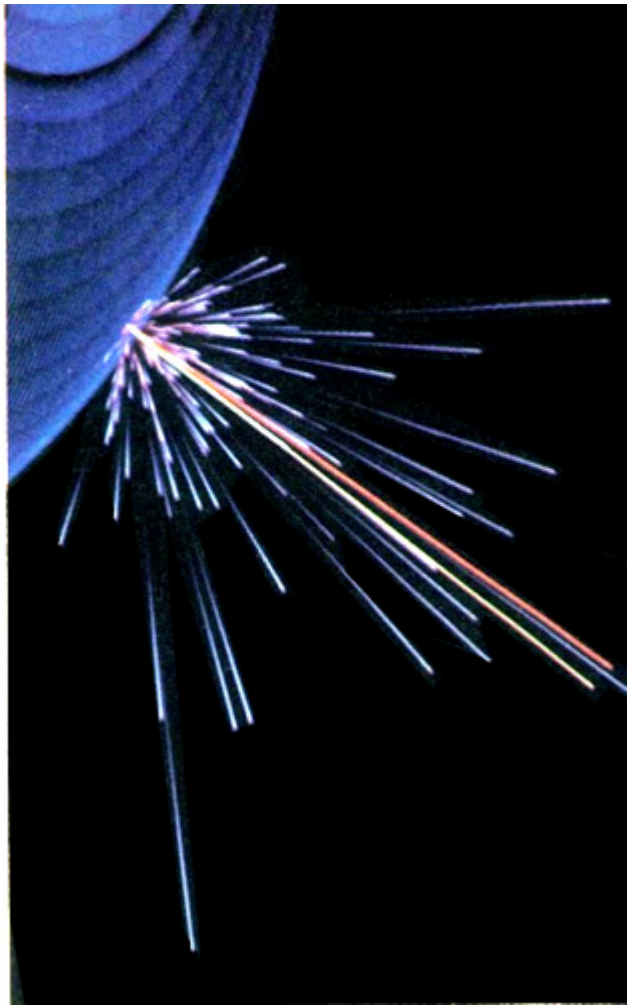


Georgopoulos et al., 1986, Science

Codage de la direction du mouvement par l'activité d'une population neuronale

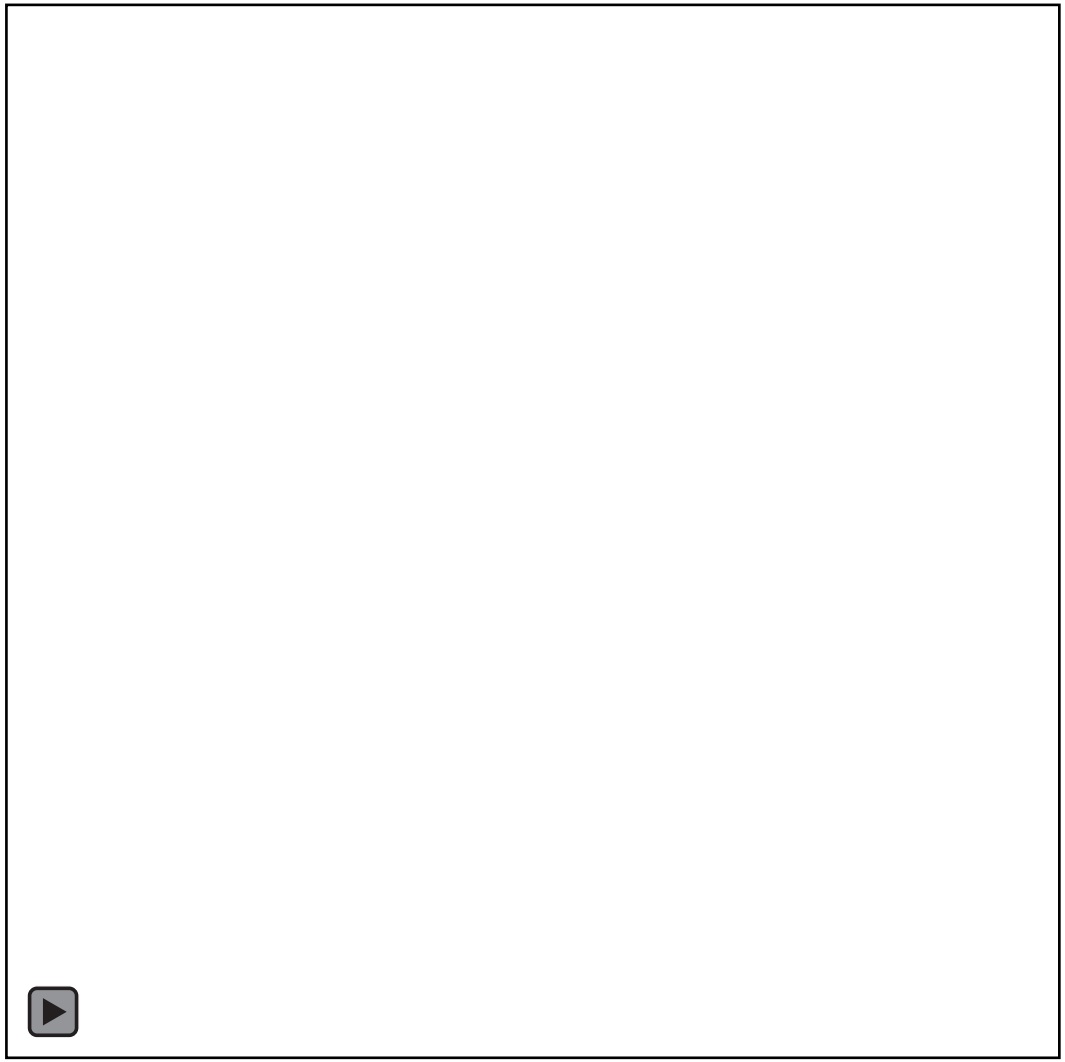


A. Georgopoulos

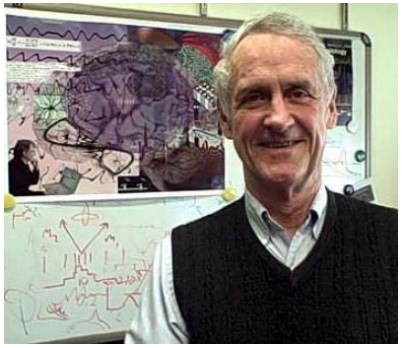


Georgopoulos et al., 1986, Science

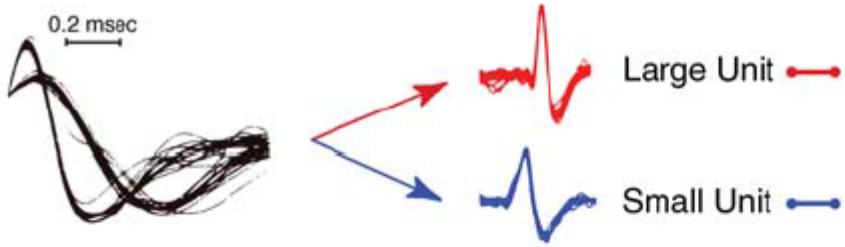
Codage de la direction du mouvement par l'activité d'une population neuronale

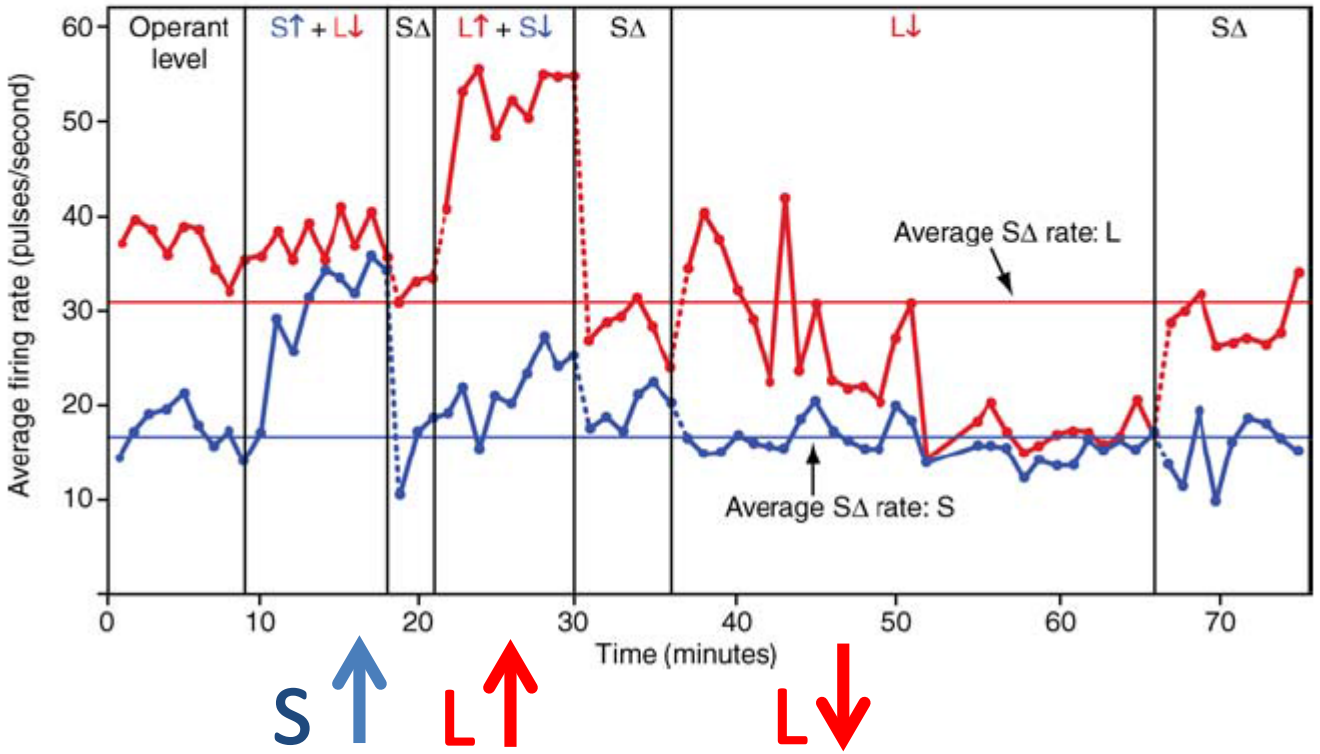


Contrôle volontaire de l'activité neuronal: implications pour les interfaces cerveau-machine



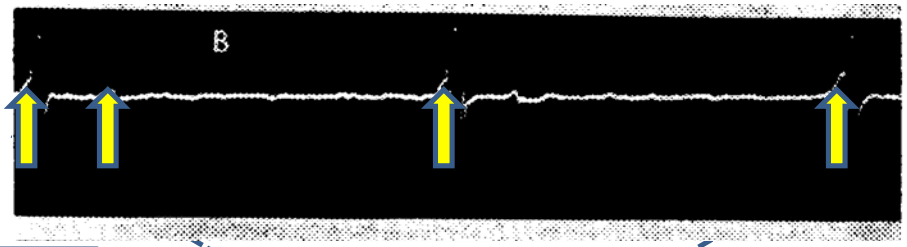
Eberhard Fetz
Univ. of Washington

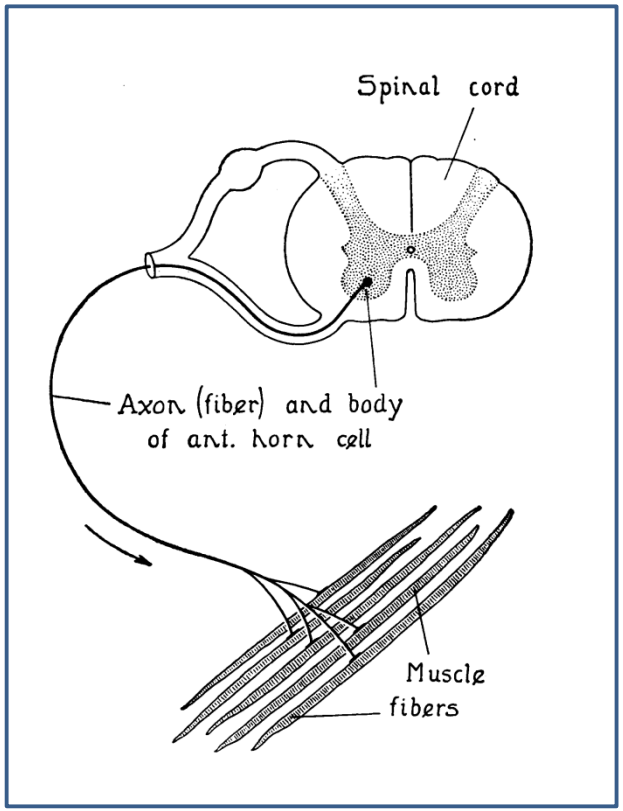


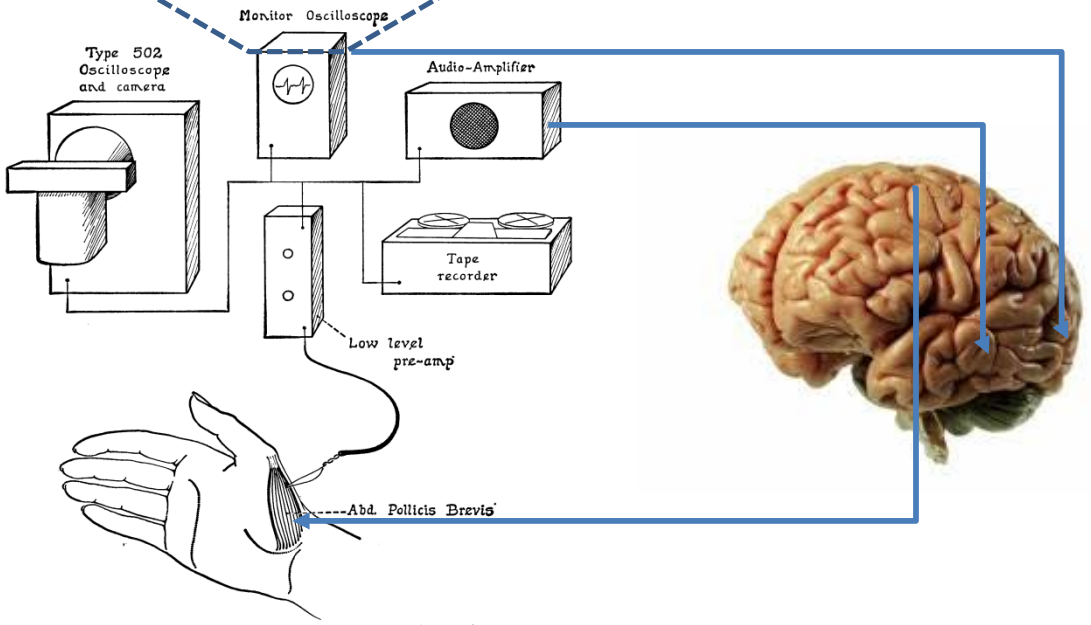


Fetz 1969 Nature
Fetz 2007 *J. Physiol.*

Contrôle et entrainement d'unités motrices individuelles



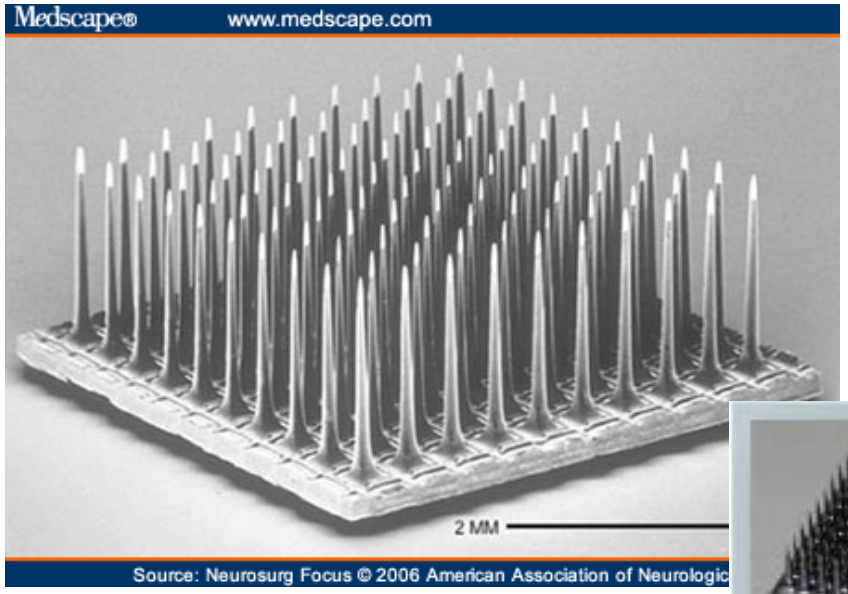


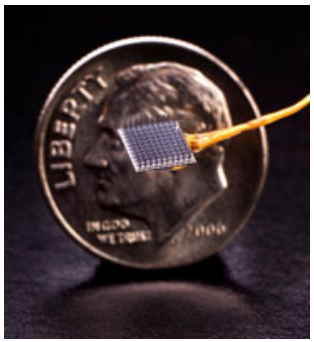


Les expériences montrent qu'avec le retour auditif et visuel, un sujet peut contrôler la contraction d'une unité motrice unique!! Après entrainement, le sujet peut reactiver différentes unités utilisant la pensé et inhiber d'autres.

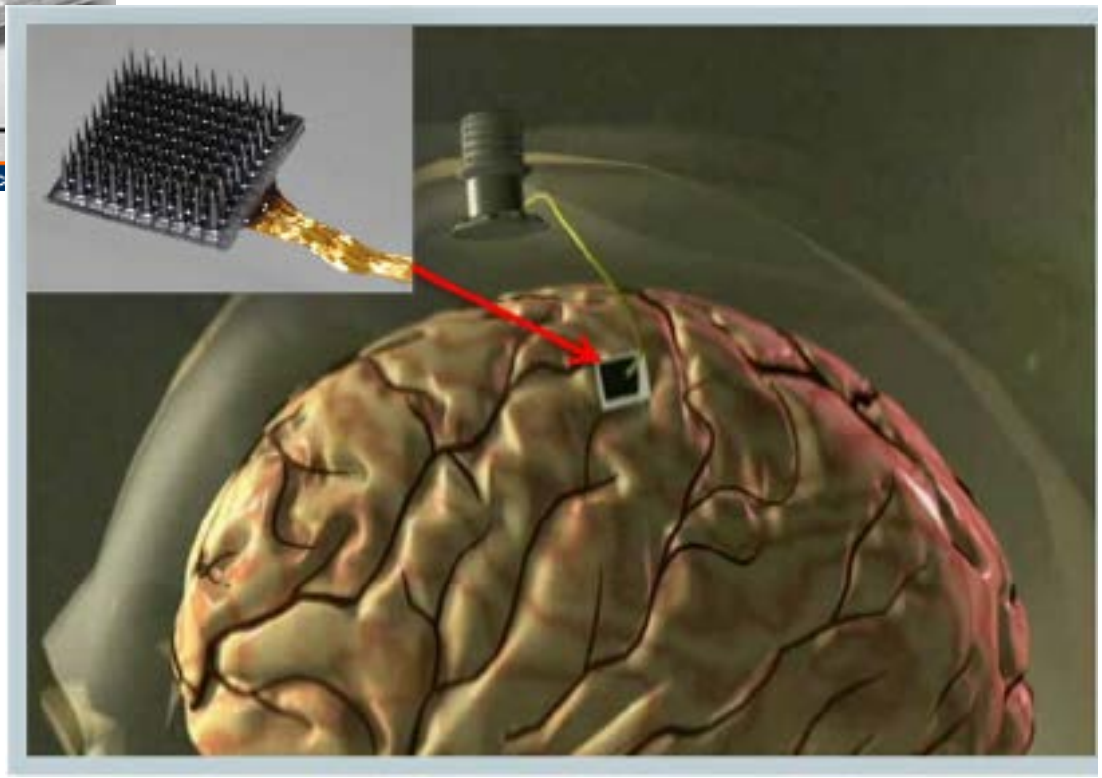
J. V. BASMAJIAN
Queen's University, Kingston, Ontario
Science 1963

Des électrodes pour l'enregistrement de l'activité nerveuse corticale

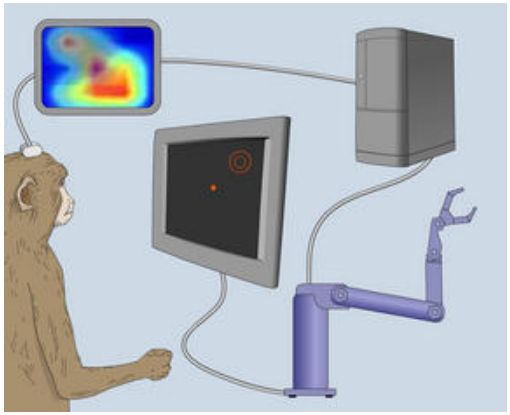


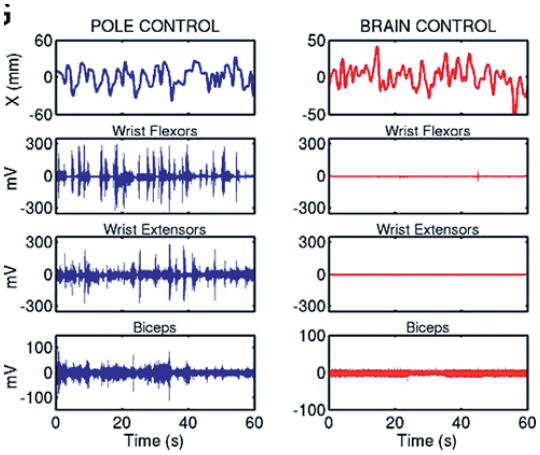


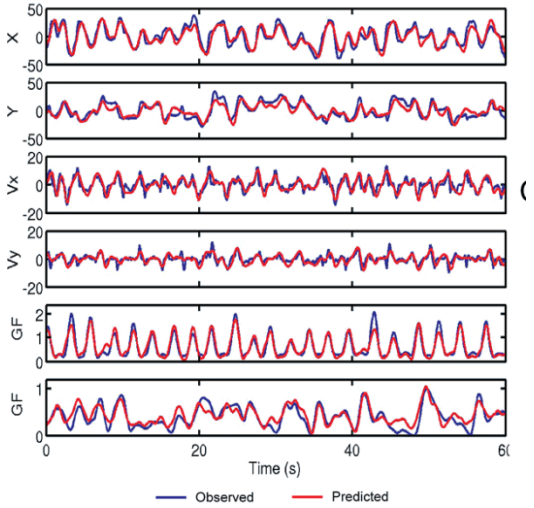
Utah arrays: 100 électrodes

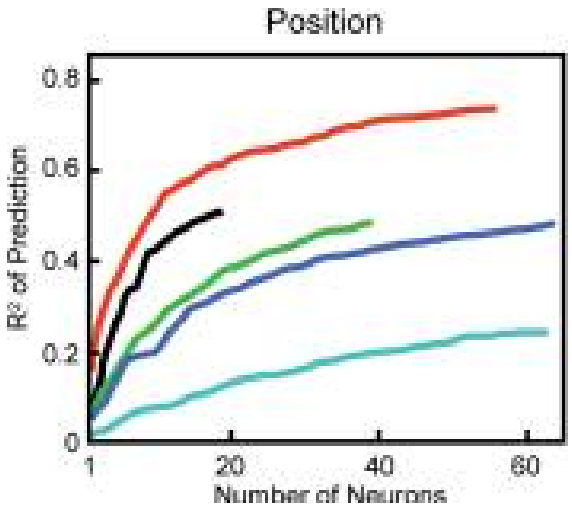


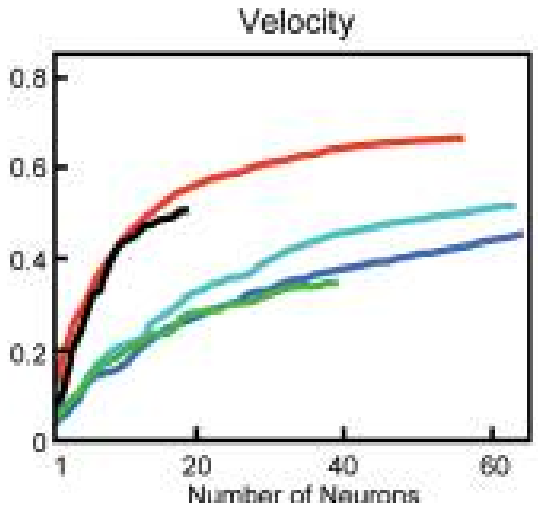
Prédiction des paramètres du mouvement en fonction du nombre de neurones et des aires corticales

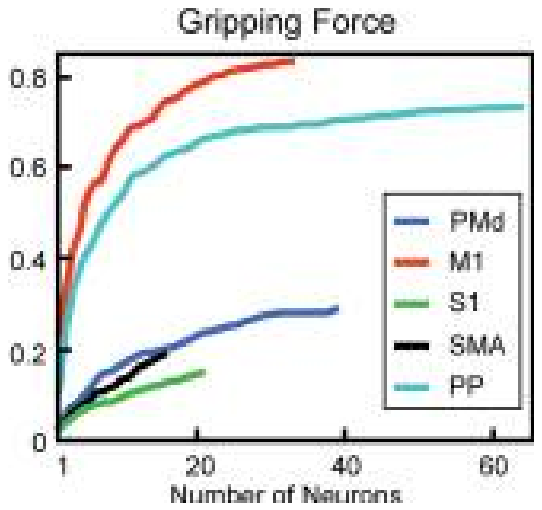












Carmena et al., 2003

Nature. 2008 Jun 19;453(7198):1098-101. doi: 10.1038/nature06996. Epub 2008 May 28.

Cortical control of a prosthetic arm for self-feeding.

Velliste M[1], Perel S, Spalding MC, Whitford AS, Schwartz AB.

For the movie see:

https://speakingofresearch.com/2008/05/30/monkeys-robots-and-the-university-of-pittsburgh-new-hope-for-paralysis-victims/

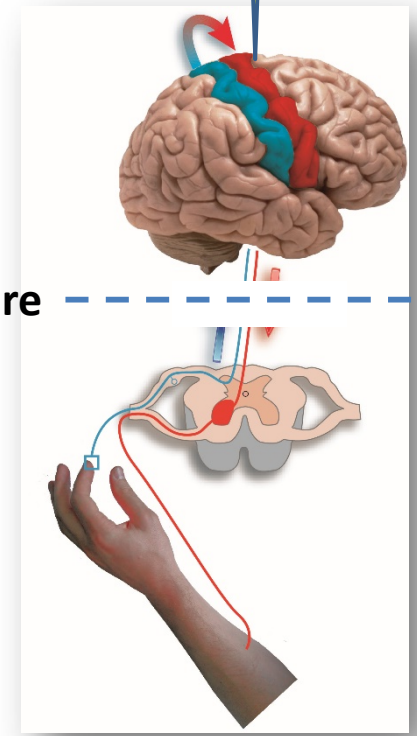
Reach and grasp by people with tetraplegia using a neurally controlled robotic arm.

Hochberg LR, Bacher D, Jarosiewicz B, Masse NY, Simeral JD, Vogel J, Haddadin S, Liu J, Cash SS, van der Smagt P, Donoghue JP.
Nature. 2012 May 16;485(7398):372-5. doi: 10.1038/nature11076.

For the movie go to:
https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3640850/

2 strategies pour le contrôle de l'ICM

EEG, LFP, Spikes

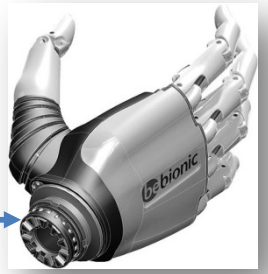


Lésion médullaire

Σ

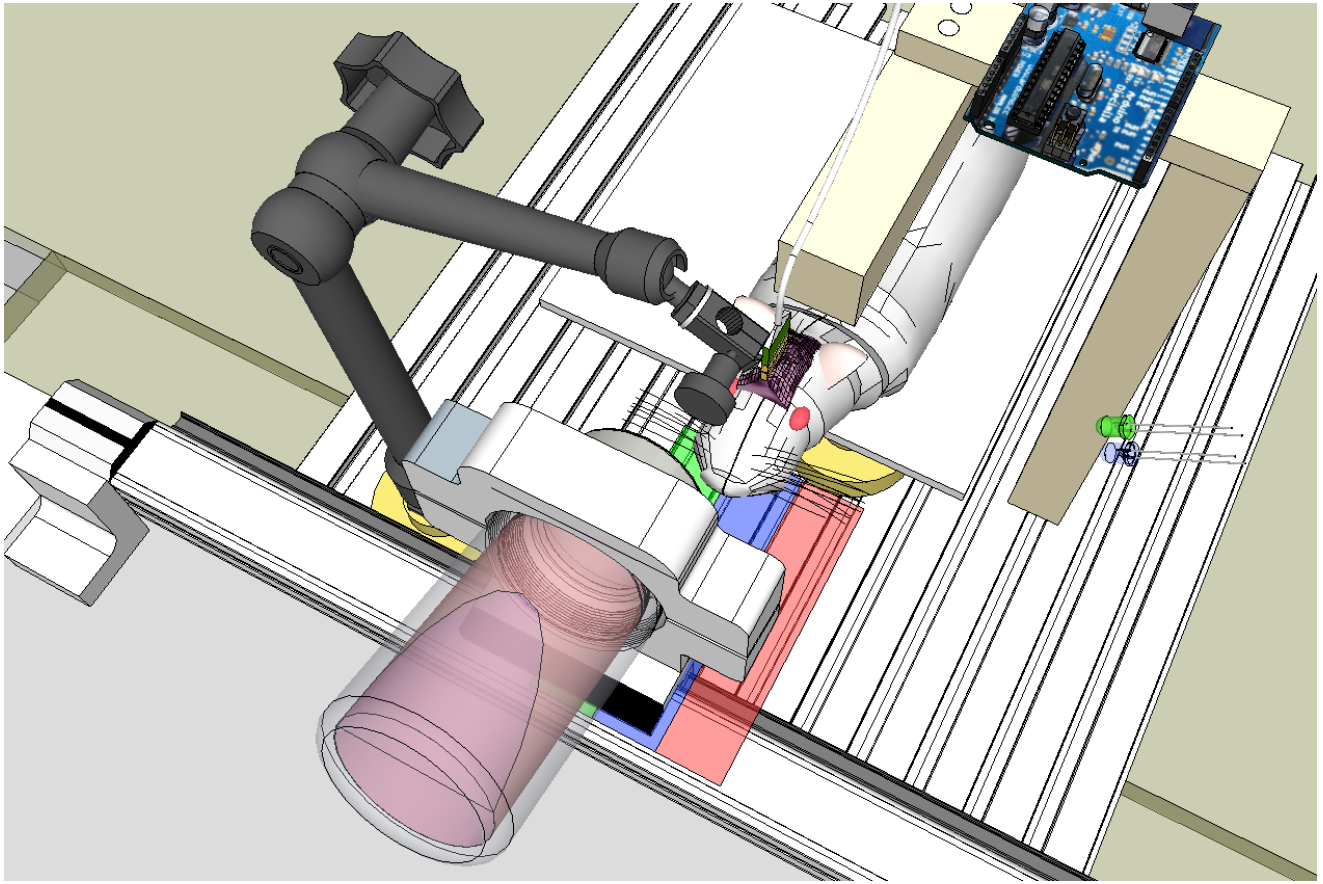
- Décodage de l'activité

- Conditionnement cellulaire



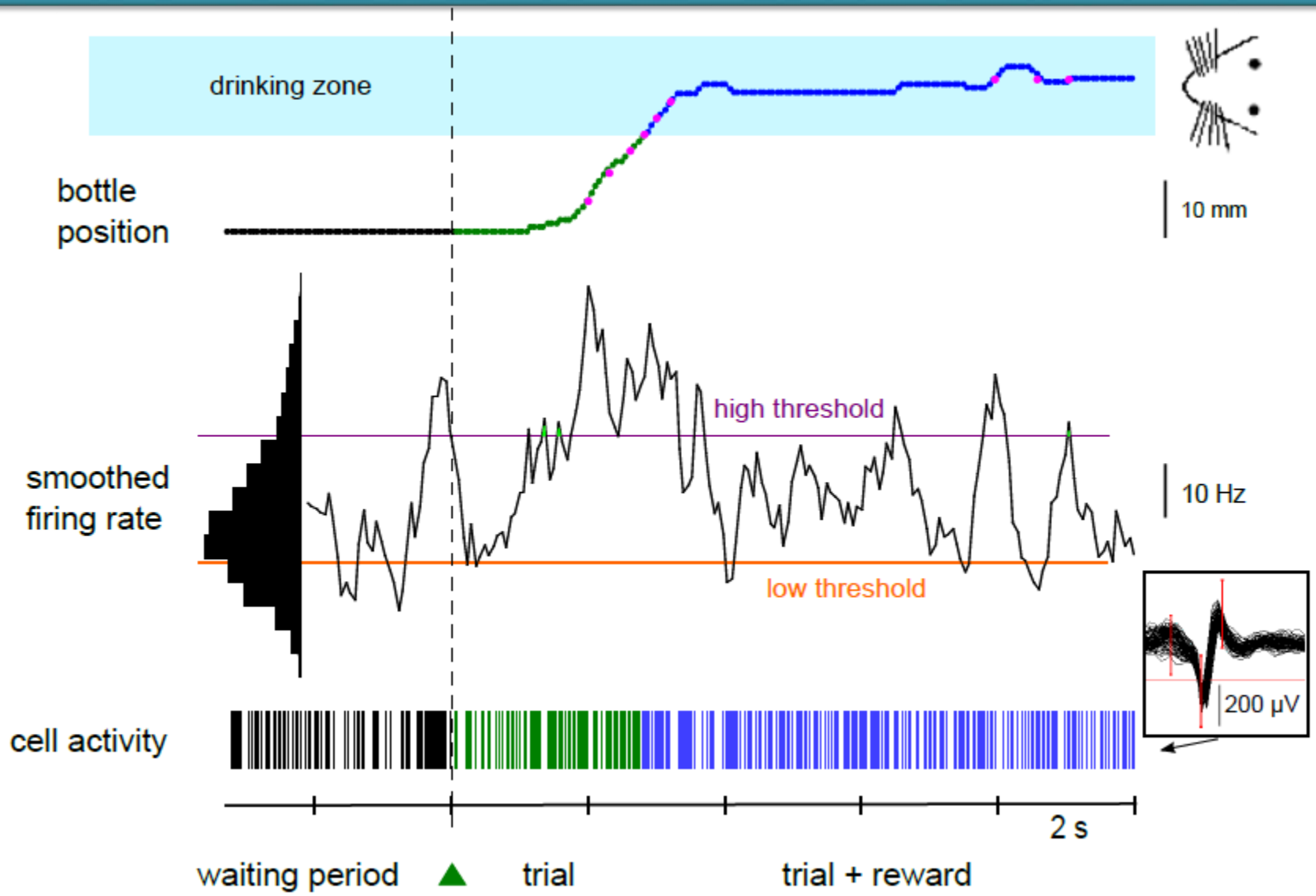
Robot
Exosquelette

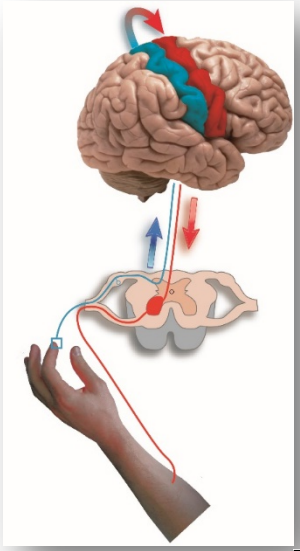
Conditionnement opérant de neurones corticaux pour le contrôle d'une prothèse par la fréquence de décharge neuronale



Arduin, Frégnac, Shulz & Ego-Stengel (2013) (J. Neuroscience)
Arduin, Frégnac, Shulz & Ego-Stengel. (2014) (Frontiers in Neuroprosthetics)

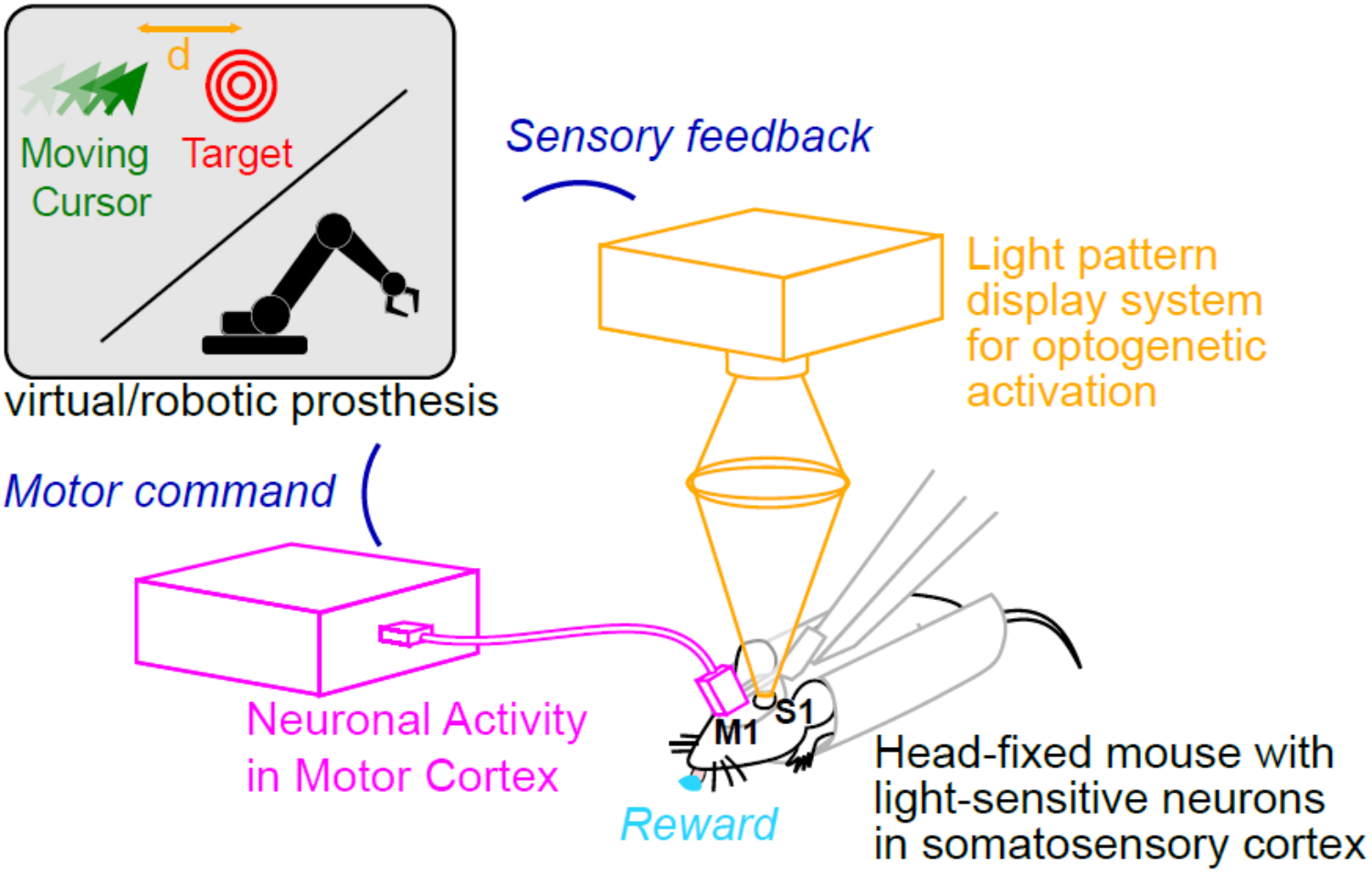
Conditionnement opérant de neurones corticaux pour le contrôle d'une prothèse par la fréquence de décharge neuronale



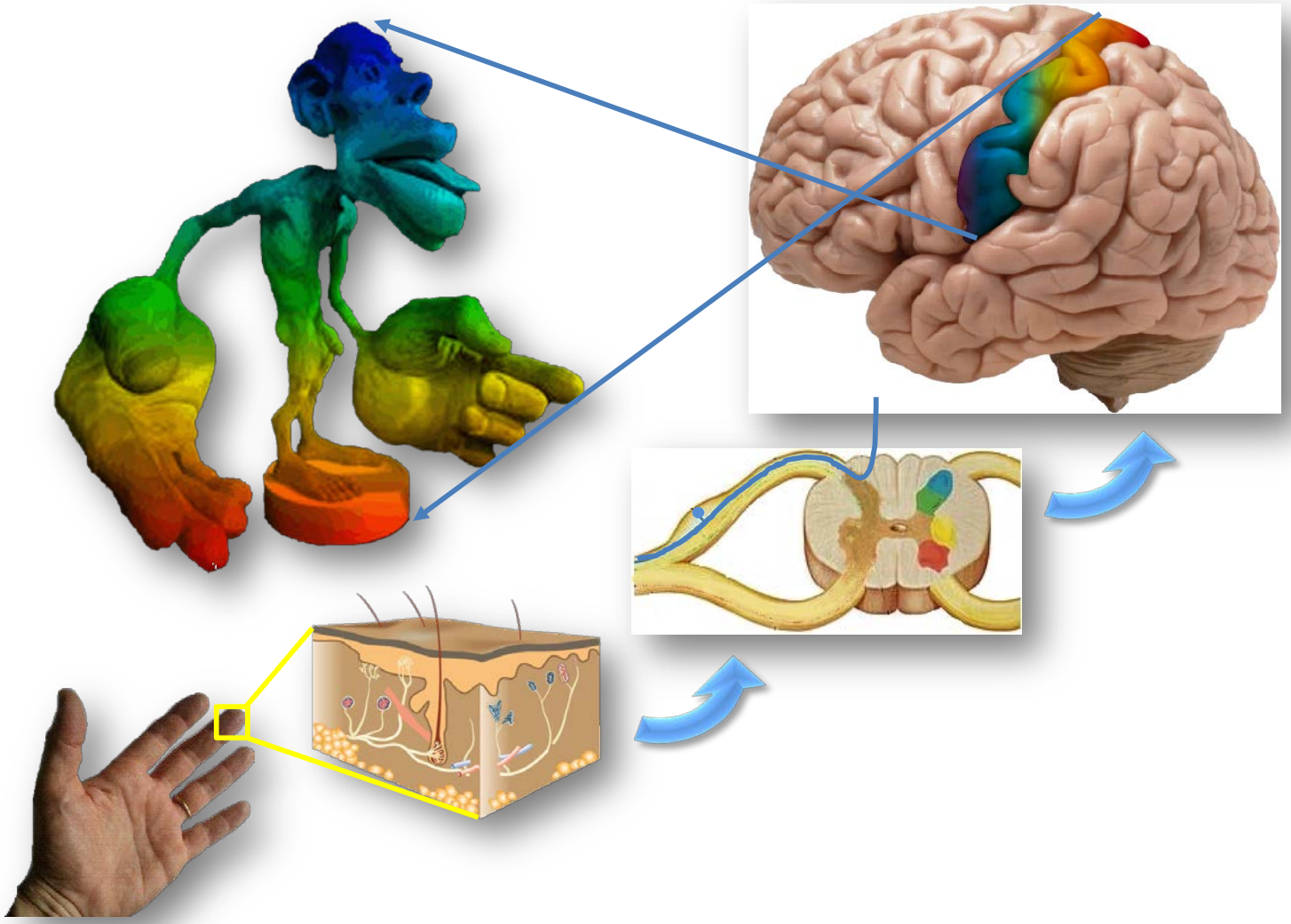


Dégradation du contrôle moteur en l'absence de retour sensoriel

ICM avec retour sensoriel par activation optogénétique



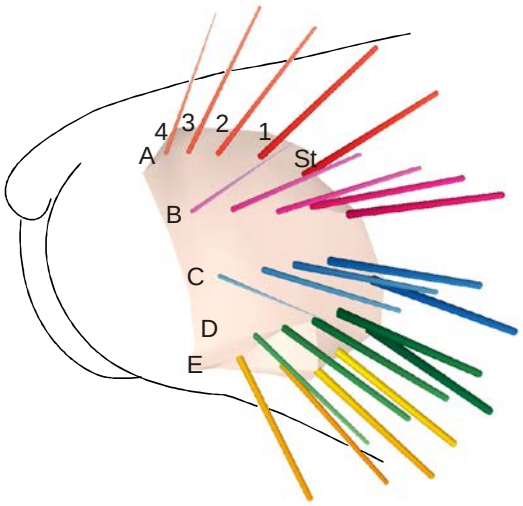
De la peau au cerveau: l'homunculus sensoriel



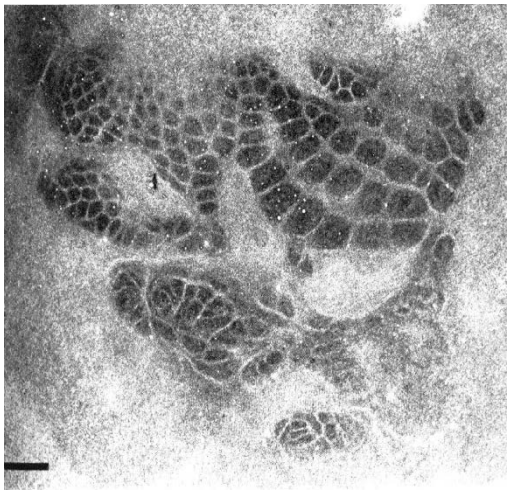
Ces cartes décrites par Wilder Penfield montrent que chaque partie du corps est représentée sur une bande du cortex cérébral, le cortex somatosensoriel, qui reçoit les sensations du toucher. Les doigts et la bouche occupent une partie élargie de la carte.

Des moustaches au cerveau: le ratunculus

The mystacial pad

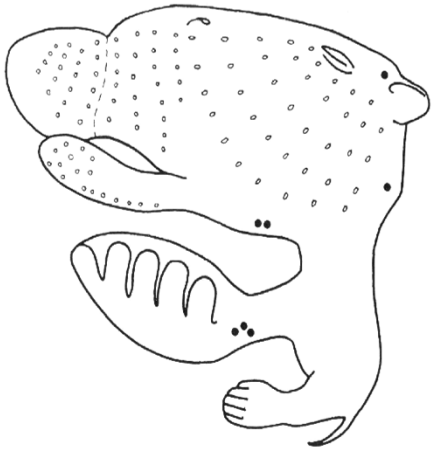


Barrel cortex



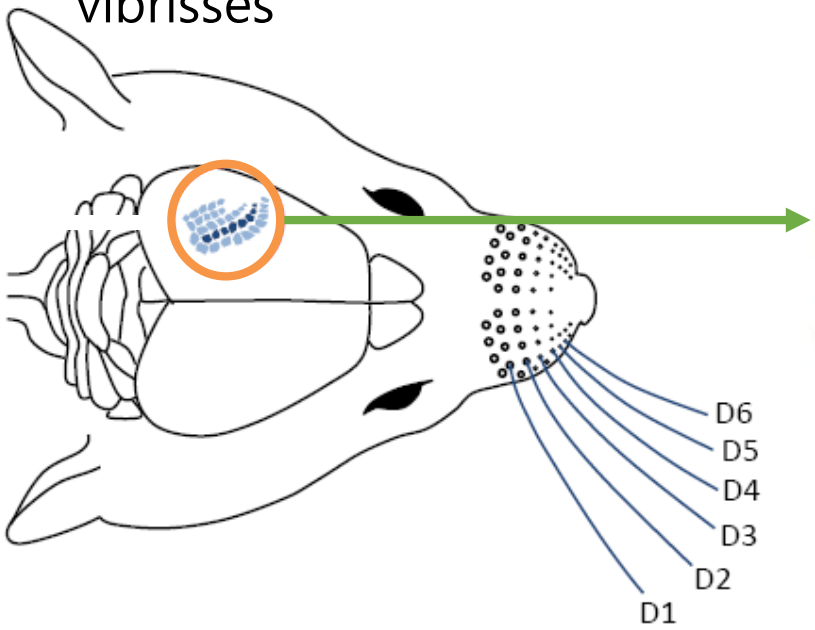
Dawson & Killakey (1987)

Ratunculus

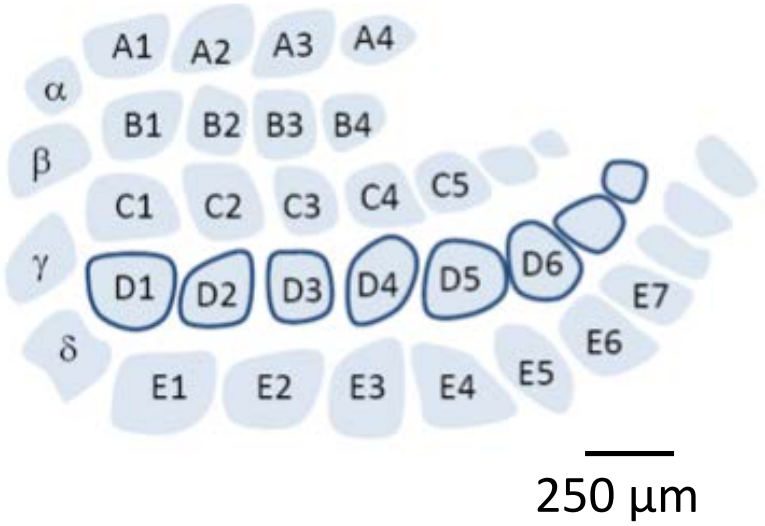


Le cortex sensoriel ou cortex à tonneaux

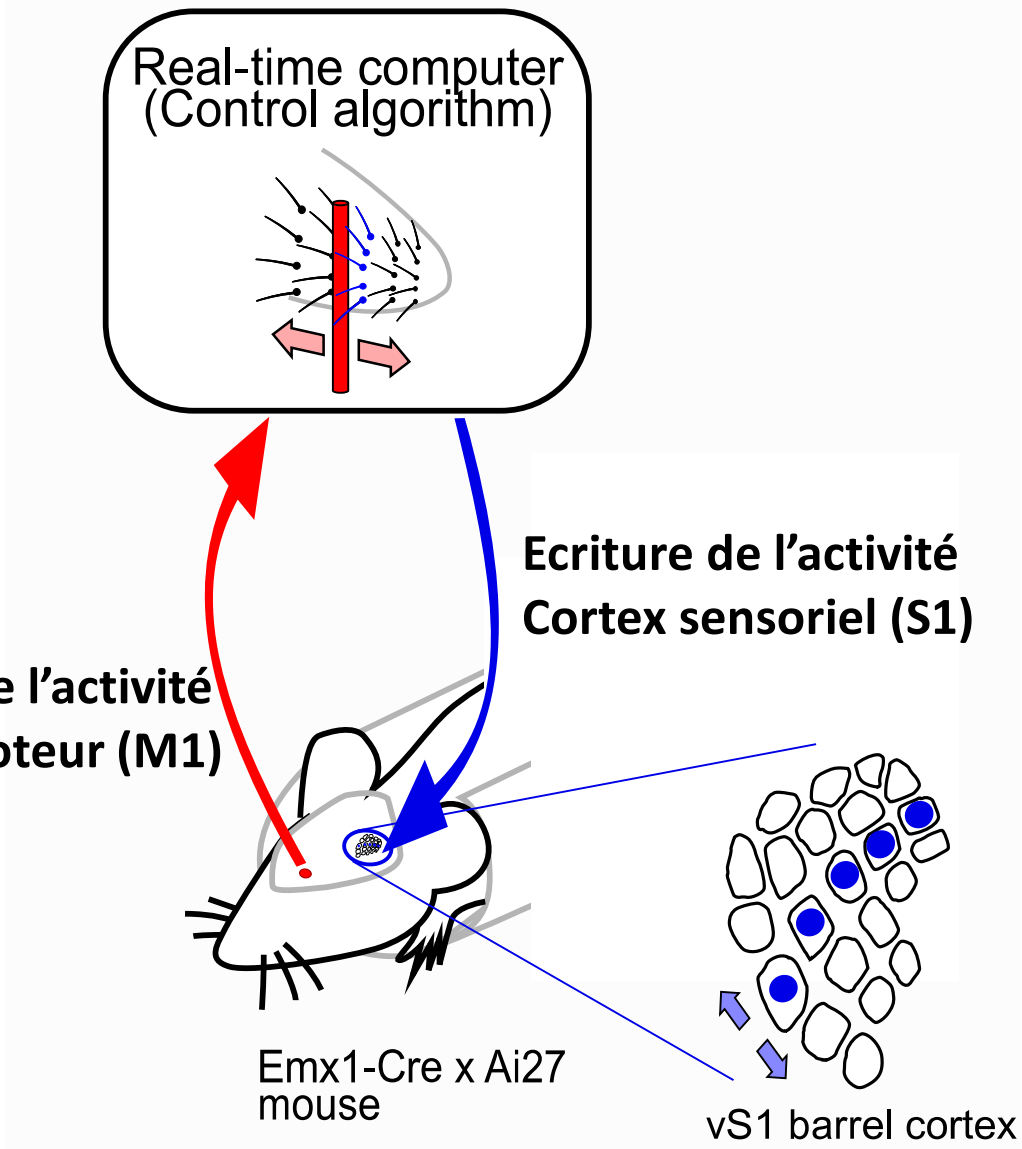
Le système de vibrisses



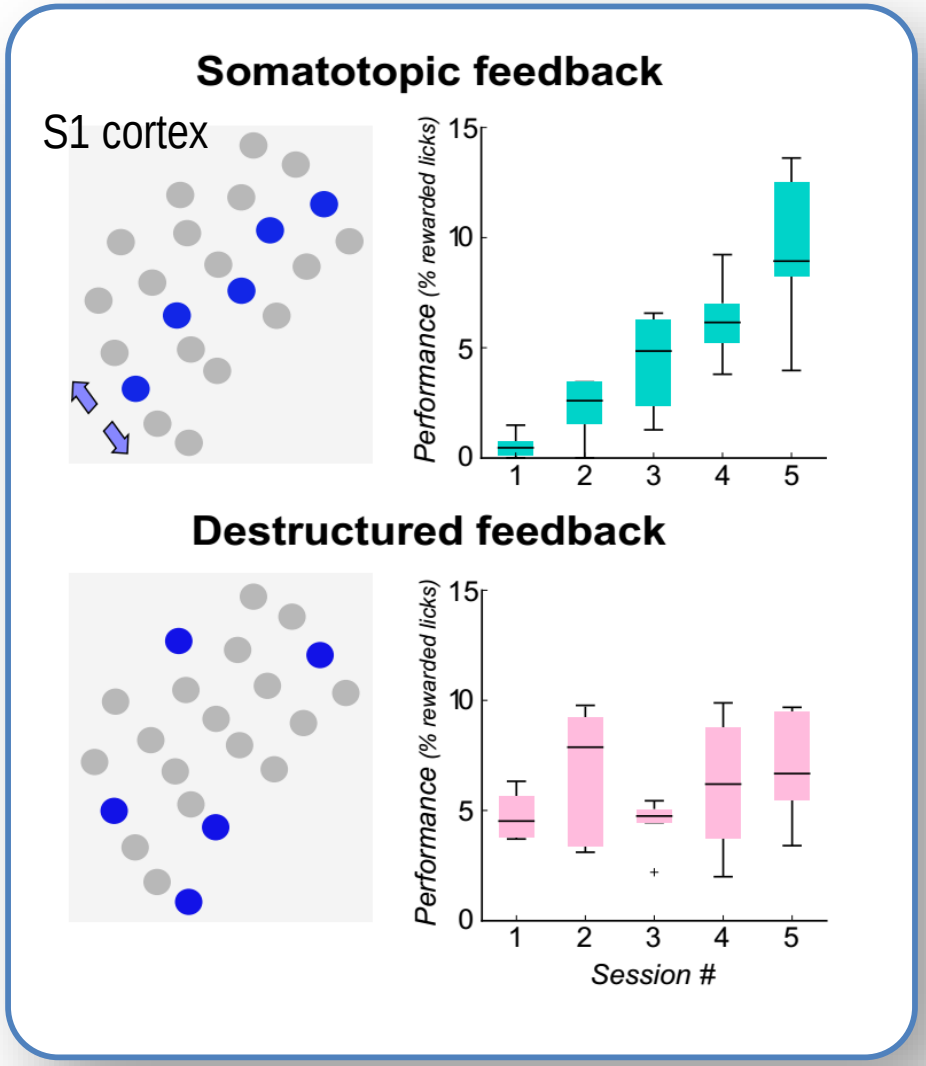
Des tonneaux dans le cortex somatosensoriel



Une boucle sensorimotrice entre le cortex moteur et le cortex somatosensoriel

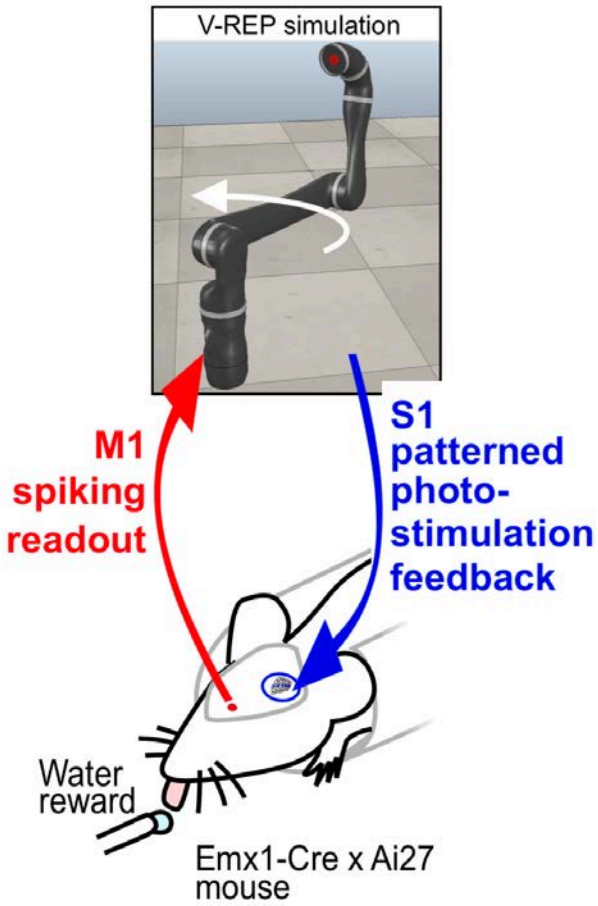


Le retour sensoriel structuré améliore la performance

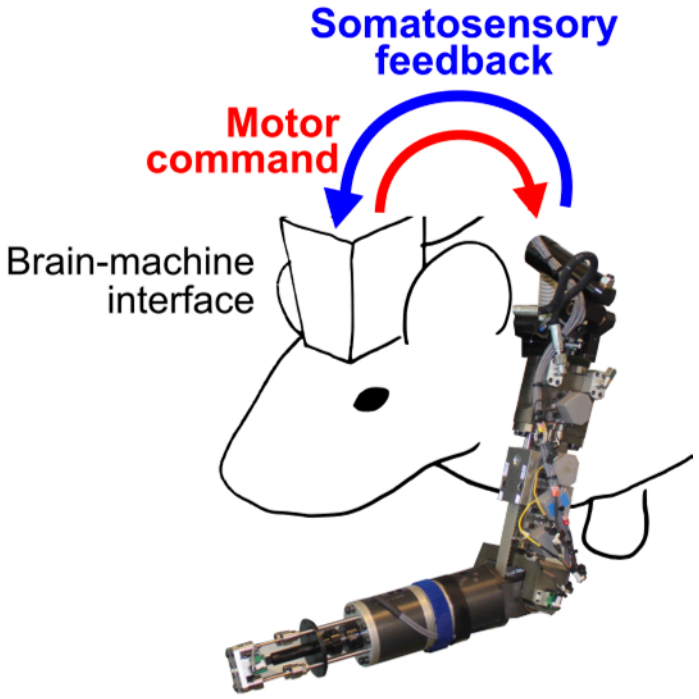


Future developments: interfacing with real-world prostheses

Closed-loop control of a robotic arm simulation

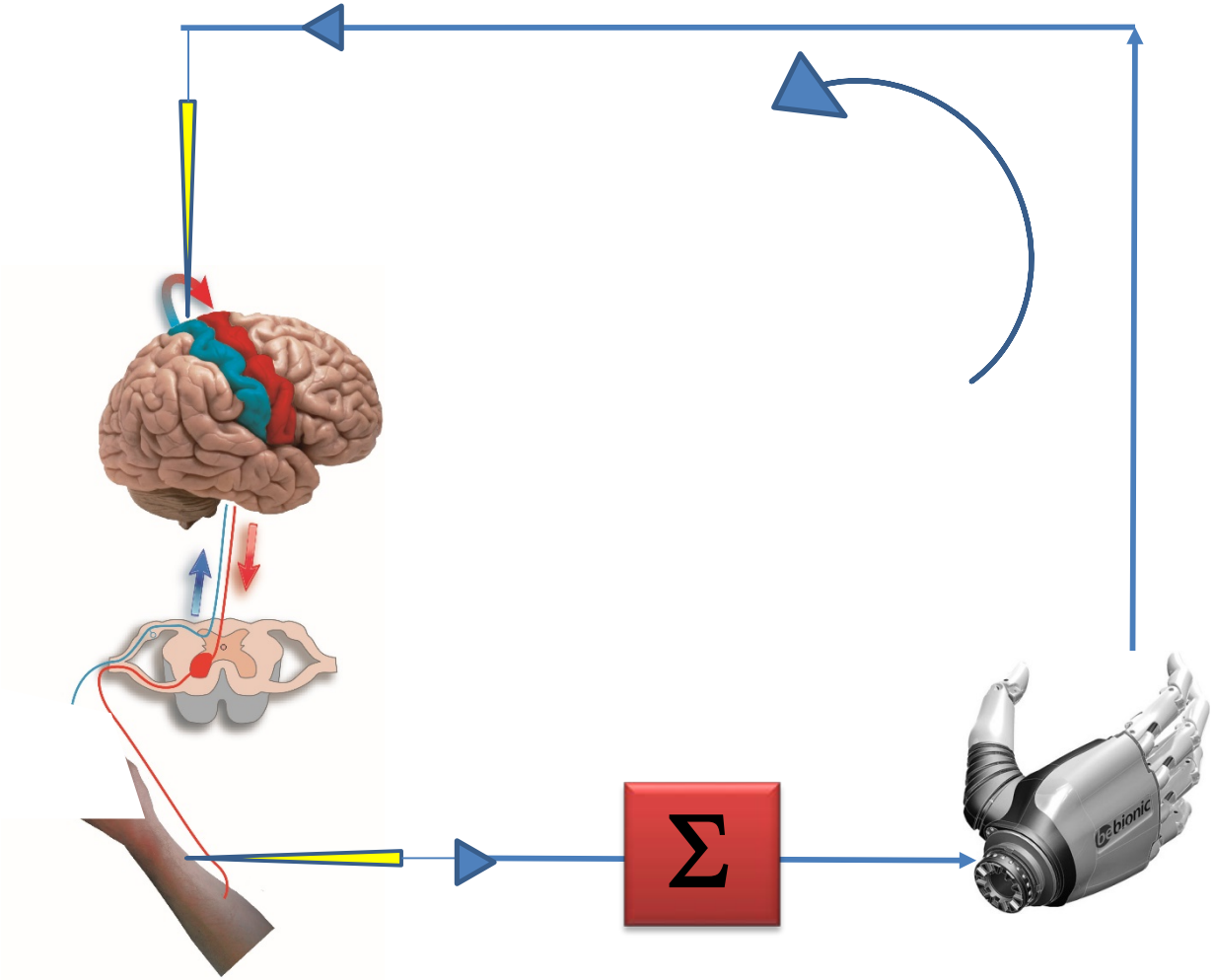


Controling a mouse-scale exoskeleton with a brain-machine interface

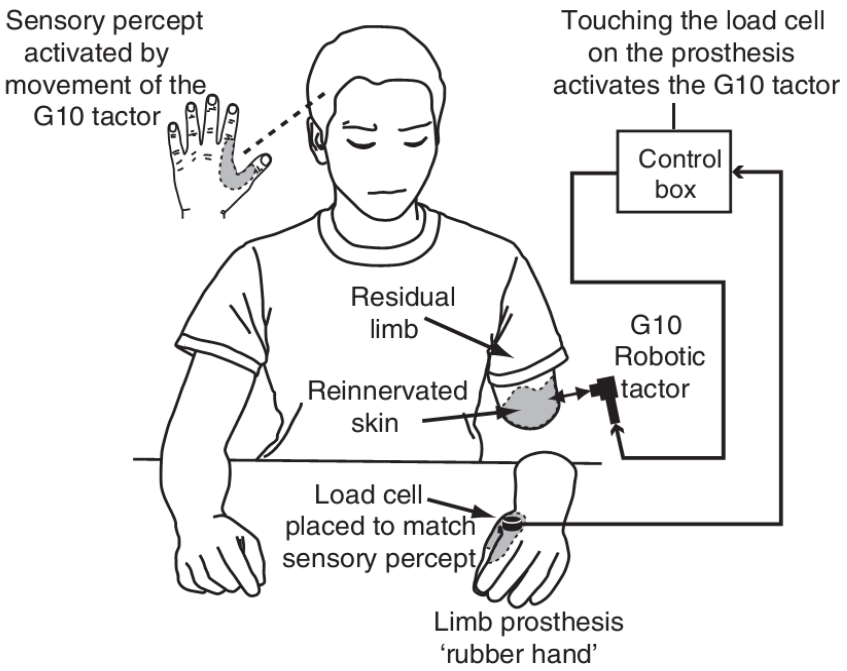


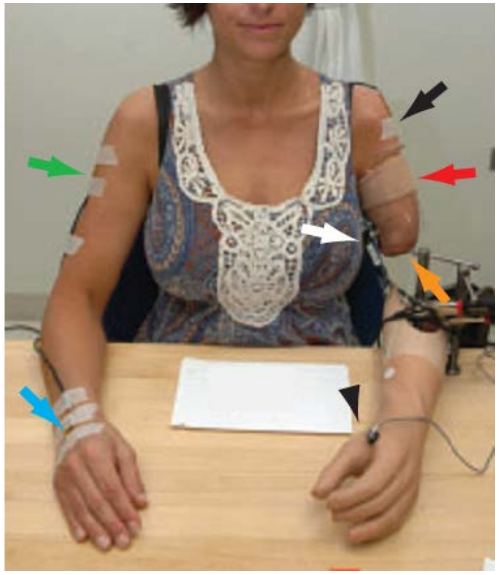
Miniaturized arm with actuators and touch sensors

ICM - ICO



Incorporation (embodiement) étudiée avec l'illusion de la main prosthétique





"After a few minutes I moved my phantom hand and expected the prosthetic to move and was surprised it did not"

Marasco et al. (2011) *Brain*

Team: Sensori-motor processing and Plasticity

PI: Daniel Shulz

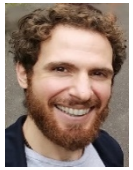
(DR1 CNRS, HDR)

Supported by CNRS, EU FET, ANR, FRM, UPSaclay, ENP, HFSP, France-Berkeley Fund

Valérie Ego-Stengel (CR, CNRS, HDR)

Luc Estebanez (CR, CNRS)

Isabelle Férézou (CR, CNRS, HDR)



Matías Goldin (Postdoc)

Evan Harrell (Postdoc)

co-directed with Brice Bathellier (ICN)

Aamir Abbasi (PhD student)

Dorian Goueytes (PhD student)

Sophie Hubatz (PhD student)

T. Jost-Mousseau (PhD student)

Henri Lassagne (PhD student)