



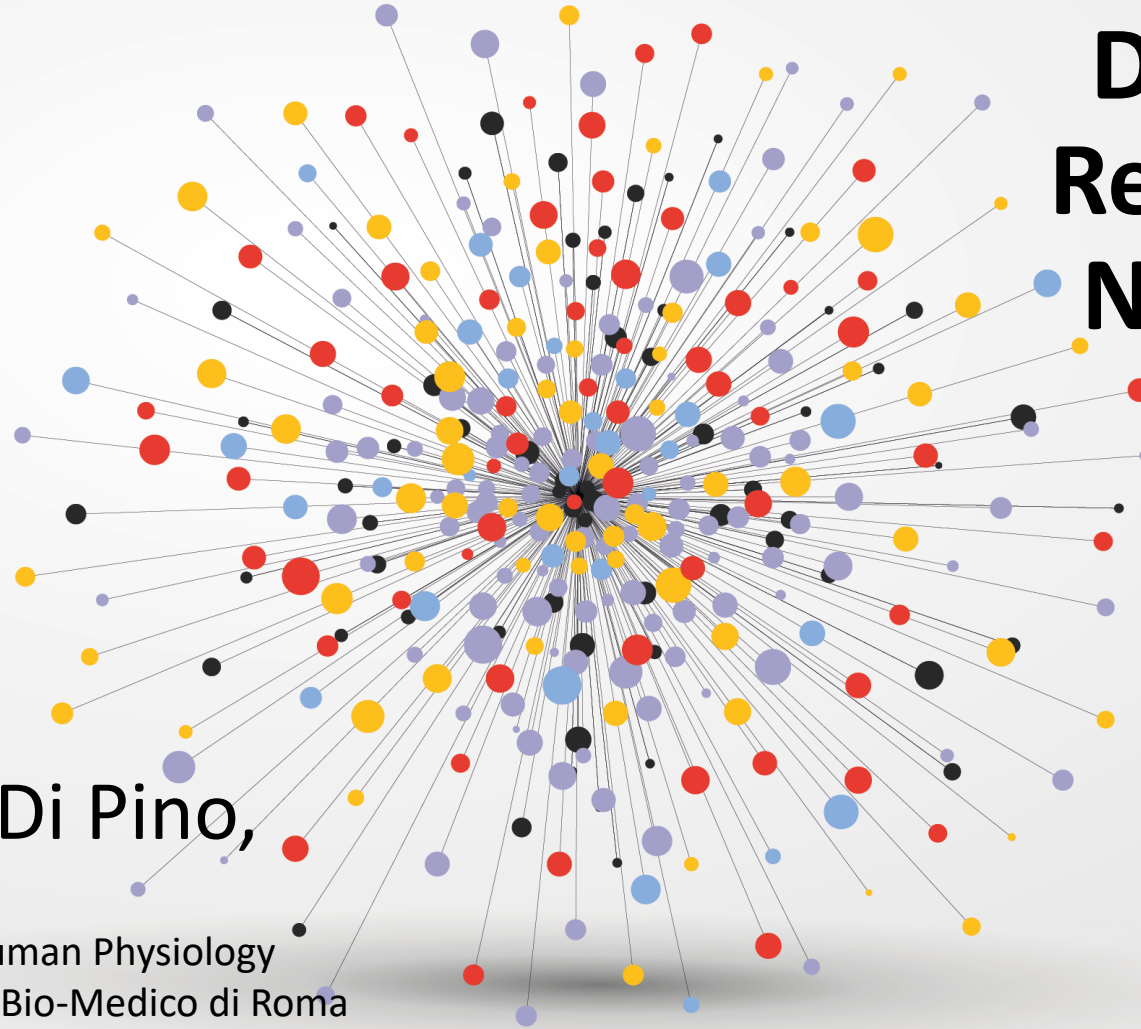
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Research on Diversity & Diversity in Frontier Research

Brussels, Tuesday 28 November 2023



Diversity in Body Representation for Neuroprosthetics

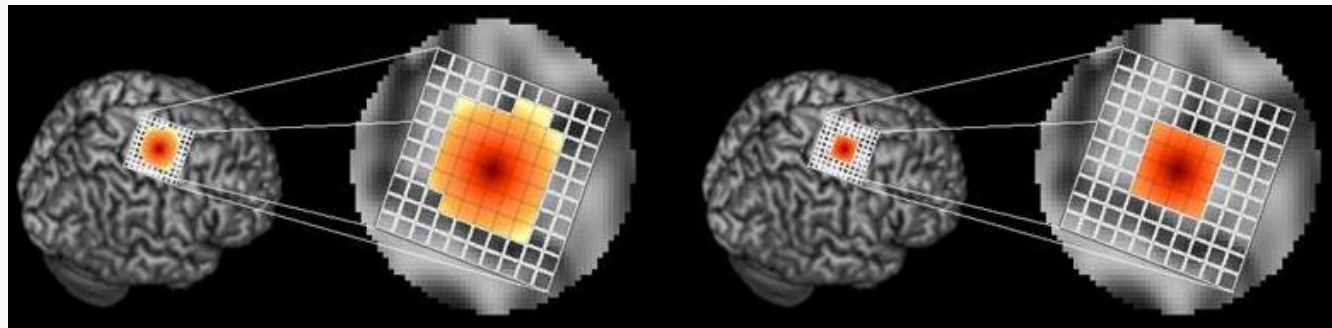
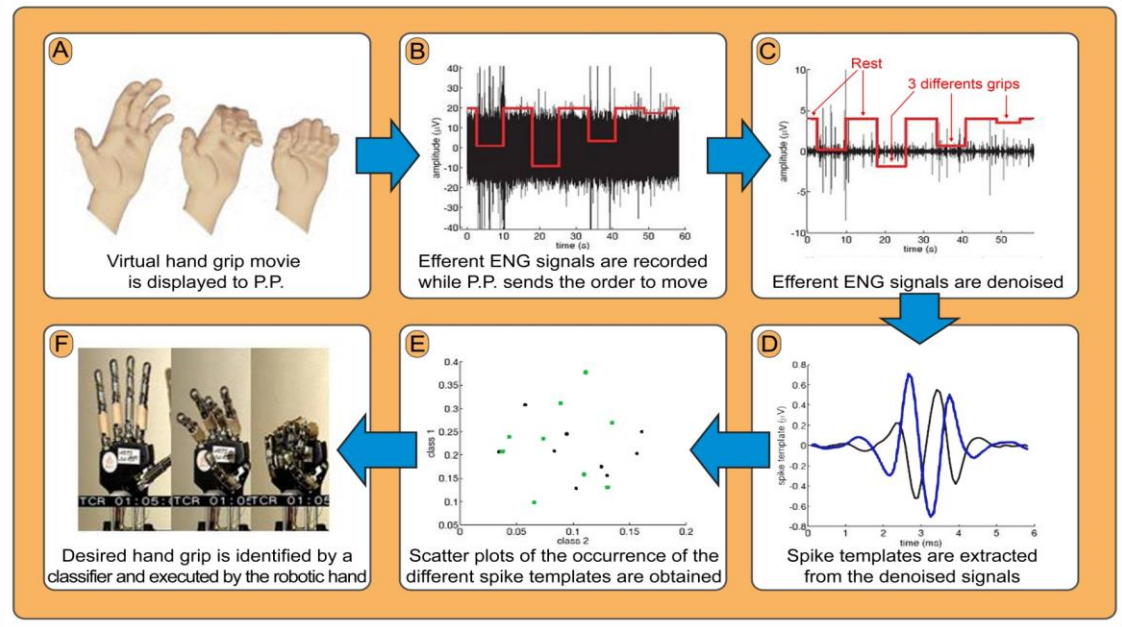
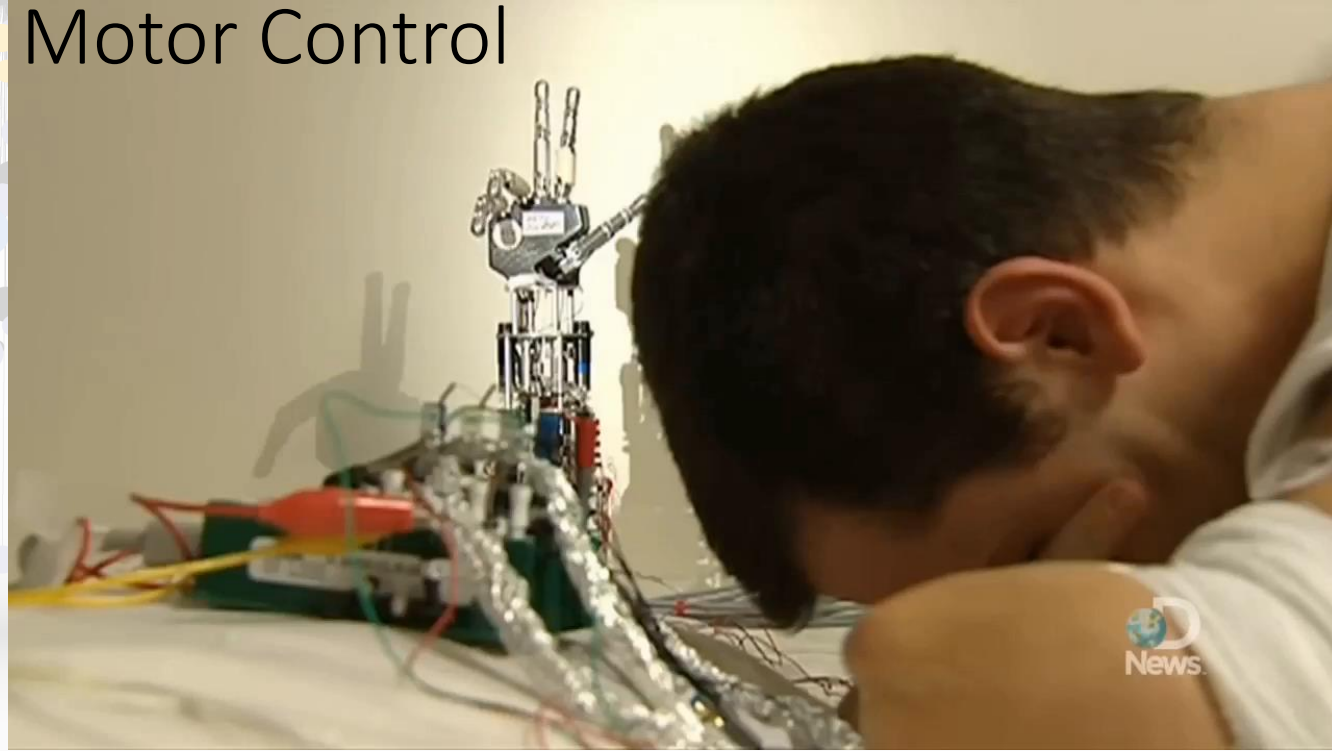
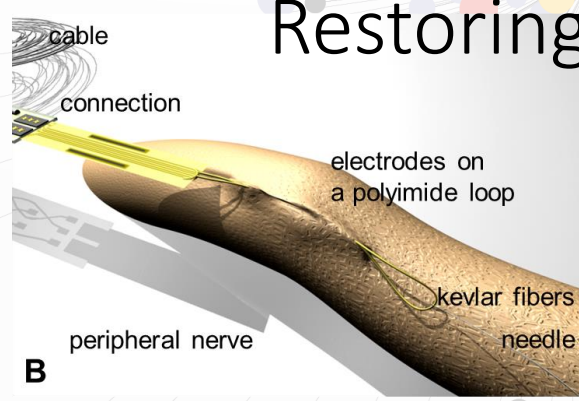
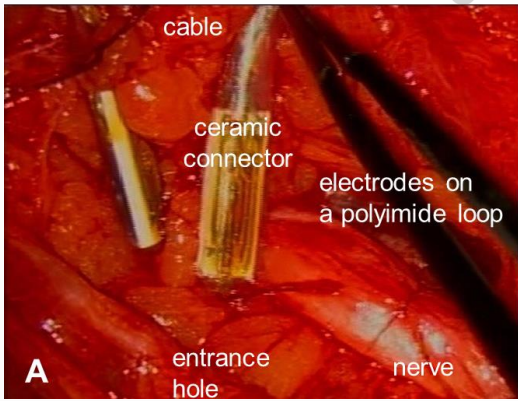


Giovanni Di Pino,
MD\PhD
Full Professor of Human Physiology
Università Campus Bio-Medico di Roma
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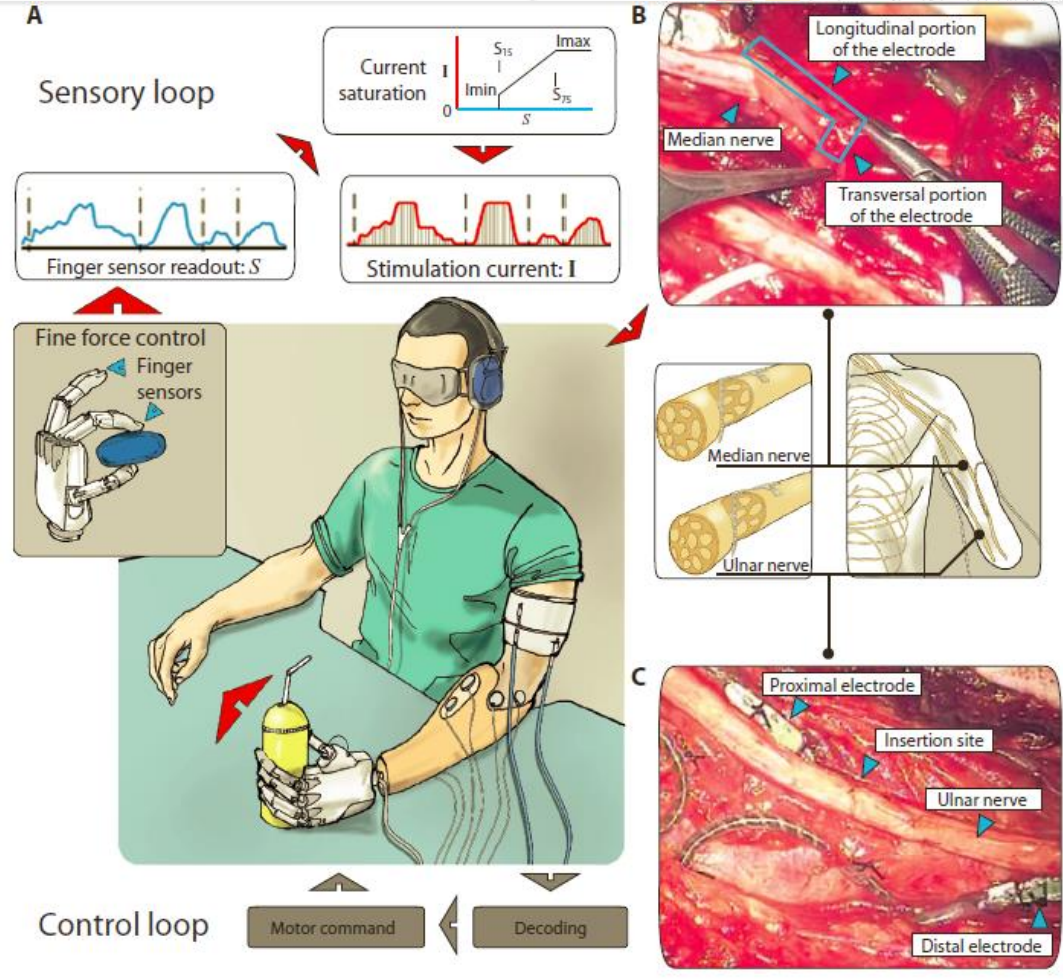




Restoring Motor Control



Restoring Somatosensory Feedback



SENSING COMPLIANCE: HARD

Sensing Compliance



Somesthetic sensory feedback through intraneural electrodes

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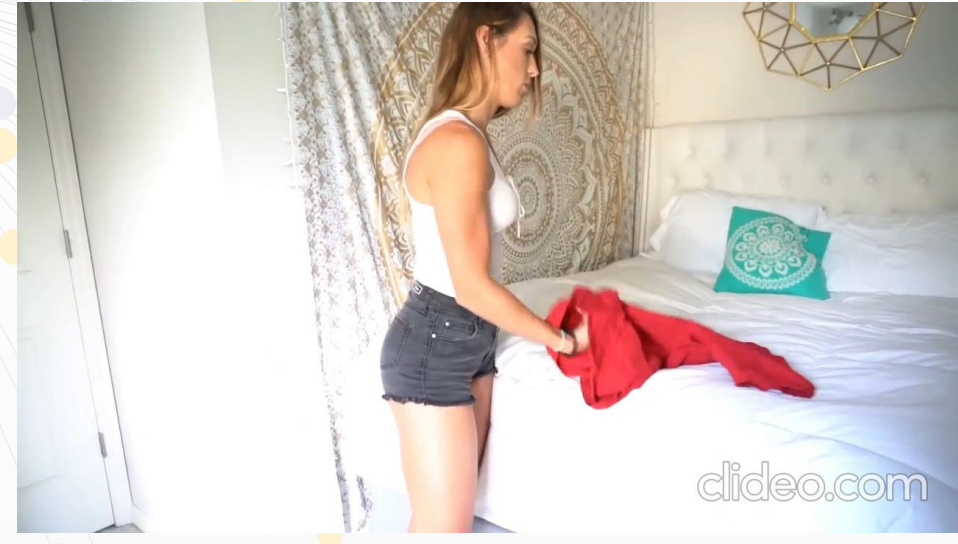
Closing the loop: sensory driven manipulation

INAIL





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Bimanual tasks
performed by amputees

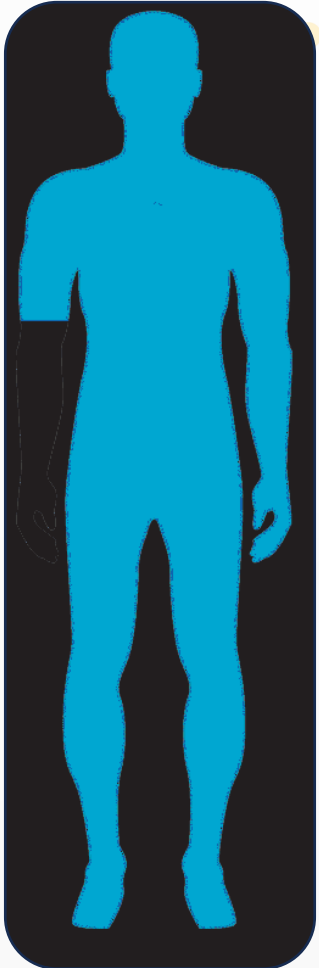




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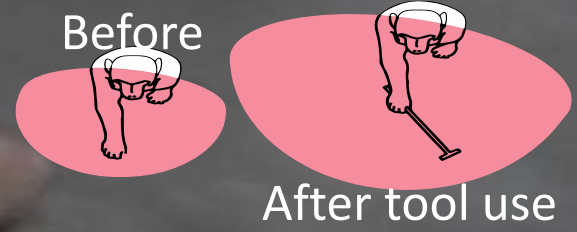
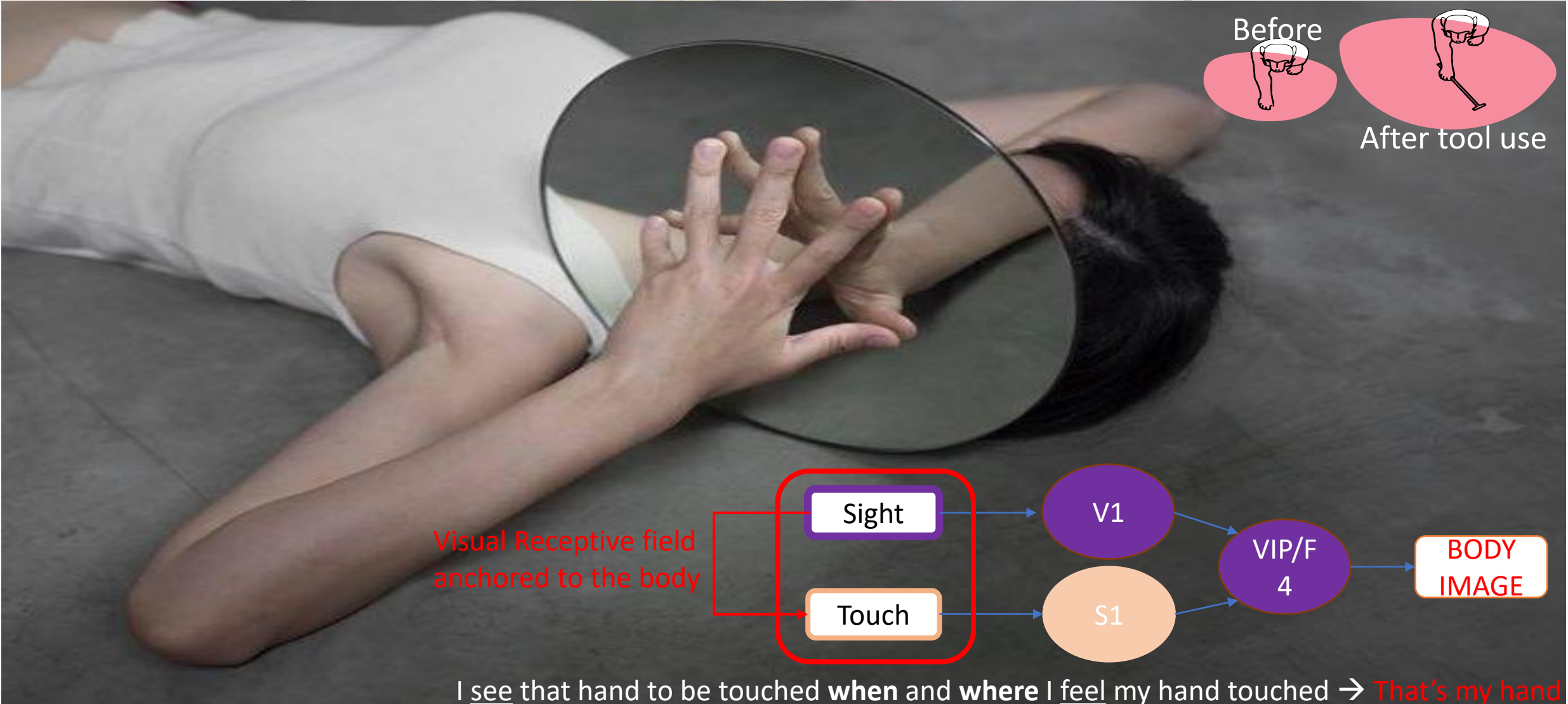
Somatoparaphrenia



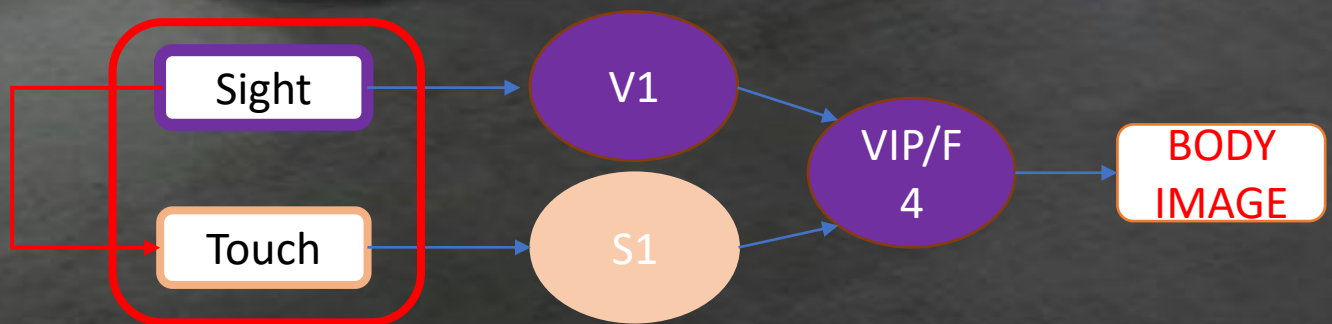
Alien limb : lesion (stroke) of the temporo-parietal junction of the right hemisphere



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Visual Receptive field anchored to the body



I see that hand to be touched **when** and **where** I feel my hand touched → **That's my hand**



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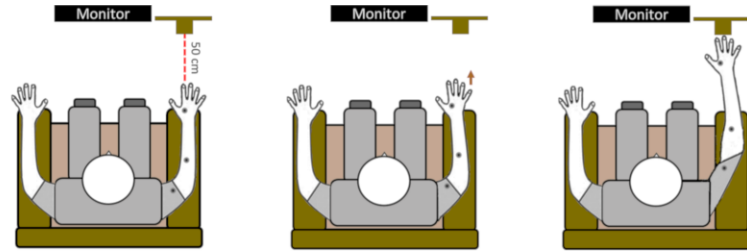
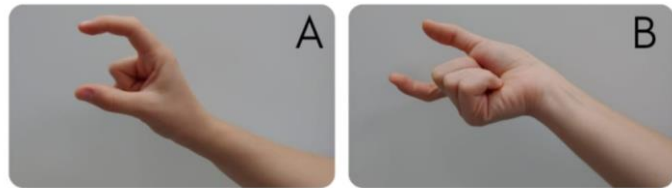
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RESHAPERS

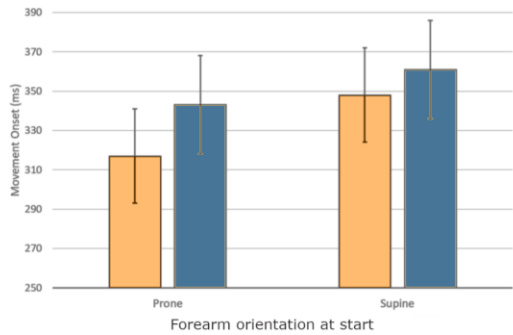


REstoring the Self with embodiabLe HANd ProsthEsEs

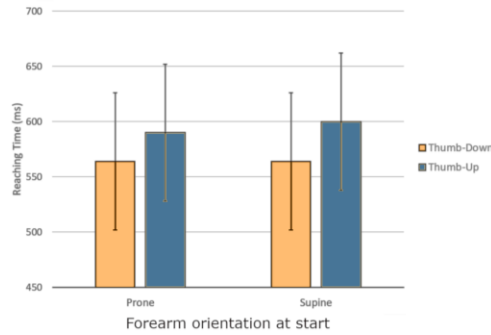
Favored Posture in the Hand Representation for Action



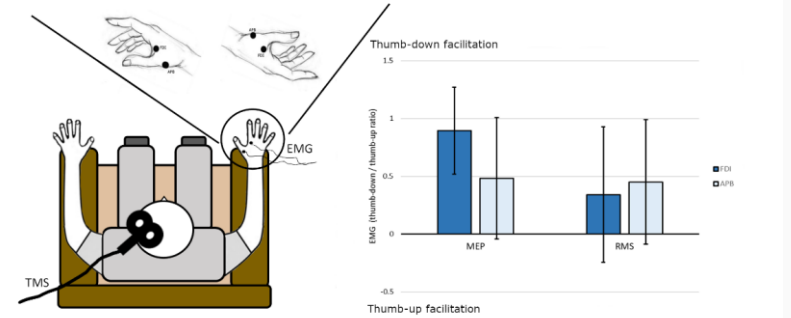
Time to Movement Onset



Reaching Time

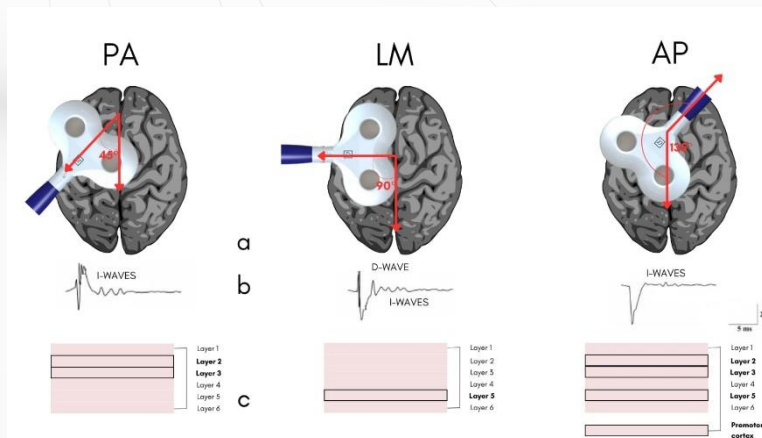


- **Neurophysiological evidence: increased corticospinal excitability**
 - independently on pre-stimulus tonic muscle contraction
 - also when only observed, imagined, or prepared, actually keeping the hand at rest

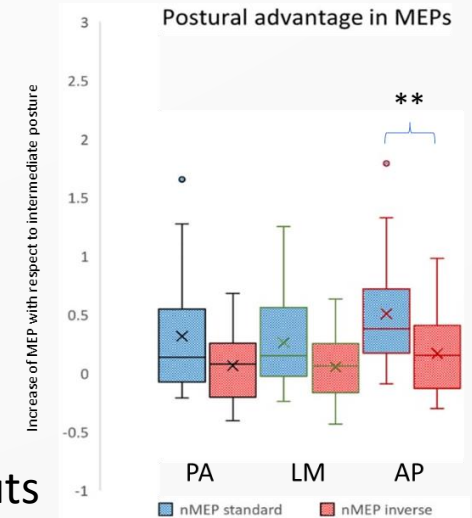


for thumb down pinch:

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

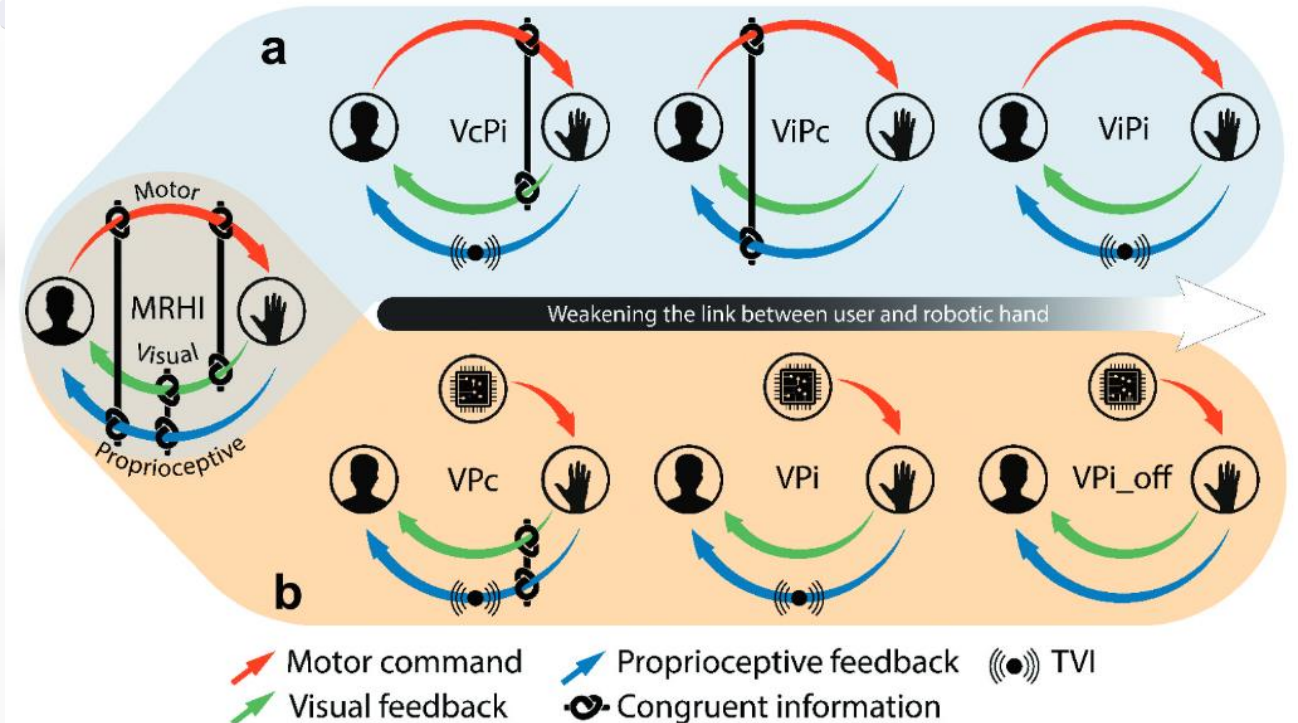


Higher excitability due to premotor inputs



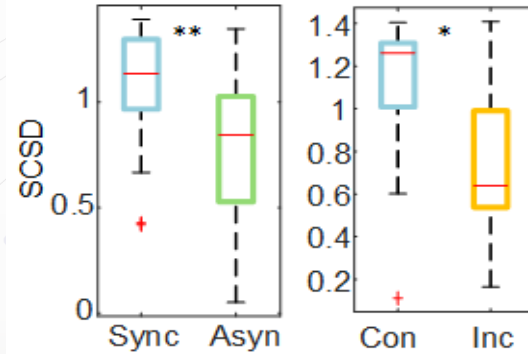
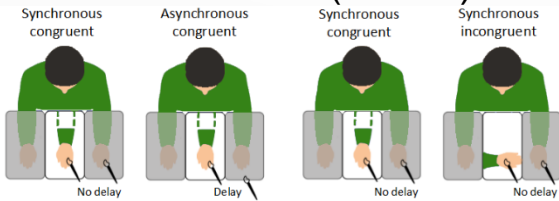
Building Ownership and Agency of a Robotic Hand

- **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**



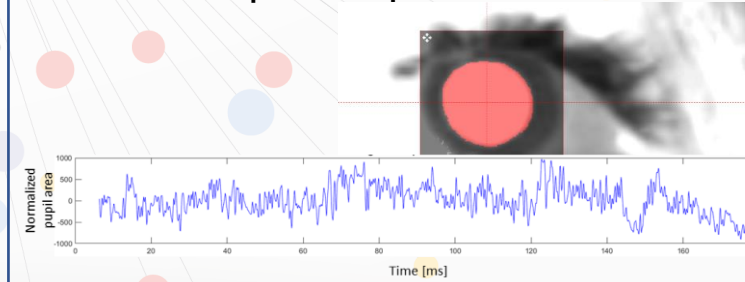
Body Representation Impacts efferent autonomic activity

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

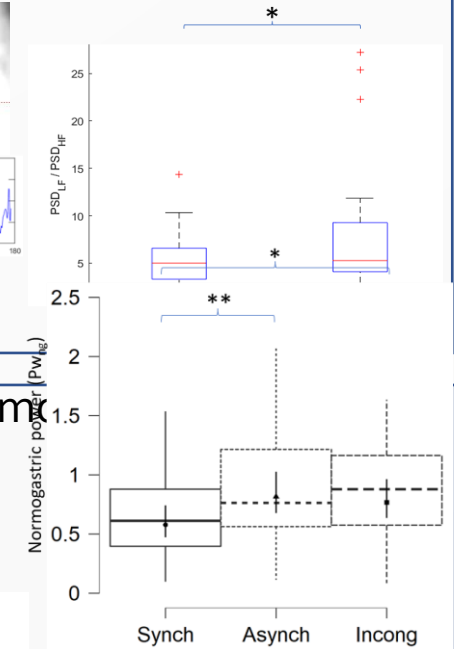


D'Alonzo et al., *Journal of Cognitive Neuroscience*, 2020

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

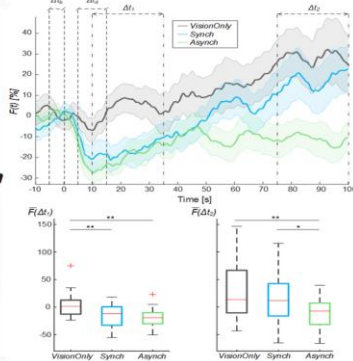


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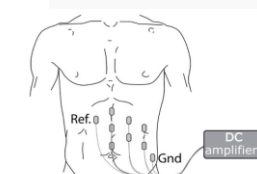
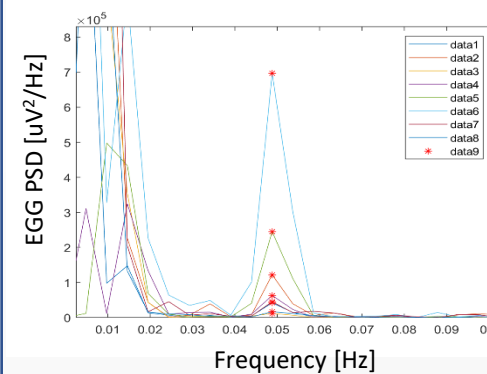
Synch Asynch Incong

increases blood flow to the investigated limb

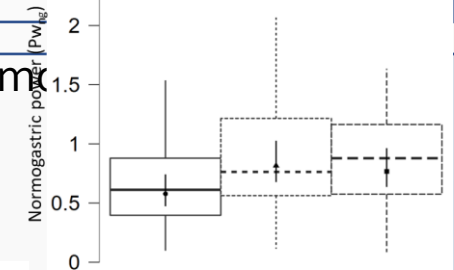


Di Pino et al., *Open Research Europe*, 2022

Decreases the spectral power of norm



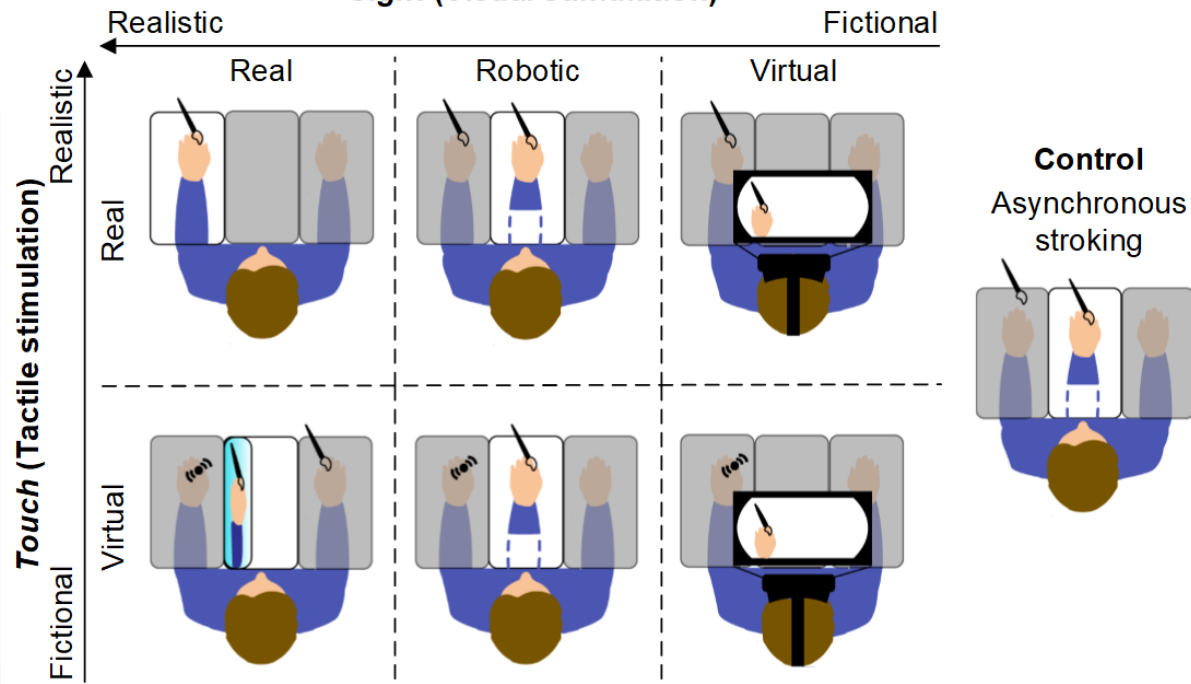
Unpublished



Synch Asynch Incong

Integrating real and artificial stimuli

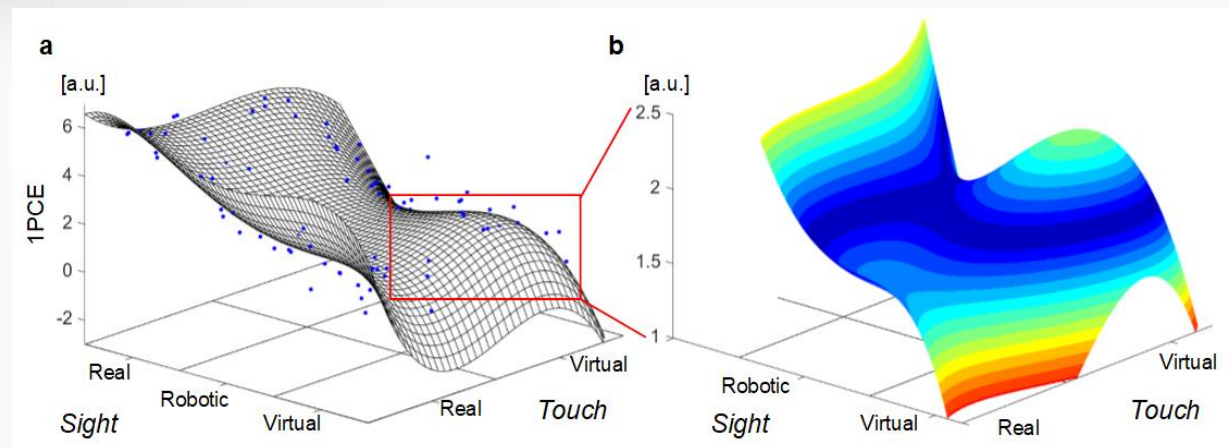
Sight (Visual stimulation)



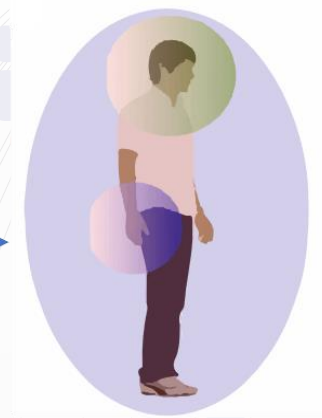
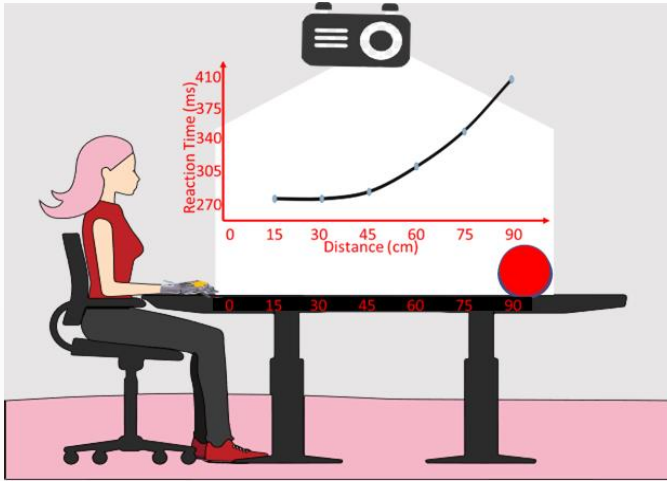
matched degree of virtualization

Different level of virtualization of sight and touch

uncanny valley of avatar's hand embodiment

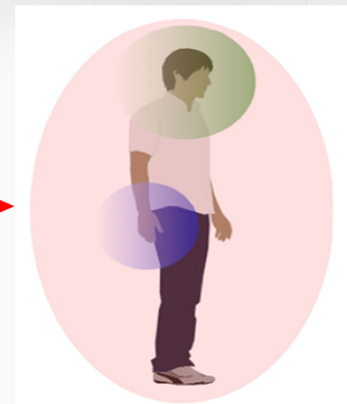
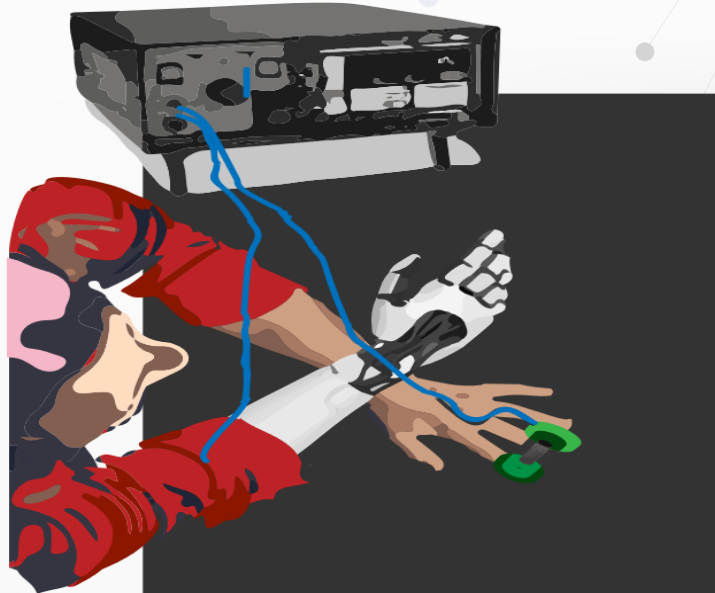


Sensory- and Action-oriented embodiment



- 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

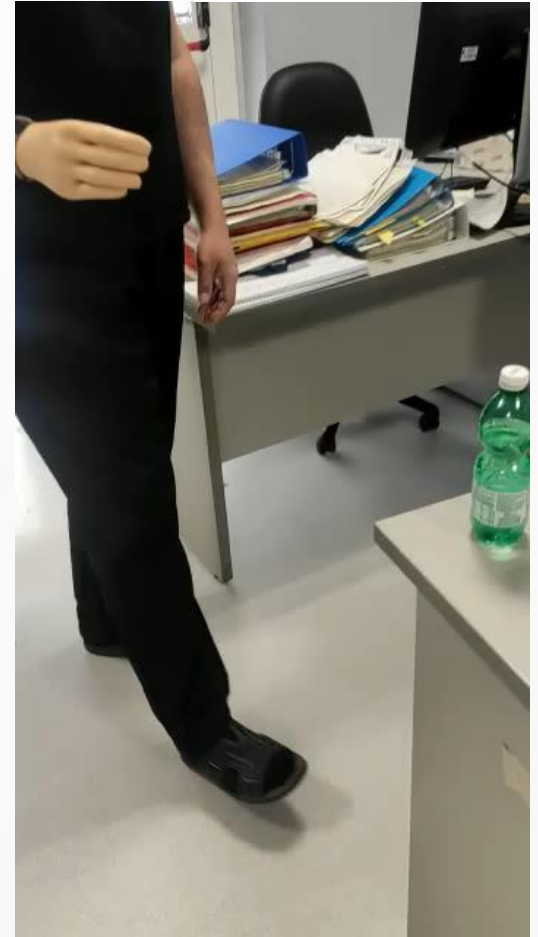
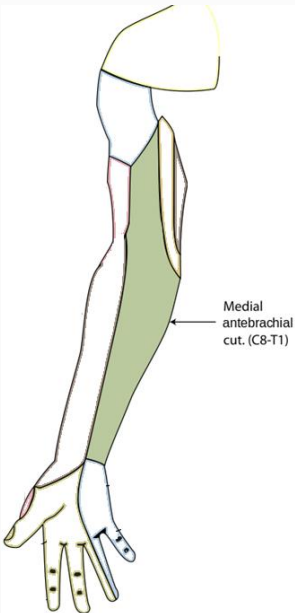


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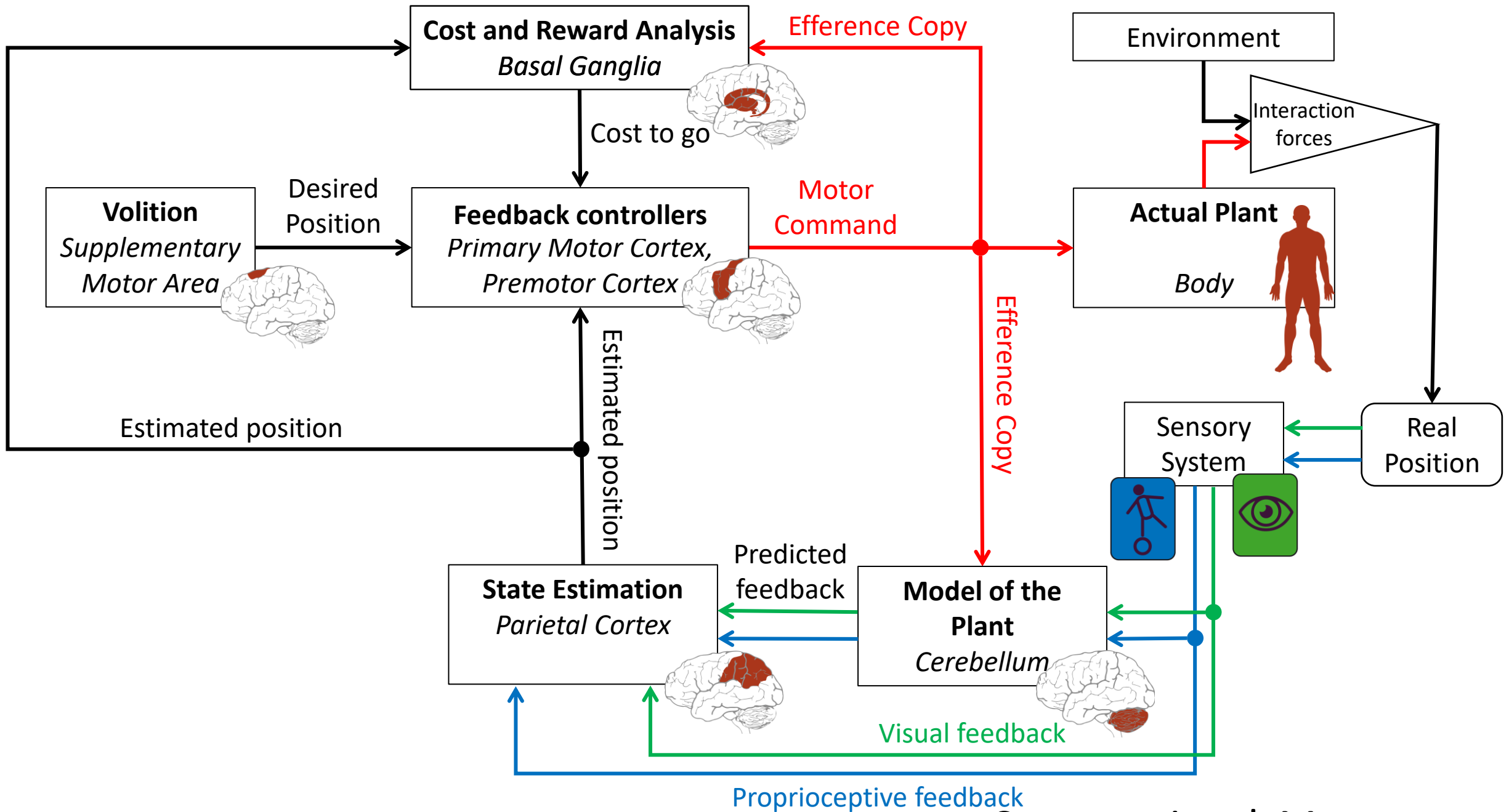


Osseointegration + Targeted Motor/Sensory Reinnervation

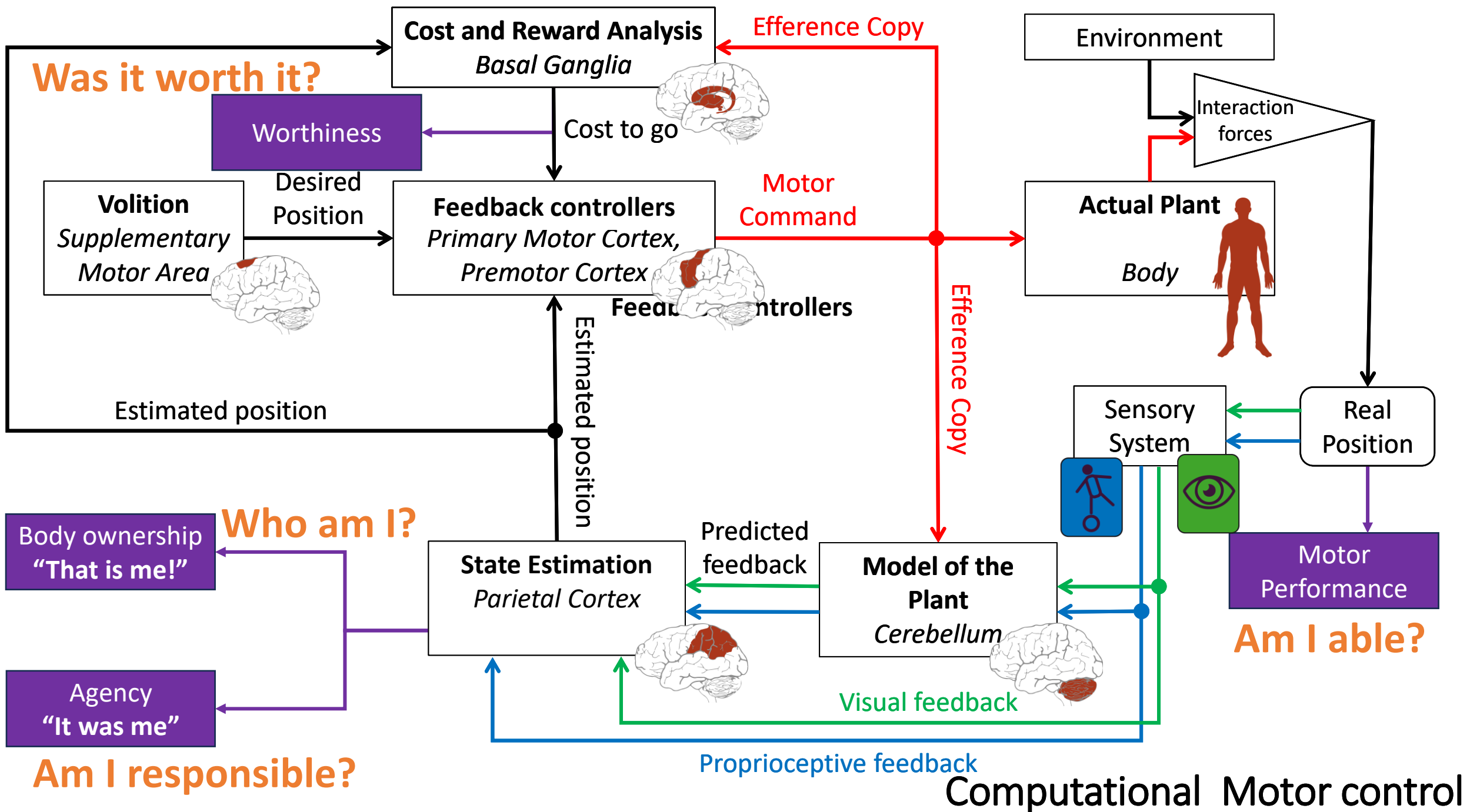
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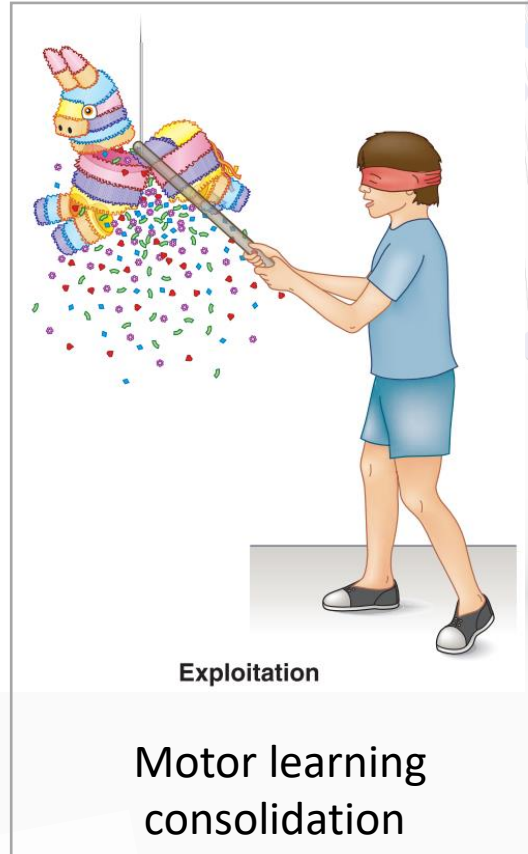


Zangrandi et al., Journal of Neurophysiology, 2021



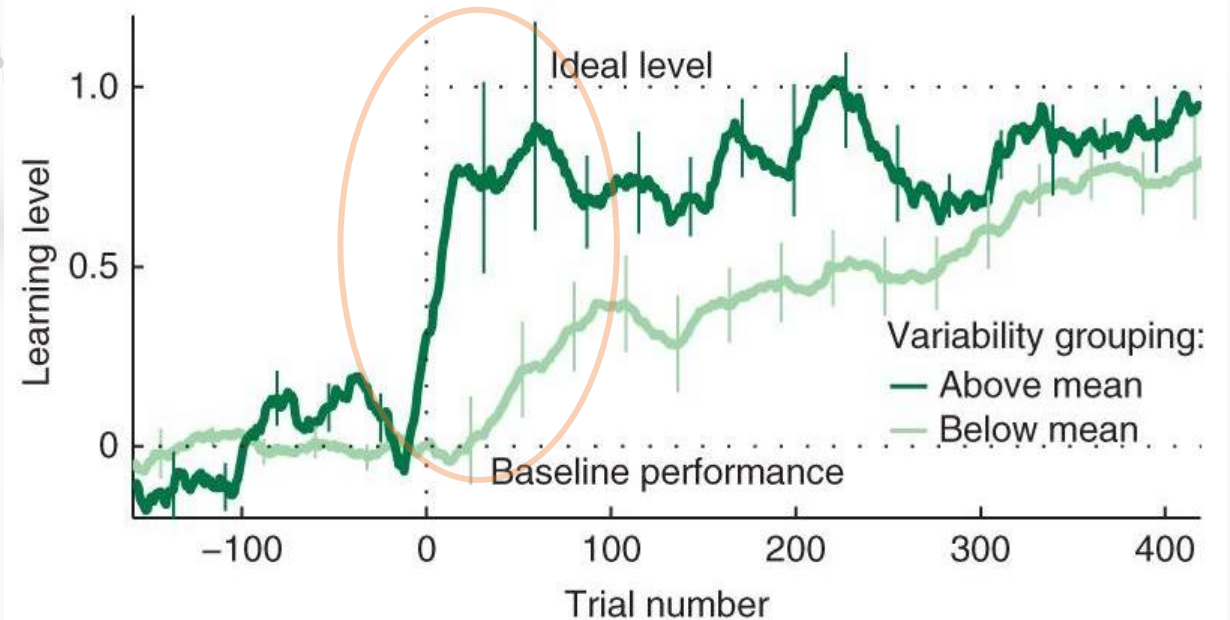
Computational Motor control





Better learning rate

Motor variability (noise) improves motor learning





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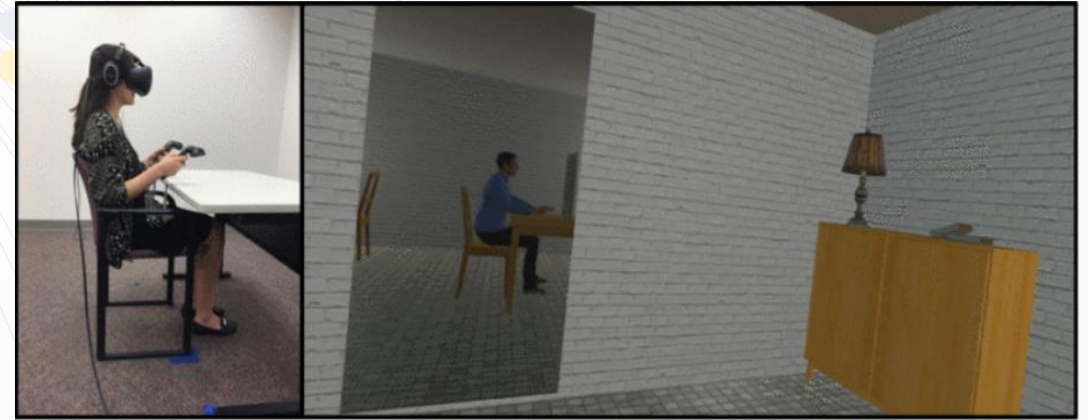
team's ethnic mix and
highly cited papers



Freeman R. and Wei H. *Nature* 2014

Diversity decreases (yet allows) embodiment

Gender



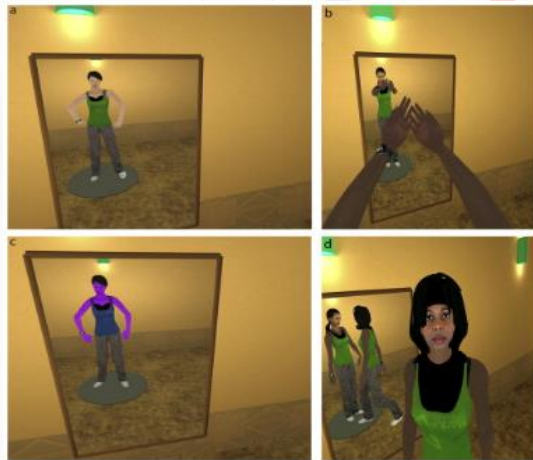
Peck et al., et al., 2018; IEEE Trans Vis Comput Graph.

Hand color



Maister et al., 2013
Consciousness and Cognition

Body skin



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

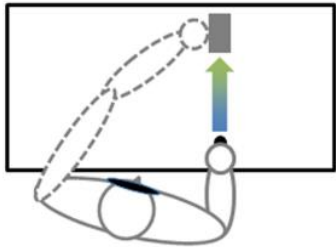
Face



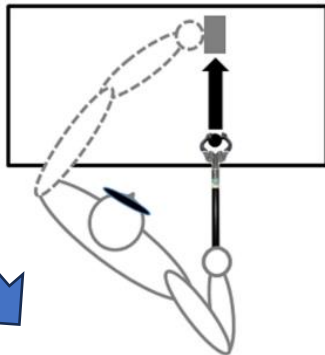
Fini et al., et al., 2018
Front. Behav. Neurosci.

Embodiment changes motor behaviors

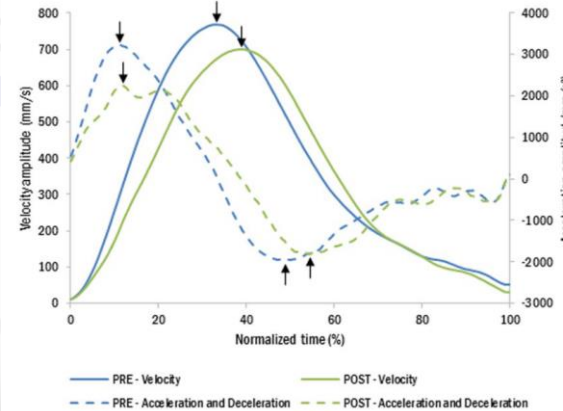
FREE-HAND GRASPING



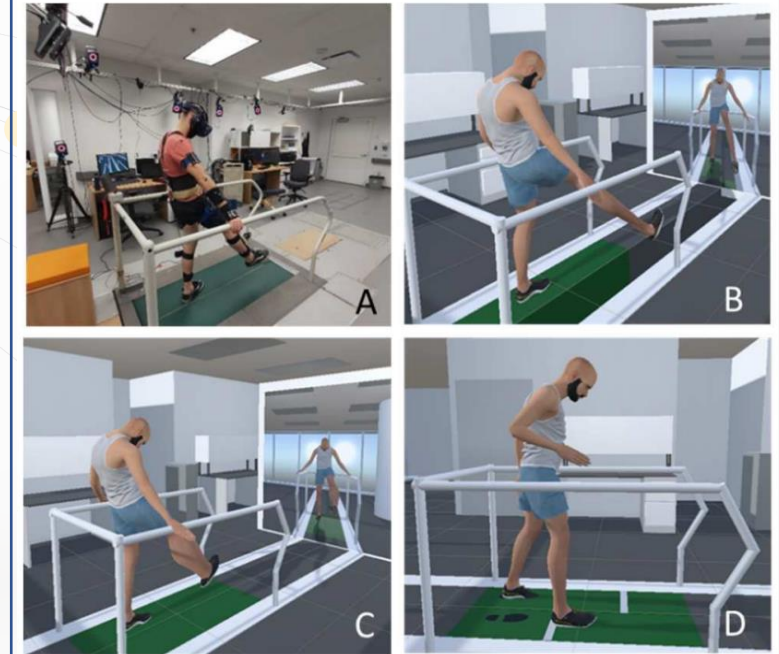
TOOL GRASPING



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



Martel et al., *Scientific Report* 2019



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



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



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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).





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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**.



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Left-Handed in a Right-Handed world





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



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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

ARM

- Created by Dean Kamen, the Segway's inventor, the Deka Arm system performs multiple movements through brain signals. The Deka, which weighs the same as a human arm, is controlled by the patient's brain and accomplishes previously impossible tasks like opening locks with keys and using zipper. STATUS: Approved by the FDA last month.

LUNG

- In February, scientists from the University of Texas's medical system announced they had engineered a pair of lungs in just three days by combining elements from two separate, damaged lungs and fostering cell growth in the newly created organ. STATUS: More than a decade away, but could be ready for animal testing by 2015.

HEART

- SynCardia's temporary artificial heart, which uses dual ventricles to pump more than nine liters of blood per minute, has a portable battery that allows patients with cardiac failure to recover outside the hospital while waiting for a permanent transplant. STATUS: Currently available and costs about \$125,000.

LIVER

- Artificial growth of liver cells was previously impossible, but last year, MIT researchers isolated two compounds that, when intermingled with donated liver cells, maintained their functionality and helped cell growth. STATUS: Implantation is still years away.

PANCREAS

- Resembling a pager, Medtronic's MiniMed 5300 features a pump and a sensor that better controls insulin flow (lessening a diabetic's risk of a hypoglycemic episode). In late 2013, the device was the first "artificial pancreas" to win FDA approval. STATUS: Currently available, and the company plans to release a MiniMed with an even more accurate glucose-management pump in Europe this summer.

VAGINA

- Wake Forest scientists announced in early April that they had created synthetic vagina, made of human cells and degradable tissue, that had been implanted in four women suffering from underdeveloped sexual organs. STATUS: Doctors hope to expand beyond this pilot study but have yet to announce additional trials.

KIDNEYS

- The FDA recently fast-tracked the development of two synthetic kidneys, one that's wearable and the other, co-created by UC San Francisco, implantable and powered by blood pressure. STATUS: Clinical trials were recently green-lit for the wearable device, while UCSF's biochip is still in the pretrial phase.

ANKLE

- The BiOM, an ankle-foot prosthetic, was created in part by MIT professor Hugh Herr in 2011. It calculates force using several microprocessors, helping patients conserve energy and allowing for a more natural gait. STATUS: Currently available for \$50,000.

EYE

- In late January, doctors at the University of Michigan implanted the Argus II Retinal Prosthesis—the "bionic eye"—into the retinas of two patients who were nearly, though not entirely, blind. When it's activated, a camera attached to the patient's glasses transmits electronic pulses to the retina, which the brain then converts into images. During early clinical studies, users have completed everyday tasks like eating and reading laundry. STATUS: Twelve U.S. hospitals are cleared for the procedure.

NOSE

- In April, the University of Basel announced the first transplant of lab-manufactured nasal cartilage. Scientists grew nasal septum-based cells and used that tissue to replace portions of a nose damaged by skin cancer. STATUS: The next step is total reconstruction of a nose, as well as an eyelid or ear.

TRACHEA

- An artificial trachea—composed of materials such as plastic fibers meshed with stem cells, a procedure pioneered in part by Dr. Paolo Macchiarini of Stockholm's Karolinska Institutet—may replace the real thing. Previous transplants came from cadavers. STATUS: About a half-dozen U.S. patients have received bioengineered tracheas, but the organ is awaiting clinical trials.

ESOPHAGUS

- Macchiarini, a specialist in the field of regenerative organs, announced in April that his team had stripped an esophagus of its cells, seeded it with bone marrow cells, and constructed a new, functional esophagus. STATUS: Currently being implanted into rats.

HAND

- The i-Limb was launched in 2007, but revamped versions of the prosthesis, which detects muscular movements in the arm and then translates them into preprogrammed hand and finger motions, are still being introduced. The latest i-Limb ultra revolution, which features a rotating thumb and fingers that move at the joints. (Journalist Miles O'Brien's experience with his prosthetic arm is on page 34.) STATUS: Currently available, with prices up to \$120,000.

BACK

- Scientists at the University of Louisville announced a new procedure in April in which electrodes, implanted along segments of the spinal cord, stimulate muscles and help paralyzed patients move their legs and feet. STATUS: Clinical trials likely in the near future.

LEG

- Northwestern and the Rehabilitation Institute of Chicago pioneered a procedure in which doctors weave nerves—ones that would otherwise be useless post-amputation—in a patient's hamstring. Electrodes that are attached to the prosthesis help the brain precisely control the movement of the limb, minimizing the risk of falling. Vanderbilt University has also designed a competing leg prosthesis that uses sensors to more accurately determine necessary angles for climbing stairs or a ladder, but its licensed design isn't commercially available. STATUS: Available for home trials by 2016.

EXOSKELETON

- Referred to as a "Segway with legs," the exoskeleton, named Indego, is available only to people who weigh 250 pounds or less. It is lighter than previous models (by about 20 pounds), contains motorized joints that move the hips and knees, and provides a wide range of motion for those suffering from severe spinal-cord injuries. STATUS: We're underp clinical trials this summer and could be available Stateside by 2016.

KEY

- Available now
- Clinical trials
- Years away



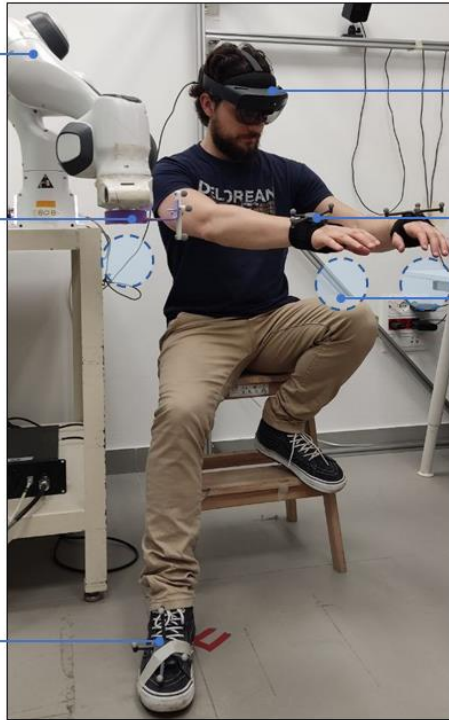
(Di Pino et al Front Syst Neurosci 2014, Eden et al., Nature Communication 2022)

Embodiment of SRLs

Supernumerary
Robotic Limb

Reflective markers
for EE tracking

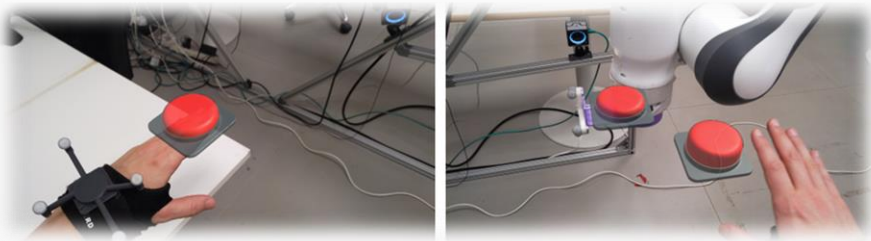
Reflective markers
for foot tracking



Augmented Reality
Head-mounted Display

Reflective markers for
hands tracking

Approximate position
of augmented reality
objects





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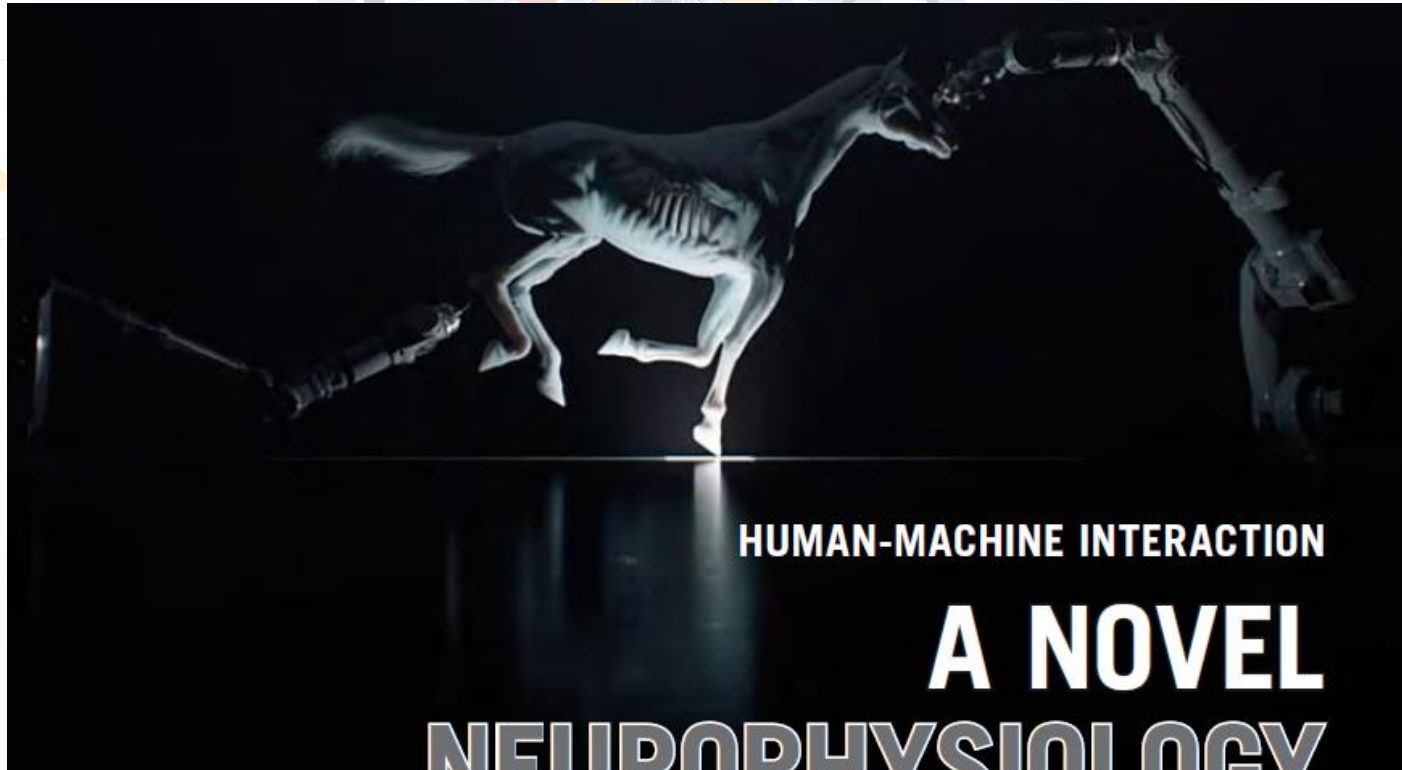


New salient inputs for the index fingertip





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HUMAN-MACHINE INTERACTION

A NOVEL NEUROPHYSIOLOGY OF HUMAN-TECHNOLOGY INTERACTION



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Ethical issues in Human-Technology Interaction



Synthetic Humans: a novel Minority?

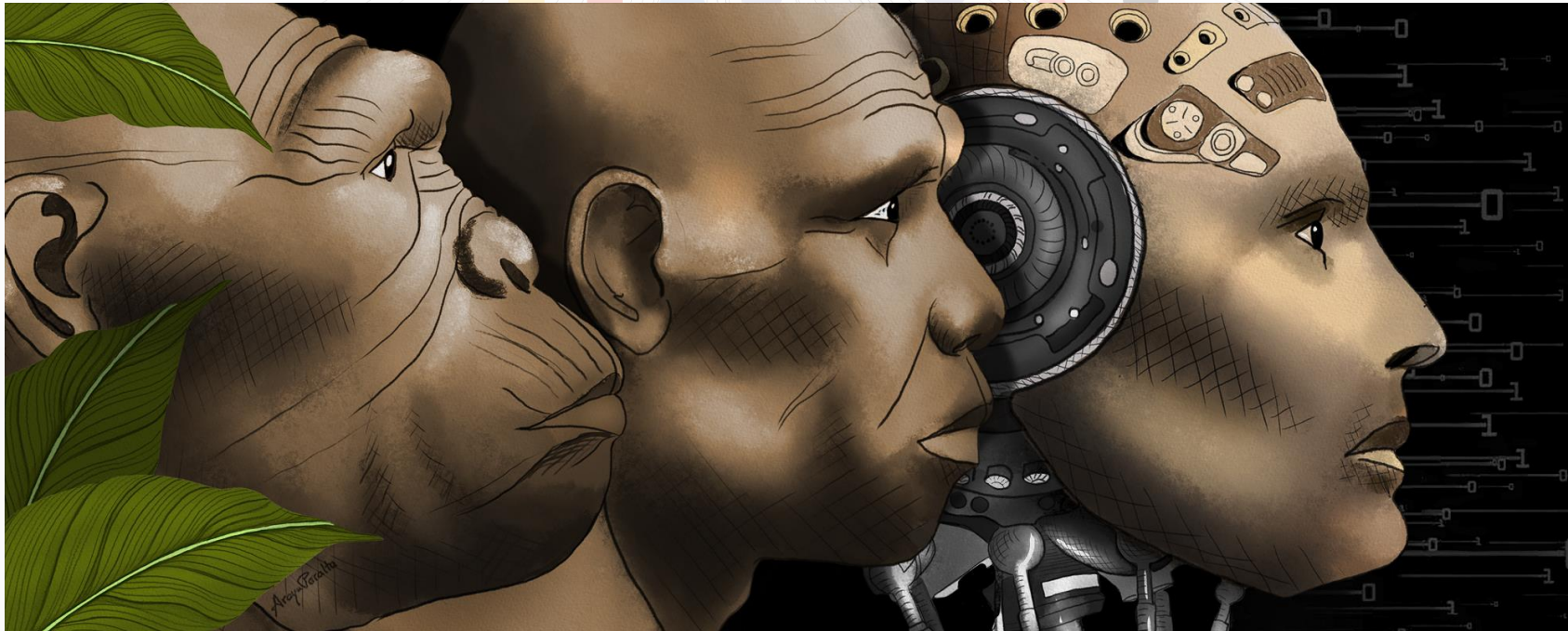


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The integration between humans and their tools cannot be stopped

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.