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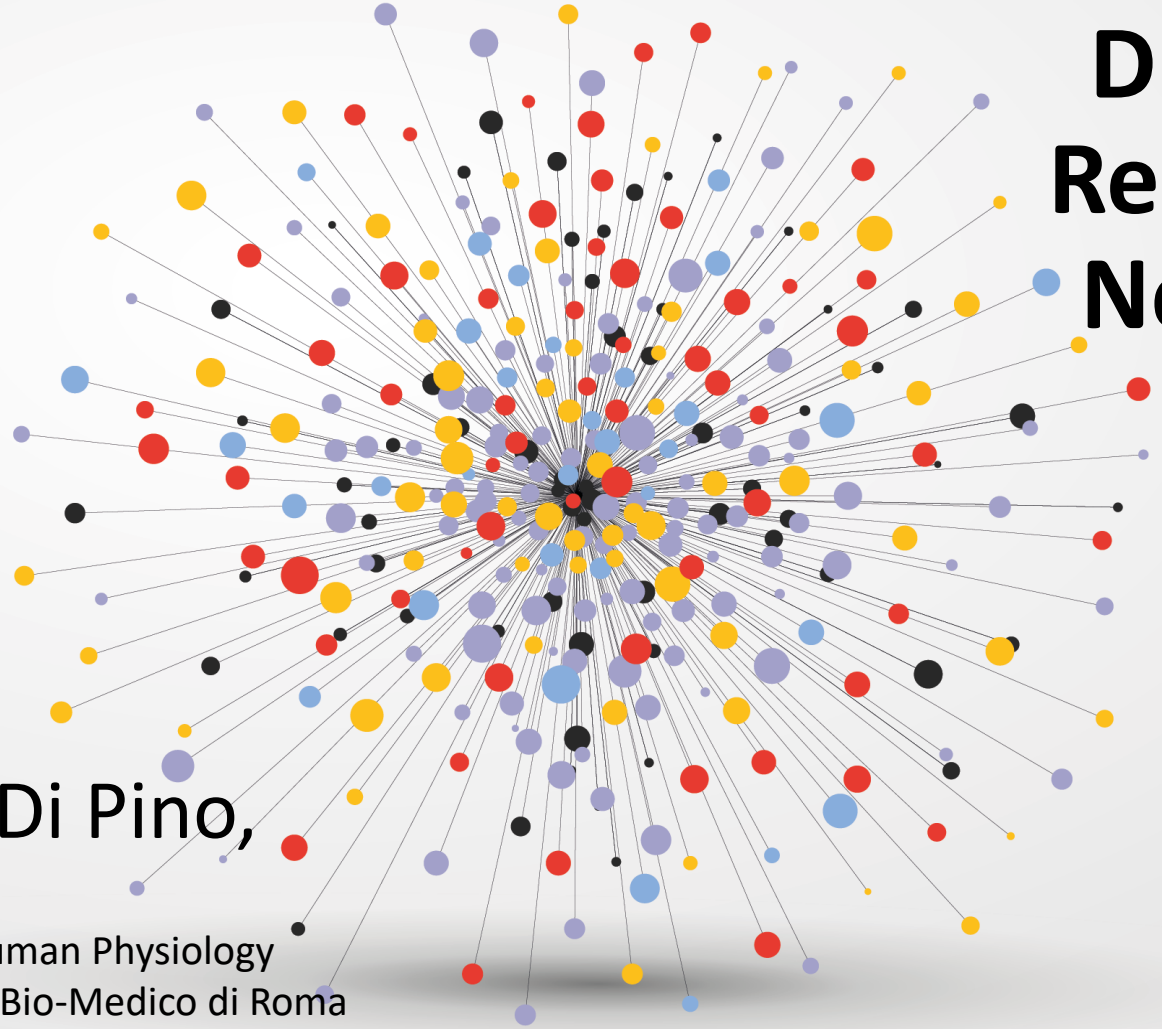
Research on Diversity
& Diversity in Frontier Research

Brussels, Tuesday 28 November 2023

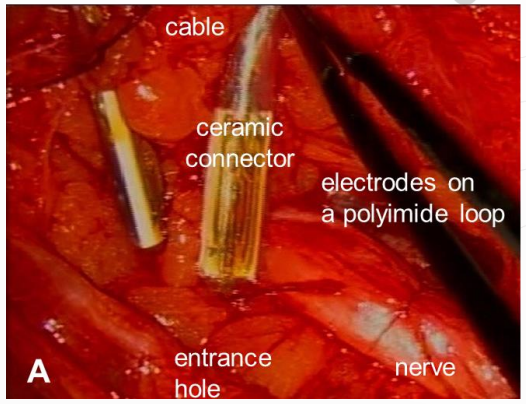
European Commission

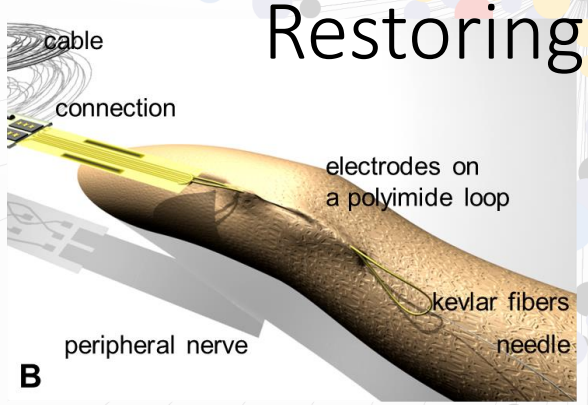
Diversity in Body Representation for Neuroprosthetics

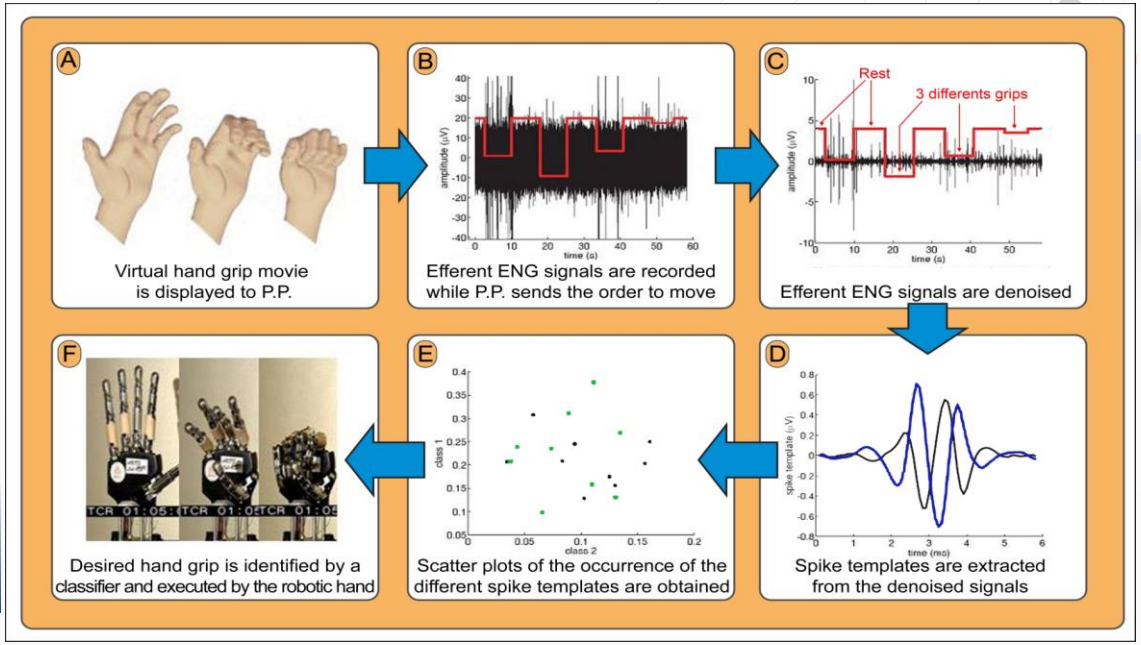


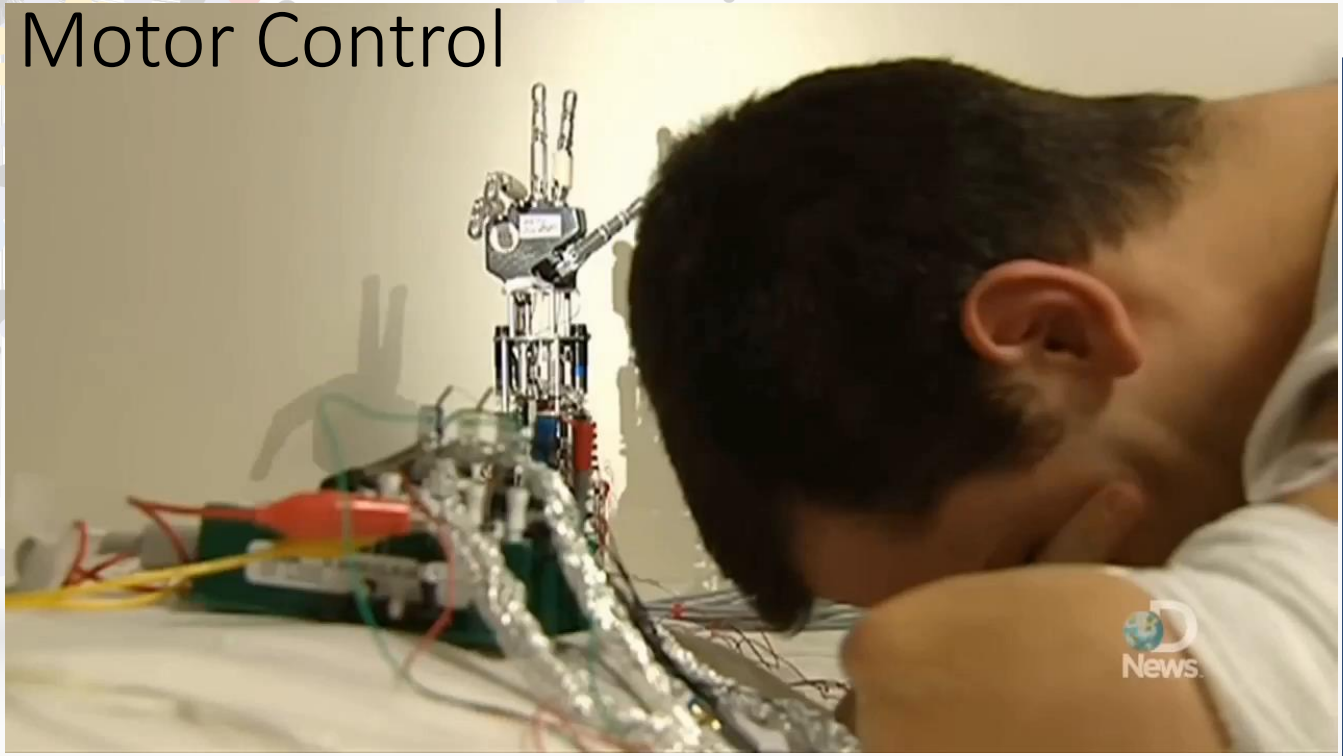
Giovanni Di Pino,
MD\PhD
Full Professor of Human Physiology
Università Campus Bio-Medico di Roma
g.dipino@unicampus.it

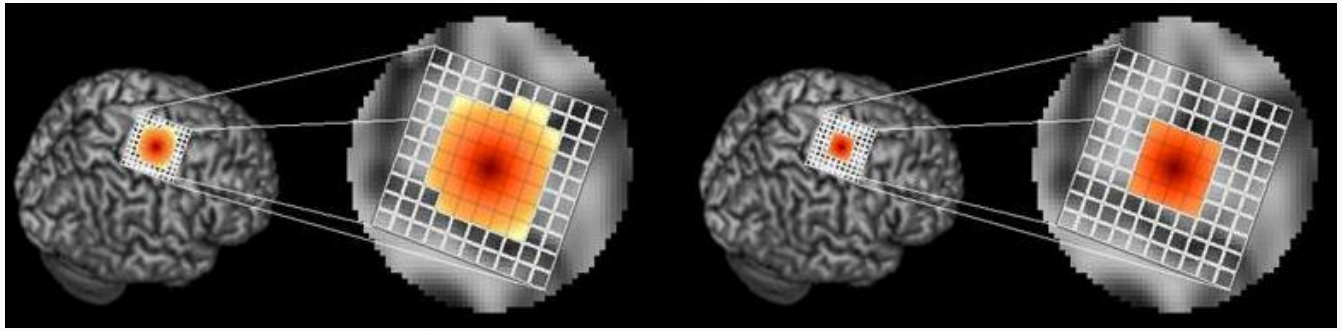
Restoring Motor Control





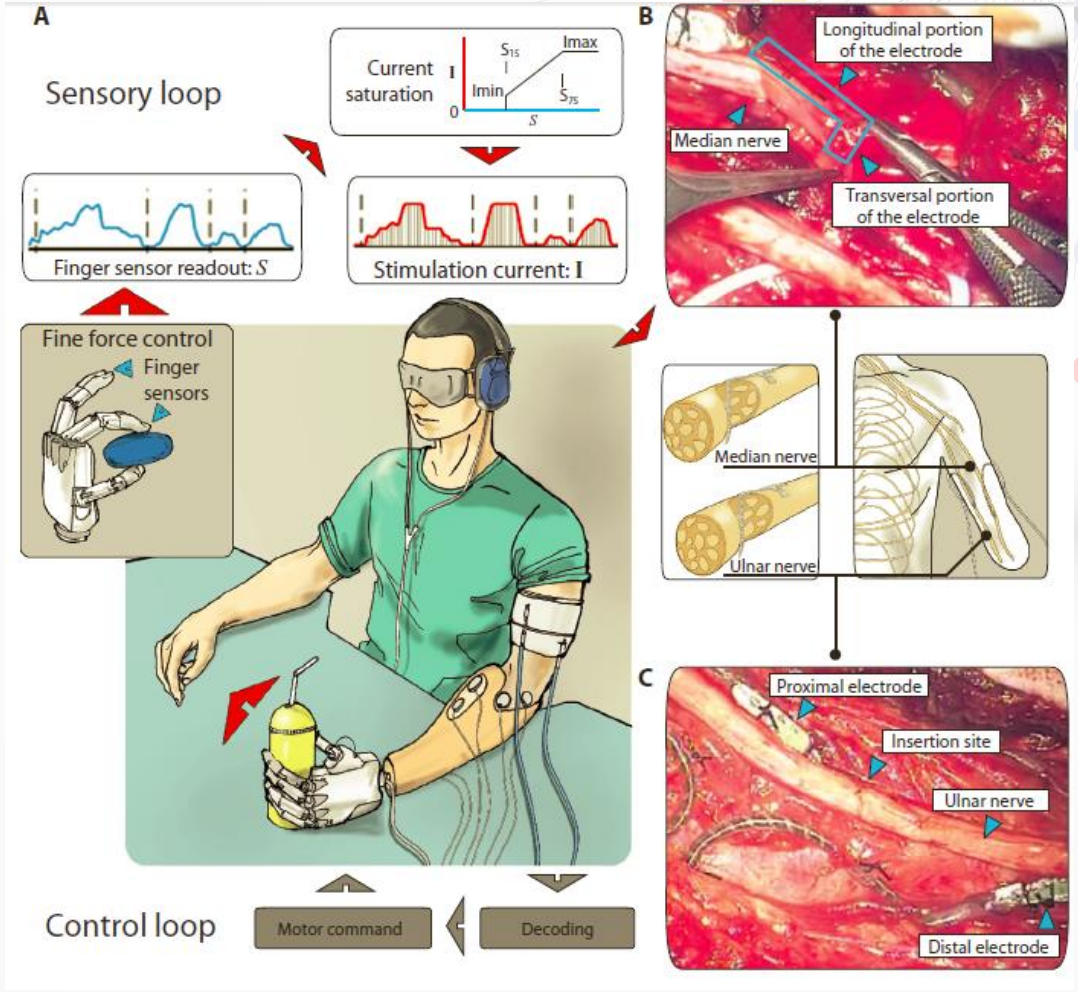






Rossini et al., *Clin Neurophysiology* 2010

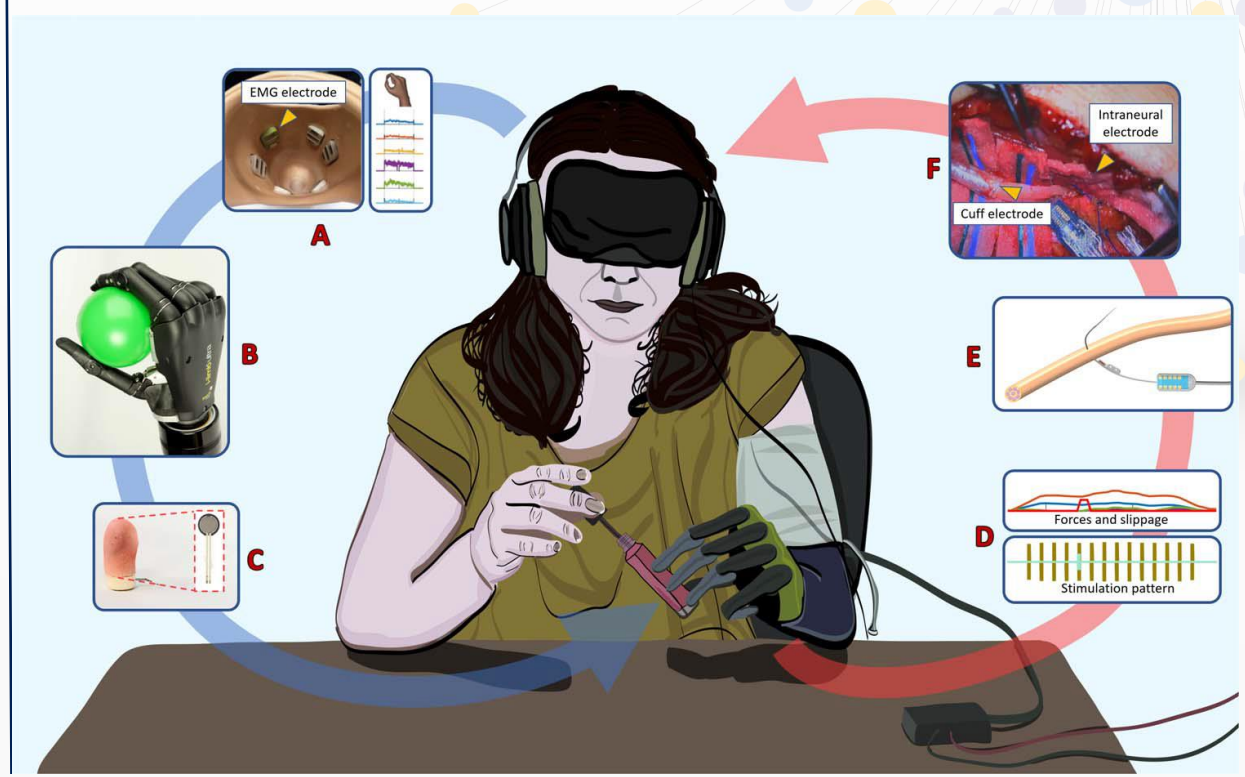
Restoring Somatosensory Feedback



Sensing Compliance

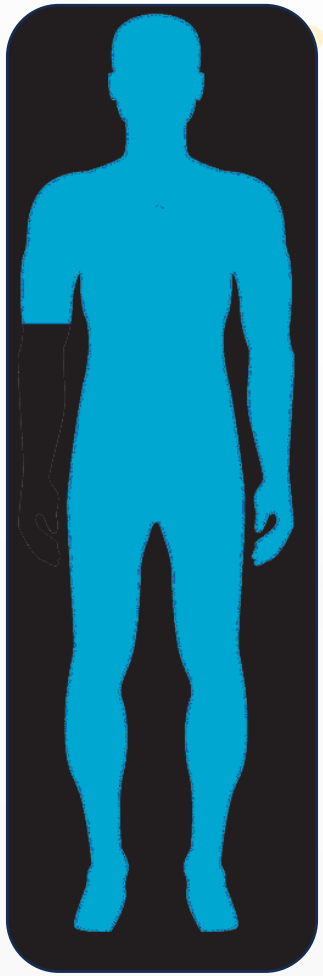
Raspopovic et al., *Science Trans Med* 2014;

Closing the loop: sensory driven manipulation



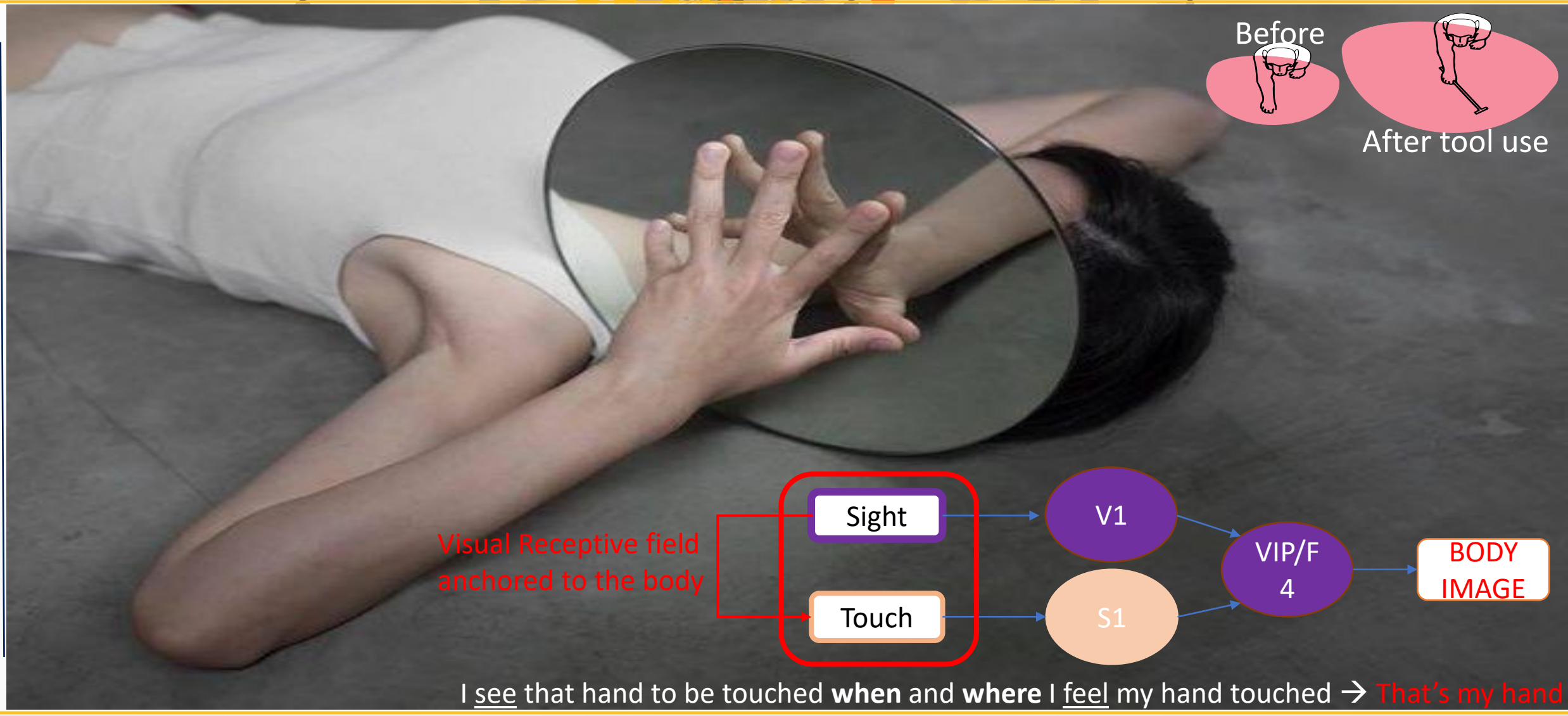
Zollo, Di Pino et al., *Science Robotics*, 2019; Ranieri et al., The Journal of Physiology, 2022

Bimanual tasks performed by amputees



Somatoparaphrenia

Alien limb : lesion (stroke) of the temporo-parietal junction of the right hemisphere


Before
After tool use
Visual Receptive field anchored to the body
Sight
Touch
V1
S1
VIP/F 4
BODY IMAGE
I see that hand to be touched when and where I feel my hand touched → That's my hand

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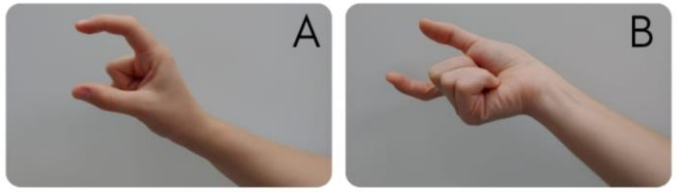
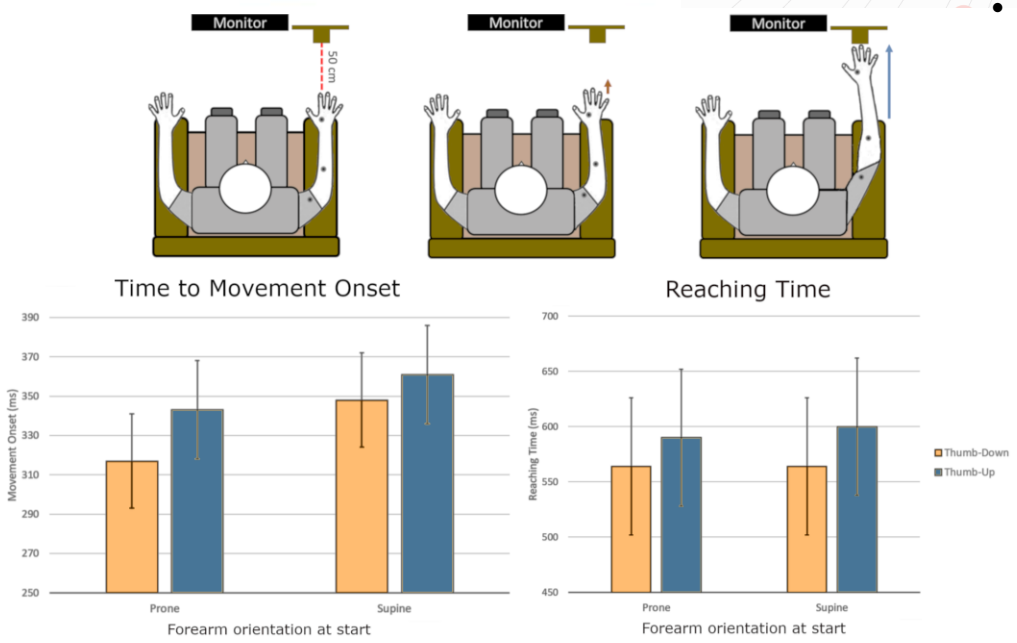
RESHAPE

REstoring the **S**elf with embodiable **HA**nd **P**rosthes**E**s

Favored Posture in the Hand Representation for Action

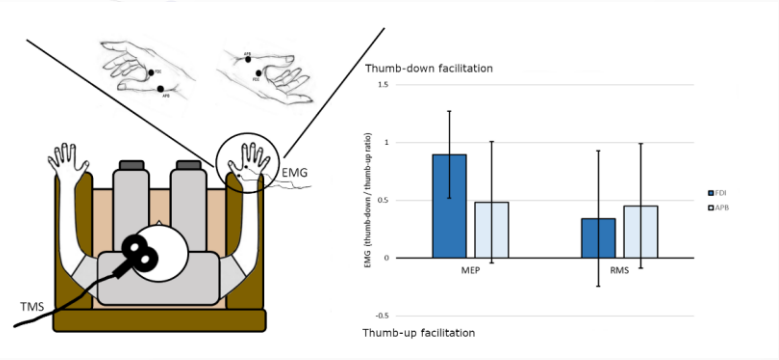


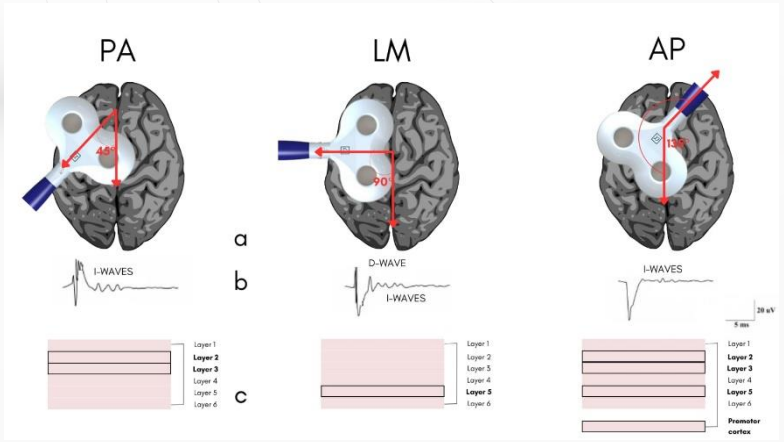


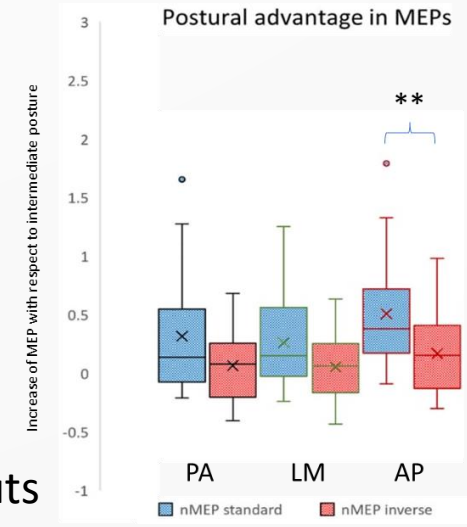
for thumb down pinch:

- *Behavioral*: **faster** movement onset and target reaching

- *Neurophysiological evidence*: **increased corticospinal excitability**
  - independently on pre-stimulus tonic muscle contraction
  - also when only observed, imagined, or prepared, actually keeping the hand at rest





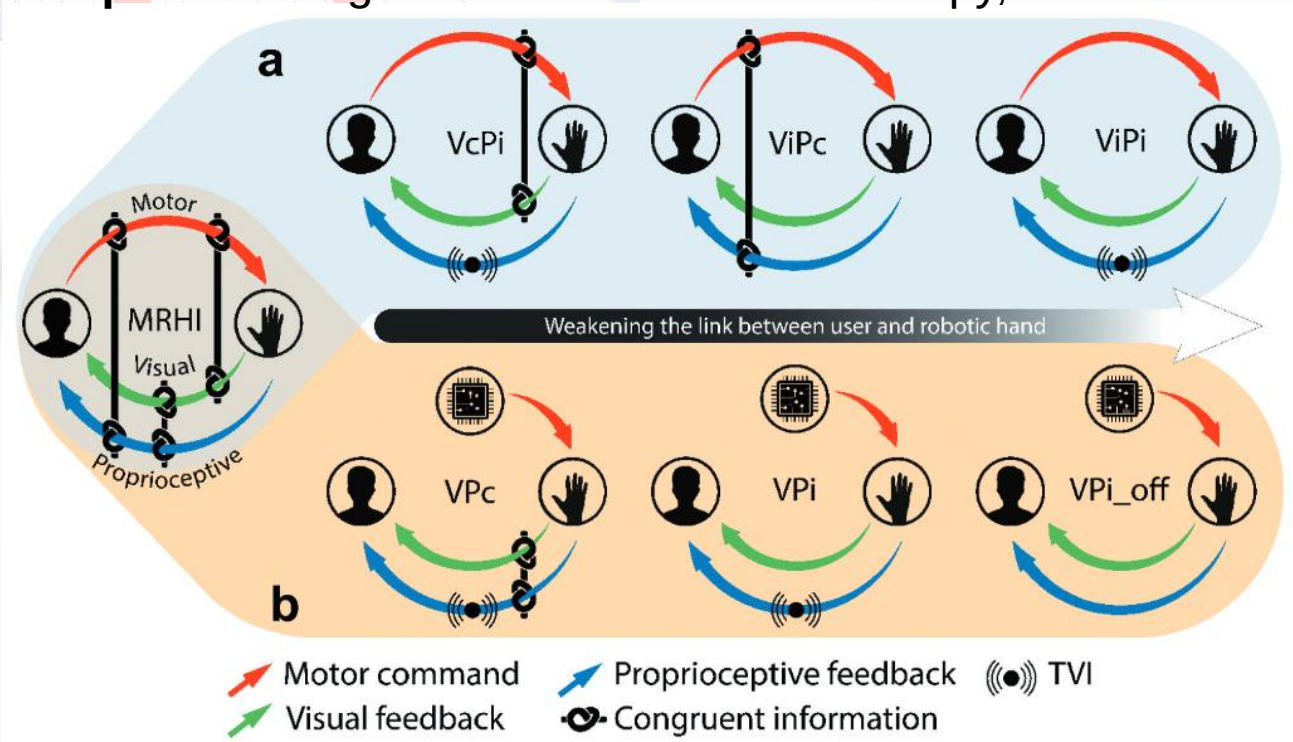


Higher excitability due to premotor inputs

Romano et al., *Cerebral Cortex*, 2021; Piombino et al., unpublished

Building Ownership and Agency of a Robotic Hand

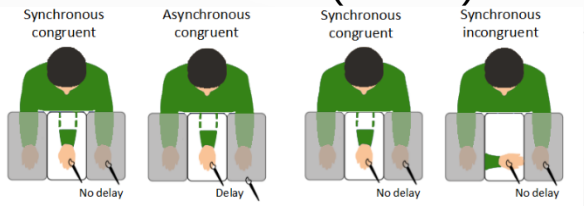
- **Efferent** component modulates sensory feedbacks **salience**.
- **Ownership** can be generated from sensory information alone
- **Agency** requires senses to be double-checked with the **prediction** generated from efference copy, which is treated as an **additional sensory modality**

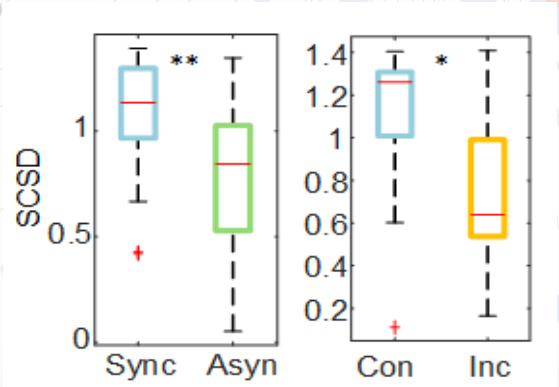


Pinardi, M., et al., Cognitive Neuroscience, 2020

Body Representation Impacts efferent autonomic activity

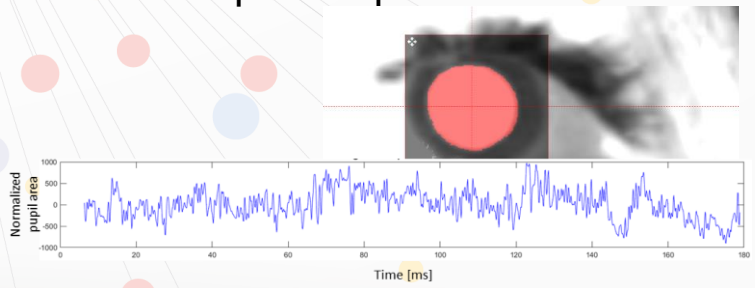
Embodiment increases the non-specific fluctuations of skin conductance (SCSD)

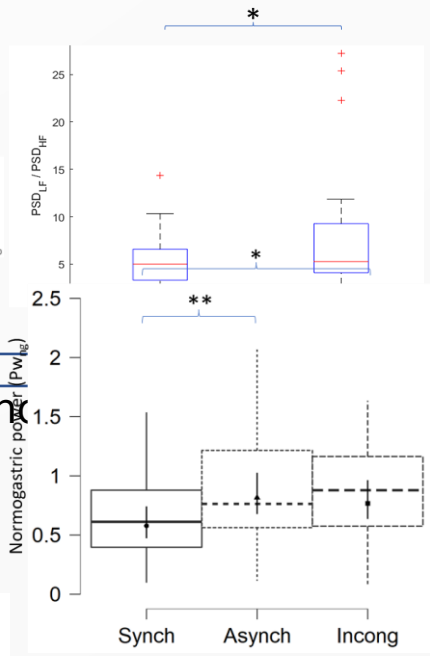




D'Alonzo et al., *Journal of Cognitive Neuroscience*, 2020

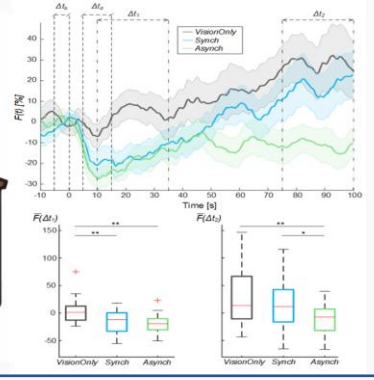
increases the low(0-1.6)/high(1.6-4Hz) ratio of pupil size fluctuation spectral power





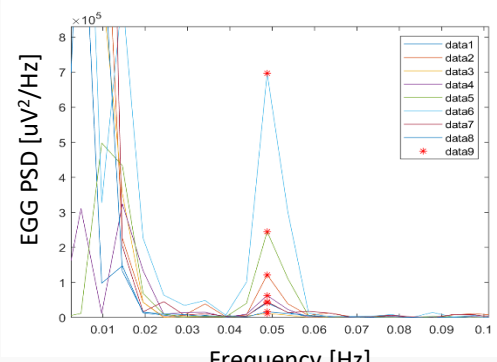
Unpublished

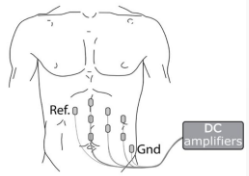
increases blood flow to the investigated limb



Di Pino et al., *Open Research Europe*, 2022

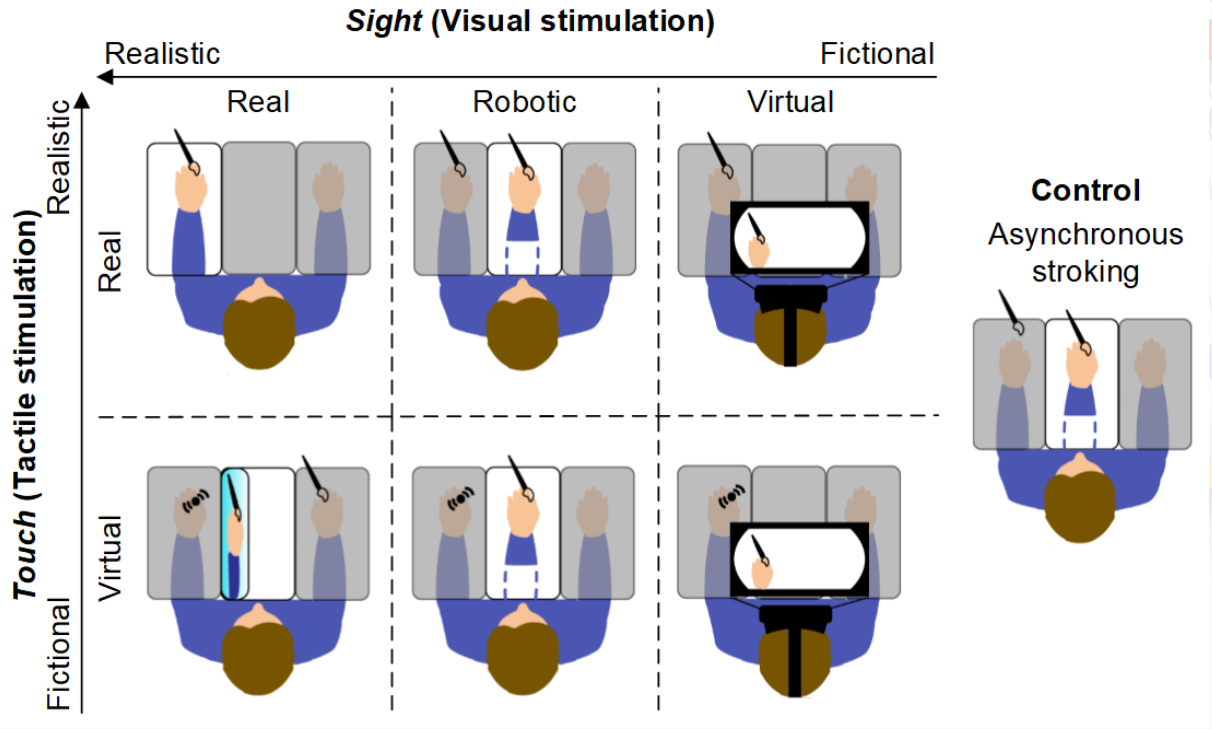
Decreases the spectral power of normo





Unpublished

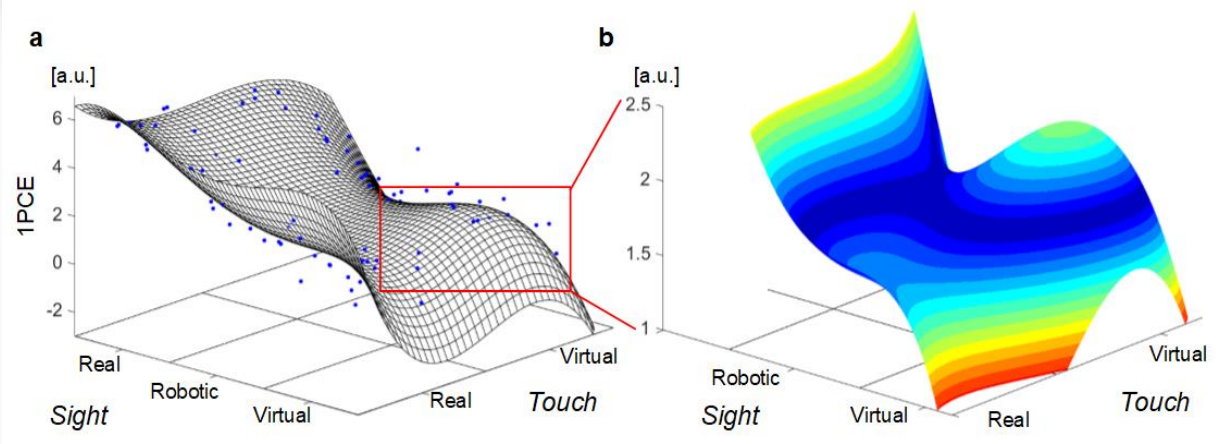
Integrating real and artificial stimuli



matched degree of virtualization

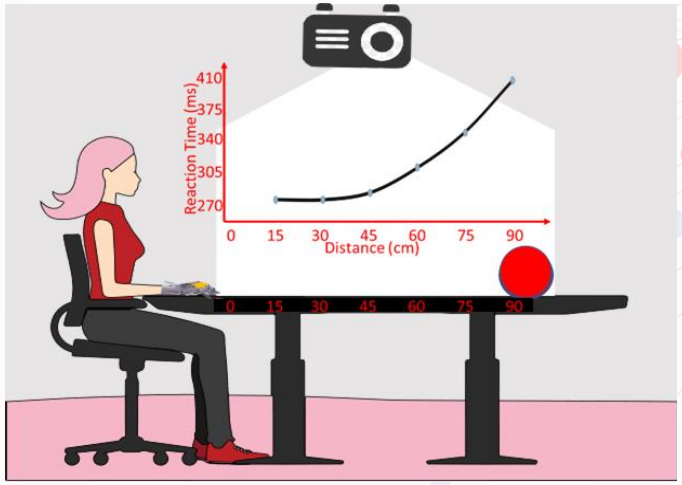
Different level of virtualization of sight and touch

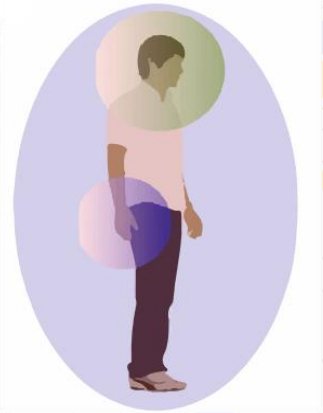
uncanny valley of avatar's hand embodiment



D'Alonzo et al., Scientific Report, 2019

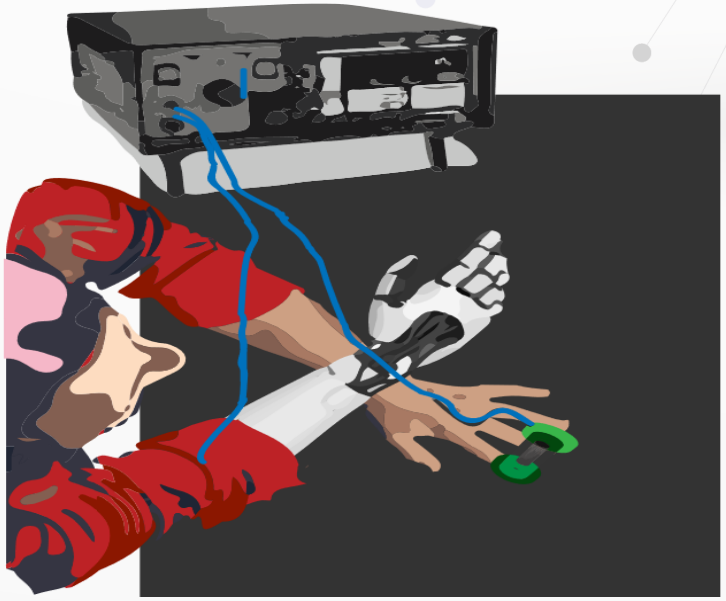
Sensory- and Action- oriented embodiment





Sensory-oriented embodiment
- Quality of sensory feedback
- Anthropomorphism

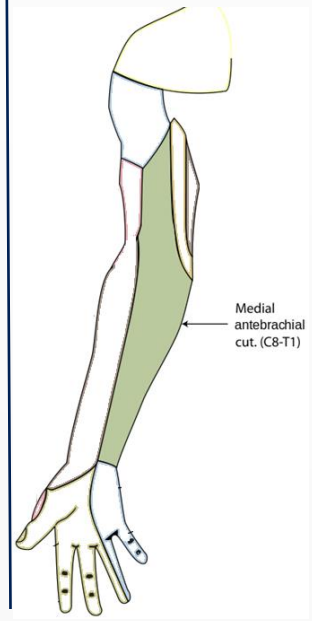
participant was stimulated **invasively** showed a behaviour more similar to the control group

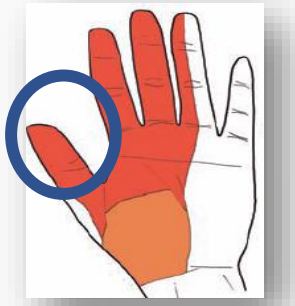


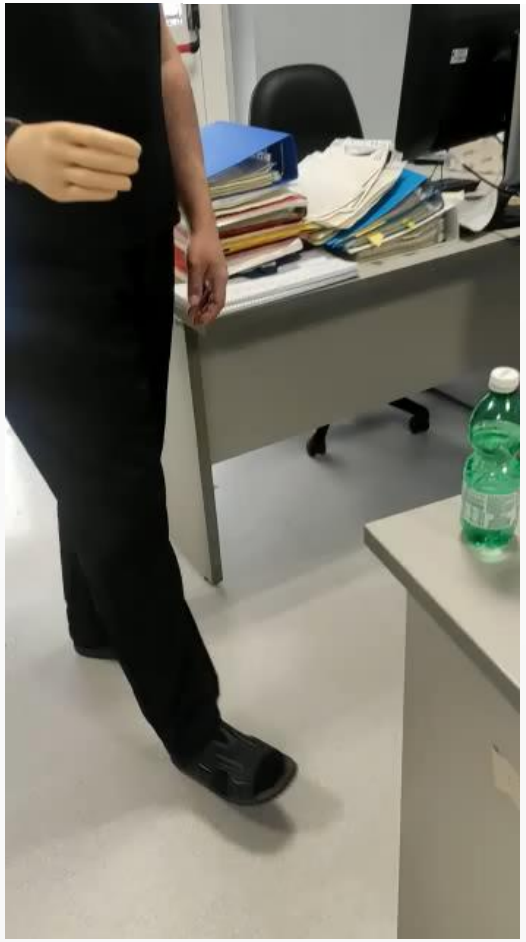
Operative tool-like embodiment
- Training

(Di Pino et al., Front Neurosci 2020)

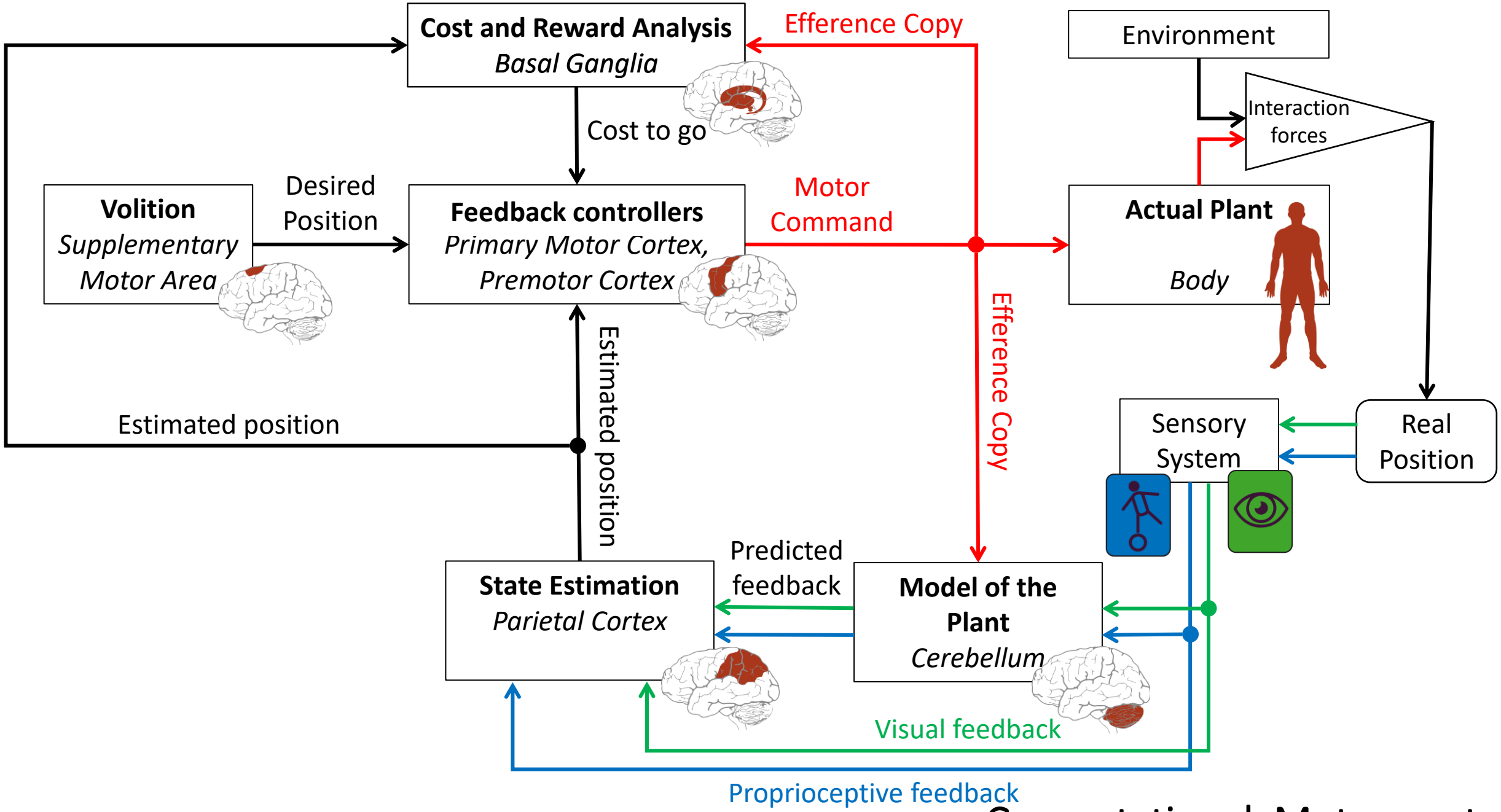
Osseointegration + Targeted Motor/Sensory Reinnervation



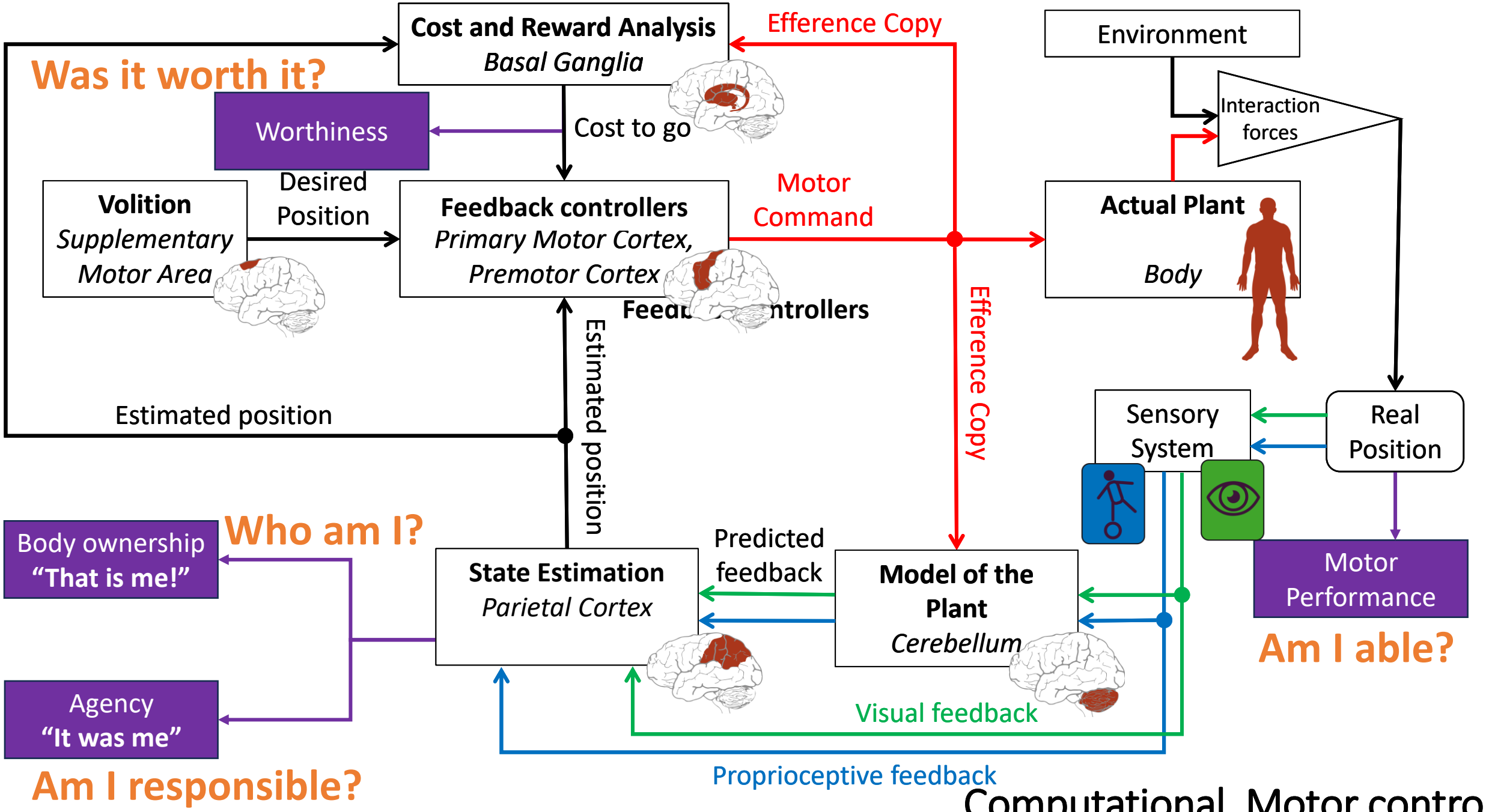




Zangrandi et al., Journal of Neurophysiology, 2021



Computational Motor control

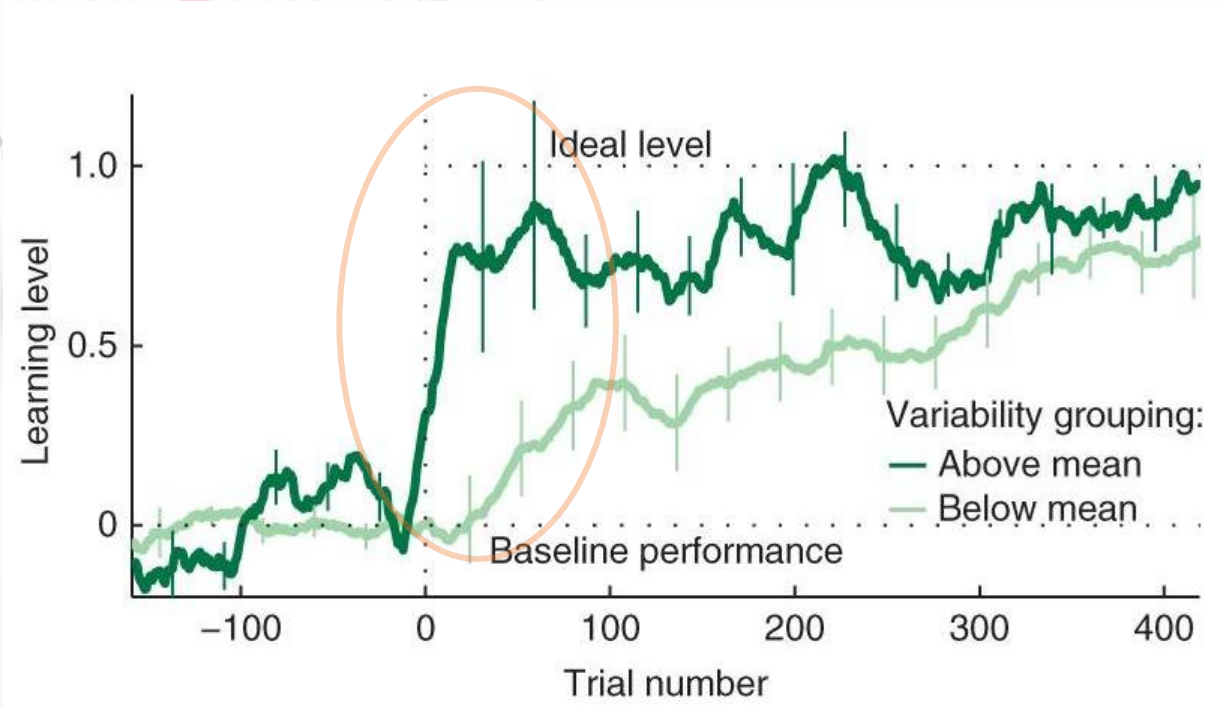

Was it worth it?
Cost and Reward Analysis
Basal Ganglia
Efference Copy
Environment
Worthiness
Cost to go
Interaction forces
Volition
Supplementary Motor Area
Desired Position
Feedback controllers
Primary Motor Cortex, Premotor Cortex
Motor Command
Actual Plant
Body
Feedback controllers
Efference Copy
Estimated position
Estimated position
Sensory System
Real Position
Who am I?
Body ownership
"That is me!"
State Estimation
Parietal Cortex
Predicted feedback
Model of the Plant
Cerebellum
Motor Performance
Am I able?
Agency
"It was me"
Visual feedback
Proprioceptive feedback
Am I responsible?
Computational Motor control

Motor variability (noise) improves motor learning

High motor variability
to explore space

Motor learning
consolidation

Better **learning rate**



Herzfeld et al., *Nature Neuroscience* 2014; Wu et al., *Nature Neuroscience* 2014

team’s ethnic mix and highly cited papers

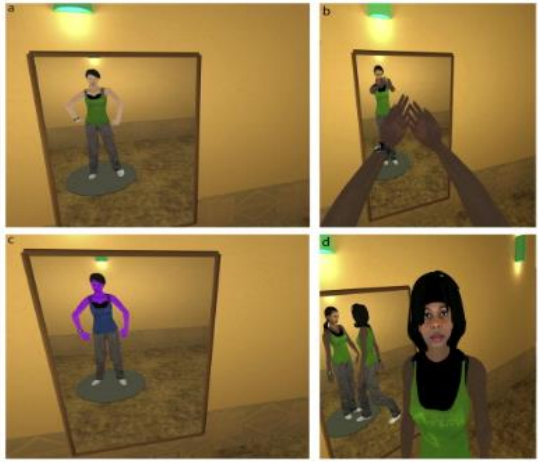
Freeman R. and Wei H. *Nature* 2014

Diversity decreases (yet allows) embodiment

Hand color

Maister et al., 2013
Consciousness and Cognition

Body skin



Peck et al., et al., 2013
Consciousness and Cognition

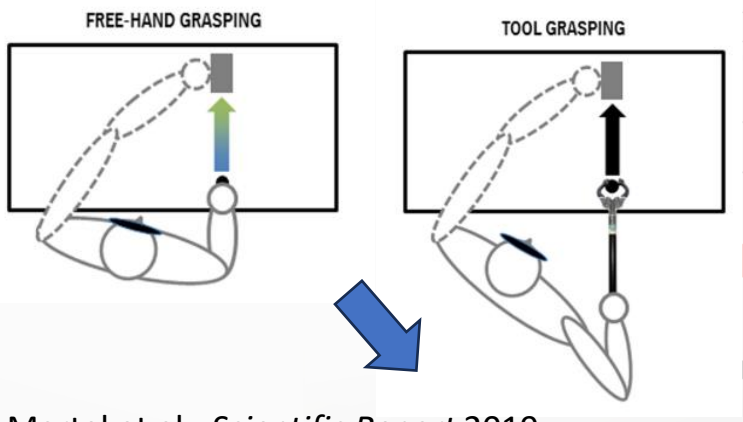
Gender

Peck et al., et al., 2018; IEEE Trans Vis Comput Graph.

Face

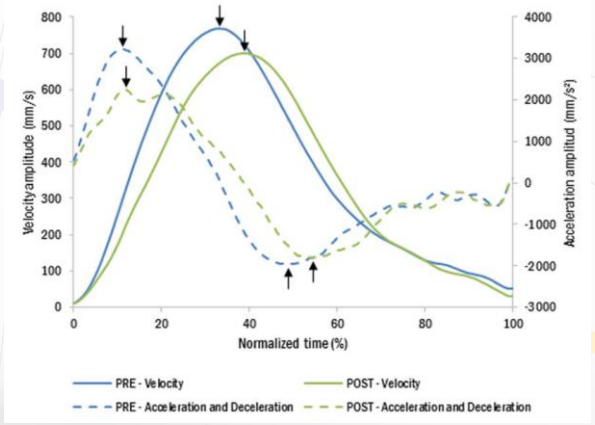
Fini et al., et al., 2018
Front. Behav. Neurosci.

Embodiment changes motor behaviors



Martel et al., *Scientific Report* 2019

Embodiment of tools leads to **kinematic adjustments** in free-hand tasks



Kilteni et al., *IEEE Trans. on Visualization and Computer Graphics* 2013

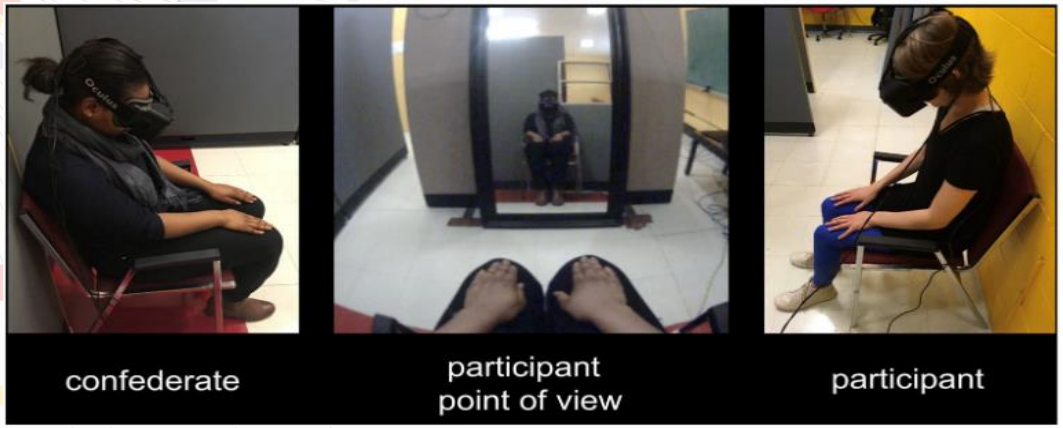
Embodiment of avatars with asymmetrical lower limbs can **impact kinematic and dynamic parameters during gait initiation**.

Vallageas et al., IEEE Conference on Virtual reality and 3D user interfaces. 2013

Embodiment affects empathy, stereotypes, and bias

Peck et al., et al., 2020. Proceedings of the 2020 Conference on Human Factors in Computing Systems

Women embodying male avatars were protected from the math stereotype, while men in female avatars experienced it.



Taking on the perspective of a different body allows for increased empathy even without directly addressing prejudice

Thériault et al., 2021. Quarterly Journal of Experimental Psychology

Experiencing the disability simulation with an avatar in a wheelchair reduces implicit bias towards people who use wheelchairs

Chowdhury & Quarles, 2022. IEEE Transactions on Visualization and Computer Graphic

- **Medical model of Disability** → Pathology

Disability is something to be diagnosed, treated and cured through rehabilitation or normalization (Moore and Slee, 2012).

- **Social model of Disability** → Socially produced inequality and dependency (Beauchamp-Pryor, 2012).

Disability so-conceived is a social category: a means of classifying and treating people in ways that lead to discrimination and oppression comparable to that experienced by ethnic minorities (see UPIAS, 1976; Shakespeare, 2006).

Gibsonian Affordance

How the environment (or a tool) suggests to interact with it

Ethical Affordance

How the tool suggests its purpose and prompts a mindful **use for good**, mostly determined by **design choices**.

Left-Handed in a Right-Handed world

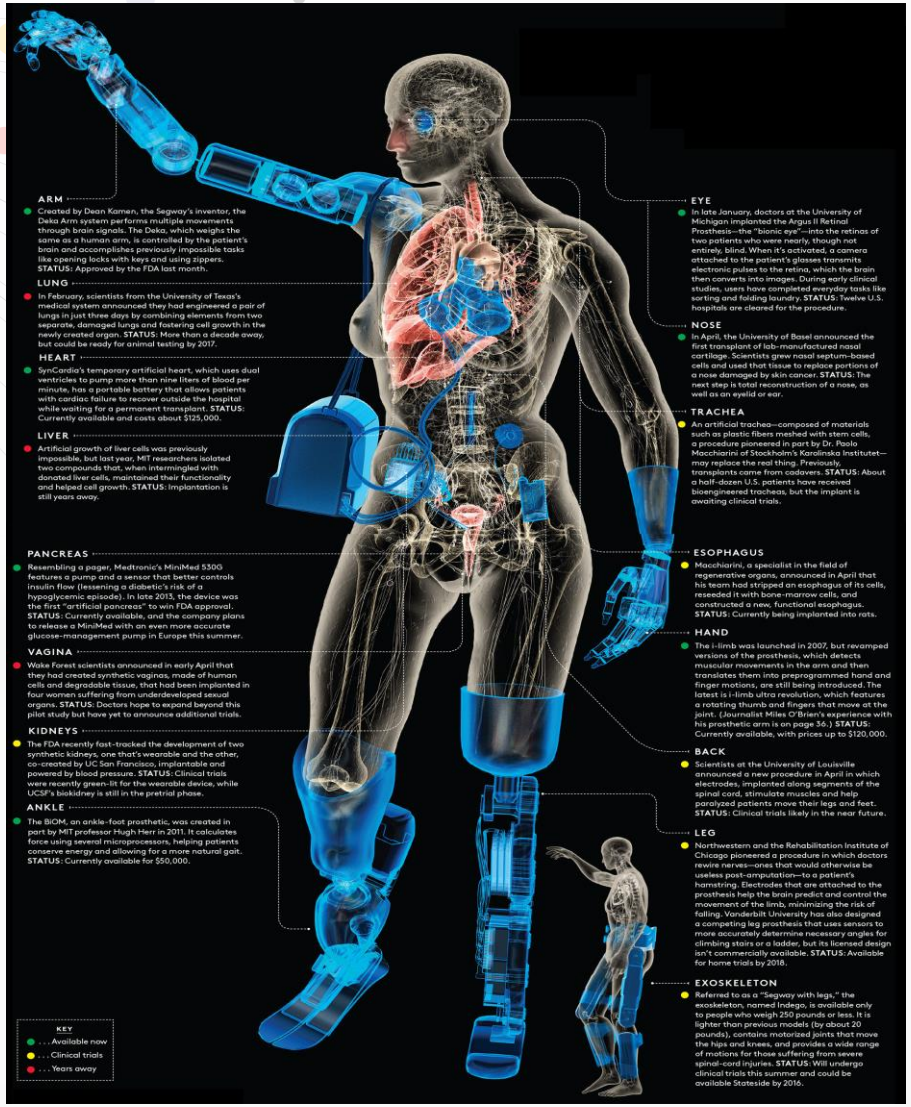





- **Ecological-Enactive Model of Disability**
  → decreased responsiveness to a field of relevant affordances.
  Toro, J., et al. (2020). Front Psychol 11: 1162.

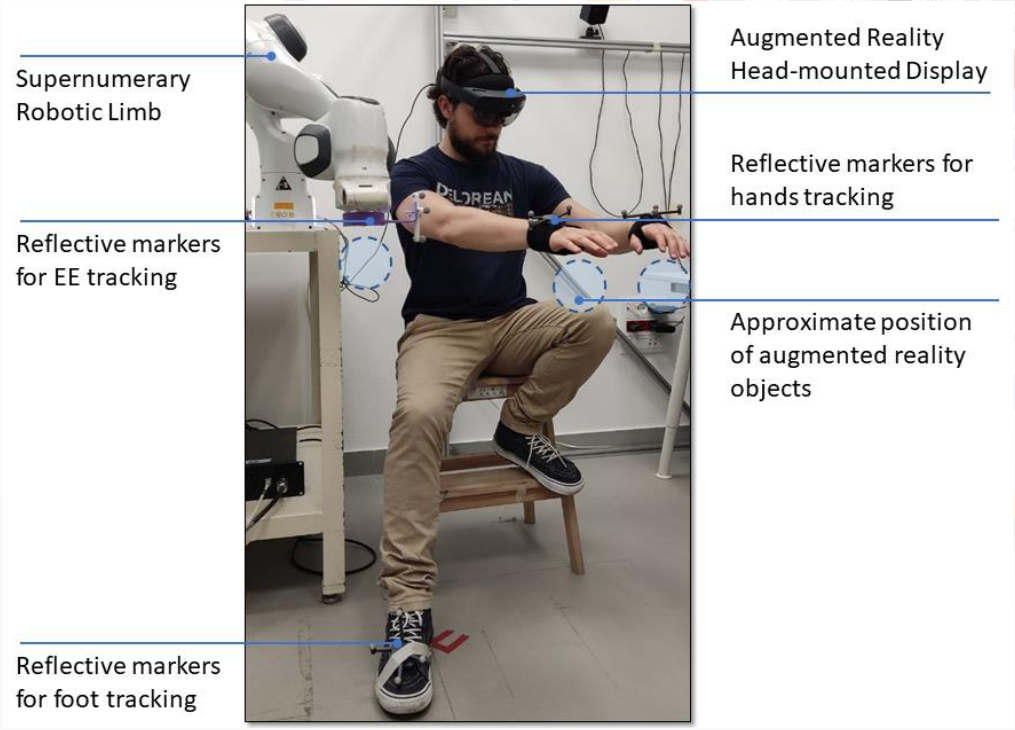
Bionics is the fusing technical sciences and biology to produce something that goes inside or is attached to the body:

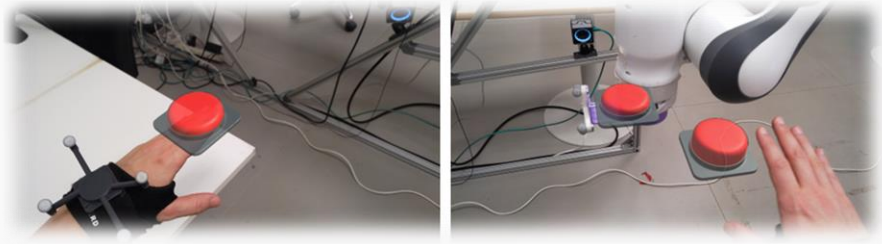
- Pacemaker
- Cochlear prostheses
- Basal Ganglia stimulator
- Visual prostheses
- Vagal or Sacral Root stimulation
- Insulin pumps
- Joint prostheses
- Endovascular prostheses
- Artificial Valves
- Sensory Substitution
- Sensory Augmentation



(Di Pino et al Front Syst Neurosci 2014, Eden et al., Nature Communication 2022)

Embodiment of SRLs





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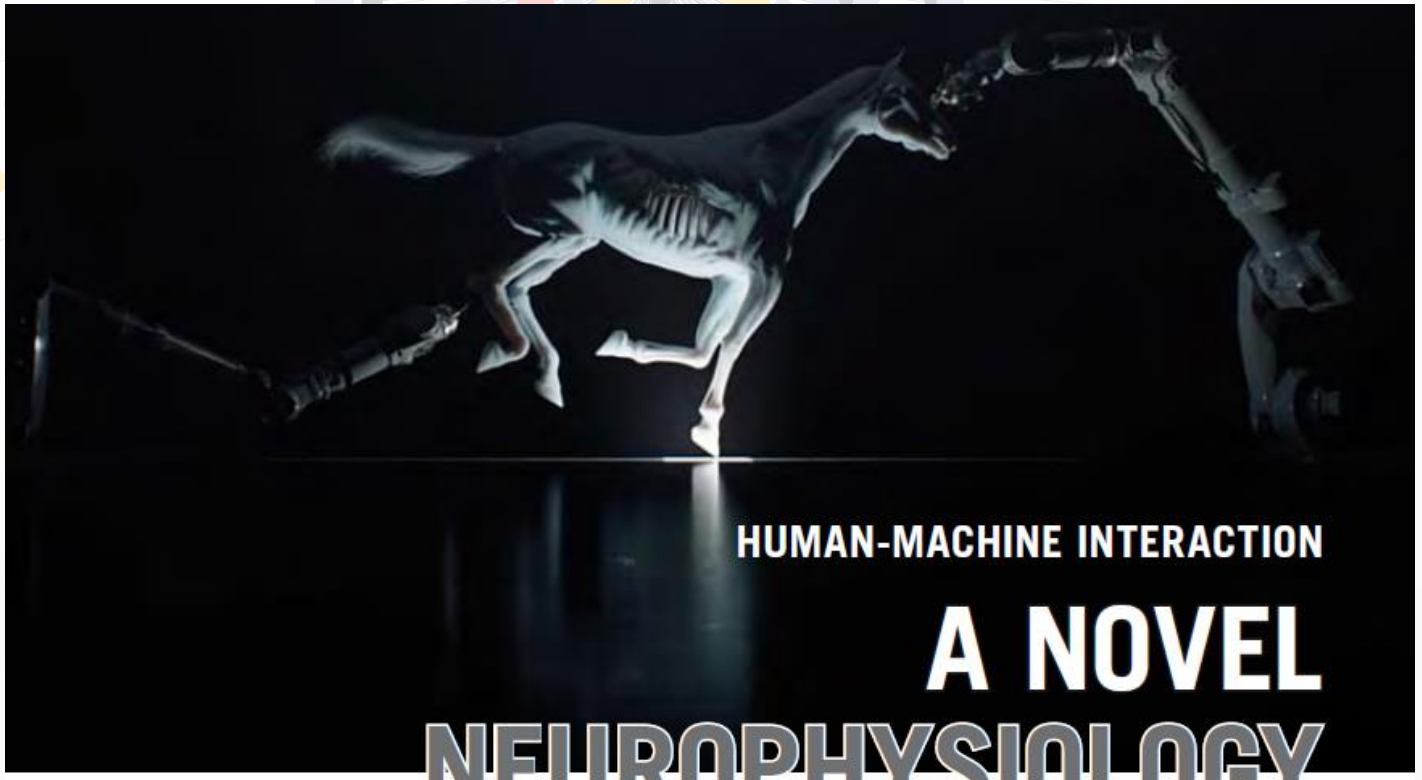
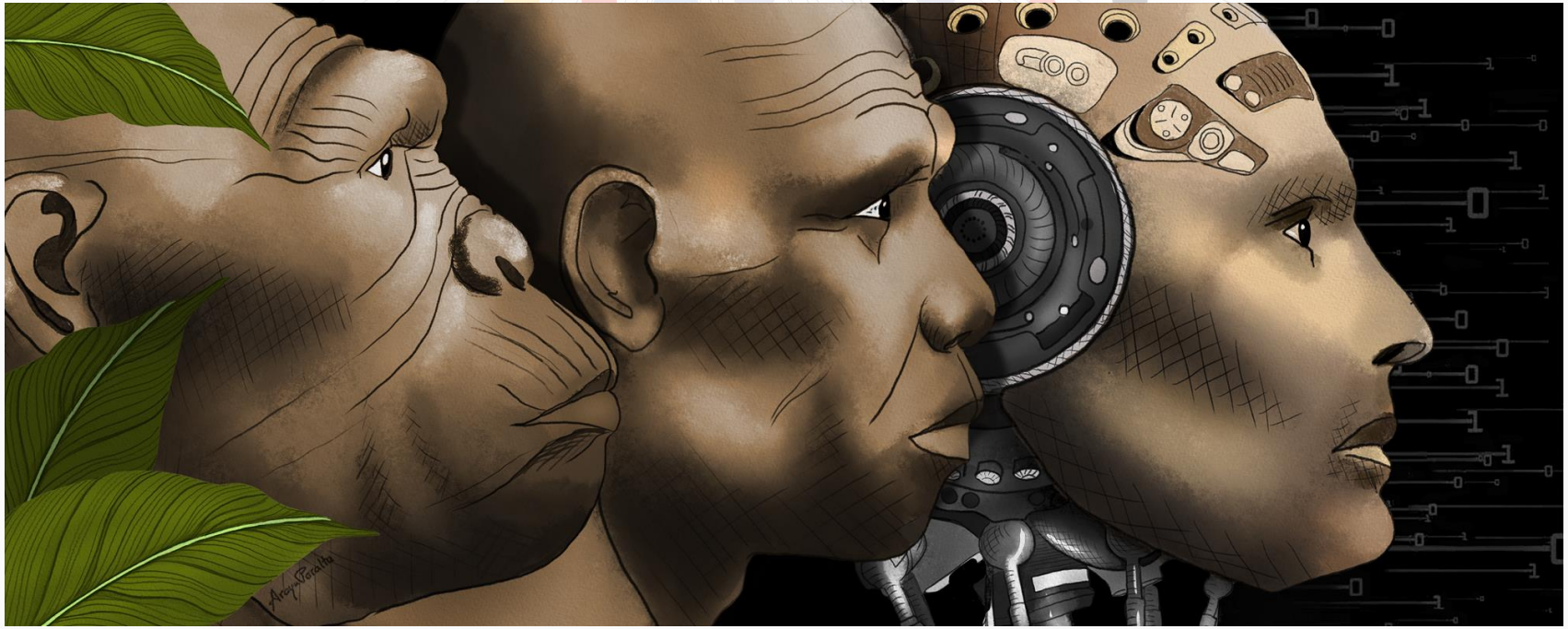


Ethical issues in Human-Technology Interaction

The integration between humans and their tools cannot be stopped

Risk of transhumanism?



The boundaries of the body and our abilities do not define us as humans; rather, it is the ethical boundaries of our responsible **actions** that define our humanity.