Implantable chronic Brain Machine Interface for movement compensation: from clinical proof of concept to daily use

G. CHARVET

F. SAUTER

WIMAGINE-BCI : a CEA technology

WIMAGINE® IMPLANT

- **Chronic ECoG recording on 64 channels**
- **Wireless transmission**
- **Remote power supply**
- **AIMD class III regulatory compliance for long-term clinical applications**

Mestais et al. 2014 *IEEE transactions on neural systems and rehabilitation engineering*.

BRAIN SIGNAL DECODER

Artificial Intelligence methods

- **High dimensional decoding (multi-limb)**
- **Real time adaptive learning of models (recursive model)**
- **Stability and Robustness over time**

Eliseyev A. et al. PLOS ONE, 2016
Benabid, A. L. et al. The Lancet Neurology 2019
Eliseyev, A., et al. 2017. Scientific reports
Moly, A., et al. 2022 J. Neural Eng.

*A portfolio of **25 patents** on the WIMAGINE-BCI technology*

BCI WIMAGINE DEVELOPMENT AND CLINICAL VALIDATION : A LONG JOURNEY

2002 2008 2013 2017 2024

TRL1-3 Early stage concept → **TRL 4** Design and Development → **TRL 5** Industrial production of prototypes → **TRL 6** Pilot Clinical trial → **TRL7-8-9** Device preseries → Post marketing

- Technological bricks
- Full system development

- Functional validation and preclinical validations

- Material selection

Specifications to answer medical needs

Industrialization
- Design for manufacturing
- Manufacturing with ISO13485 norm
- test

Safety
- Normative qualification
- Biocompatibility
- Cleaning process and sterilization validation

Submission of regulatory Files to the authorities (ANSM / SWISSMEDICS) and ethical committee (CPP / SWISSETHICS): clinical trial protocol and Investigator's brochure

Functional demonstrator

Proof of concept clinical trials

BCI&Tetraplegia clinical trial

STIMO-BSI&T2G clinical trial for paraplegic

Prototype for clinical trial

ARC BCI

ONWARD® Medical -CEA Agreement for Exclusive Rights to WIMAGINE® BCI Technology into its ARC-BCI system

TRL : Technology readiness level

Clinical trial “BCI & Tetraplegia”

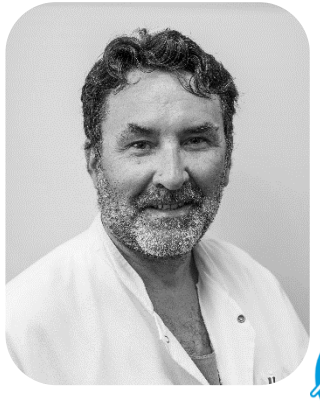
1st clinical evaluation of the WIMAGINE-BCI technology

Goal

Providing the proof of concept that it is possible, for tetraplegic patients to control complex effectors, such as a 4-limb exoskeleton, thanks to brain activity monitoring and decoding

Under the scientific direction of
Professor Alim-Louis BENABID
(*Lasker~DeBakey Prize 2014 & Breakthrough Prize 2015)*

Principal Investigator:
Professor Stéphan Chabardès



Clinical trial “BCI & Tetraplegia”

Proof of concept of a high dimensional control of complex effector using ECoG brain signal

Walking control
1D brain switch

3D continuous trajectories and pronation/supination control of 2 arms
8D multi-limbs control

THE LANCET Neurology

Benabid, A. L., Costecalde, T., Eliseyev, A., Charvet, G., Verney, A., Karakas, S., ... & Chabardes, S. (2019). An exoskeleton controlled by an epidural wireless brain–machine interface in a tetraplegic patient: a proof-of-concept demonstration. *The Lancet Neurology*, *18*(12), 1112-1122.

Brain signal decoder based on machine learning techniques

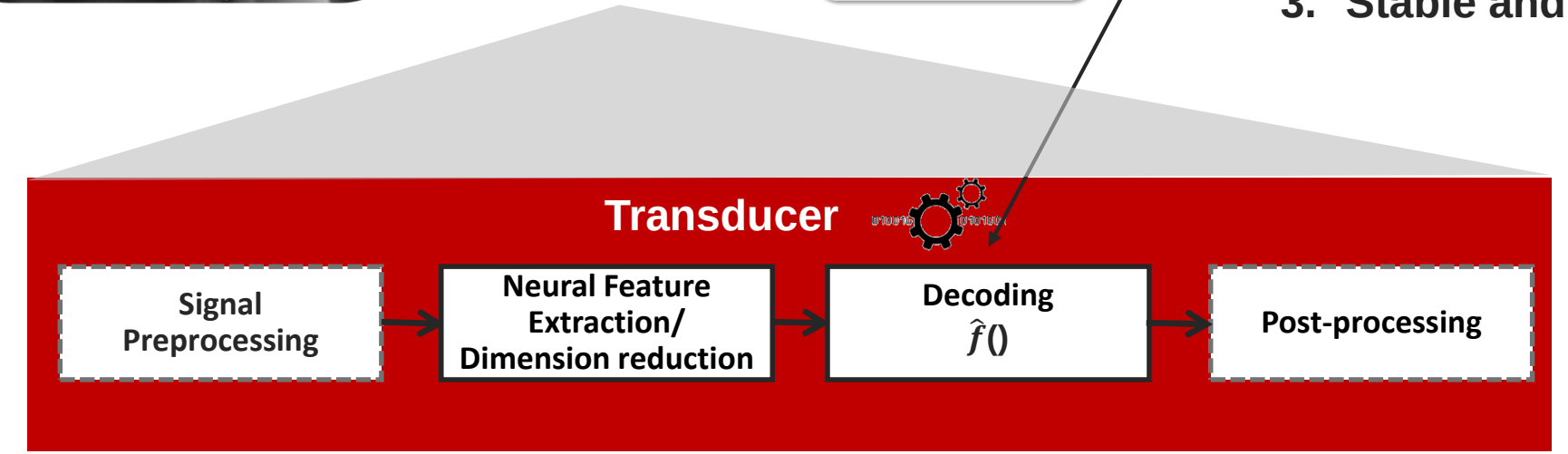
Decoding of movement intentions from the brain activity

Functional substitution devices

To improve the mobility of patients with motor disabilities

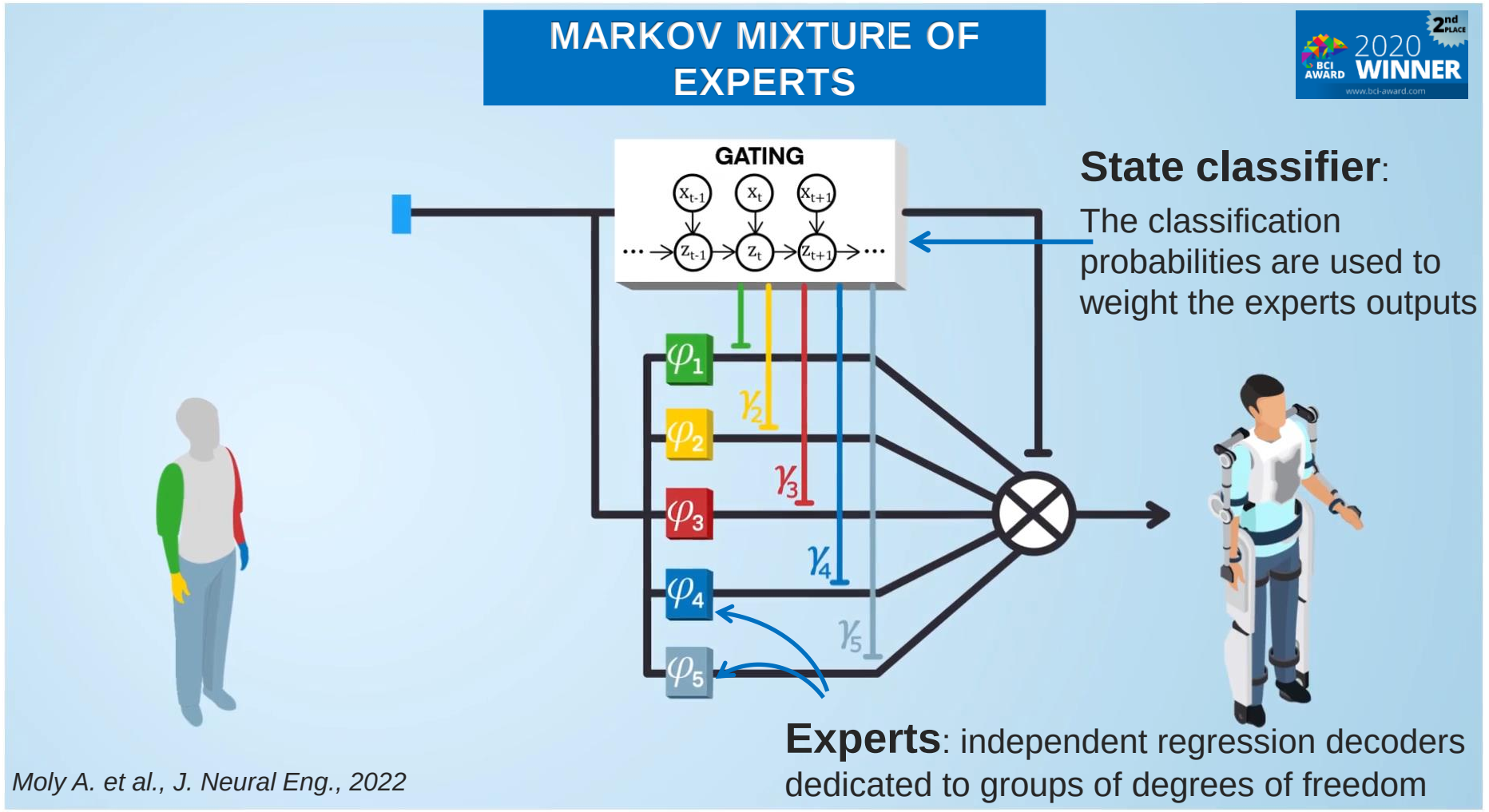
Key features of the brain signal decoder

1. High dimensional continuous decoding (multi-limb)
2. Real time adaptive training of models (supervised training of a recursive model)
3. Stable and Robust model over time

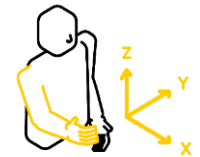


Eliseyev A. et al. PLOS ONE, 2016
Eliseyev, A., et al. 2017. Scientific reports
Moly, A., et al. 2022 J. Neural Eng.

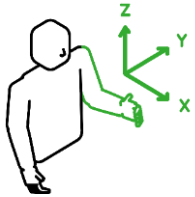
RECURSIVE EXPONENTIALLY WEIGHTED MARKOV-SWITCHING MULTI-LINEAR MODEL (REW-MSLM)



Moly A. et al., J. Neural Eng., 2022



3D right hand translation



3D left hand translation


1D right wrist rotation


1D left wrist rotation


Idle State

Real-time Incremental training

Movement instructions for mental tasks

Brain signals
ECoG recording with WIMAGINE® implant

Movement Feature extraction

Neural Feature extraction

Complex Continuous wavelet transform

Model update 0.7Hz

Incremental (adaptive) learning using current data block of 15s

Building of the model

Current model

Current model use 10Hz

Prediction of movement each 100ms

Movement command

Kinematic output variable for effectors control

Virtual avatar visual feedback

If prediction is OK

Model fixed

Eliseyev et al, 2017, *Scientific reports*, **7**(1)

A progressive training (real / virtual effectors)

Walking control training sessions

- **Mental tasks:**

- **Brain switch** to activate an automatic walking cycle

- **Training with virtual environment and exoskeleton**

Game (Runner)

Avatar

Walking training session

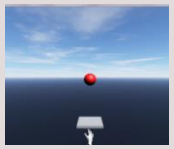
Upper limb control training session

- **Mental tasks:**

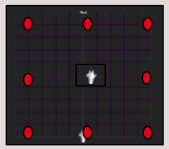
- **Continuous trajectories decoding:**
  wrist translation

- **Training with virtual environment and exoskeleton**

Game (Pong)



TARGET 2D



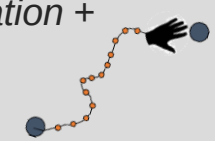
3D avatar

Left arm control training session

Multi-limb control Training session

- **Mental tasks:**

- **Continuous trajectories decoding:**
  alternative wrists translation + rotation



- **Training with virtual environment and exoskeleton**

3D avatar

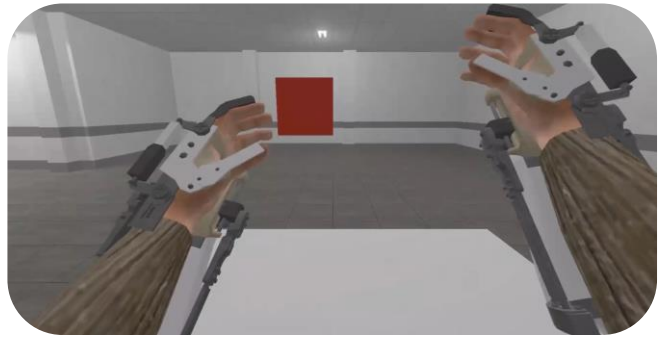
Multi-Limb training session

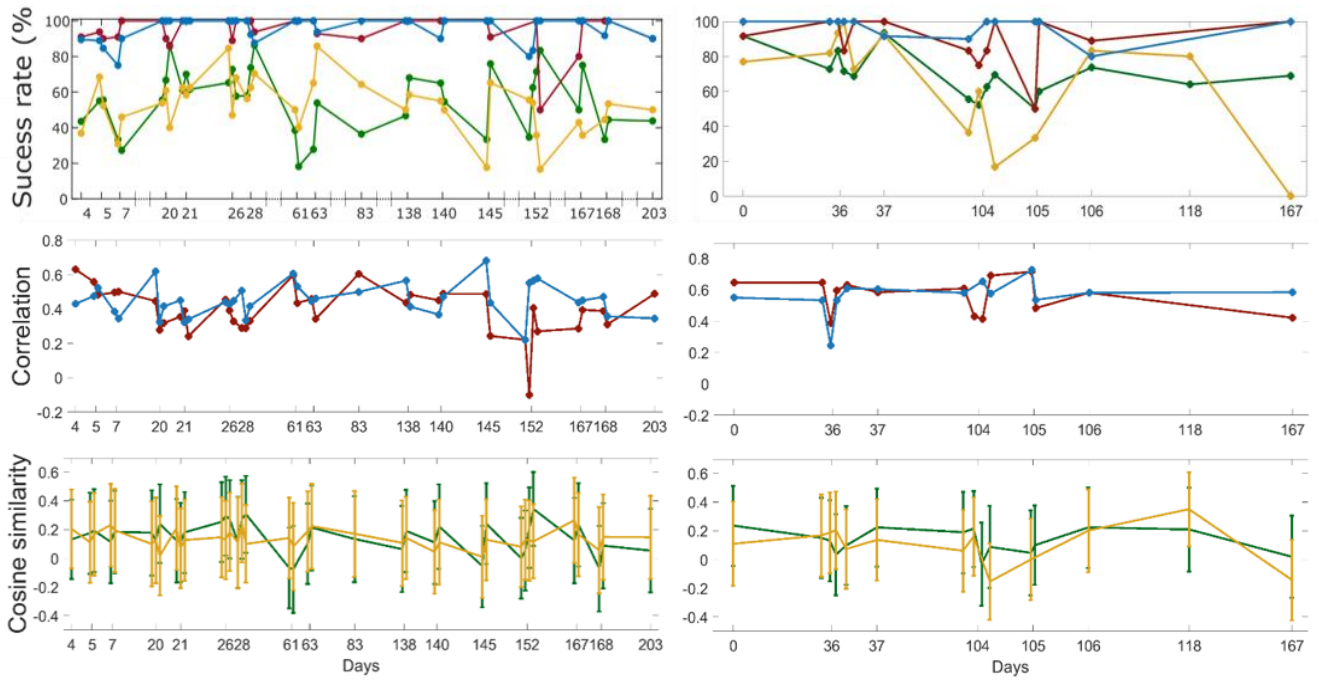
Demonstration of a long-term stable and robust bimanual control

Demonstration of the stability of performances with an 8D decoding model over a period of 6 months without recalibration :

- 8D exoskeleton experiment (167 days)
- 8D virtual avatar experiment (203 days)

Perspectives of chronic use of the WIMAGINE technology

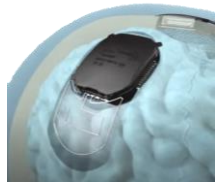




Moly et al. 2022, An adaptive closed-loop ECoG decoder for long-term and stable bimanual control of an exoskeleton by a tetraplegic. 2022 *J. Neural Eng.*

BCI and sensor-based shared control to assist and secure user for mobility and reach-and-grasp tasks

WIMAGINE cortical implant with 64 channels for electrocorticographic signal recording

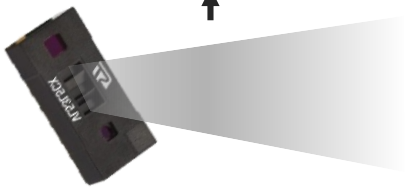


BCI decoding

BCI control

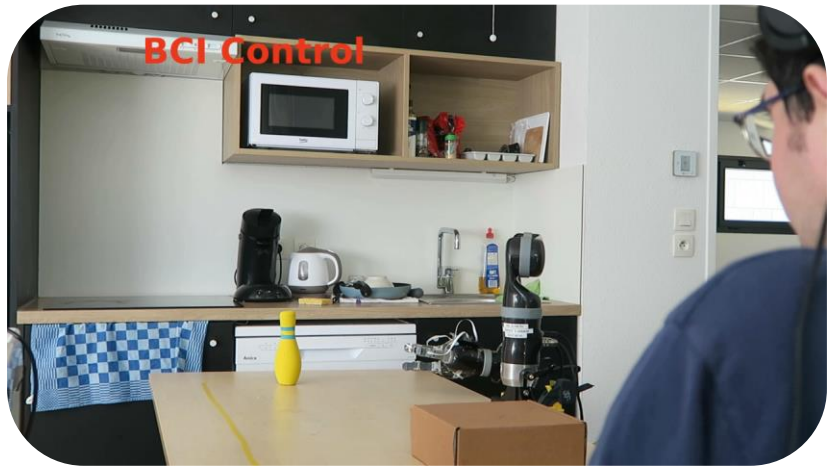
Robotic control

Points of interest extraction



Time of Flight (ToF) proximity sensors for close environment detection

Grasping assistance (robotic arm control)

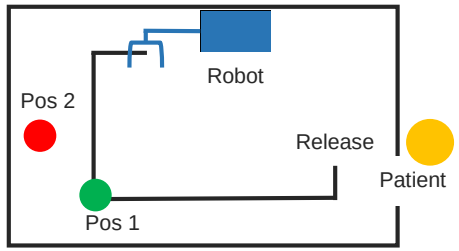


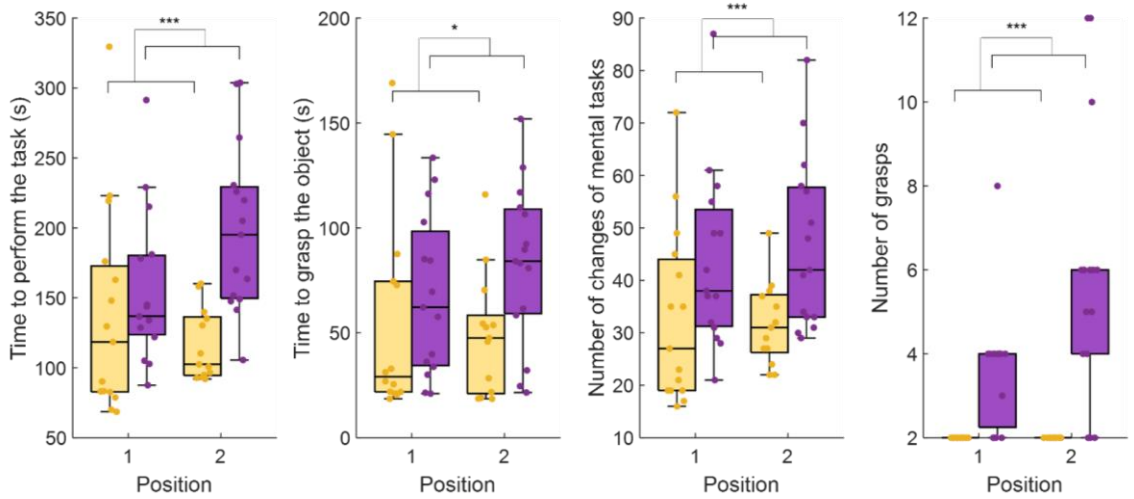
Mobility assistance (wheelchair driving)

Bellicha, A., Struber, L., Pasteau, F., Juillard, V., Devigne, L., Karakas, S., ... & Charvet, G. (2025). Depth-sensor-based shared control assistance for mobility and object manipulation: toward long-term home-use of BCI-controlled assistive robotic devices. *Journal of Neural Engineering*.

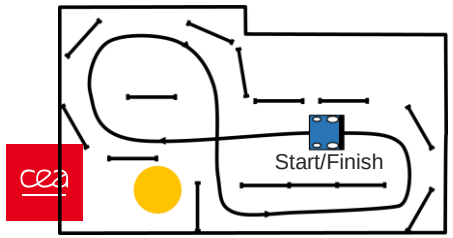
Evaluation of BCI and sensor-based shared-control technology

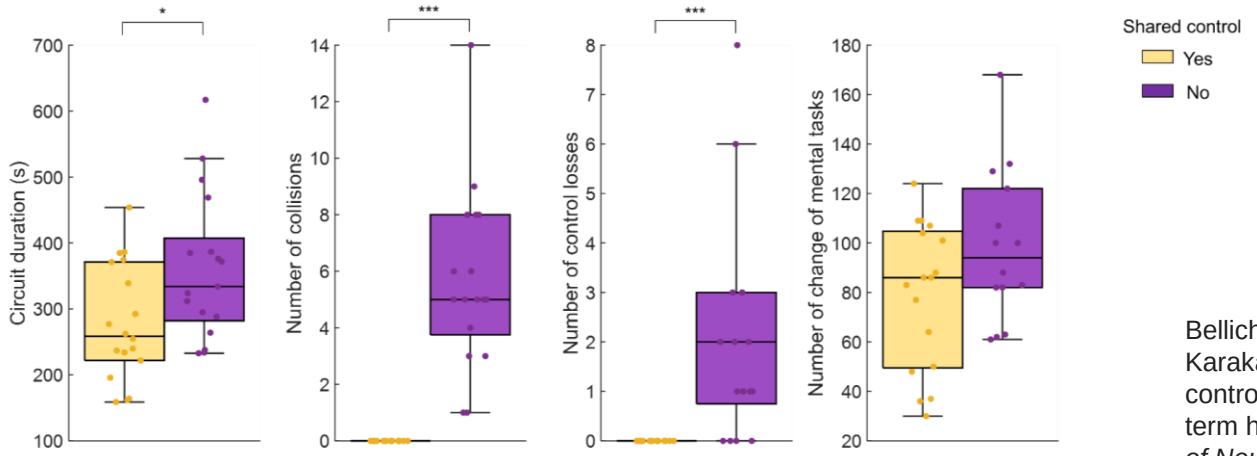
Grasping tasks (robotic arm control with and without shared control)





Mobility tasks (wheelchair driving with and without shared control)



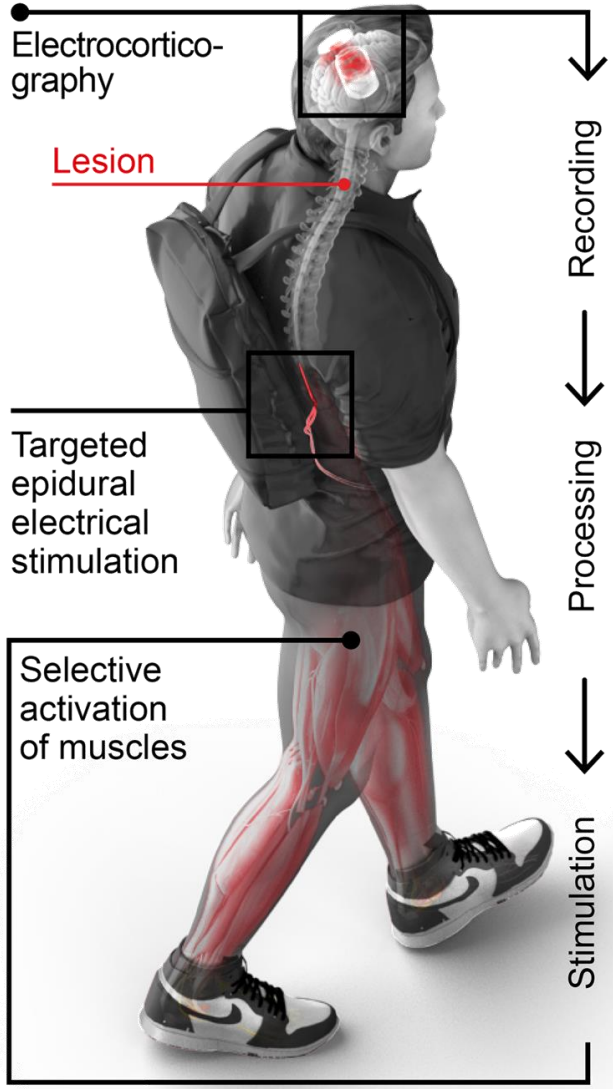


Shared control benefits:

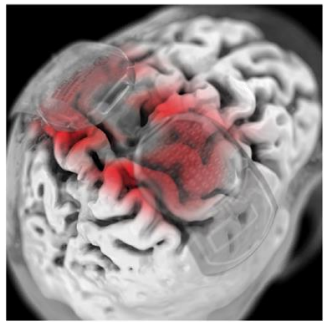
- **Time to perform the task : ↘ 28 %**
- **Cognitive load (estimated) : ↘ 24 %**
- **All collisions avoided in wheelchair driving**
- **No « unwanted » grasps in robotic arm control**

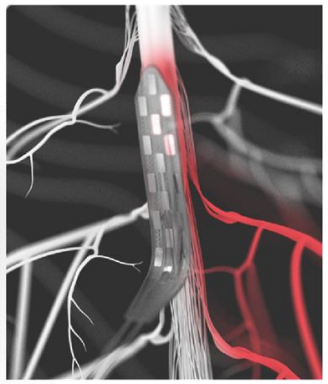
Bellicha, A., Struber, L., Pasteau, F., Juillard, V., Devigne, L., Karakas, S., ... & Charvet, G. (2025). Depth-sensor-based shared control assistance for mobility and object manipulation: toward long-term home-use of BCI-controlled assistive robotic devices. *Journal of Neural Engineering*.

GAIT RESTORATION FOR PARAPLEGIC PATIENT WITH A BRAIN SPINE INTERFACE



Cortical implants





WIMAGINE-BCI technology

Spinal Cord Stimulation implantable technology

Grégoire Courtine

Jocelyne Bloch

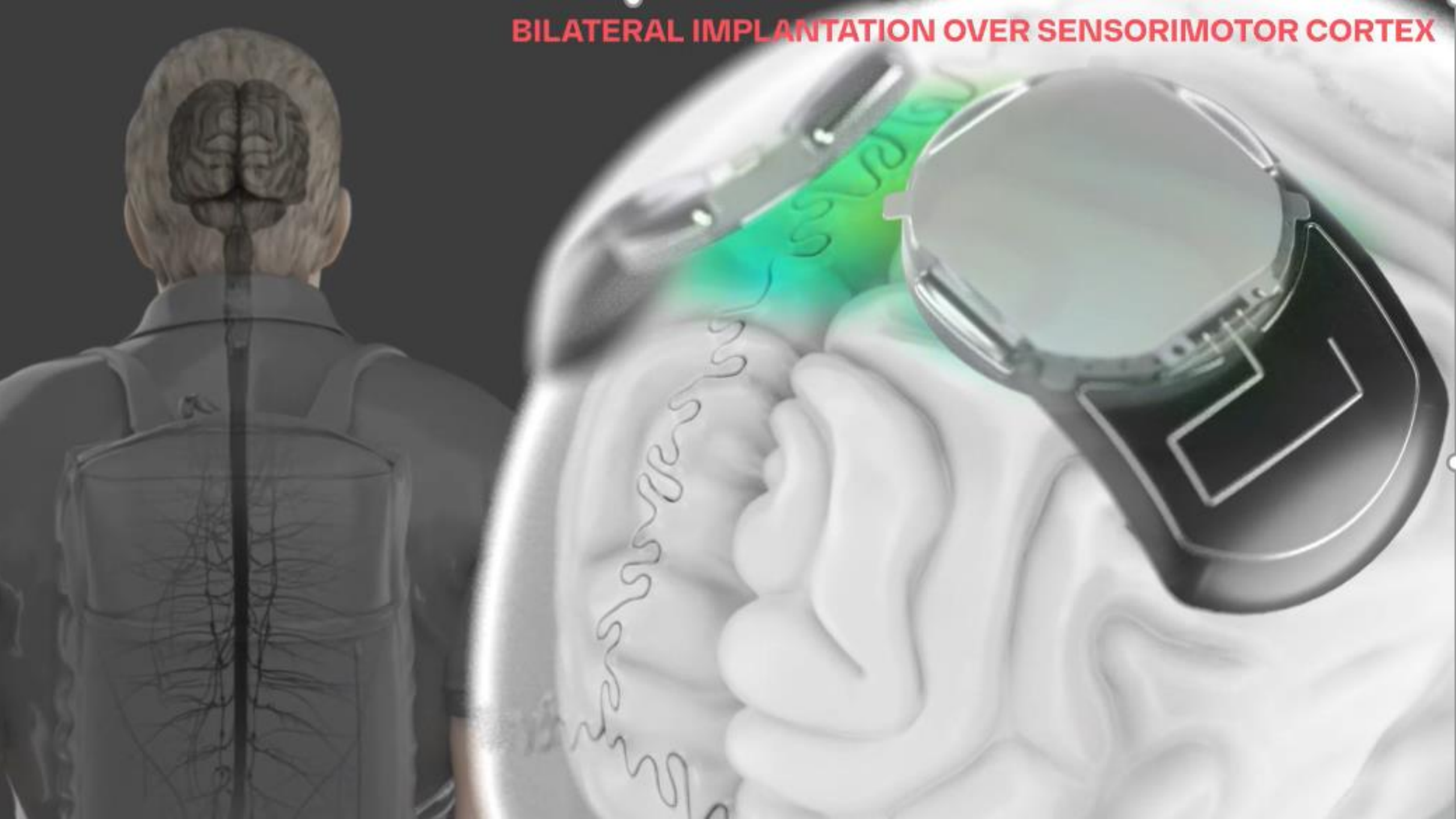
Henri Lorach

nature

Article

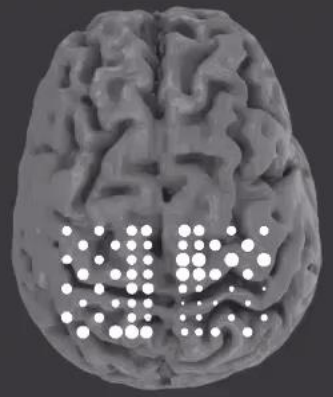
Walking naturally after spinal cord injury using a brain–spine interface

Lorach, H., Galvez, A., Spagnolo, V., Martel, F., Karakas, S., Intering, N., ... G. Charvet, J. Bloch & Courtine, G. (2023). Walking naturally after spinal cord injury using a brain–spine interface. *Nature*, *618*(7963), 126-133.


BILATERAL IMPLANTATION OVER SENSORIMOTOR CORTEX

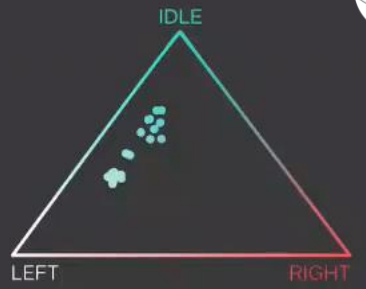
CONVERTING THOUGHTS INTO ACTIONS

Recorded brain signals



clinatec®

Decoding



Spatial stimulation

Stimulation amplitude

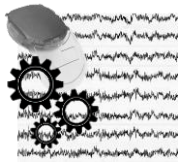
INDEPENDANT USE BY THE PARTICIPANT FOR REHABILITATION AND DAILY LIFE ACTIVITES

Next steps: towards fully autonomous home-use BCI system

PORTABLE, EASY TO USE AND ESTHETIC SYSTEM FOR EVERYDAY USE AND ENHANCED ACCEPTABILITY

BCI DECODING INTEGRATED CIRCUIT FOR MINIATURIZATION

ADAPTIVE DECODER FOR LONG TERM USE



BRAIN-GUIDED SPINAL CORD STIMULATION FOR BEST MOTOR PERFORMANCES

European Innovation Council

REVERSE PARALYSIS

nemobmi

ONWARD EMPOWERING MOVEMENT

EPFL

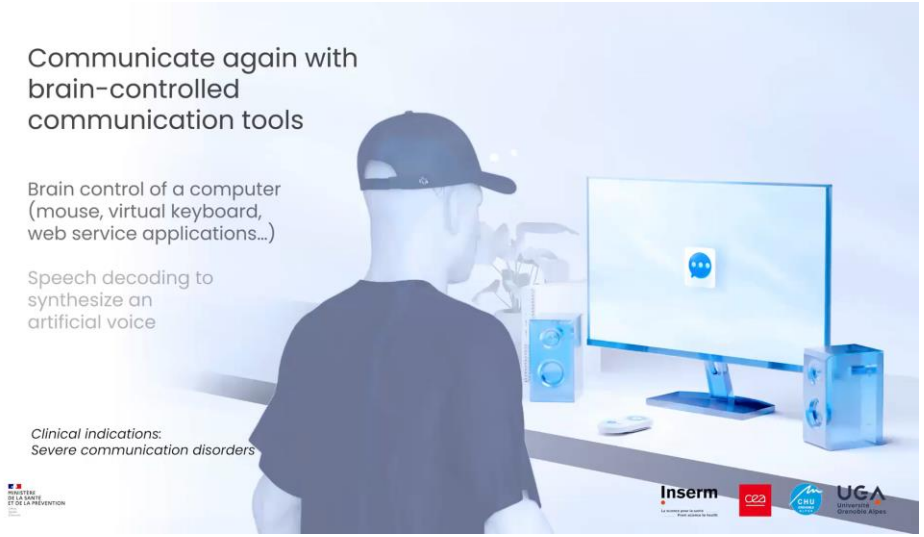
Sint Maartenskliniek

DTS

IICT

Towards the evaluation of new clinical applications

RESTORING COMMUNICATION IN LOCKED-IN SYNDROME PATIENTS



Computer cursor control and speech decoding based BCI

NEUROREHABILIATION FOR POST-STROKE PATIENT

Upper limb and lower limb restoration in chronic stroke patients with BCI combined to rehabilitation effectors

PHRC BCI Speech

REVERSE STROKE

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