Neuroingeniería

28 Septiembre 2022

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UNIVERSITAS Miguel Hernández

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medical robotics group

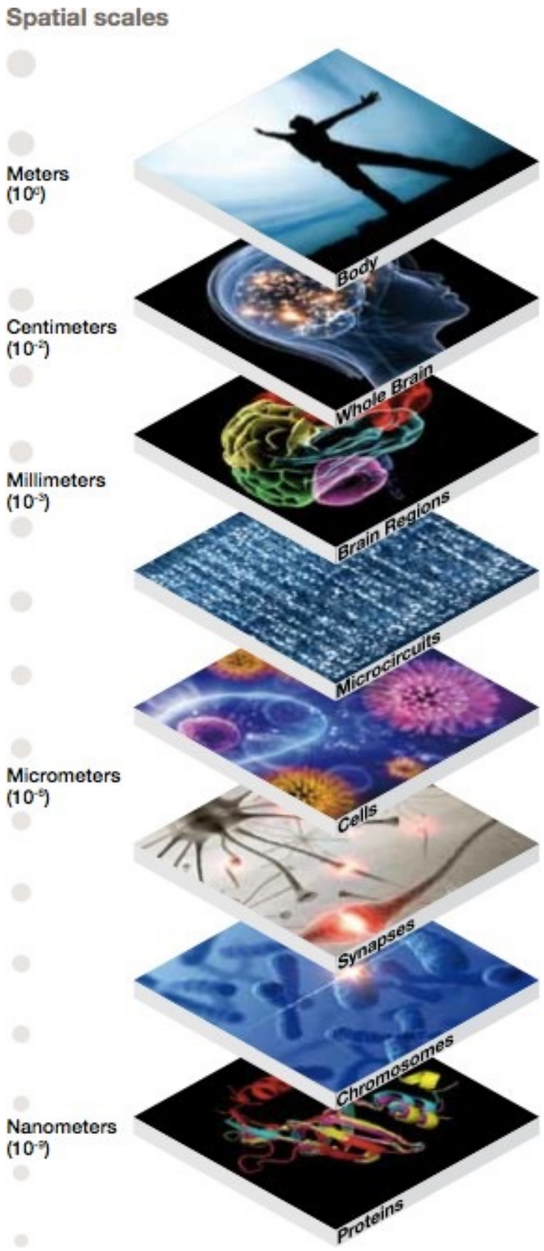
¿de qué vamos a hablar?

- ¿Qué es la **Neuroingeniería**?
  - El milagro de la plasticidad cerebral
  - Imagen médica para el cerebro.
- Ejemplos de **Robots de neurorehabilitación** - *Human-Centered Design*
  - Ejemplos rehabilitación miembro superior
  - Ejemplos rehabilitación mano
- Ejemplos de **Robots para neurocirugía** – *patient-based Design*
  - Proyecto Craneeal

"No he fallado. He encontrado 10,000 formas en que no funcionará"
Thomas Alva Edison

NEUROENGINEERING

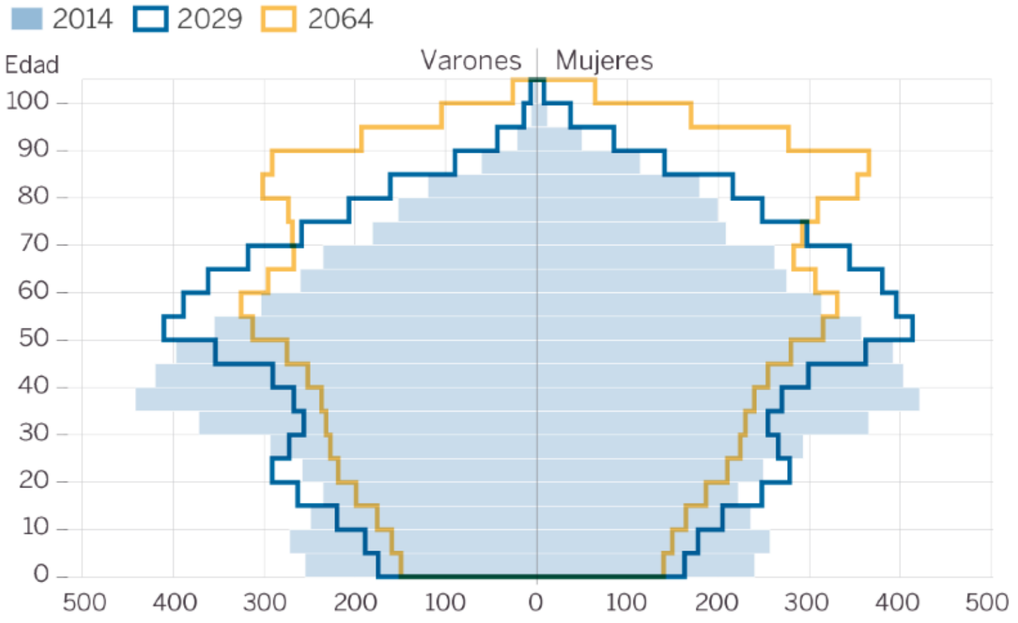
FIFA world cup 2014



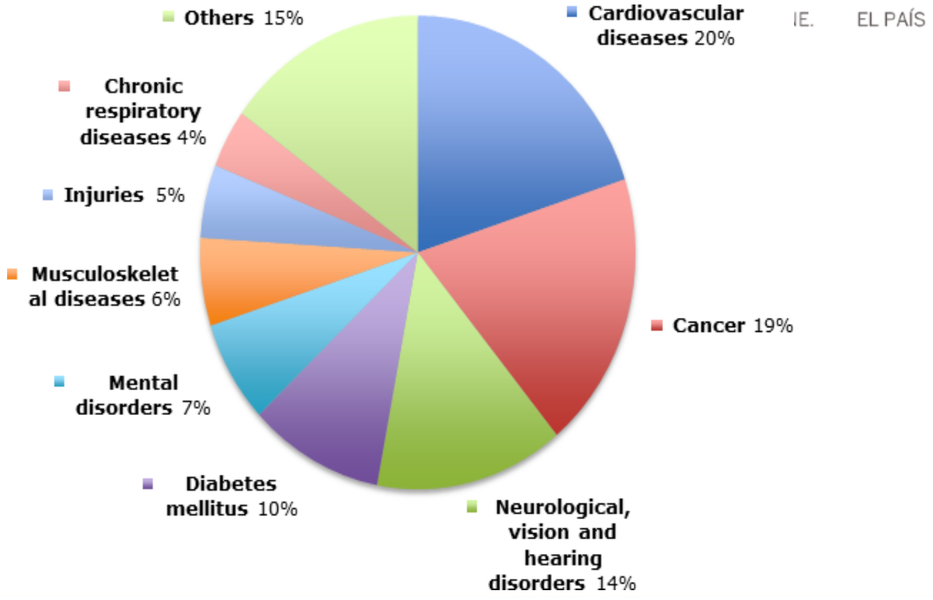
Neuroingenieria

- Conjunto de dispositivos y herramientas que sirven para analizar el sistema nervioso e interactuar con él.
- Objetivo: Mejorar significativamente los sistemas actuales de diagnóstico y tratamiento de las enfermedades neurales.

EVOLUCIÓN DE LA PIRÁMIDE DE POBLACIÓN



IE. EL PAÍS

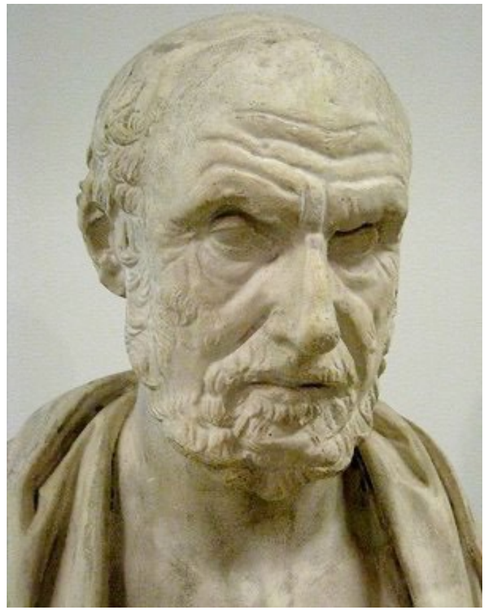


Maria A. Blasco
Mónica G. Salomone

Morir joven, a los 140

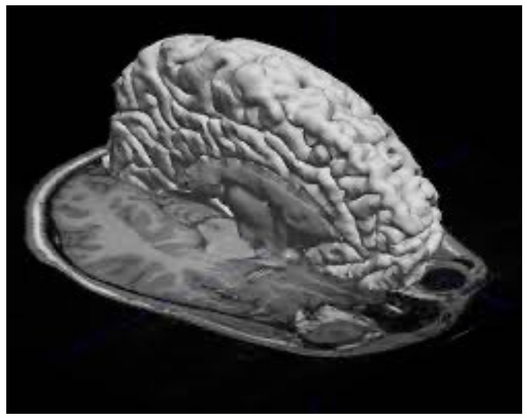
El papel de los telómeros en el envejecimiento y la historia de cómo trabajan los científicos para conseguir que vivamos más y mejor

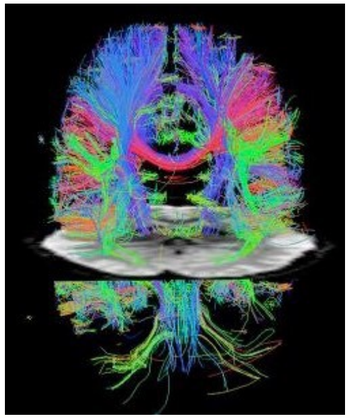
PAIDÓS

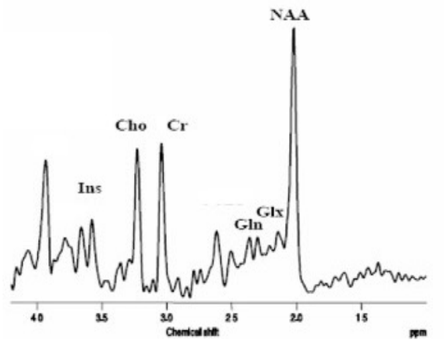


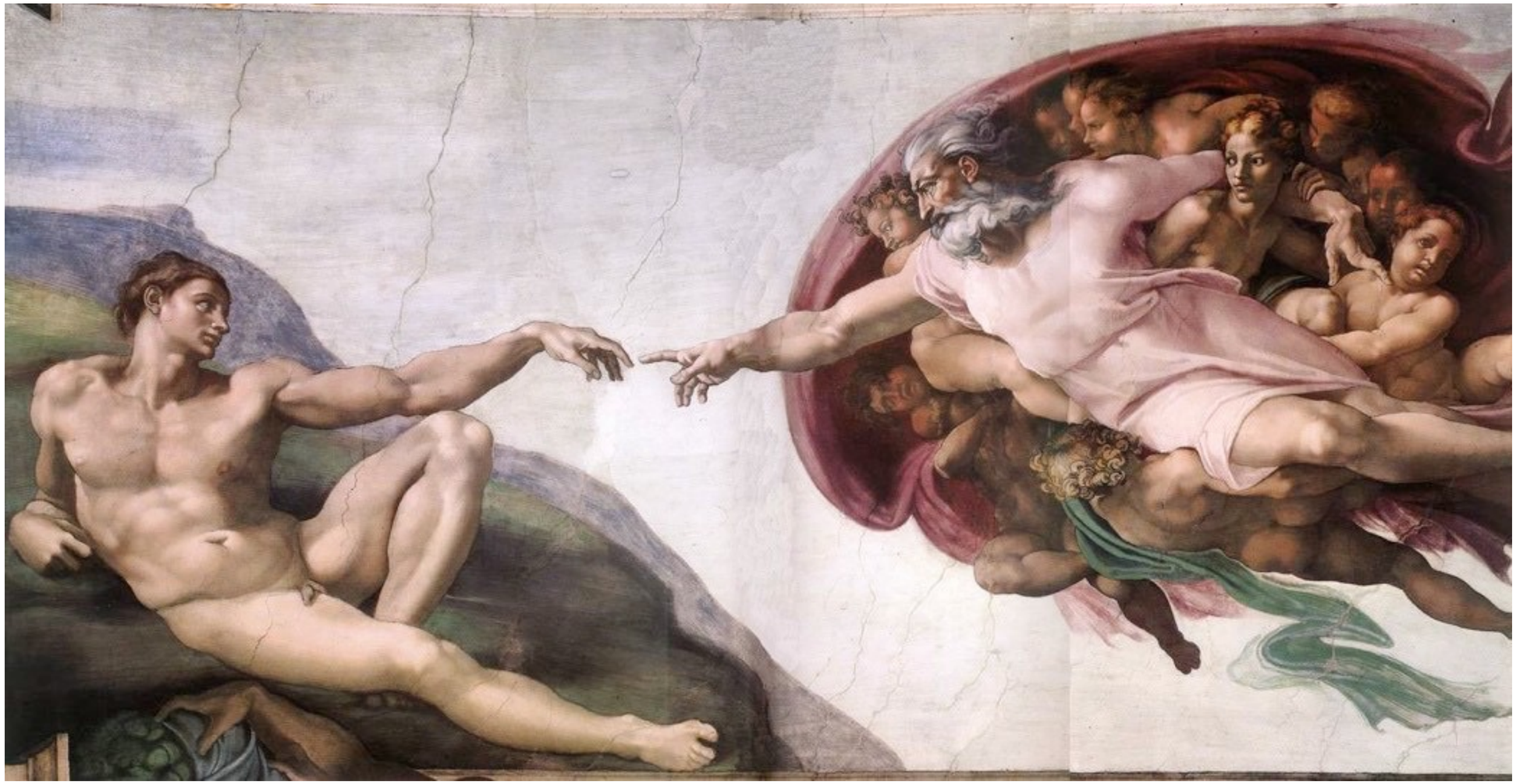
"***El hombre debería saber que, desde el cerebro, y exclusivamente desde el cerebro, surgen nuestros placeres, dichas, risas y bromas además de nuestras penas, dolores, tristezas y lágrimas***. *Mediante el cerebro pensamos, vemos y distinguimos lo feo de lo bello, lo malo de lo bueno, lo agradable de lo desagradable.... También nos hace delirantes o locos y nos infunde miedo o pavor, sea de noche o de día, así como los sueños y los delirios indeseables, las preocupaciones que no tienen razón de ser, la ignorancia de las circunstancias presentes, el desasosiego y la torpeza".*

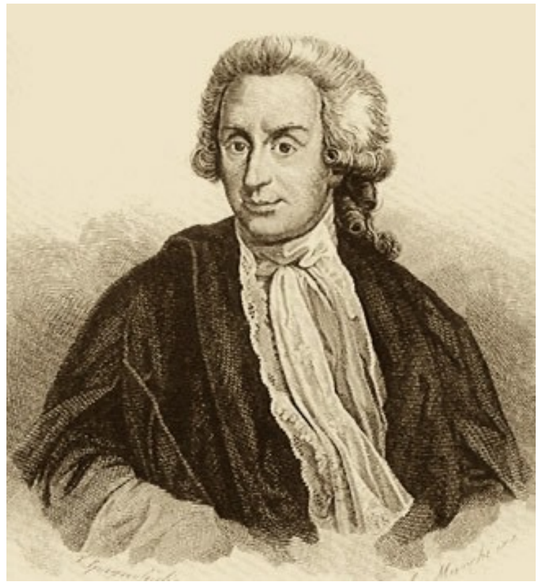
Hipócrates, s.V.a.C.





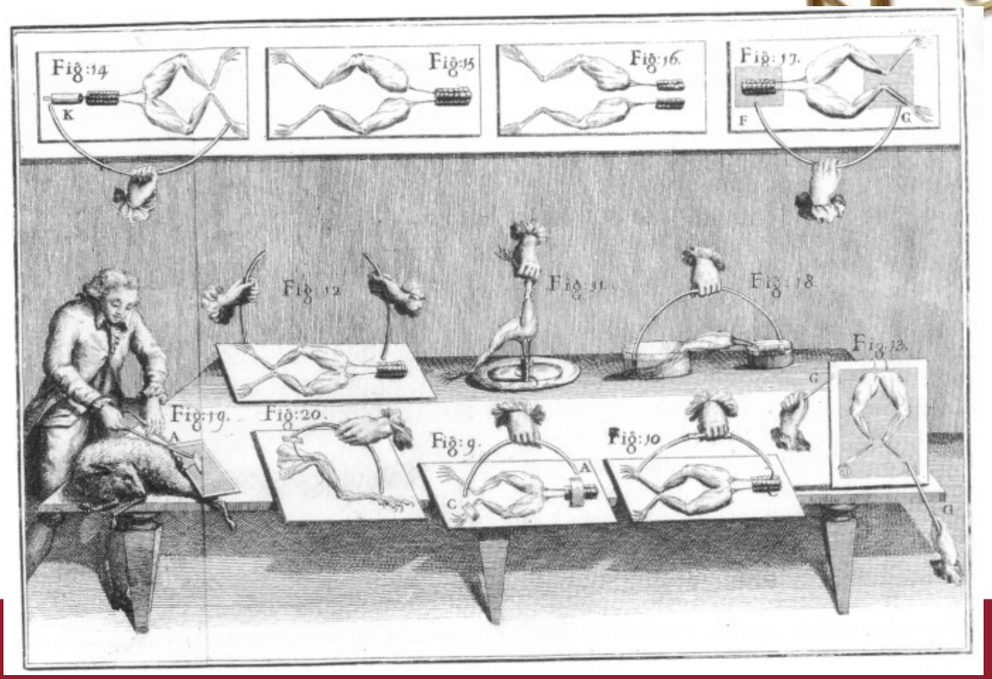






Luigi Galvani, 1791

Alessandro Volta 1745-1827



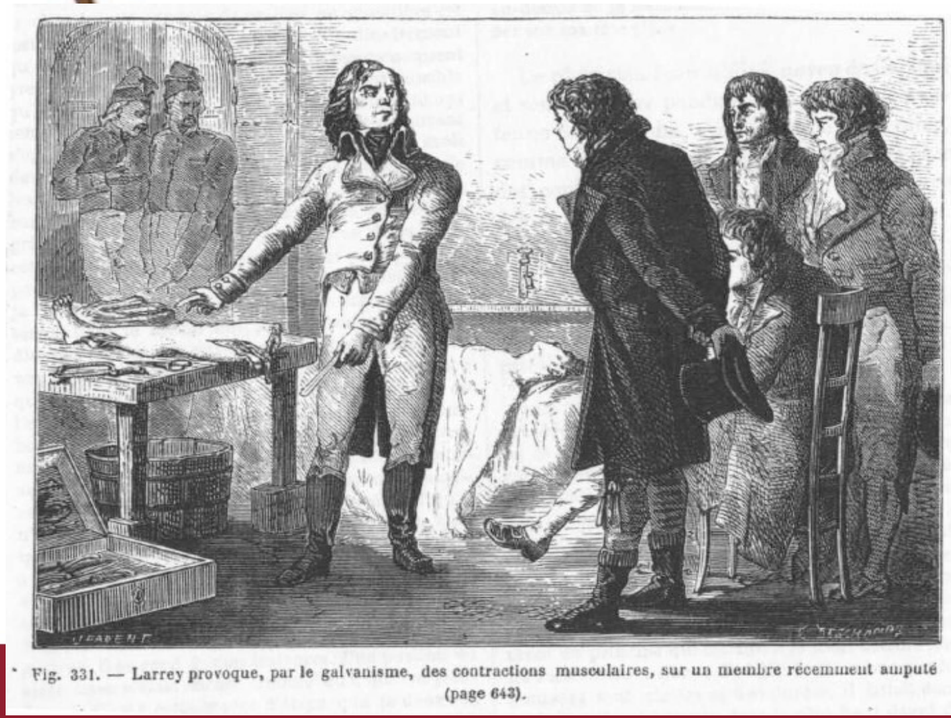
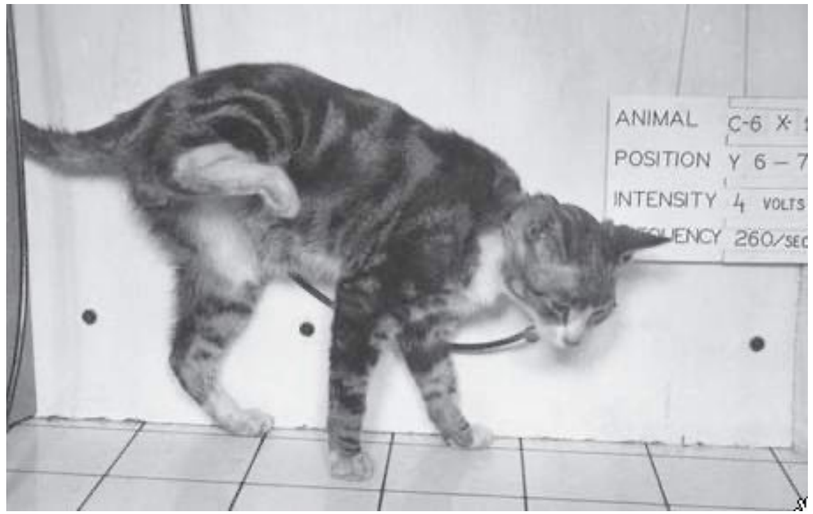


Fig. 331. — Larrey provoque, par le galvanisme, des contractions musculaires, sur un membre récemment amputé (page 643).

The work of Jose Manuel Rodriguez Delgado ....



CAT LIFTED ITS HIND LEG in response to stimulation by an electrode implanted in its brain (experiment done in the early 1950s)

"The most interesting aspect of the transdermal stimoceivers is the **ability to perform simultaneous recording and stimulation of brain functions**, thereby permitting the establishment of feedbacks and 'on-demand' programs of excitation with the aid of the computer"

Delgado et al., 1975

Matador' With a Radio Stops Wired Bull
By JOHN A. OSMUNDSEN
New York Times (1857-Current file); May 17, 1965; ProQuest Historical Newspapers The New York Times
pg. 1

'Matador' With a Radio Stops Wired Bull

Modified Behavior in Animals Subject of Brain Study

By JOHN A. OSMUNDSEN

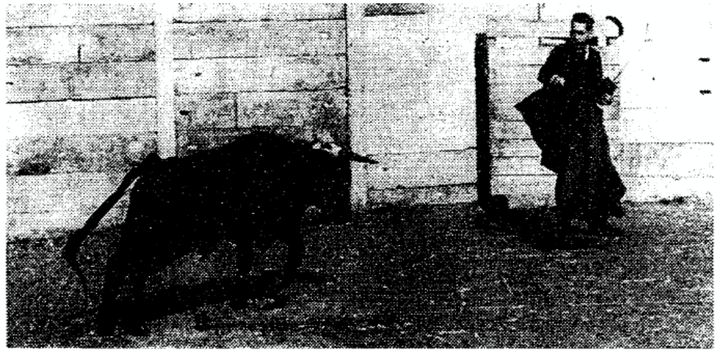
Afternoon sunlight poured over the high wooden barriers into the ring as the brave bull bore down on the unarmed "matador" — a scientist who had never faced a fighting bull.

But the charging animal's horns never reached the man behind t..e heavy red cape. Moments before that could happen, Dr. José M. R. Delgado, the scientist, pressed a button on a small radio transmitter in his hand, and the bull braked to a halt.

Then, he pressed another button on the transmitter and the bull obediently turned to the right and trotted away.

The bull was obeying commands from his brain that had been called forth by electrical stimulation—by the radio signals—of certain regions in which fine wire electrodes had been painlessly implanted the day before.

The experiment, conducted last year in Cordova, Spain, by Dr. Delgado of Yale University's School of Medicine, was prob-

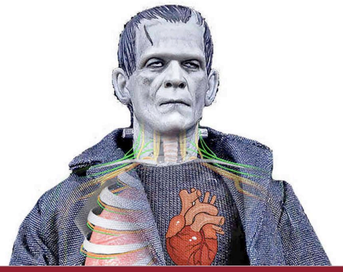


Dr. José M. R. Delgado of Yale University's School of Medicine facing a charging bull

TED Ed

Lessons Worth Sharing

The Cockroach beatbox



OPEN ACCESS Freely available online

PLoS one

The SpikerBox: A Low Cost, Open-Source BioAmplifier for Increasing Public Participation in Neuroscience Inquiry

Timothy C. Marzullo*, Gregory J. Gage

Backyard Brains, Inc., Ann Arbor, Michigan, United States of America

Abstract

Although people are generally interested in how the brain functions, neuroscience education for the public is hampered by a lack of low cost and engaging teaching materials. To address this, we developed an open-source tool, the SpikerBox, which is appropriate for use in middle/high school educational programs and by amateurs. This device can be used in easy experiments in which students insert sewing pins into the leg of a cockroach, or other invertebrate, to amplify and listen to the electrical activity of neurons. With the cockroach leg preparation, students can hear and see (using a smartphone oscilloscope app we have developed) the dramatic changes in activity caused by touching the mechanosensitive barbs. Students can also experiment with other manipulations such as temperature, drugs, and microstimulation that affect the neural activity. We include teaching guides and other resources in the supplemental materials. These hands-on lessons with the SpikerBox have proven to be effective in teaching basic neuroscience.

Citation: Marzullo TC, Gage GJ (2012) The SpikerBox: A Low Cost, Open-Source BioAmplifier for Increasing Public Participation in Neuroscience Inquiry. PLoS ONE 7(3): e30837. doi:10.1371/journal.pone.0030837

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Competing Interests: Authors TM and GG are both owners and employees of Backyard Brains, Inc. This does not alter the authors' adherence to all the PLoS ONE policies on sharing data and materials.

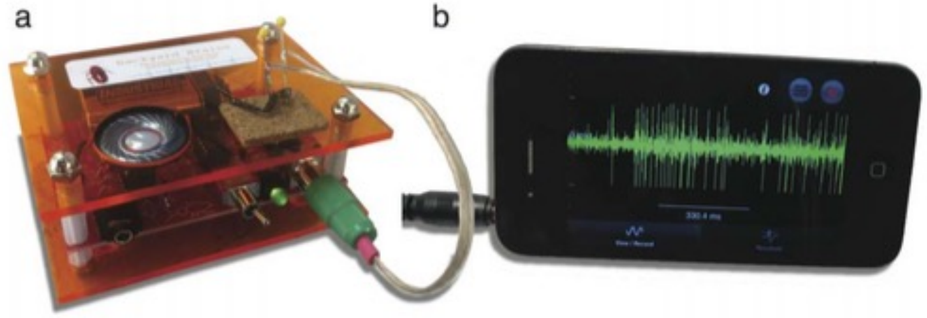
* E-mail: info@backyardbrains.com

Introduction

Not only is neuroscience absent from most K-12 curricula, but even in college, students must wait until upper level science courses to gain exposure to principles of brain function [1]. We hypothesized that neuroscience education was missing from K-12 curricula not because of a lack of interest [2], but due to a lack of simple, compelling, and inexpensive tools to investigate and understand neurons. Entry-level neurophysiology equipment used for teaching neuroscience typically costs >$3,000 and requires

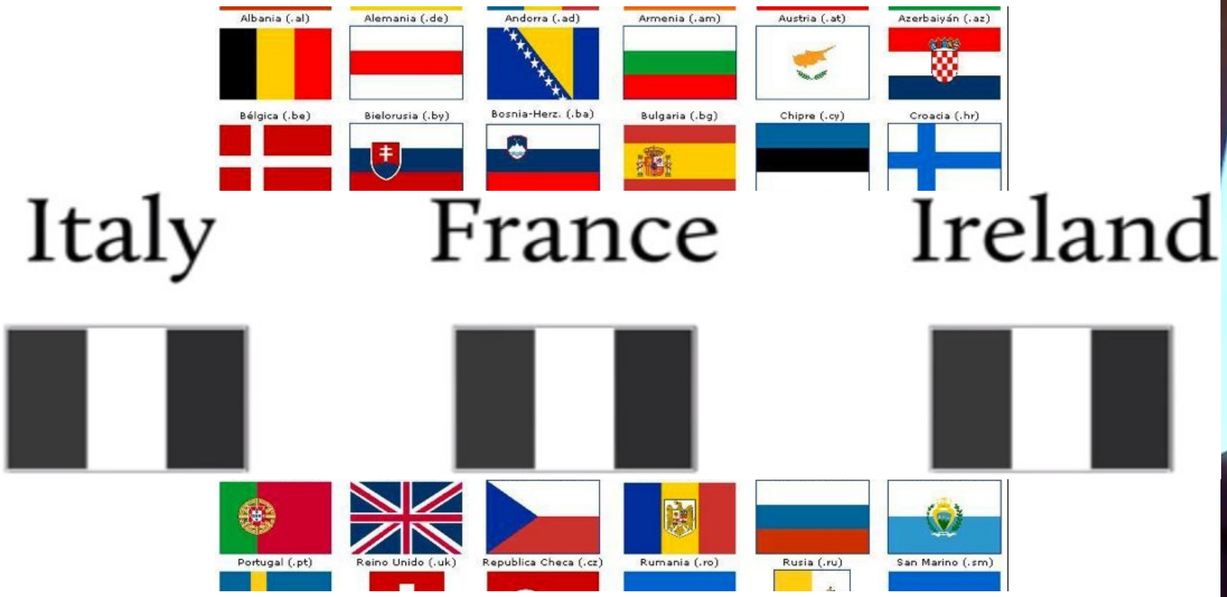
a "model discipline" for engaging students, subsequently improving performance in STEM-related fields, by combining biology, physics, electronics, health, and mathematical modeling in a single compelling field.

A widespread effort is growing to bring neuroscience into the public arena [6,7,8,9]. For example, the Society for Neuroscience and The Dana Alliance for Brain Initiatives have partnered to bring Brain Awareness Week every year to communities around the country, which offers opportunities for teachers and students to



Neil Harbisson

primer cyborg



Moon Ribas

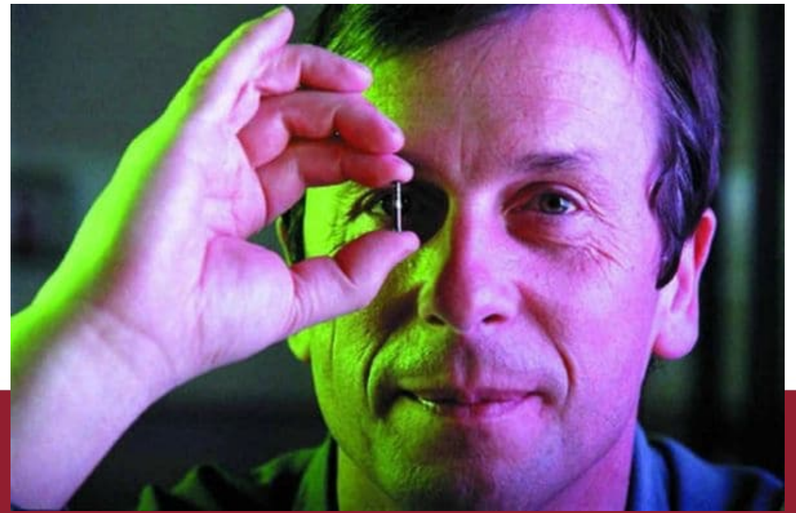
conexión con la tierra extrasensorial, gracias a un implante sísmico online en su brazo, que le permite percibir terremotos en tiempo real en cualquier lugar del planeta, mediante vibraciones.

Cris Dancy

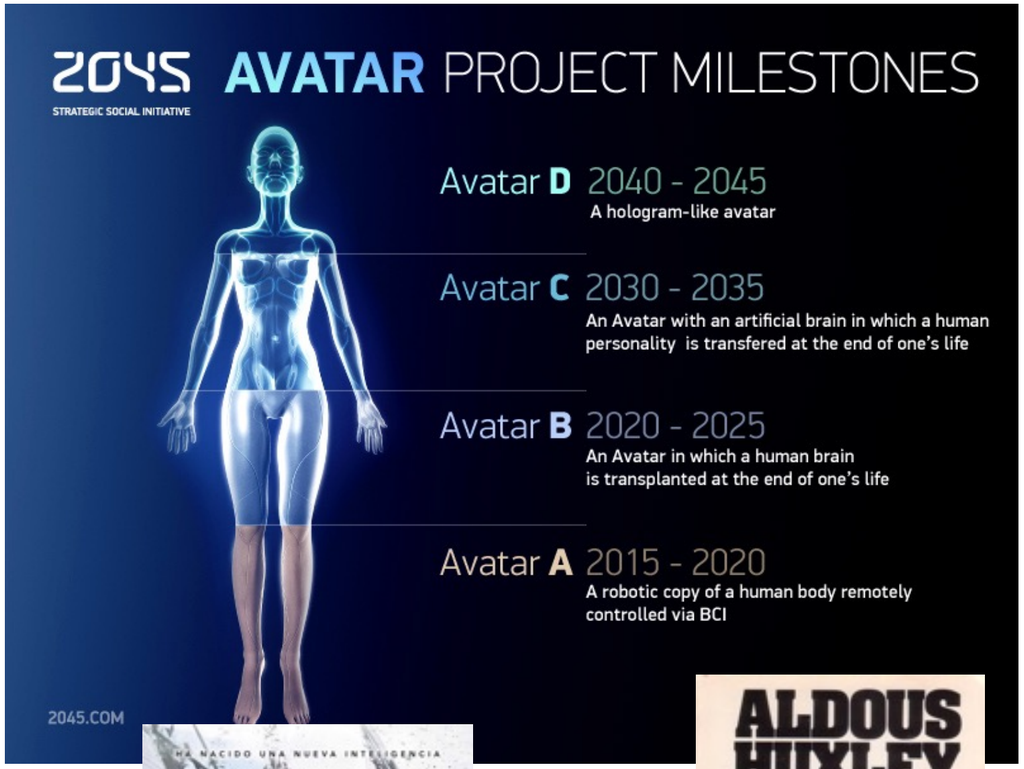
"el hombre más conectado del mundo" tiene 11 dispositivos repartidos por el cuerpo que digitalizan los movimientos, la temperatura corporal, la presión sanguínea, el oxígeno, el peso, los alimentos ingeridos, la calidad del aire que respira, el volumen de su voz, la temperatura ambiente, la humedad, la luz y el sonido.

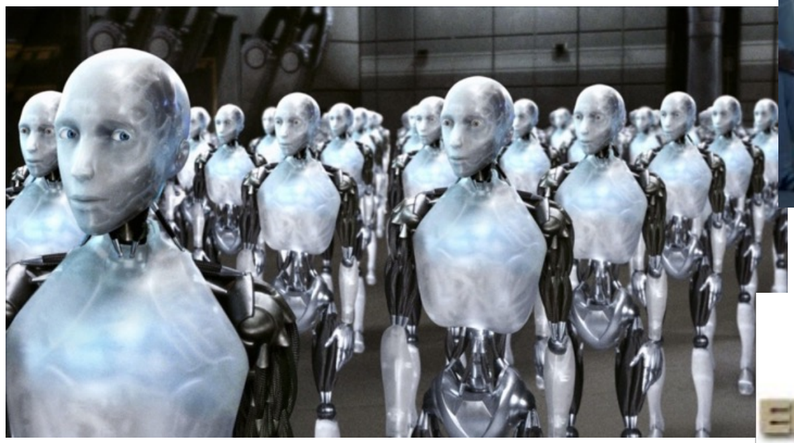
Kevin Warwick

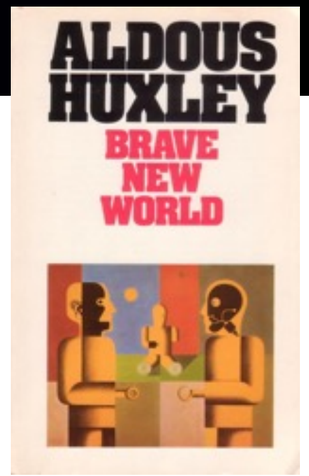
la década de los '90 se instaló en su brazo un chip que le permitió controlar luces, puertas, ascensores, e incluso otras computadoras



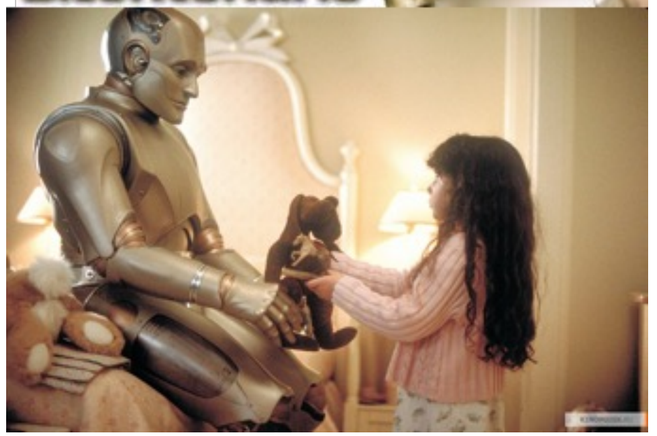
¿tiene fundamentos la transhumanidad?







Robots don't pray



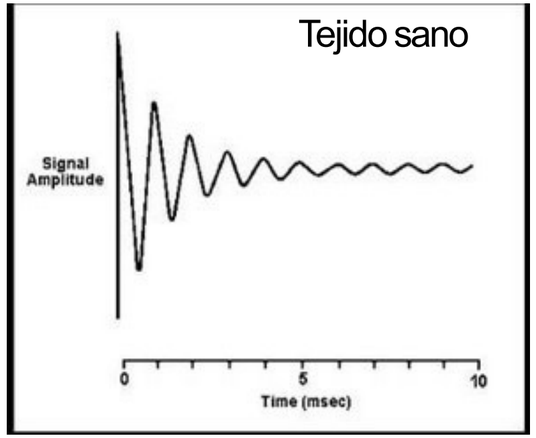
BRAIN MEDICAL IMAGE

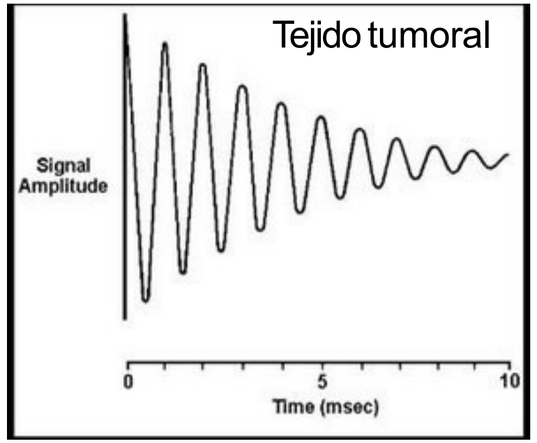
El paciente neurológico: un paciente especial

"Nadie dice - *soy un cáncer o soy canceroso* - a pesar del hecho de no ser una enfermedad provocada por un virus o una bacteria intrusa sino el resultado de la mutación de nuestras propias células. Sin embargo con **las enfermedades neurológicas** ocurre algo diferente porque **atacan a lo que imaginamos como el origen mismo de nuestro ser**. La frase - *soy epilép0co* - no nos resulta extraña, denota una **iden3ficación total de la persona con la enfermedad**"

Siri Hustvedt, *La mujer temblorosa*

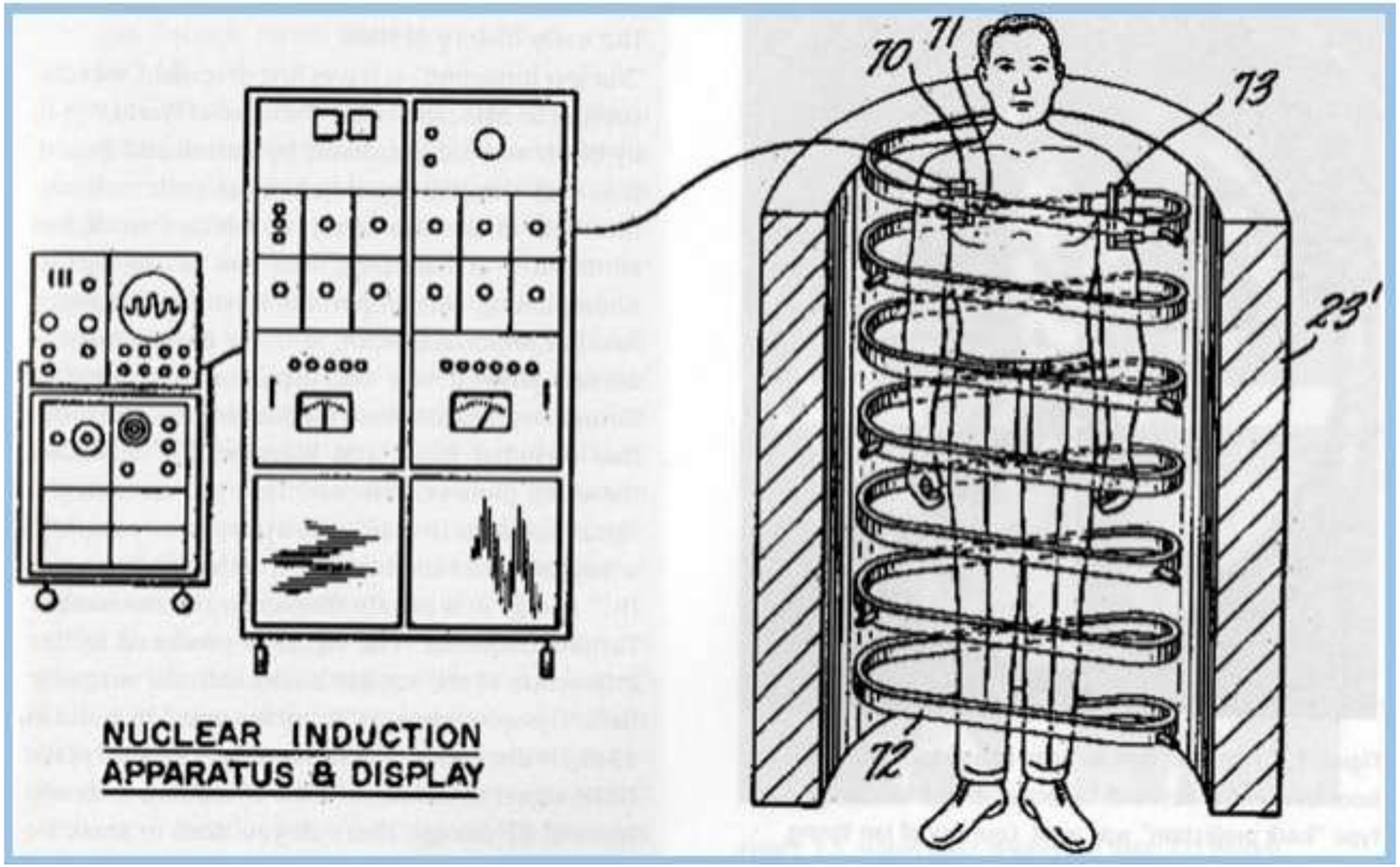
Resonancia Magnética





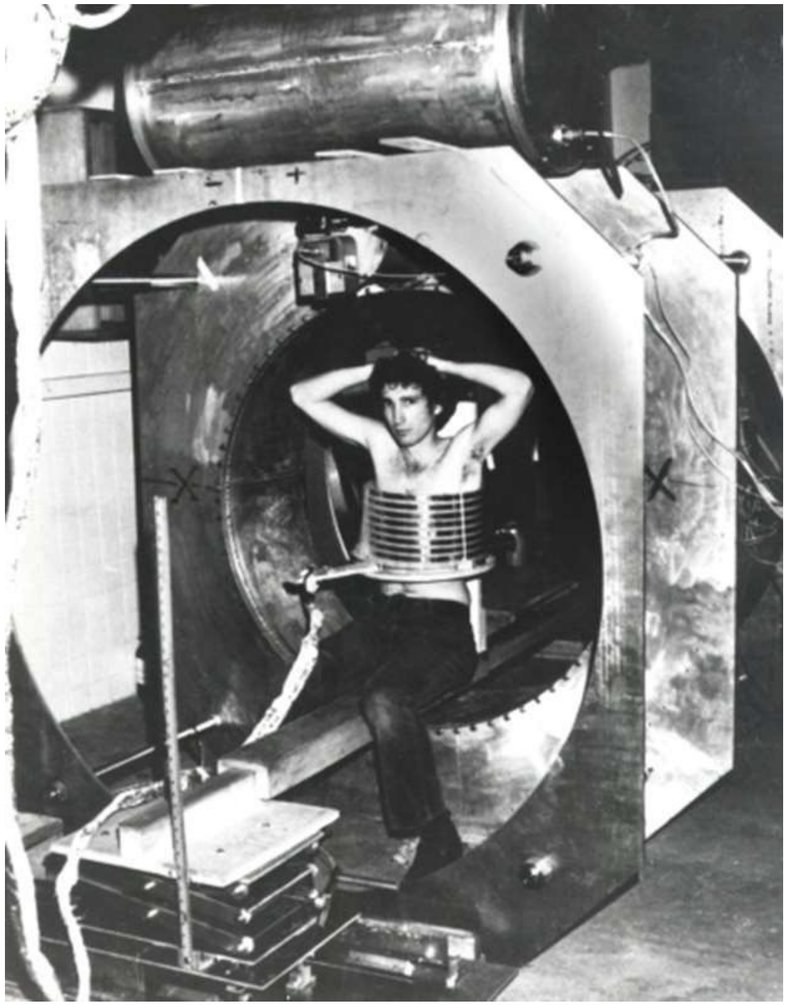
Raymond Damadian en 1971 descubrió que ciertos tumores de ratón mostraban propiedades físicas distintas a tejidos normales in vitro.

Resonancia Magnética

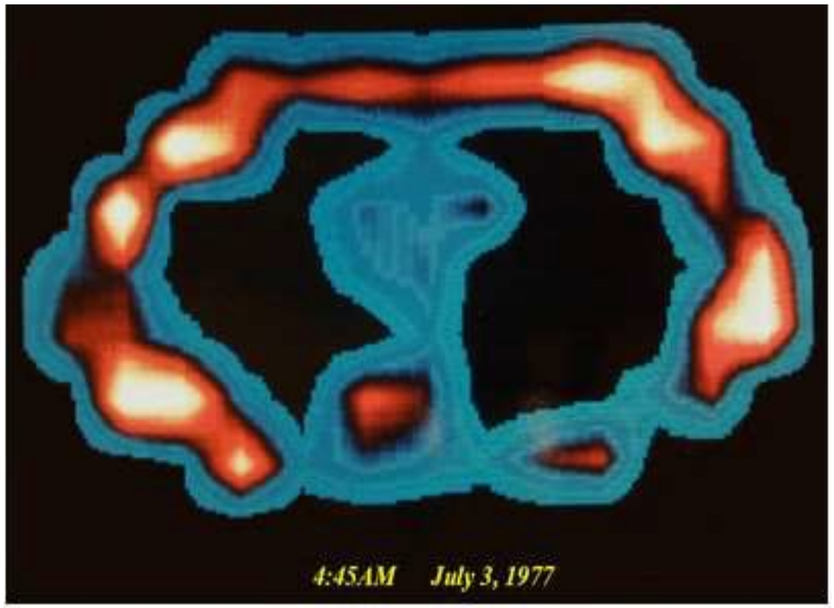


U.S. Patent " Apparatus and Method For Detecting Cancer in Tissue". #3,789,832. Filed March 17, **1972**].

Resonancia Magnética



Prototipo de 1977



The interpolated image of the Minkoff scan and the first ever MRI scan of a live human being (4:45 AM July 3, 1977). source

Resonancia Magnética

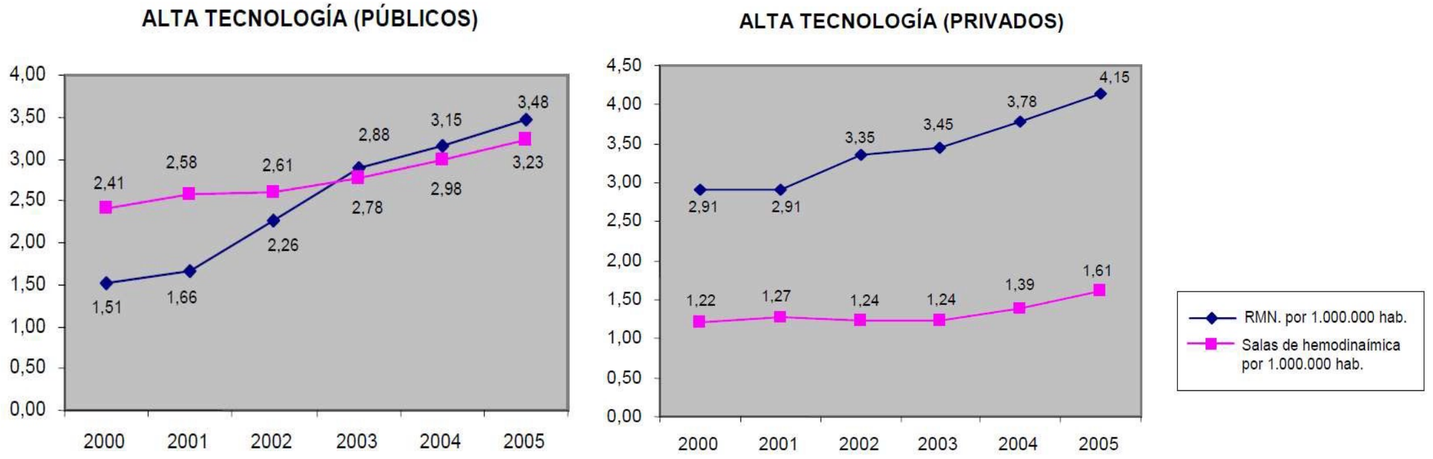
1977. Construye el primer prototipo de RM.

1980. Aparece el primer escáner clínico.

1983. 1º RM en España (Centro Médico de RM de Barcelona).

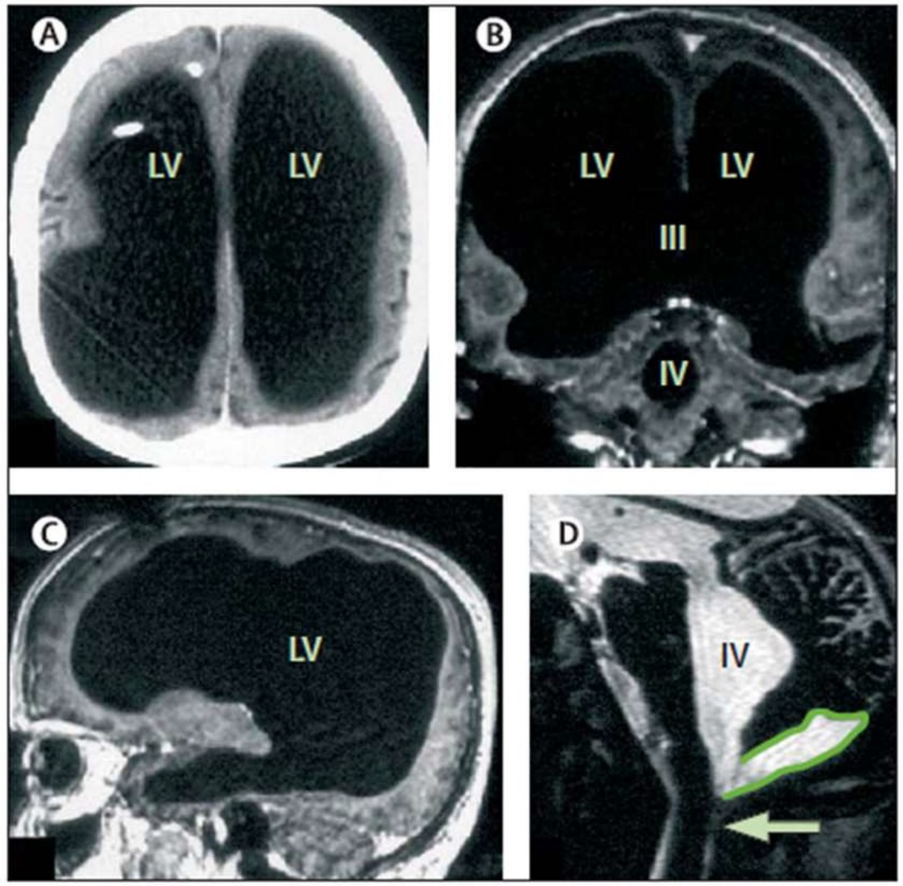
2002. 22000 equipos de RM clínicos en todo el mundo.

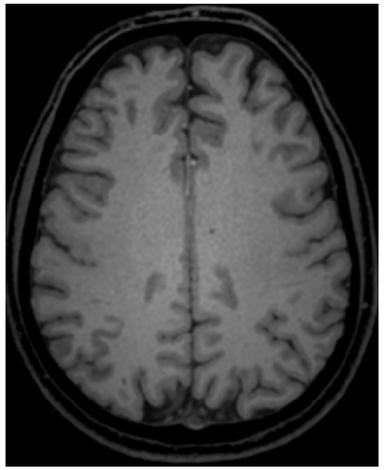
Sistema Nacional de Salud 2000-2005

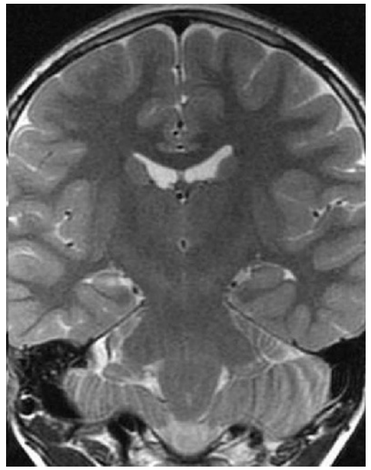


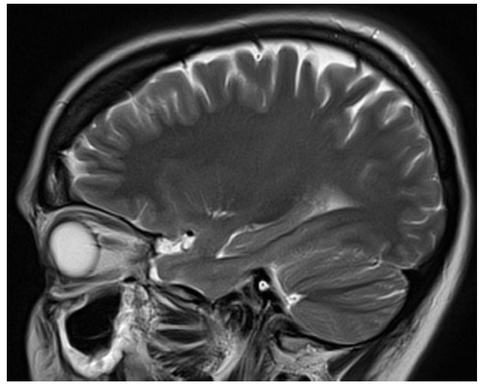
Lancet 2007; 370: 262

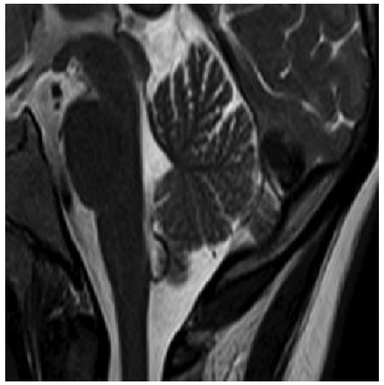
Cada cerebro es un mundo



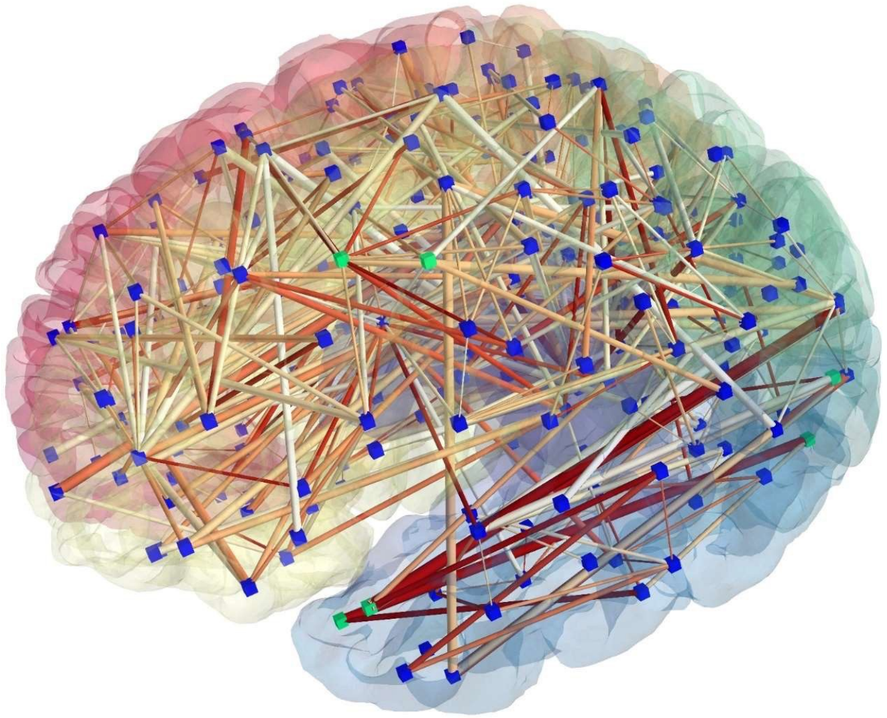




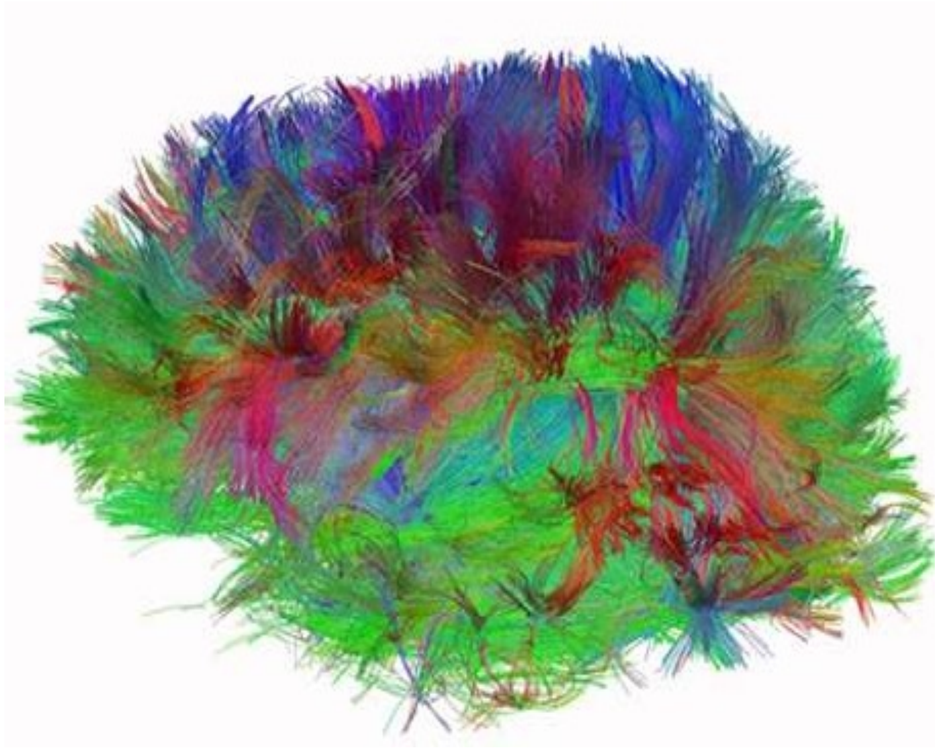




La realidad



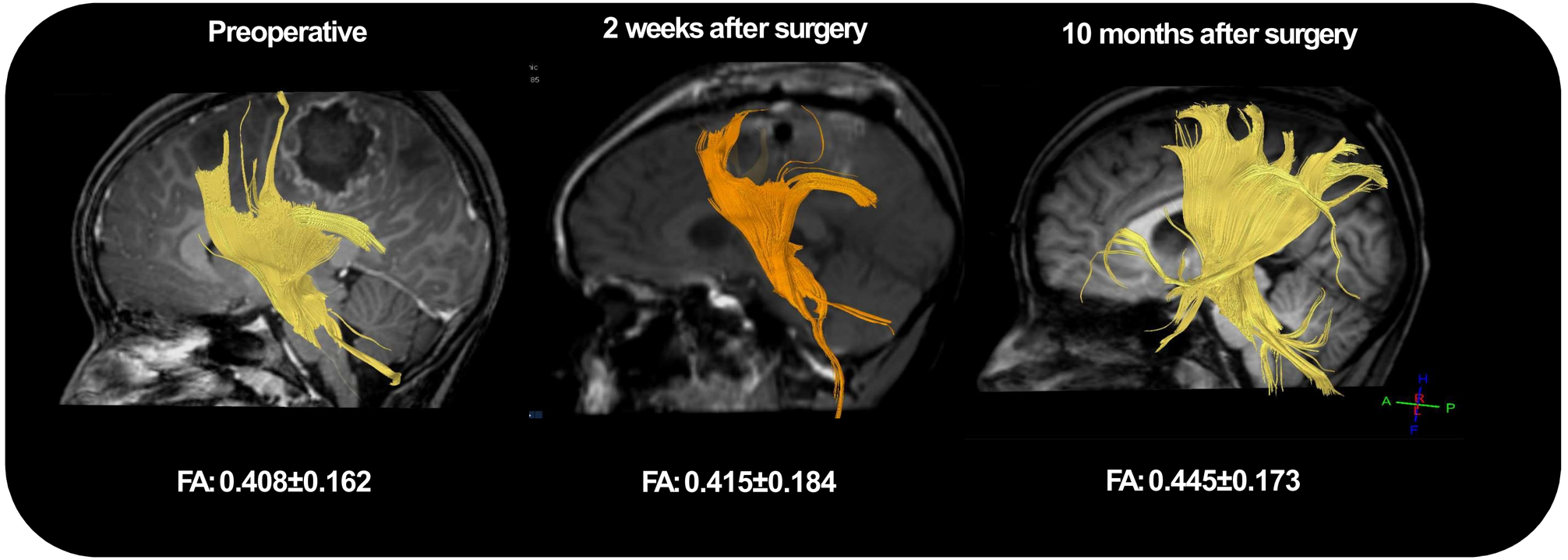
Brain networks.
Patric Hagmann, CHUV-UNIL, Lausanne, Switzerland



Brain wiring in a healthy human adult. The thread-like structures are nerve bundles, each containing hundreds of thousands of nerve fibers.

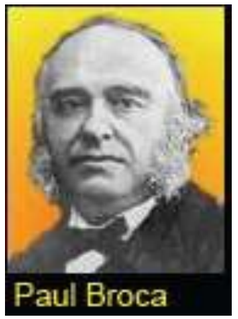
Human connectome project

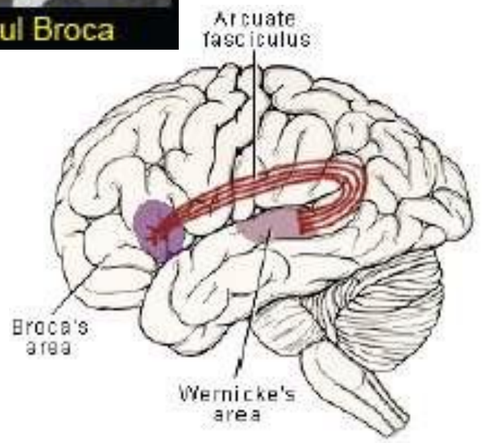
Efecto Terapia

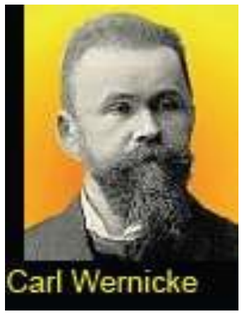


QUANTITATIVE TRACT ANATOMY

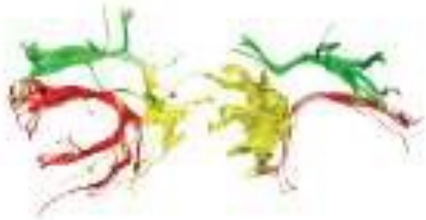
Inter-individual differences


Paul Broca



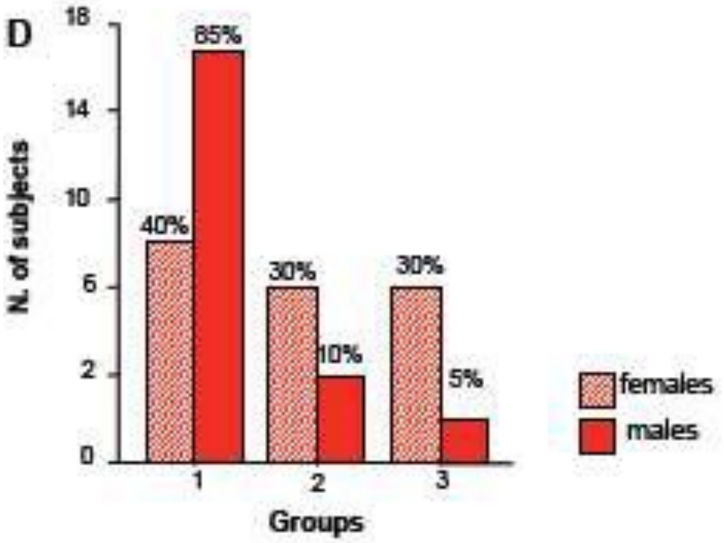

Carl Wernicke

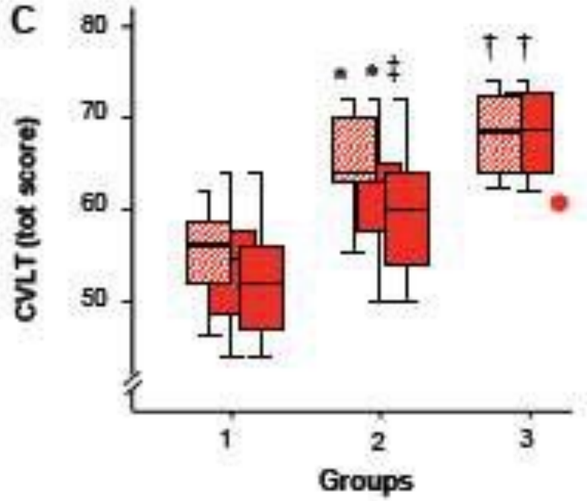
Group1 strong lateralization (62,5%)



Group2 bilateral, left lateralization (20%)

Group3 bilateral, symmetrical (17,5%)

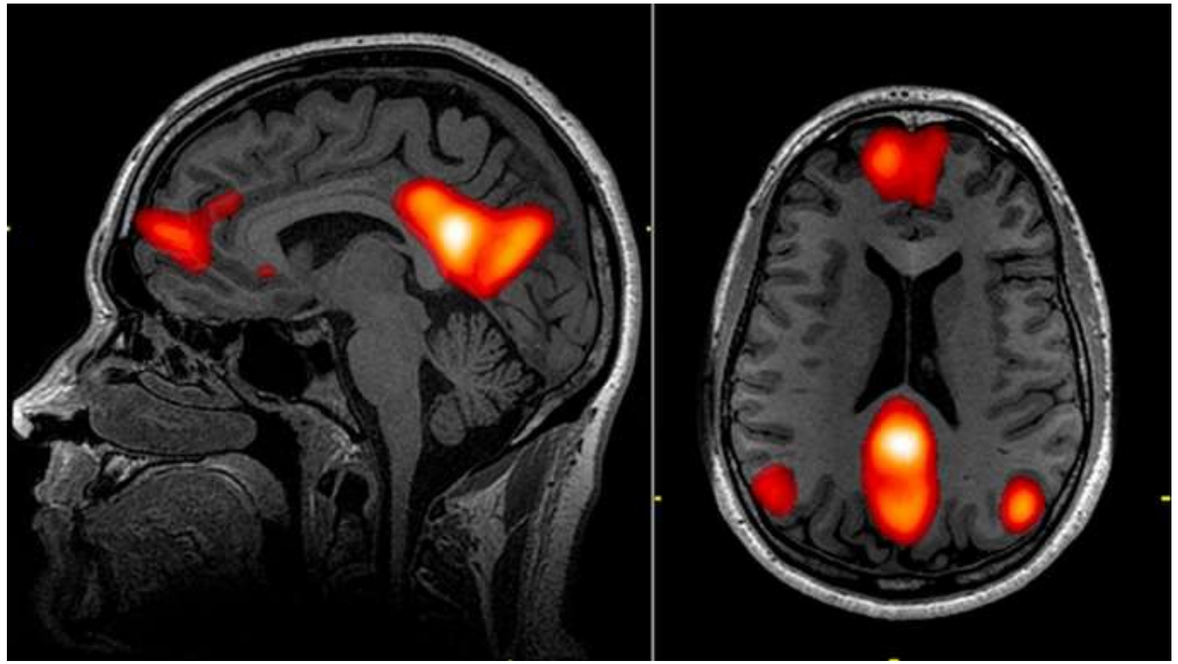


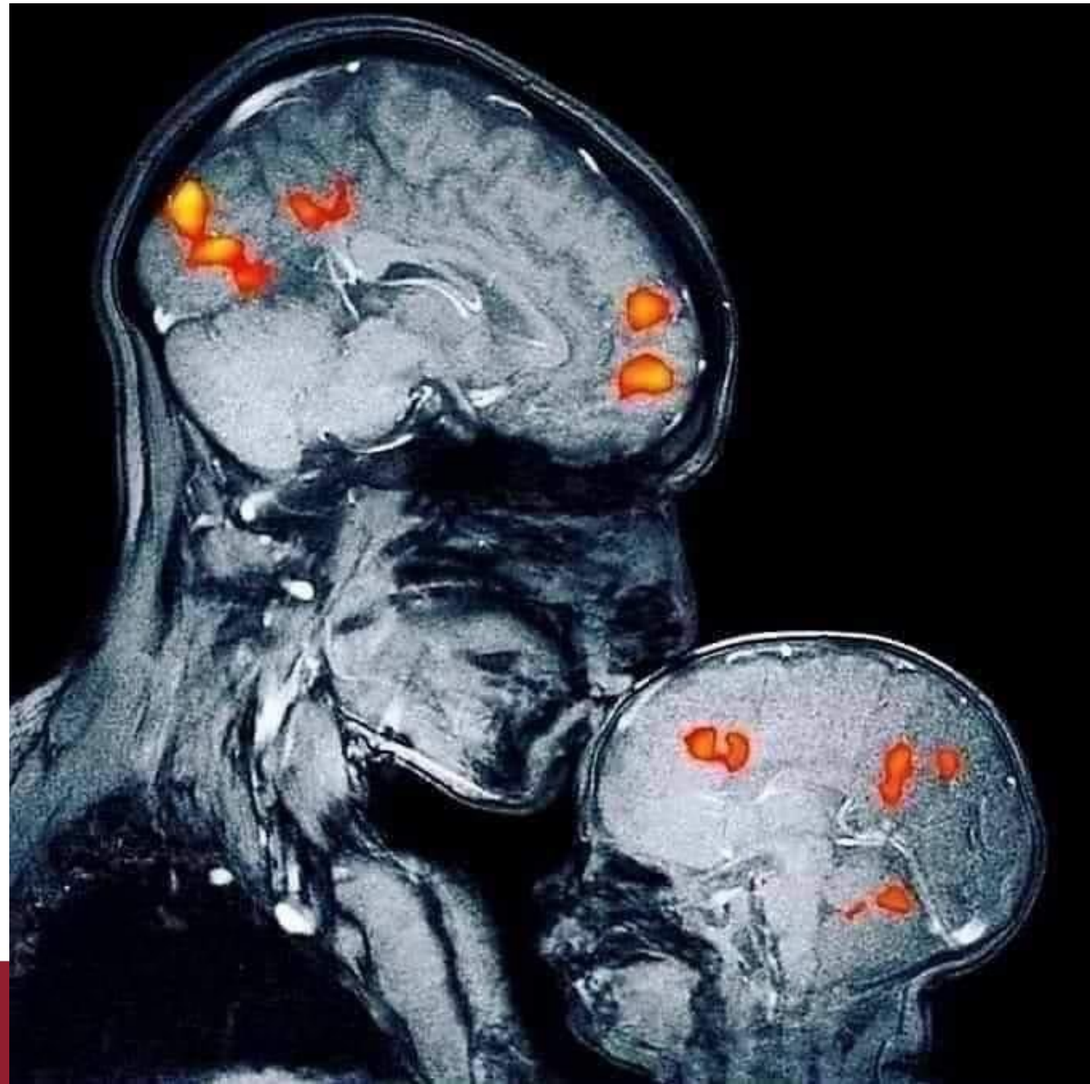


(Catani et al., PNAS, 2007)

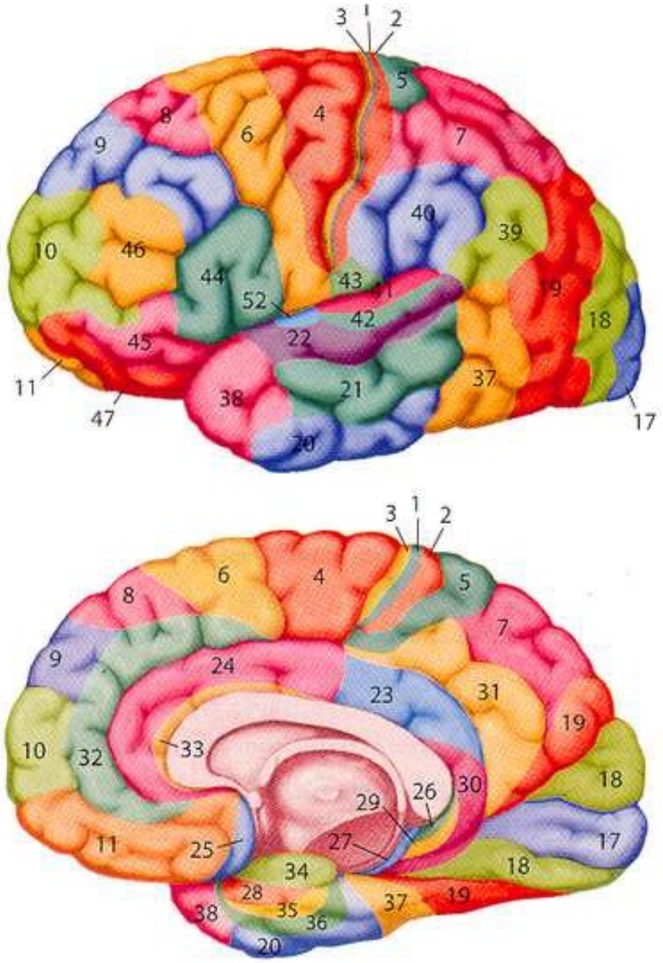
Resonancia Magnética Funcional

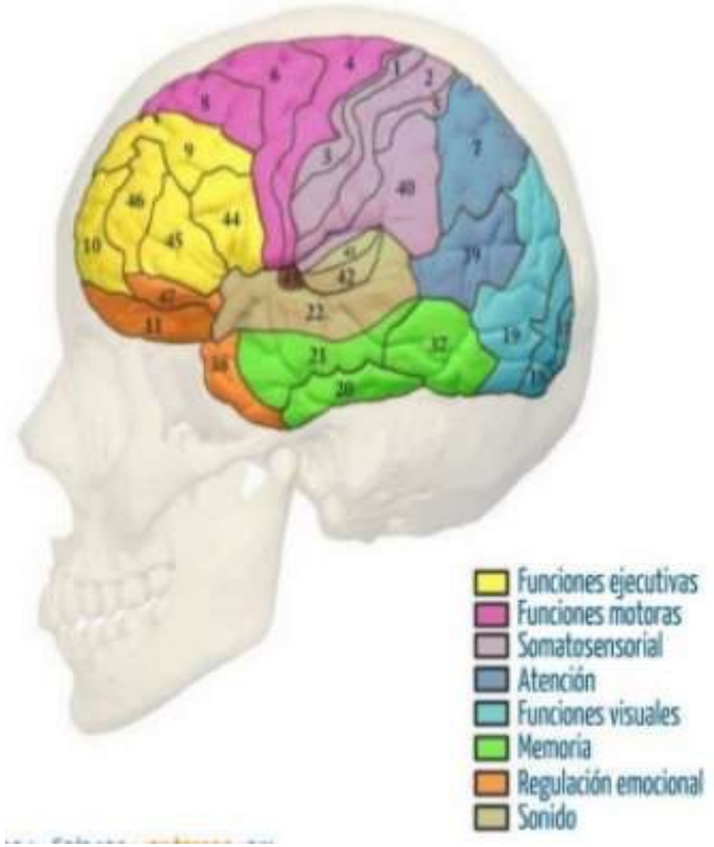
Metodología que permite conocer las áreas funcionales cerebrales involucradas en la ejecución de una tarea determinada.





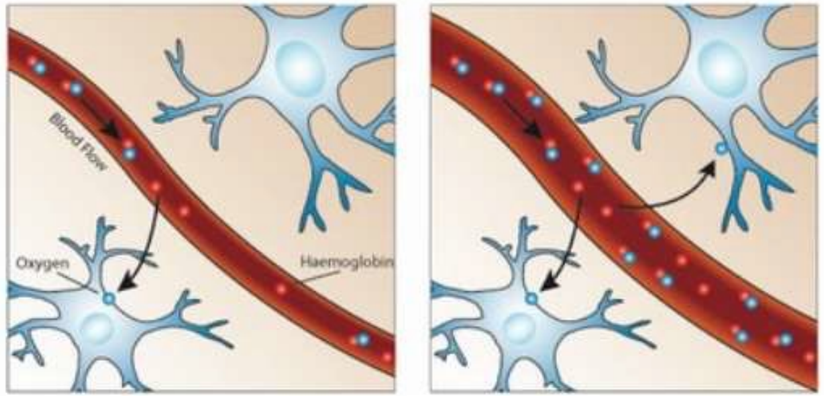
Resonancia Magnética Funcional

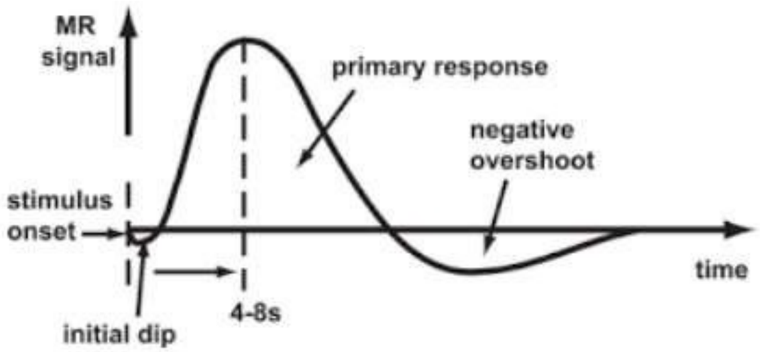




Resonancia Magnética Funcional

EFECTO BOLD (Blood Oxigen Level Dependent)





↑ Actividad neuronal

↓

↑ Perfusión + consumo de oxígeno

↓

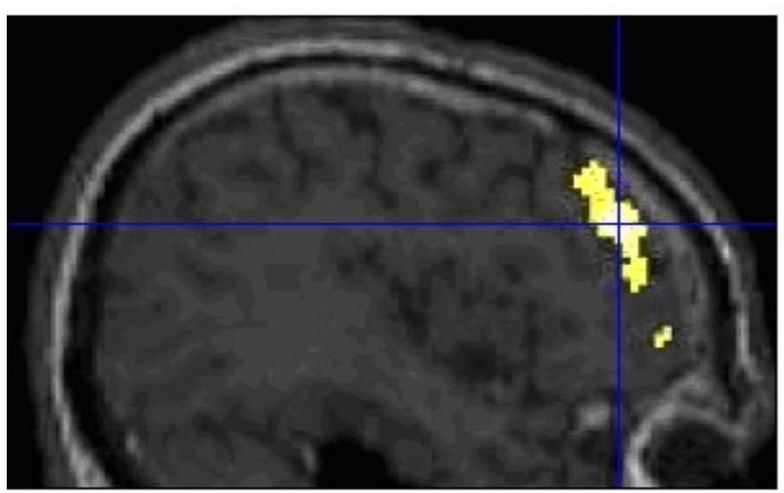
↑ OxiHb/ DesoxiHB

↓

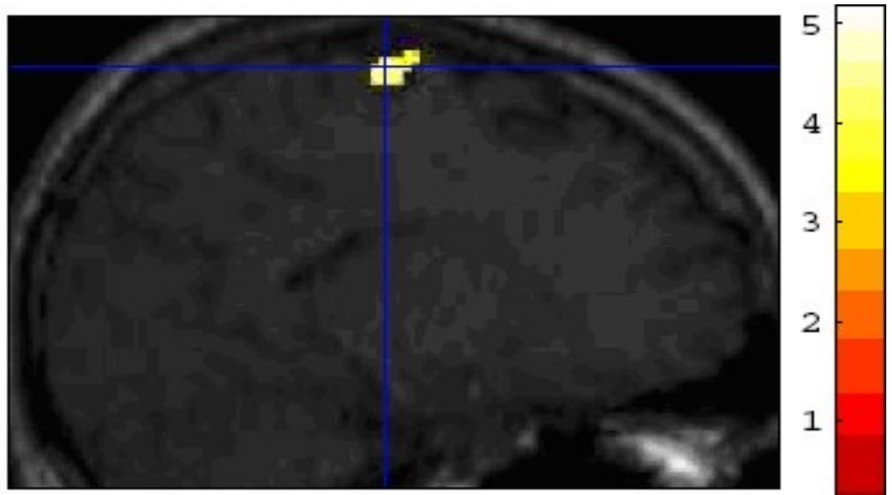
↑ T2* MR señal

EEG SYSTEM

Location of cognitive processes using fMRI



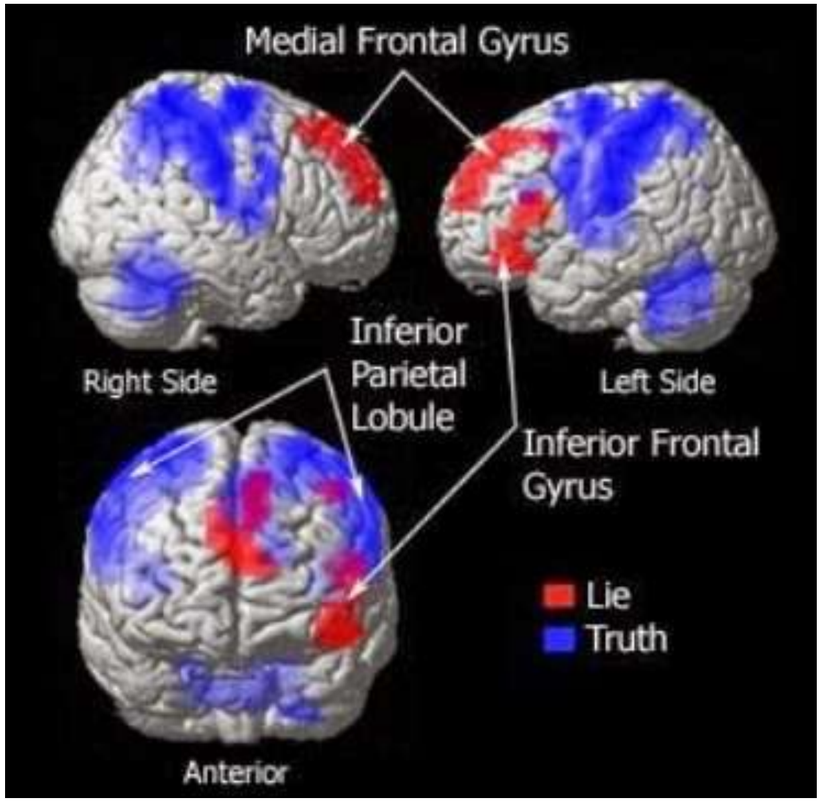
Recite “Our Father”

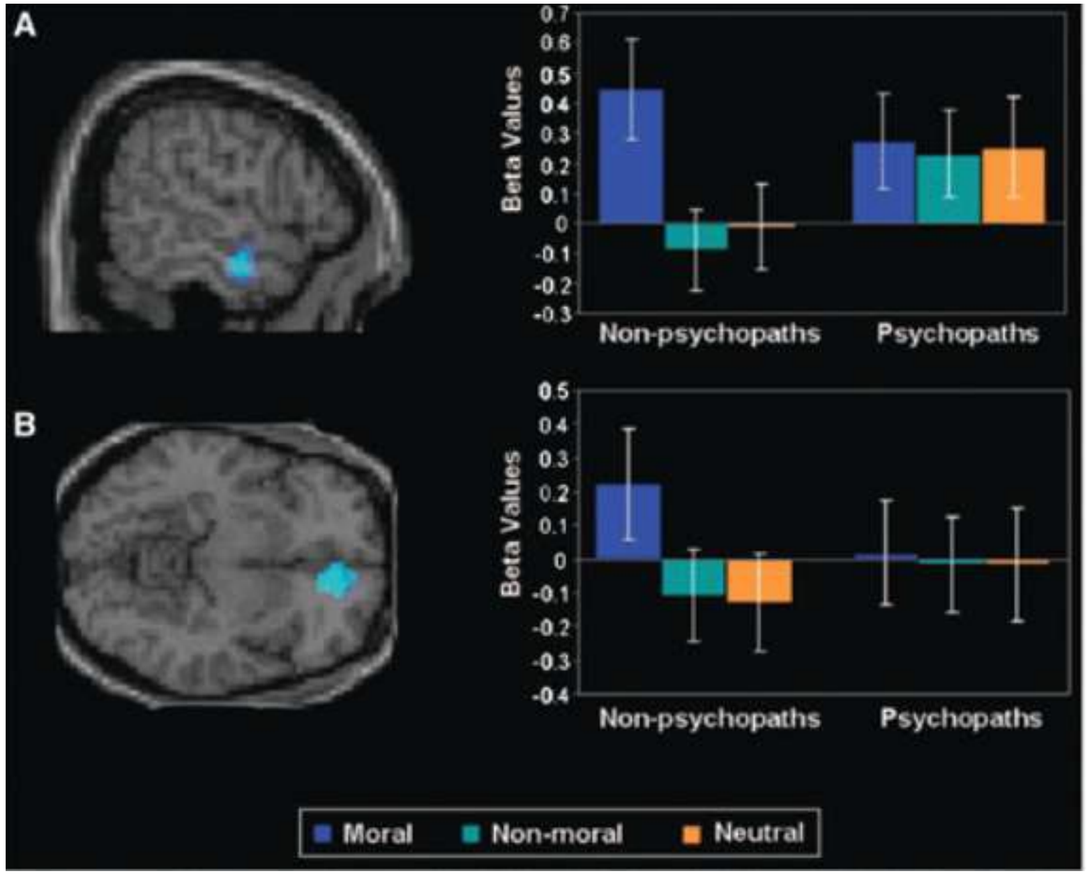


Imagine movement (right arm)

Experiment	Region	X Y Z	Cluster size
Recite “Our Father”	Prefrontal cortex	42 38 26	324
Imagine movement of the right arm	Suplementary motor area	-16 -20 72	57

Resonancia Magnética Funcional





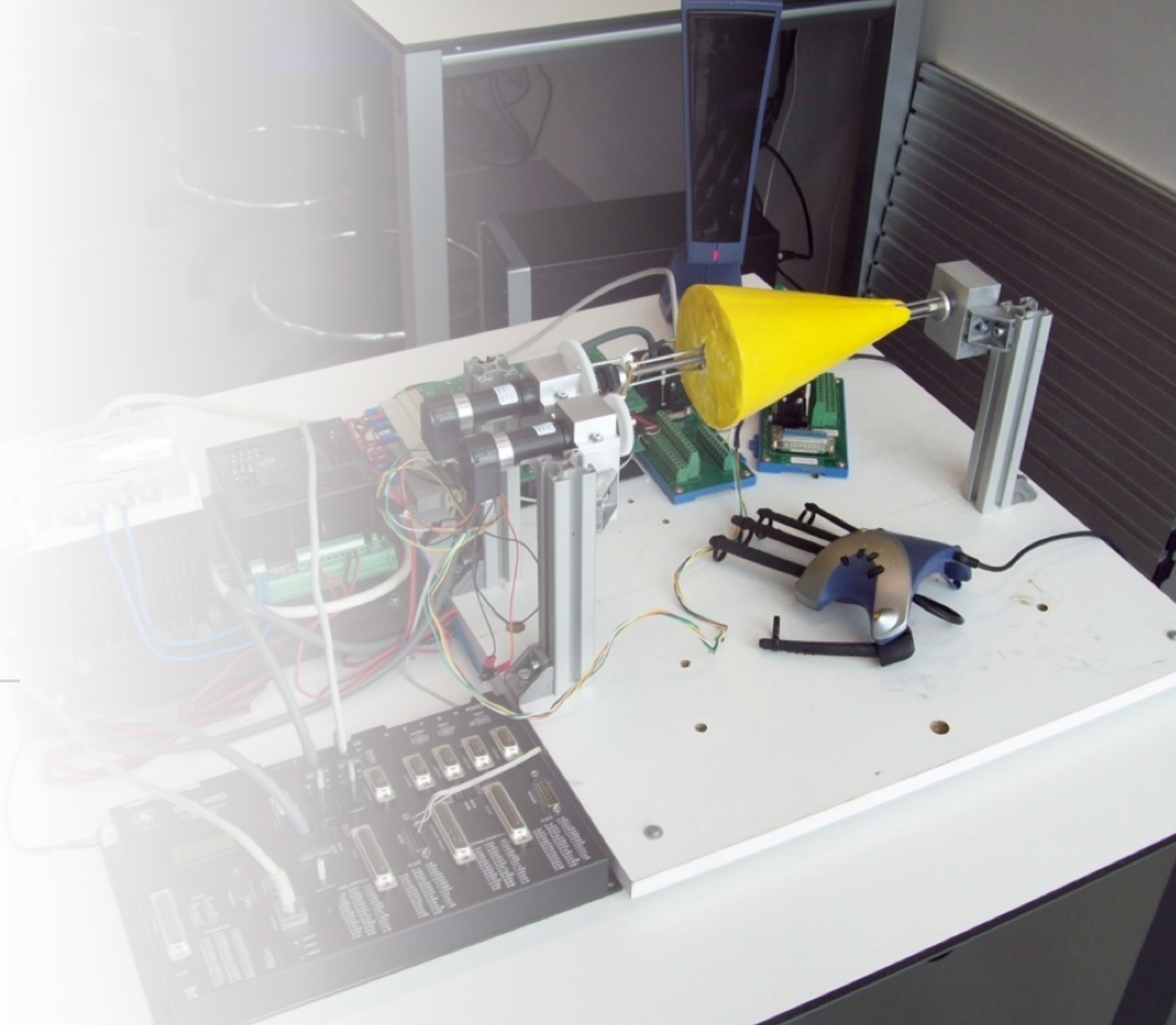
Moll *et al.*, 2011


NEXT

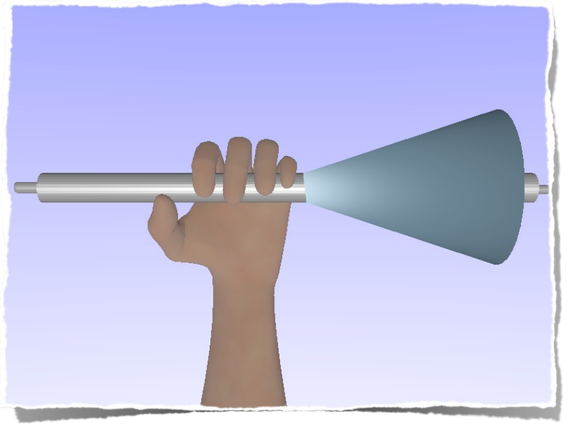
Rehabilitation robotics

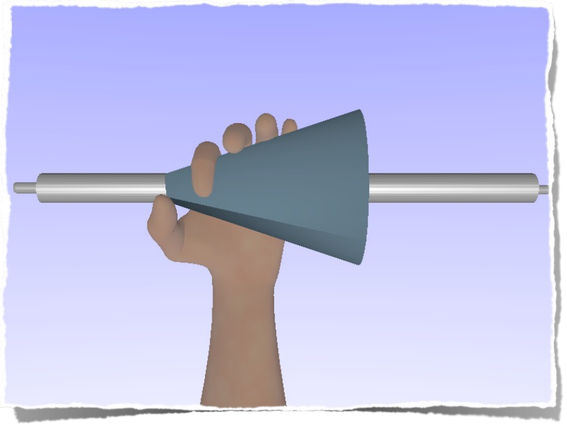
1st Phalanx rehab robot

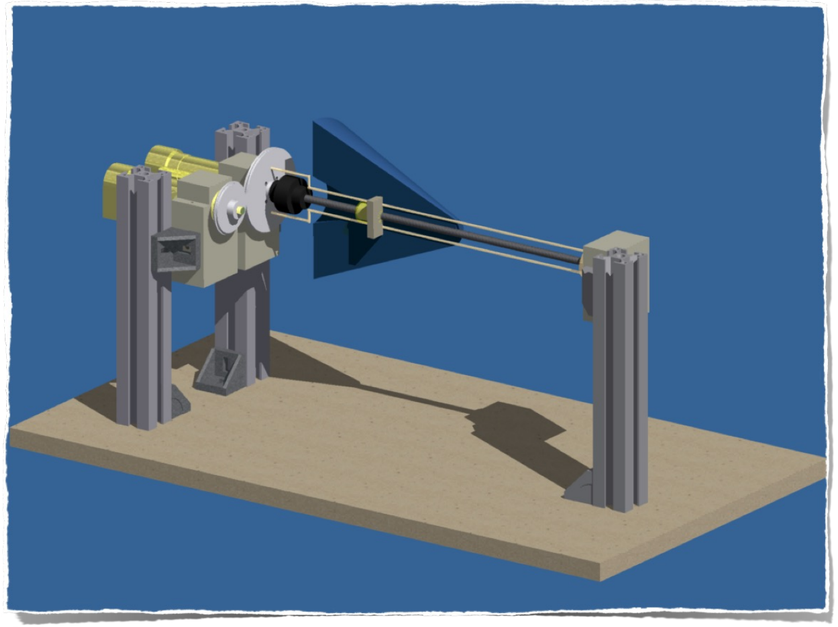
Example of design

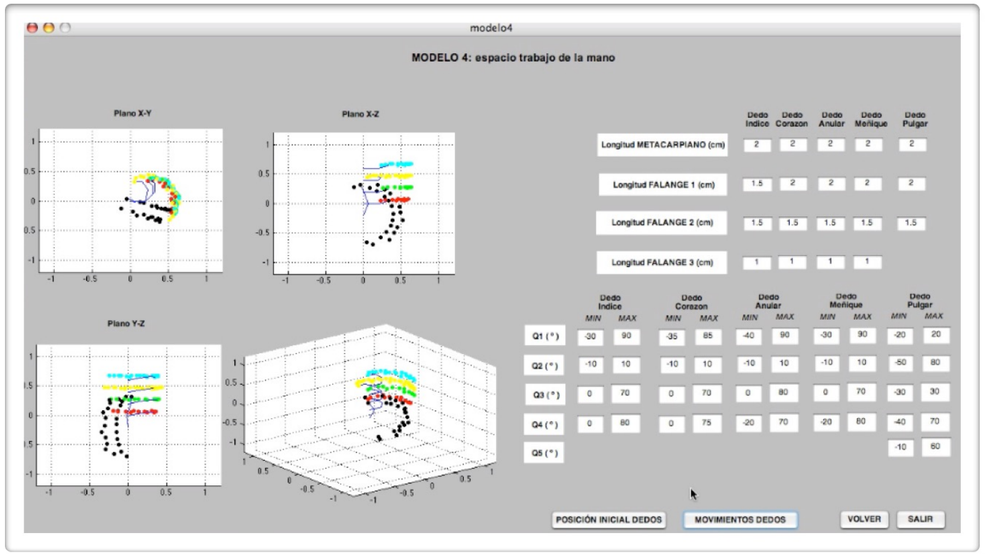


1st phalanx rehab robot



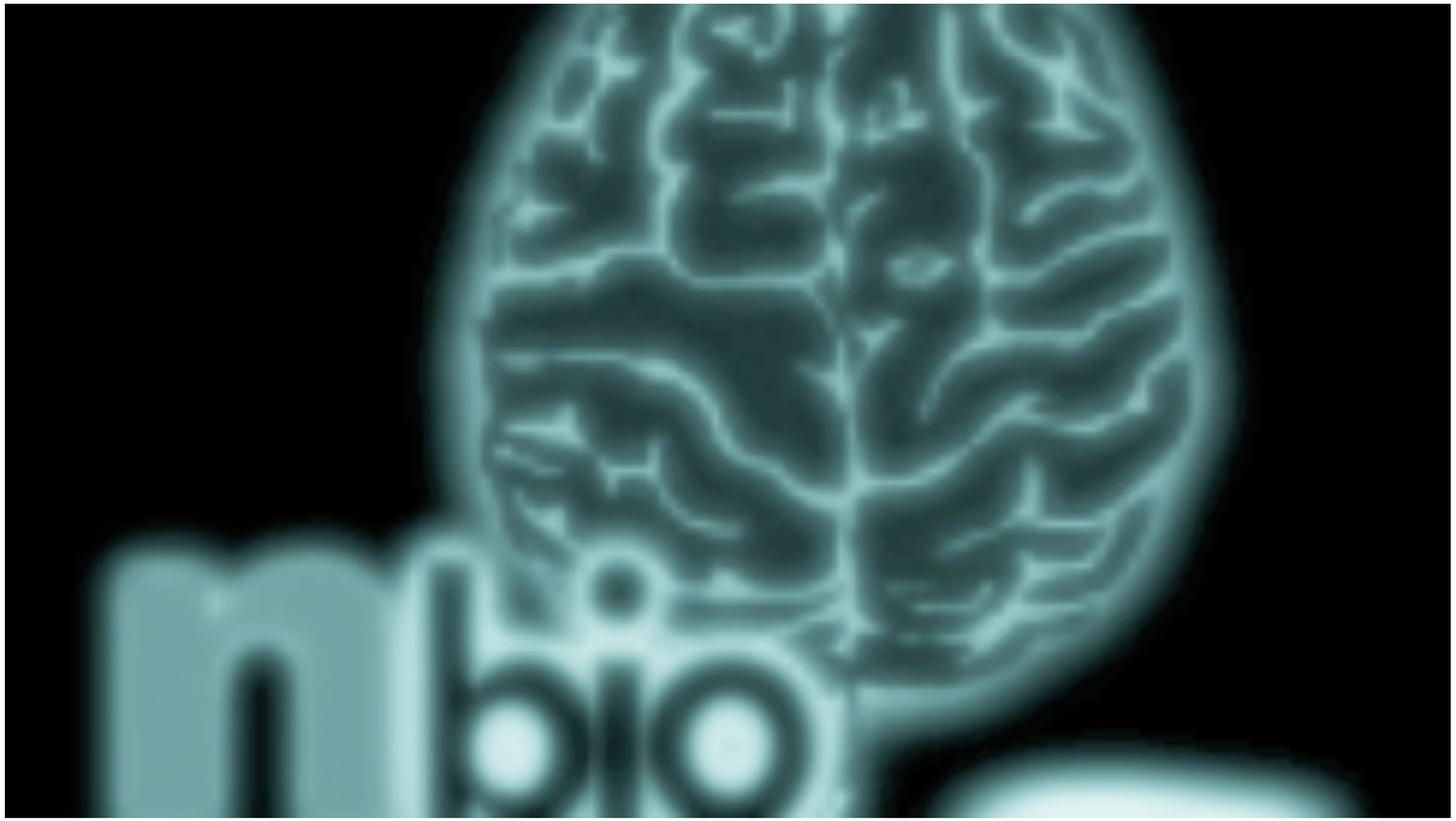






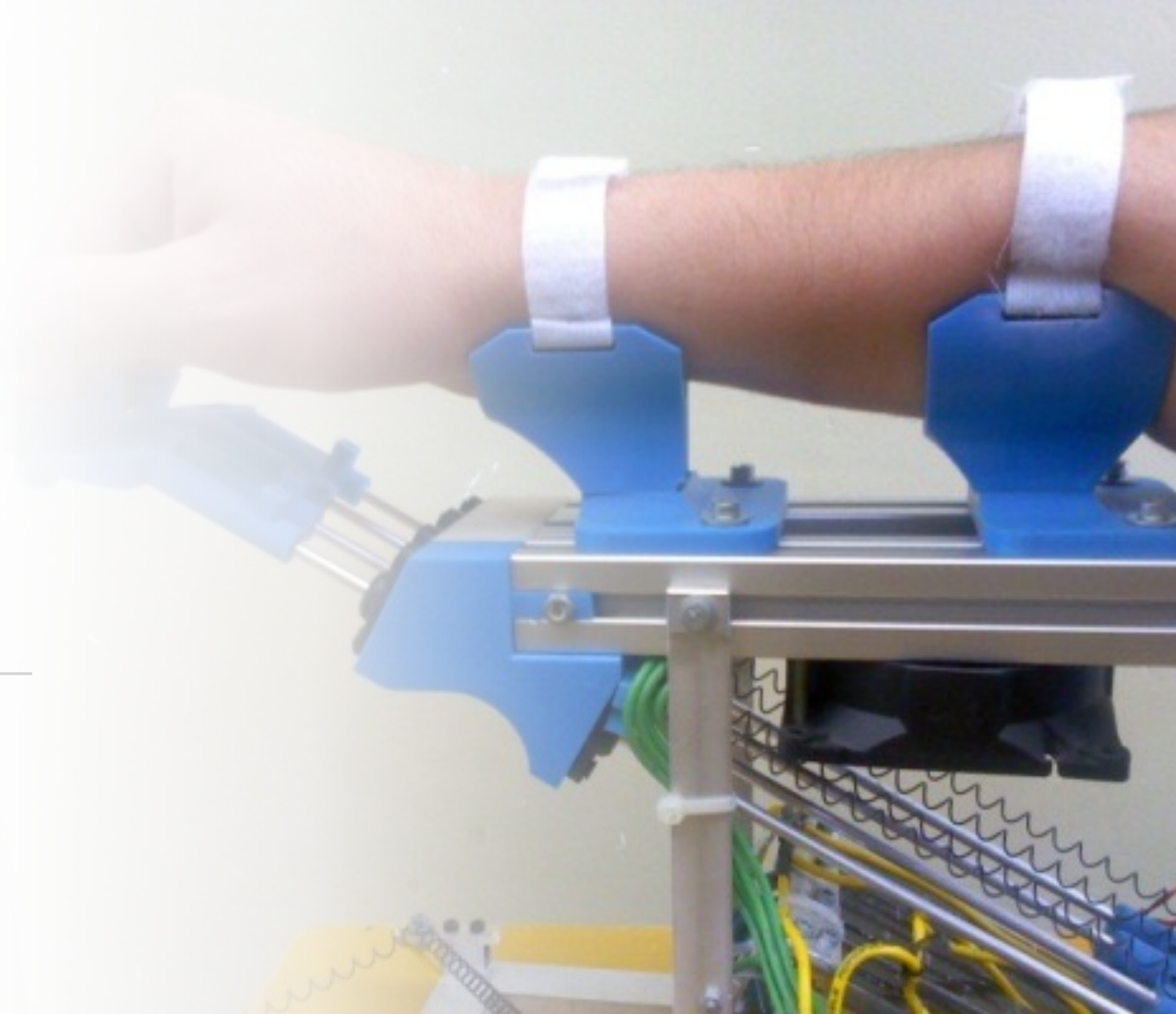
- 2 DC micromotors Faulhaber
- 1 Galil motion DMC-4080
- Elemento cónico
- Husillo de bolas en miniatura
- Acoplamiento flexible

1st phalanx rehab robot



2nd Phalanx rehab robot

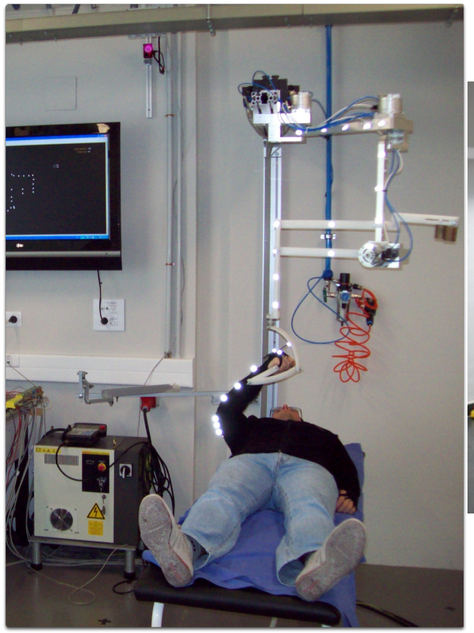
Example of design



3D upper arm rehab robot

Example of design

3D upper arm rehab robot

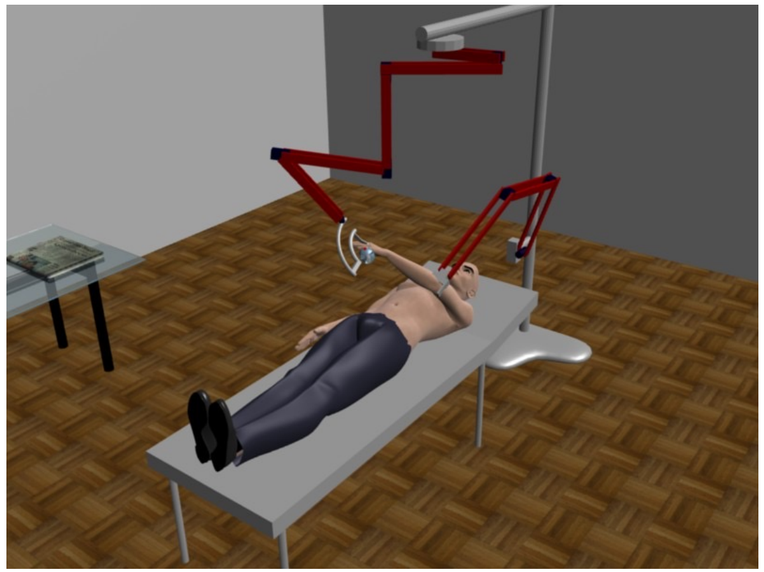


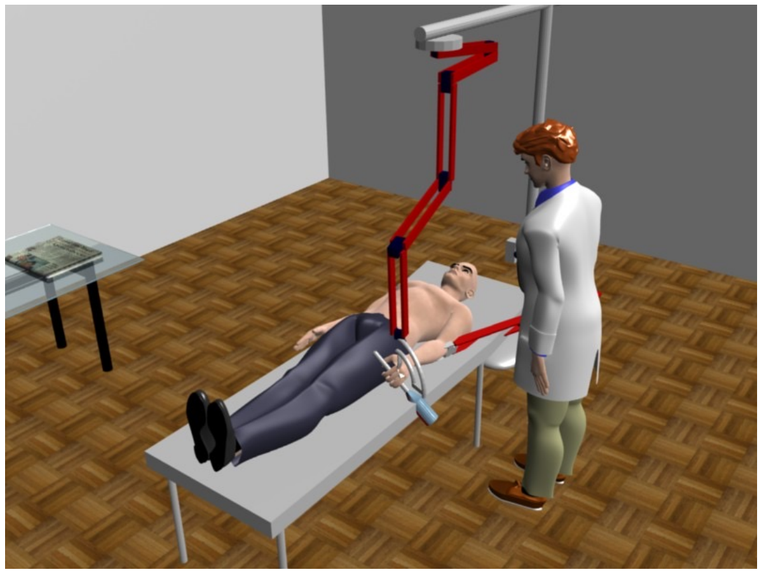
System development process

The designed robot solution comprises two arm robots:

1. three active degrees of freedom to control the patients' hand (Robotic Arm 1)
2. three active degrees of freedom to control the movements of the patients' elbow (Robotic Arm 2)

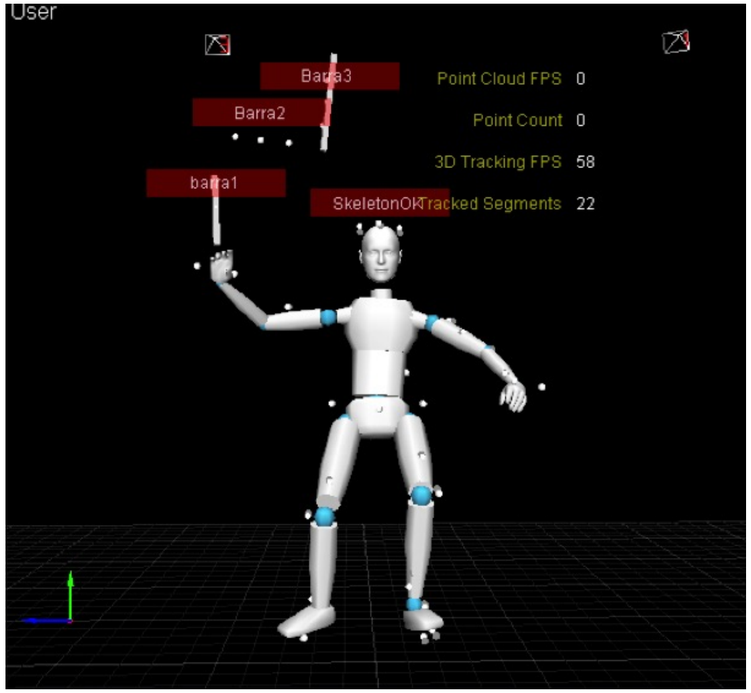
This configuration tries to mimic the way that the physiotherapists do the manual PNF movements.





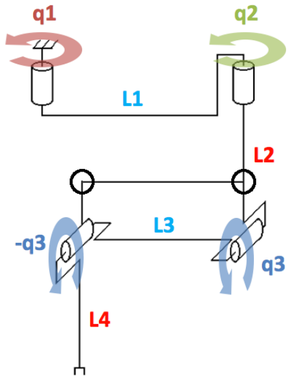
System development process

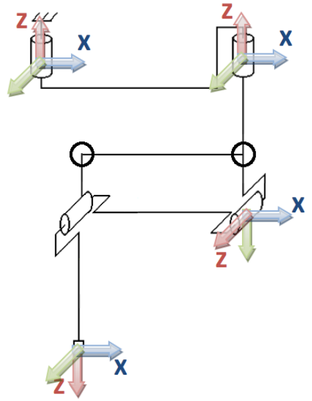
Patient side



Robot side

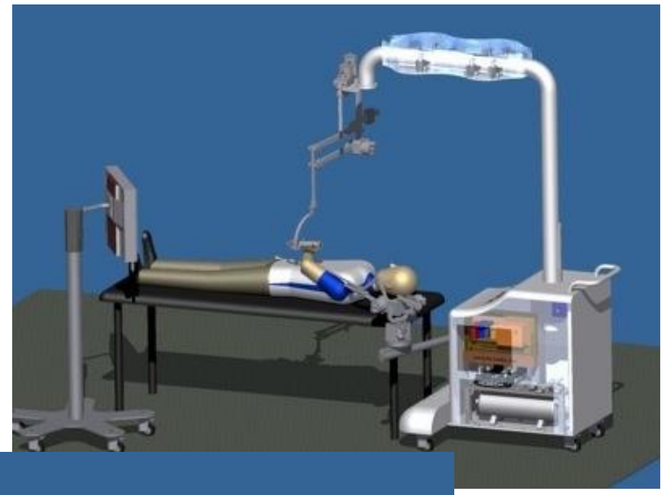
	θ	d	a	α
1	q_1	0	L_1	0
2	$q_2+\pi/2$	$-L_2$	0	$\pi/2$

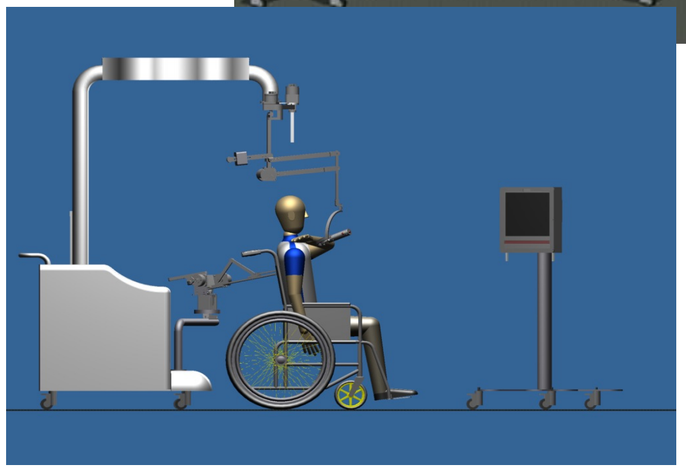




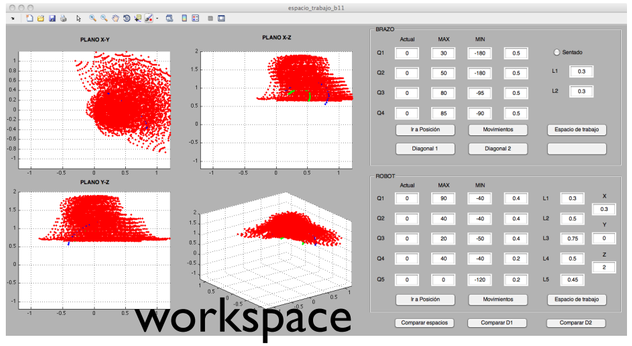
Kinematics

Patient side

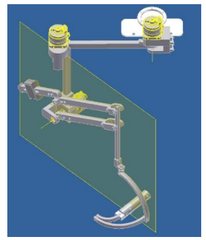


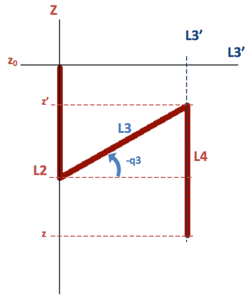


Robot side



Inverse Kinematic (Robotic Arm 1)

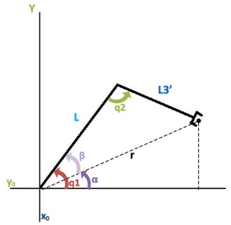


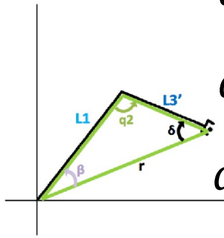


$$z = z' - L_4 \rightarrow z' = z + L_4$$

$$z' = -L_2 + L_3 \sin(-q_3)$$

$$\sin(q_3) = -\frac{z + L_4 + L_2}{L_3}$$





$$q_3 = arcsin\left(-\frac{z+L_4+L_2}{L_3}\right) \text{ para } z >= L_2$$

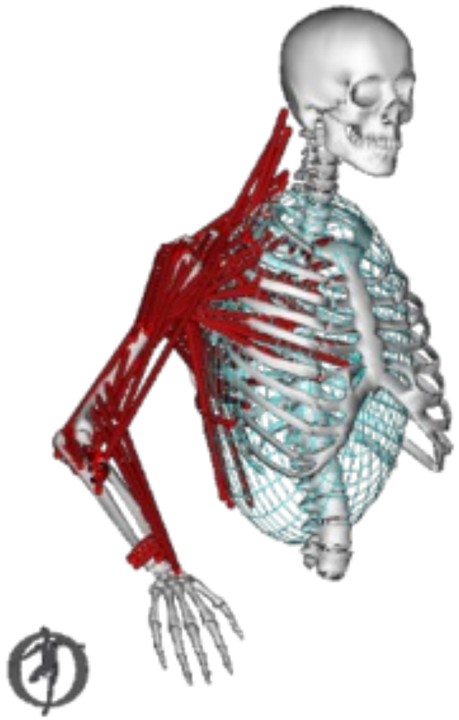
$$q_3 = -arcsin\left(-\frac{z+L_4+L_2}{L_3}\right) \text{ para } z < L_2$$

$$q_2 = arccos\left(\frac{r^2 - L_1^2 + L'^2_3}{-2L_1L'_3}\right)$$

$$q_1 = arctan\left(\frac{y-y_0}{x-x_0}\right) + arcsin\left(\frac{L'_3 sin(q_2)}{r}\right)$$

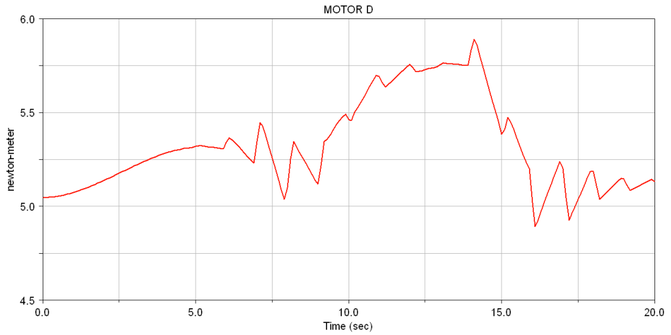
Dynamics

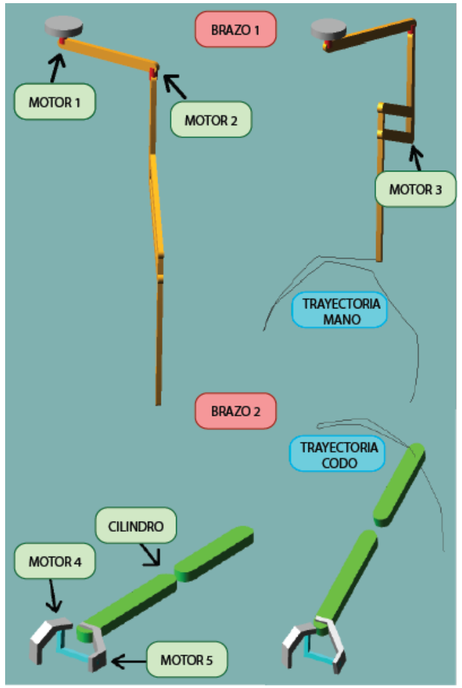
Patient side



Robot side

Dynamic requirements of the actuators
ADAMS® software
Preliminary analysis.

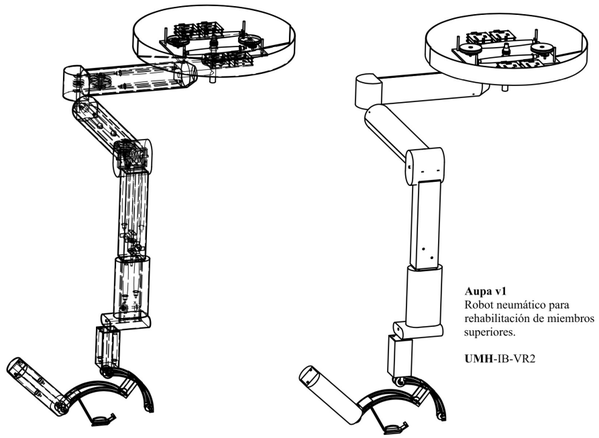




Selección de servoacc

Selección de los accionamientos:

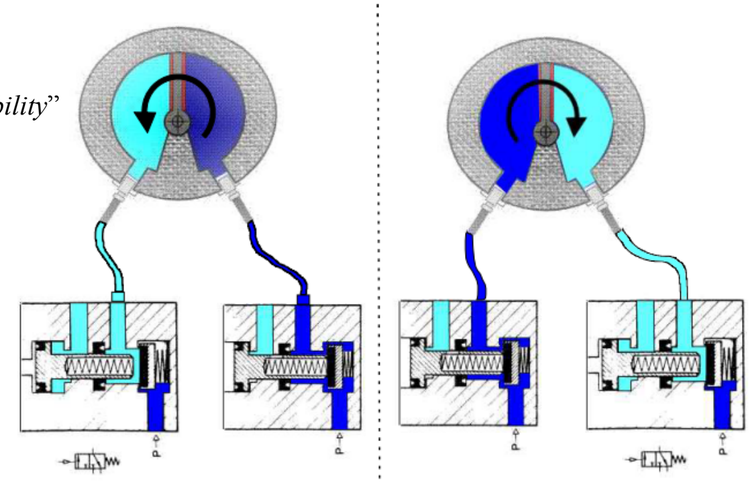
Festo DSMI	25	40	63
Construcción	Aleta pivotante. Eje de accionamiento, rodamiento de bolas.		
Funcionamiento	Doble efecto.		
Detección de posiciones	Analógico, con potenciómetro de plástico conductor.		
Vel. máx. de maniobra [º/s]	2000		
Ángulo de giro [º]	0…270		
Momento de giro [Nm]	5 (6 bares)	20 (6 bares)	40 (6 bares)
Fuerza radial máxima [N]	120	50	500
Fuerza axial máxima [N]	50	120	500
Frecuencia máx. de giro [Hz]	2		1



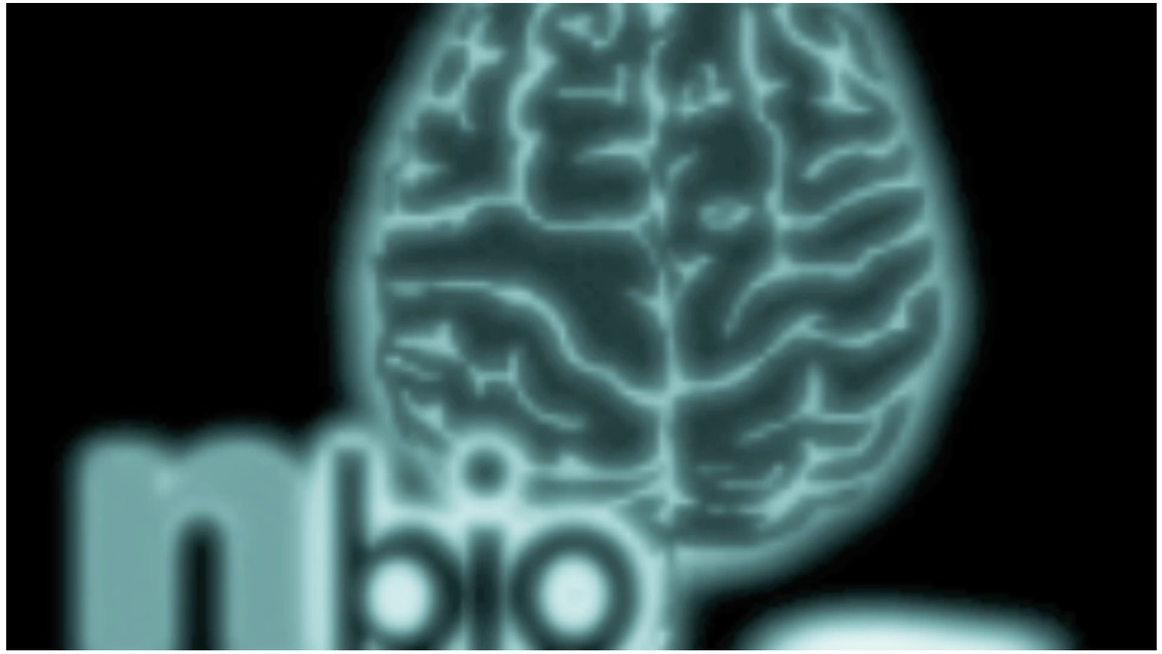
Control del sistema robótico propuesto

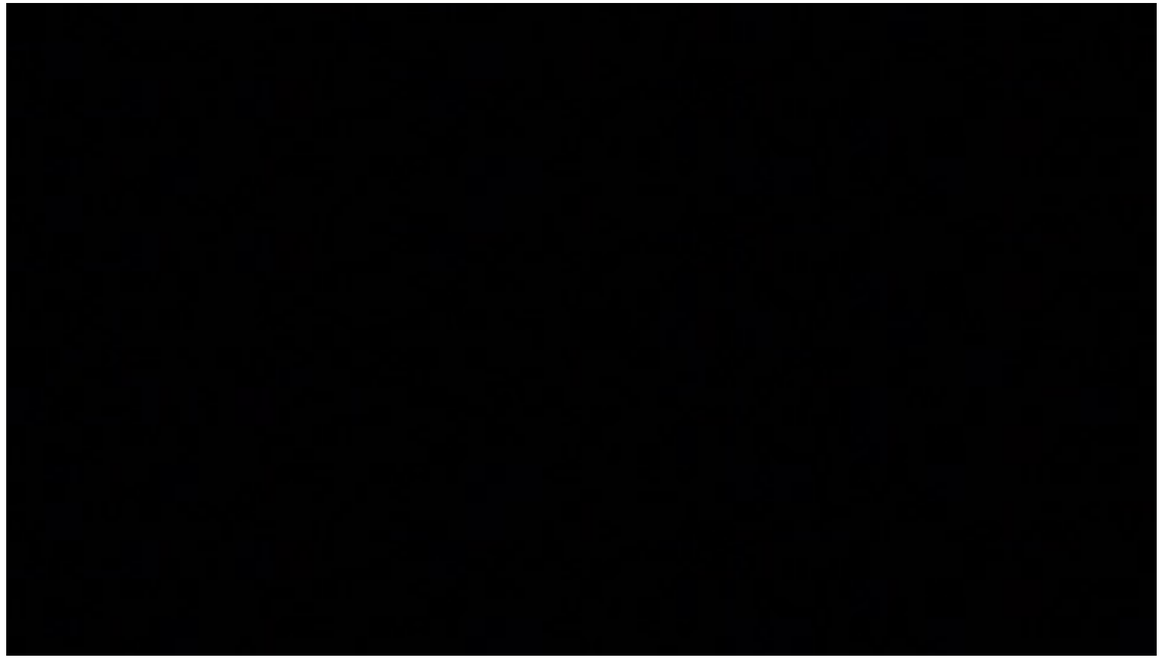
Bloques de válvulas y motor neumático

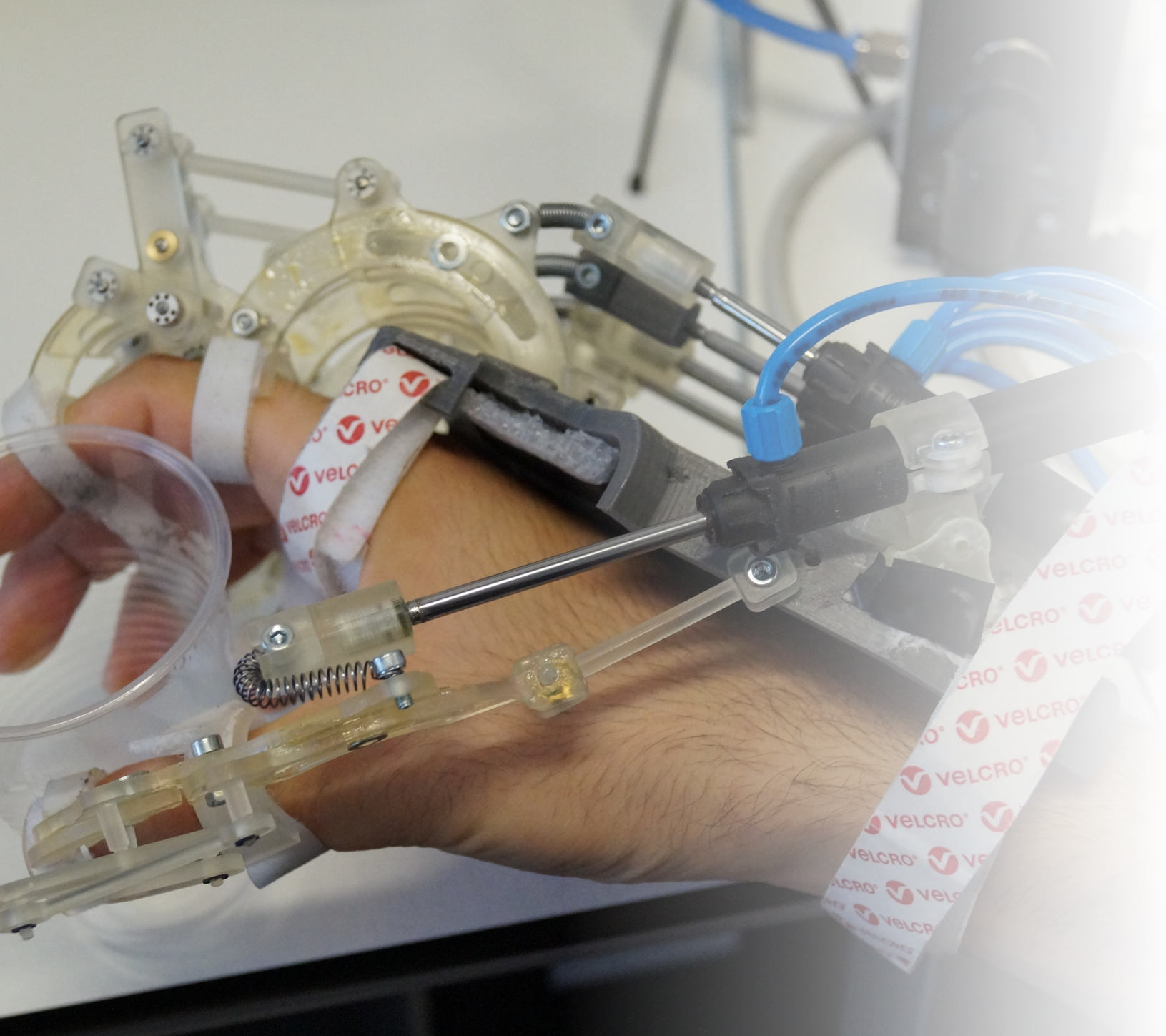
- ✓ Seguridad
- ✓ "*Backdrivability*"



Desde Aupa a Helper







3rd Phalanx rehab robot

Example of design

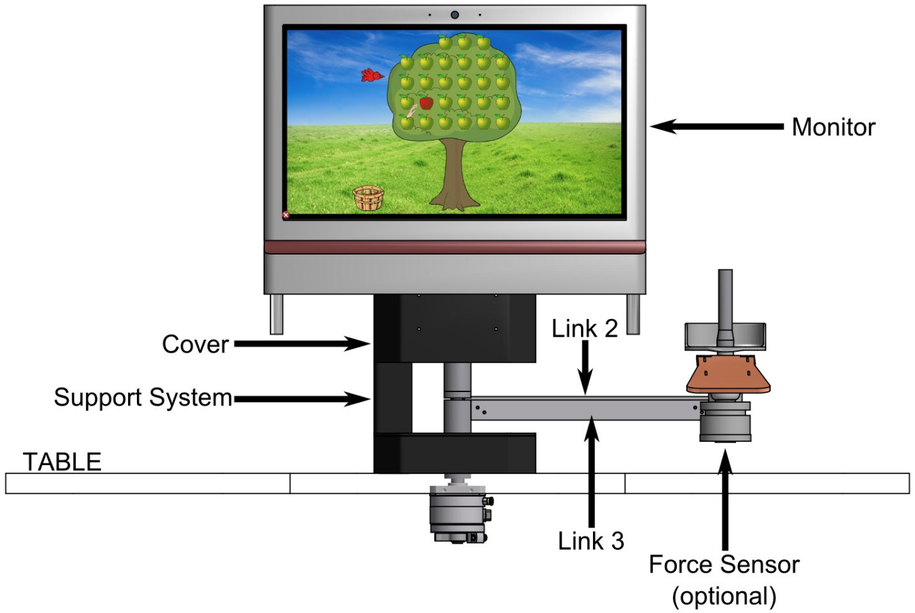
Planar upper arm rehab robot

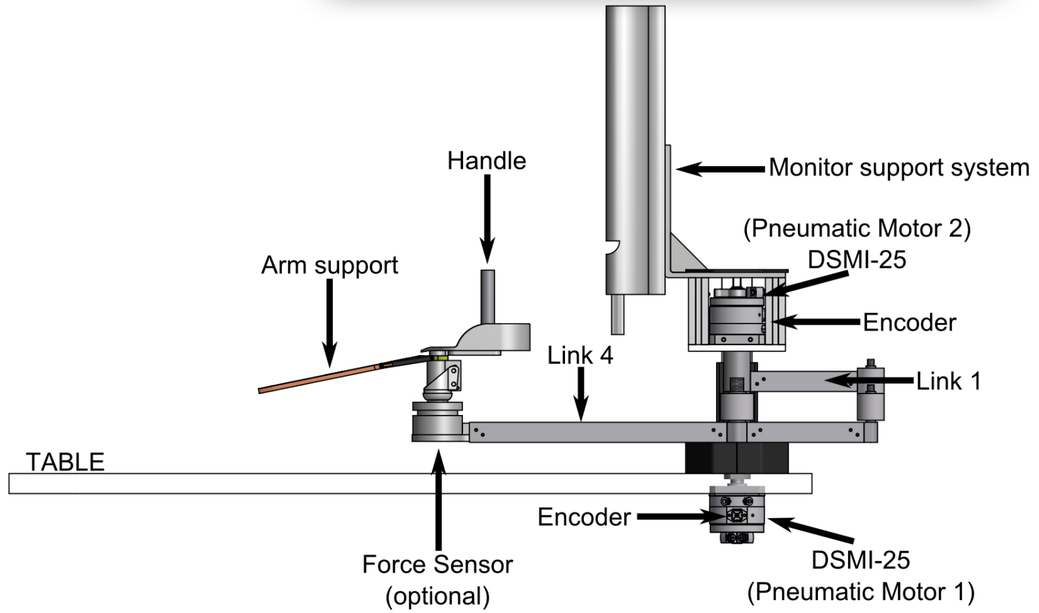
Example of design

PupArm

The pneumatic rehabilitation robot based on a four bar mechanism similar to the MIT-MANUS rehabilitation robot.

- The mechanism is configured as a generic planar two-dimensional manipulator

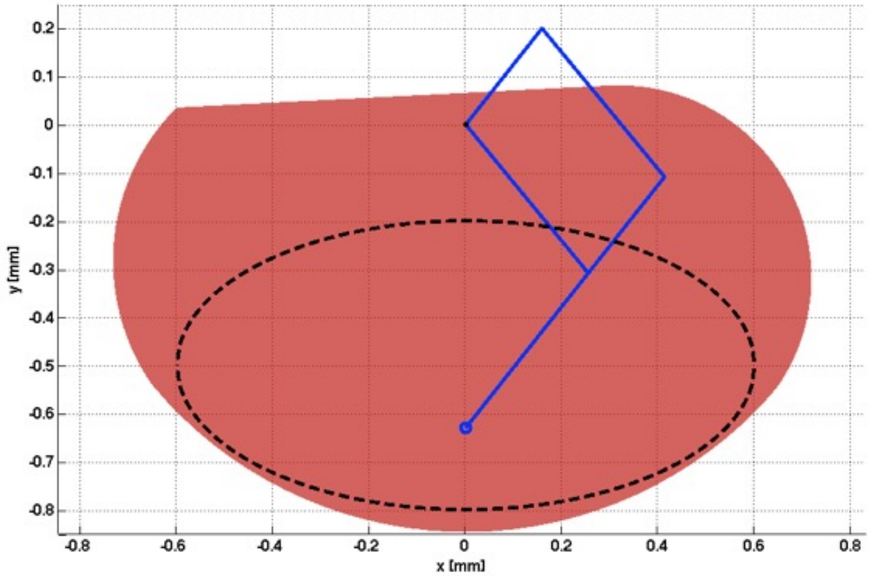




PupArm

The four bar mechanism has been designed using the information provided by a previous analysis of reaching activities and a simple model of human arm reachable workspace (ARW).

- The kinematic data of the human arm during different reaching tasks were collected using two wireless inertial measurement units (IMUs) attached to subject's arm and forearm.
- Using the simplified kinematic model of human arm and the information provided by the IMUs, 2D trajectories for each reaching task in the worst case were computed.
- The final conclusion of this analysis was that desired workspace that can be reached by an adult arm is an ellipse with its major and minor axis equal to 1200mm and 600 mm



PupArm

Dynamics analysis of the four bar mechanism: a right selection of link lengths produces the possibility of obtaining a configuration-independent and decoupled inertia matrix.

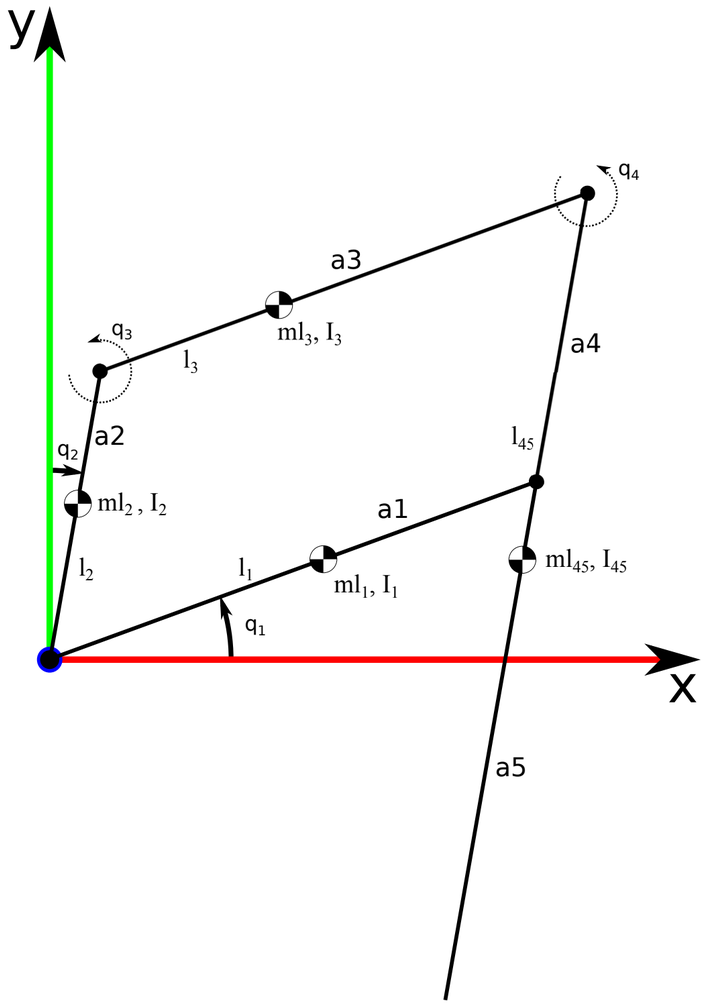
$$\boldsymbol{\tau} = \mathbf{B}(\mathbf{q})\ddot{\mathbf{q}} + \mathbf{C}(\mathbf{q}, \dot{\mathbf{q}})\dot{\mathbf{q}} + \mathbf{g}(\mathbf{q})$$

$$\mathbf{B}_a = \begin{bmatrix} b_{a11} & b_{a12} \\ b_{a21} & b_{a22} \end{bmatrix},$$ inertia matrix

$$\begin{aligned} b_{a11} &= I_{l_1} + I_{l_3} + m_{l_1} l_1^2 + m_{l_3} l_3^2 + m_{l_{45}} a_1^2, \\ b_{a12} &= b_{a21} = (a_1 m_{l_{45}} (l_{45} - a_2) \\ &\quad - a_2 l_3 m_{l_3}) \sin(q_1 + q_2), \\ b_{a22} &= I_{l_2} + I_{l_{45}} + m_{l_2} l_2^2 + m_{l_3} a_2^2 \\ &\quad + m_{l_{45}} (a_2^2 + l_{45}^2 - 2 a_2 l_{45}). \end{aligned}$$

$$\frac{m_{l_{45}} \bar{l}_{45}}{m_{l_3} l_3} = \frac{a_2}{a_1}, \longrightarrow (b_{a12} = b_{a21} = 0)$$

inertia matrix is diagonal

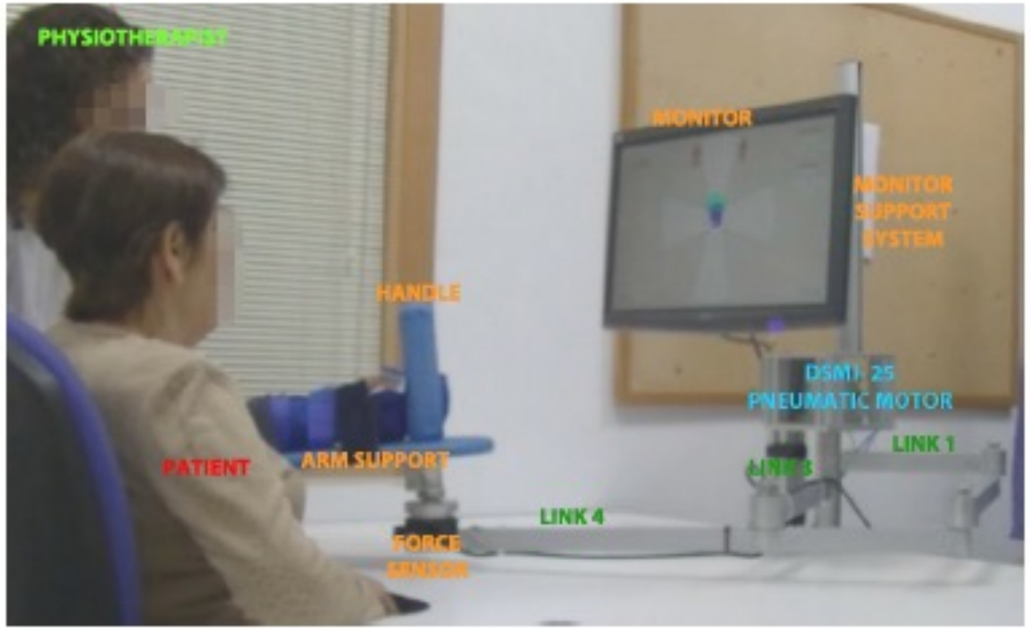


As a consequence the dynamic model can be considered
decoupled from the control point of view

PupArm

An extensive clinical trial with post-stroke patients are being carried out at a dedicated room at Histology and Anatomy Department of Miguel Hernandez University of Elche. Two people were present: a patient and a specialized physiotherapist

The clinical study has the ultimate goal of determining the efficacy of upper extremity robot therapy (from now,
robot group) compared to the classical therapy (from now, control group) in patients with hemiplegia secondary
due to stroke.

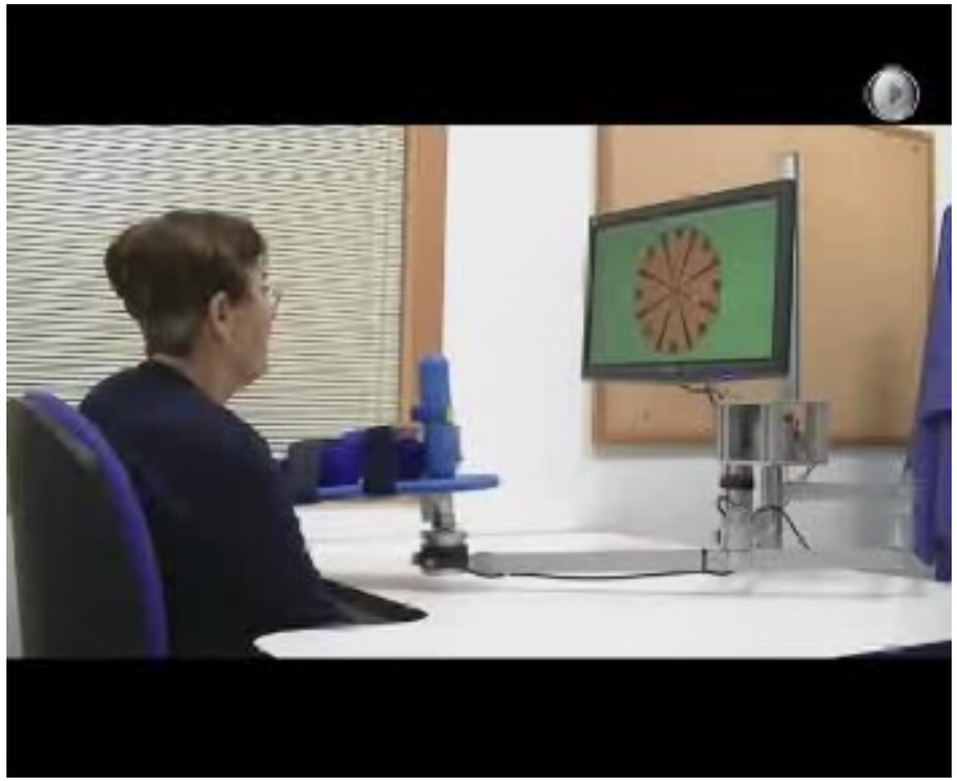


Over a three month period, both groups are receiving 36 sessions of robot-assisted or manual therapy plus 36 sessions of their classical therapy treatment.

PupArm

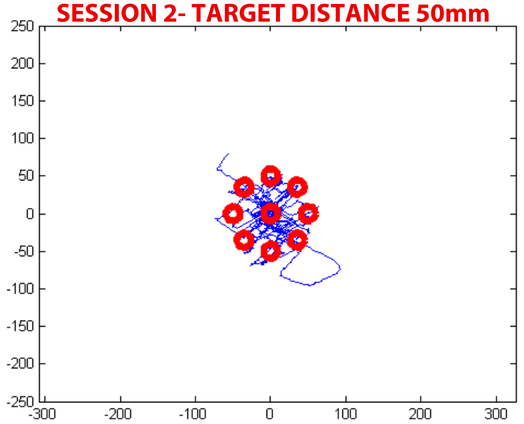
Session 2

Session 10

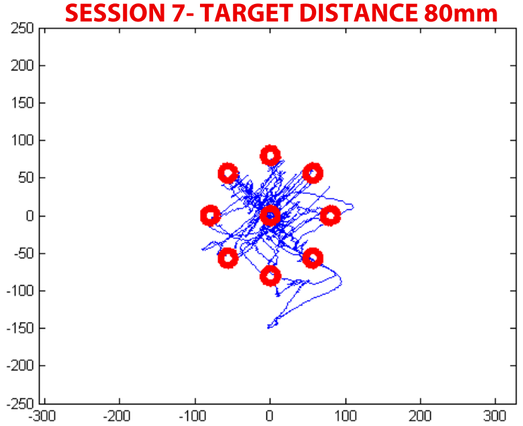


PupArm

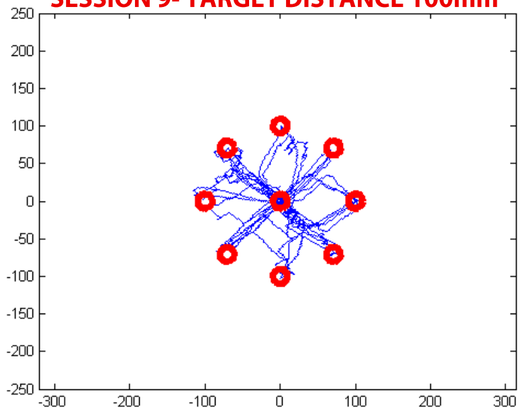
SESSION 2- TARGET DISTANCE 50mm



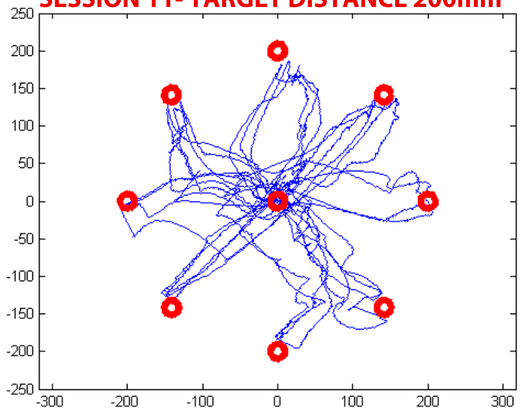
SESSION 7- TARGET DISTANCE 80mm



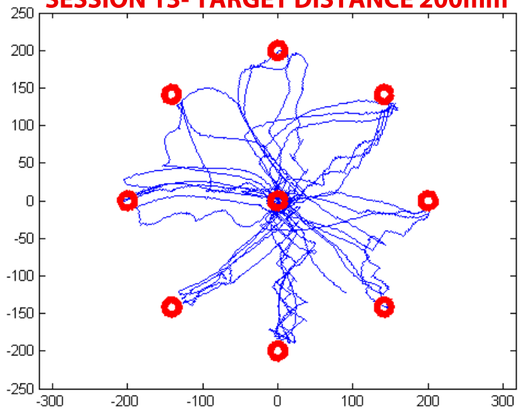
SESSION 9- TARGET DISTANCE 100mm



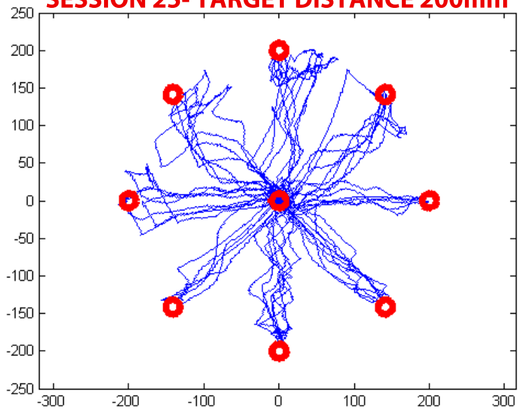
SESSION 11- TARGET DISTANCE 200mm



SESSION 13- TARGET DISTANCE 200mm



SESSION 25- TARGET DISTANCE 200mm

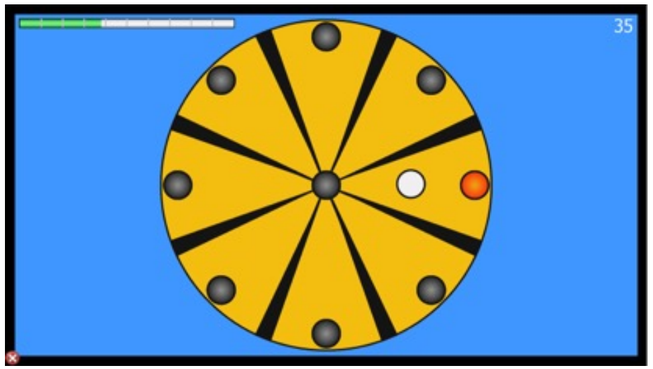


PupArm

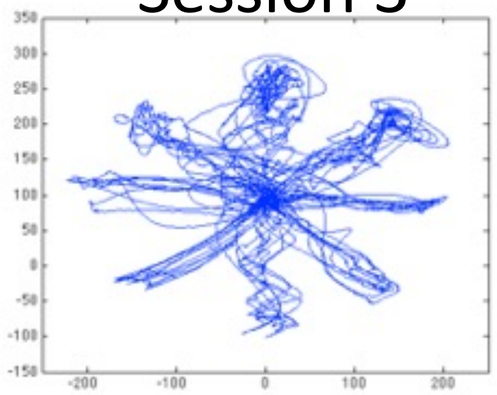
Session 1

Session 7

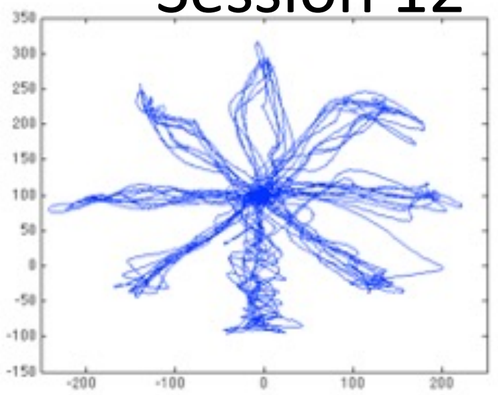
PupArm



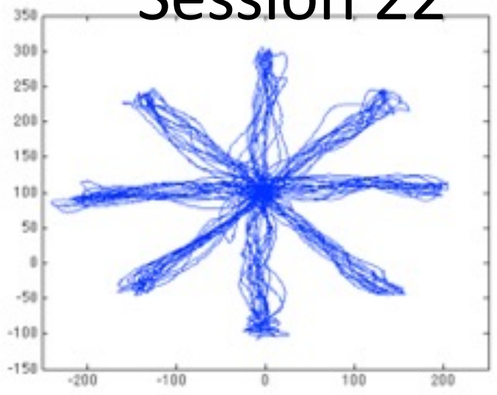
Session 3



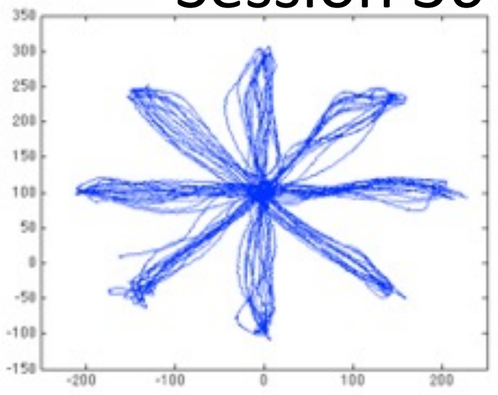
Session 12



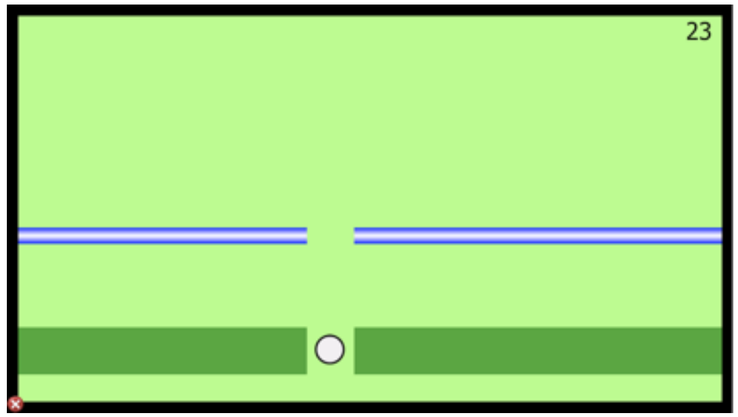
Session 22



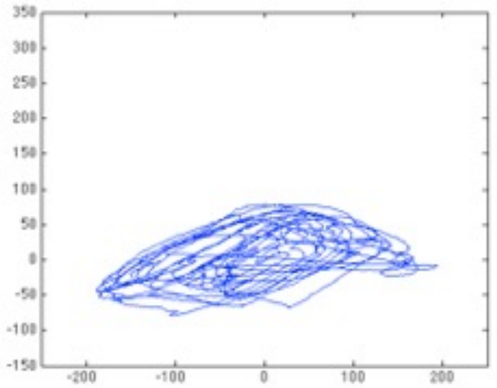
Session 36



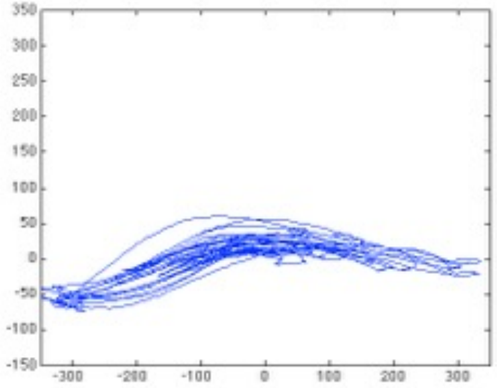
PupArm



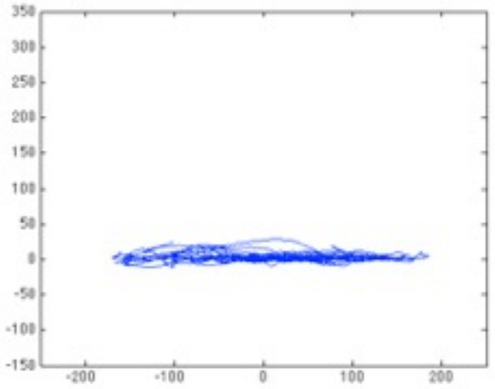
Session 3



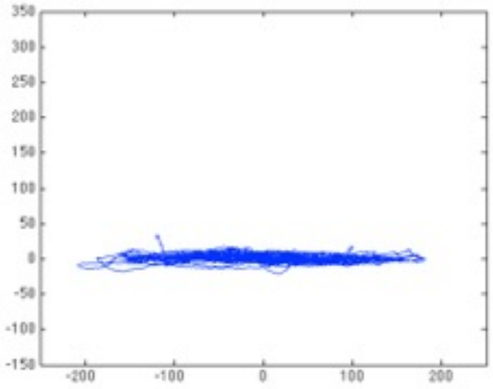
Session 12



Session 22



Session 36

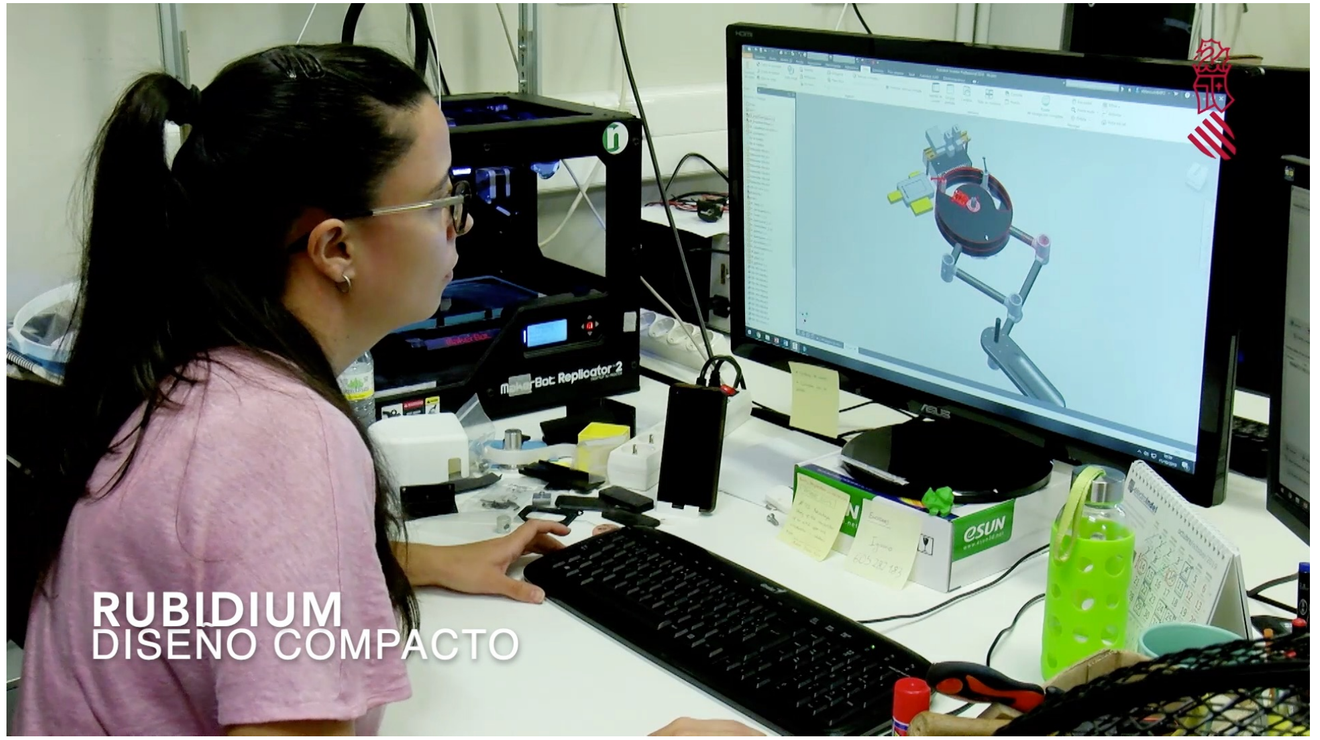


PupArm

PupArm

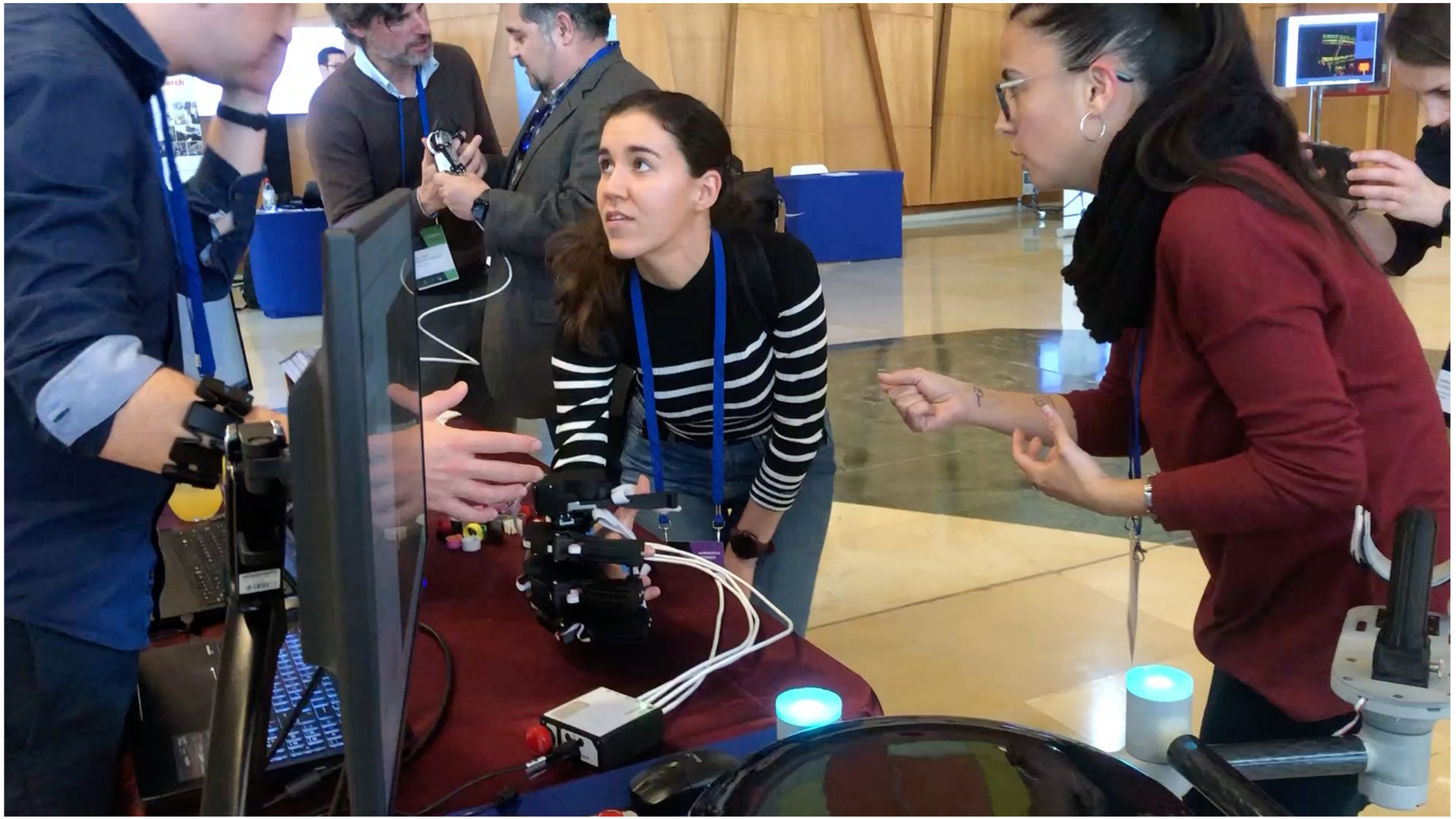
Una aplicación real de **rehabilitación** multimodal

Desde puparm a Rubidium



4rd Phalanx rehab robot (Helium)

Example of design

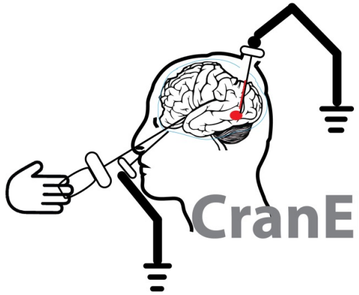


NeuroSurgical robotics

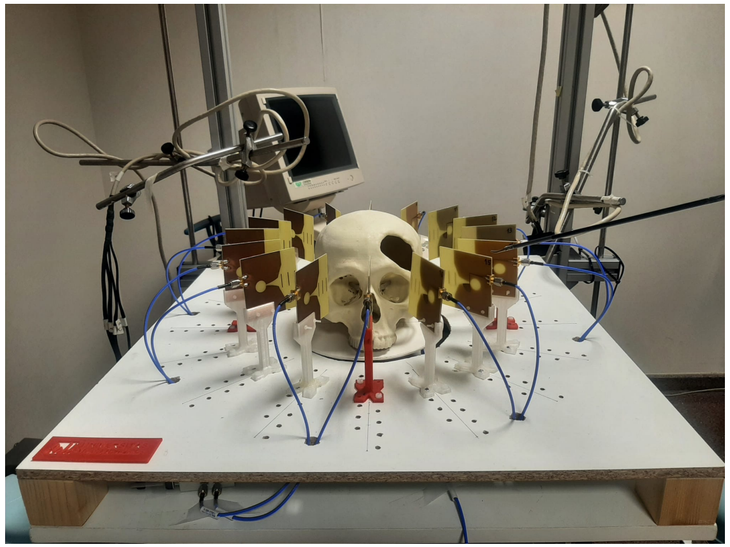
a simpler example: - Rosetta device -

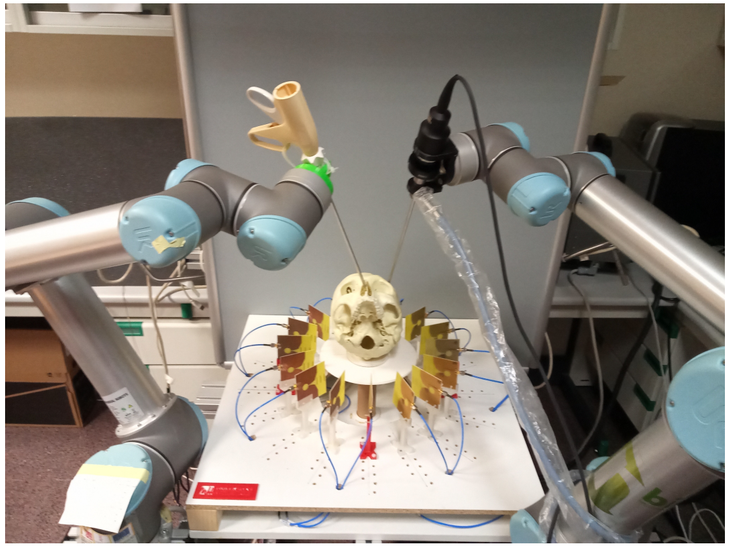
Rompiendo moldes…

CRANEEAL

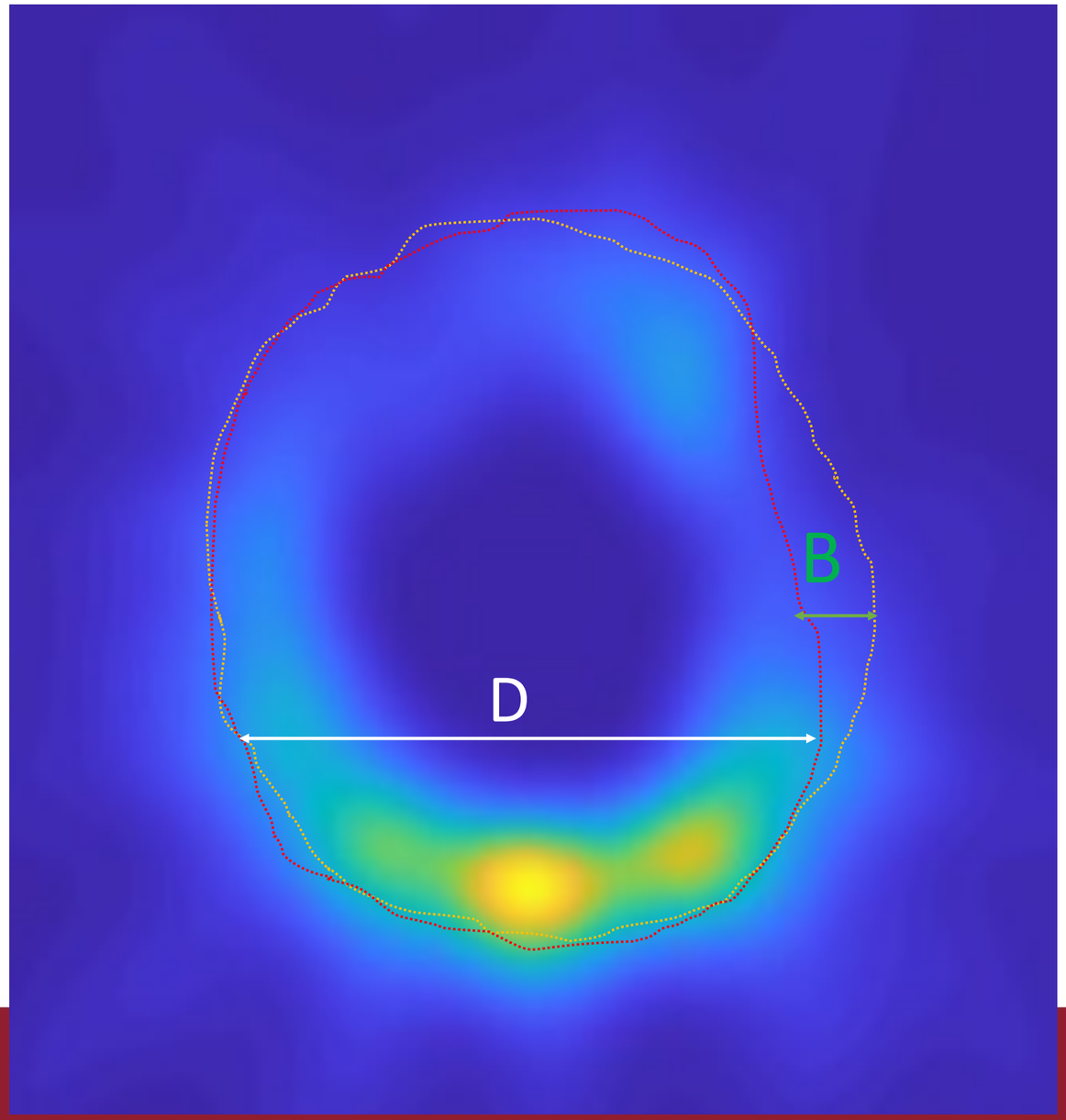

CranEEAI

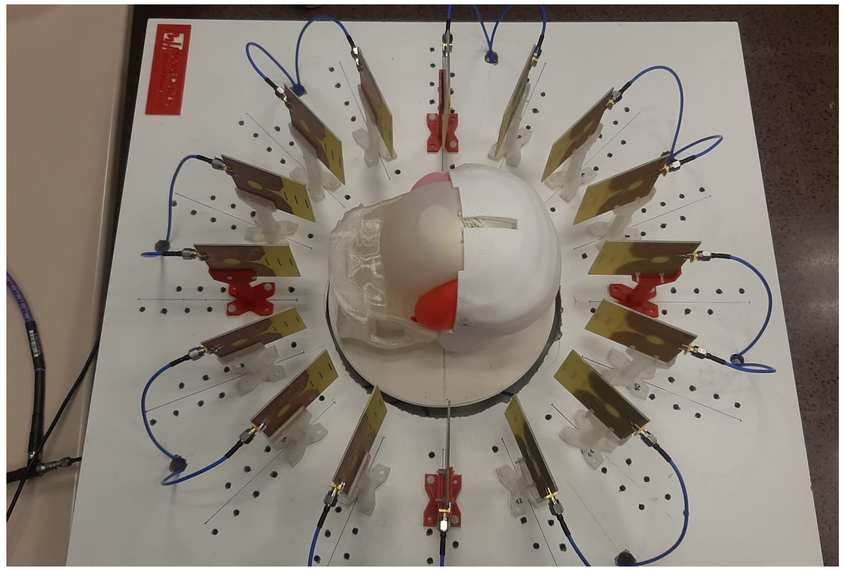

Surgical Robot
ROS
Surgical navigator
openIGTLink
Fusion images
Image analysis
Medical image processing
RF image

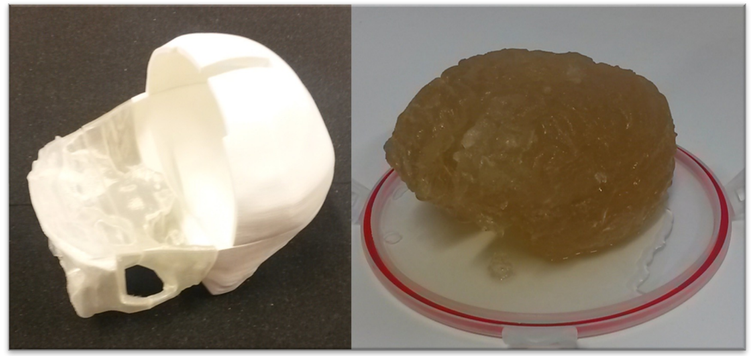




Follow internal structures

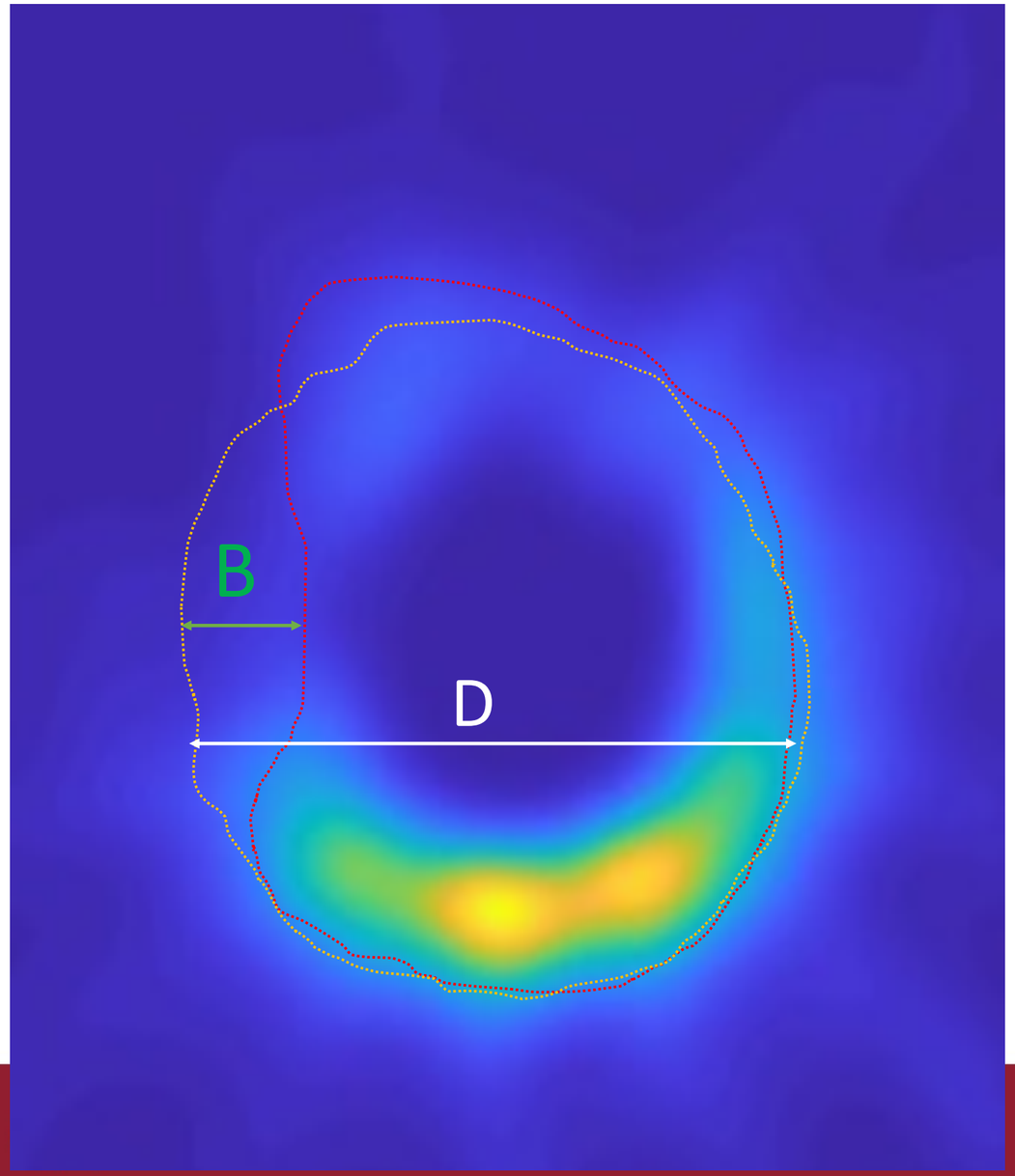


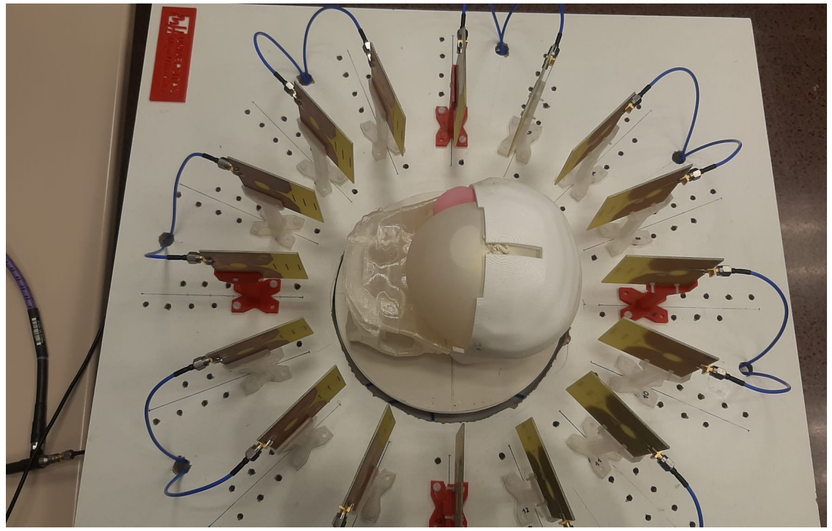




Desplazamiento leve en 90º
D=11.8cm
B=1.34cm (11.4%)

Follow internal structures





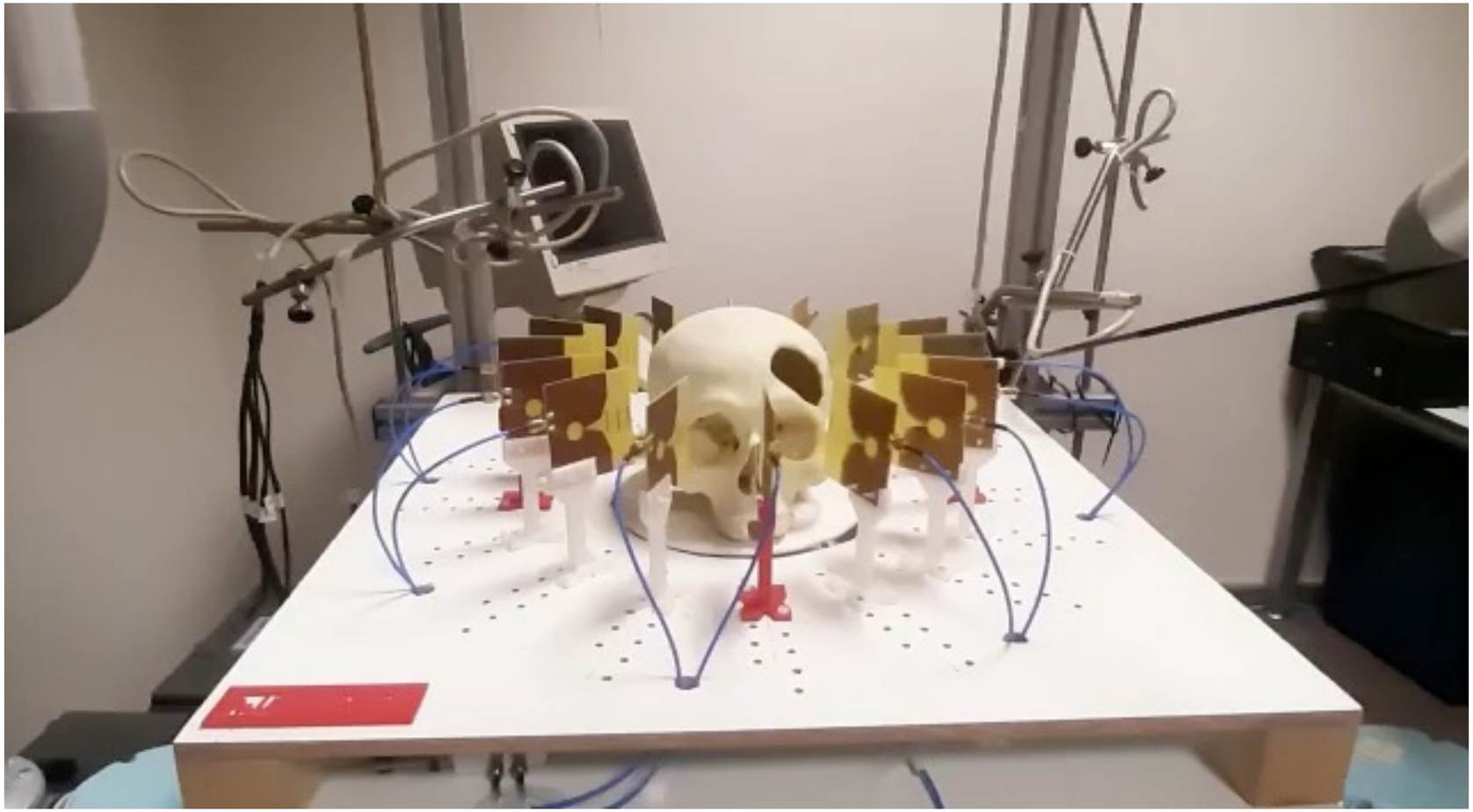
Desplazamiento moderado en 270º

D=11.8cm

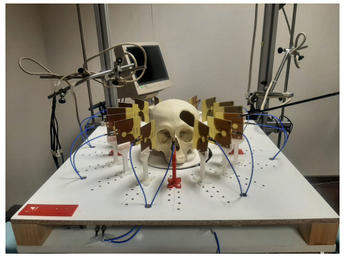
B=2.23cm (18.9%)

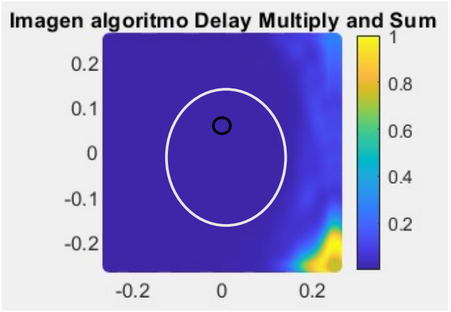
Navigation of surgical tool

- Sistema “radar” para imagen intraoperatoria

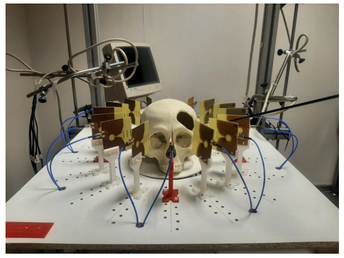


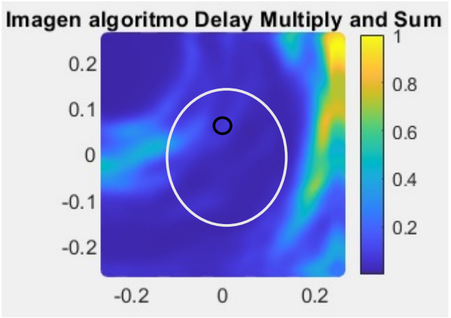
Posición 1



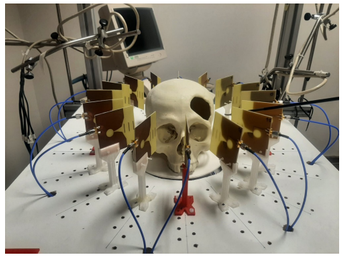


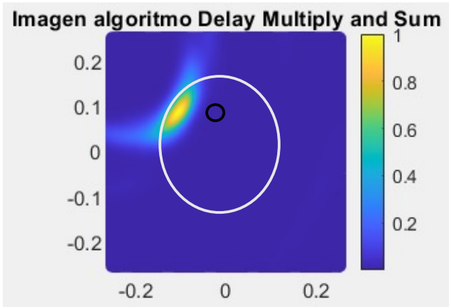
Posición 2



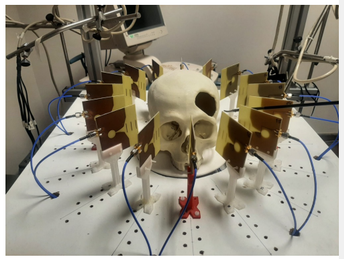


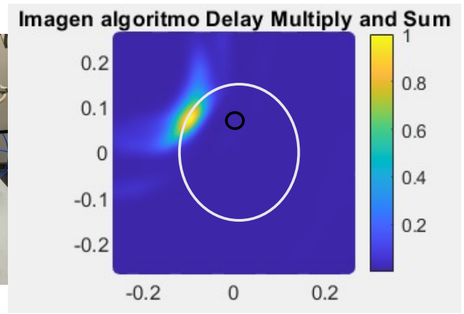
Posición 3



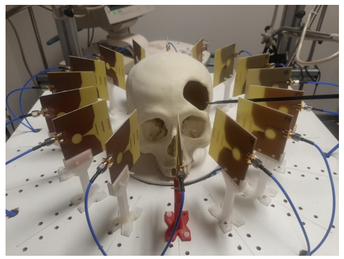


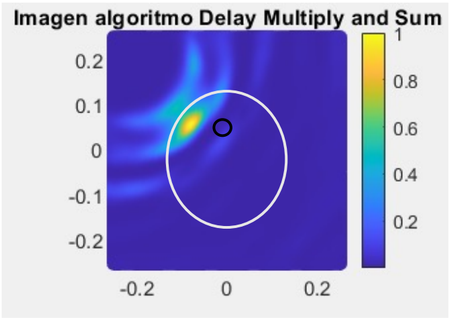
Posición 4



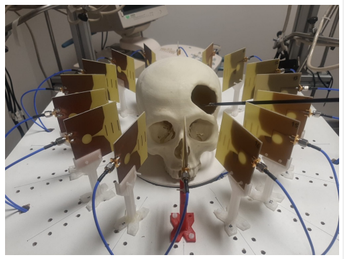


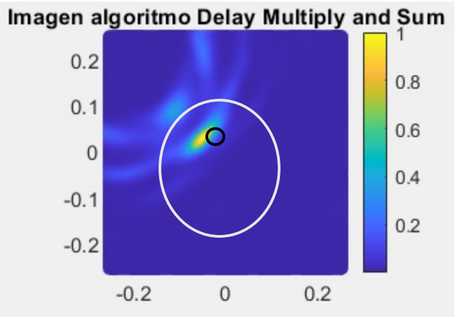
Posición 5





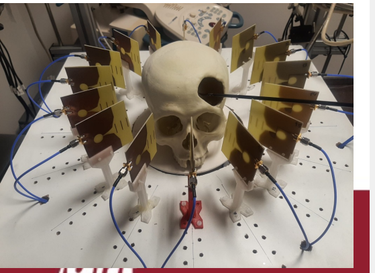
Posición 6

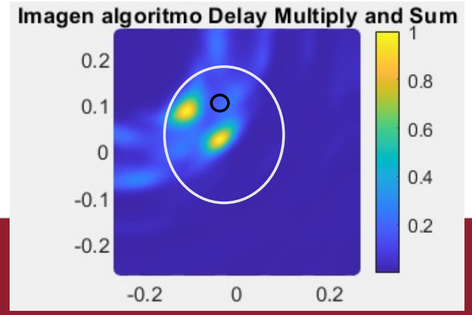




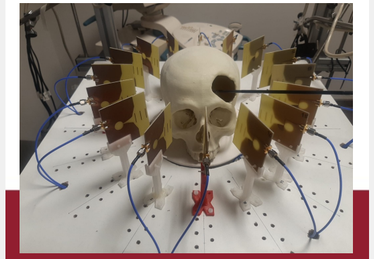
Medidas en las que se ve solo la herramienta con algoritmo Delay Multiply and Sum

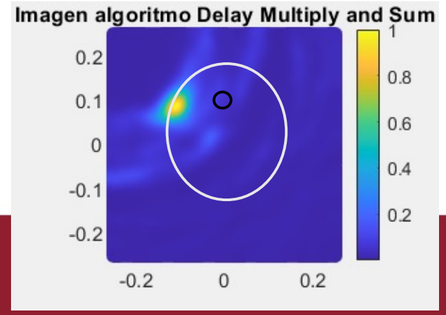
Posición 7

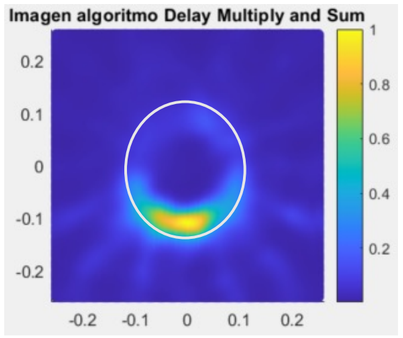


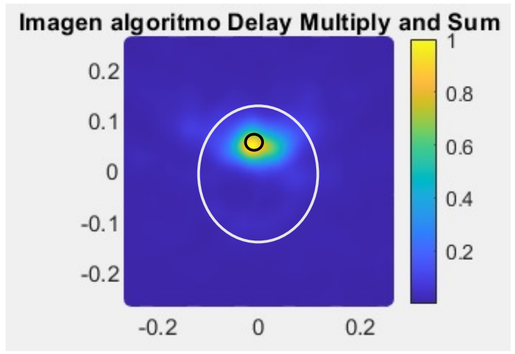


Posición 8

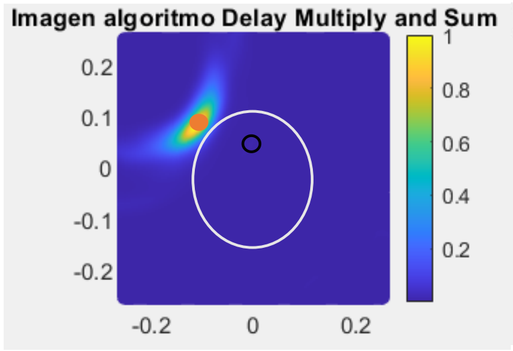




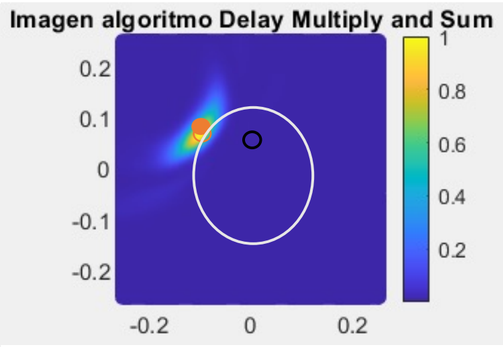




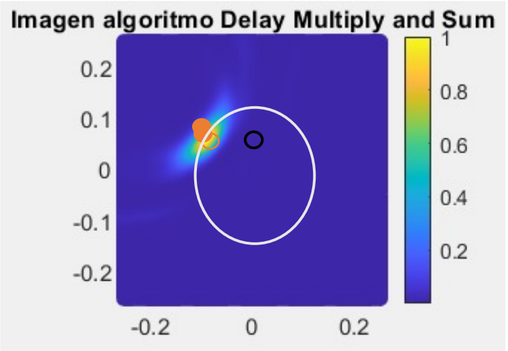
Pos 3-Pos 2



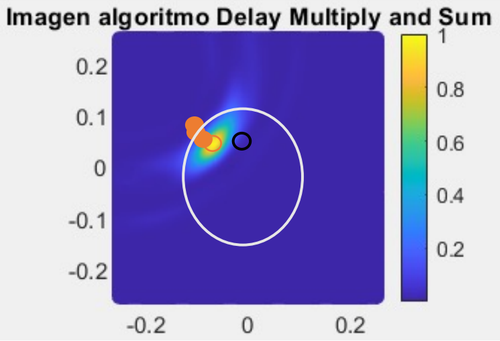
Pos 4-Pos 3



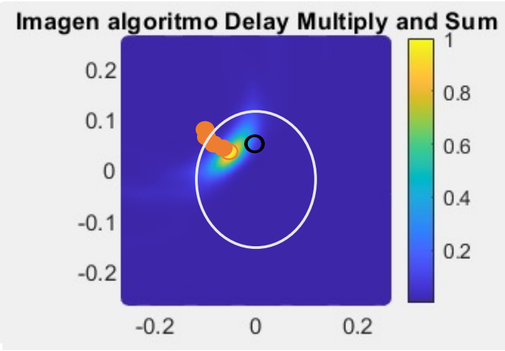
Pos 5-Pos 4



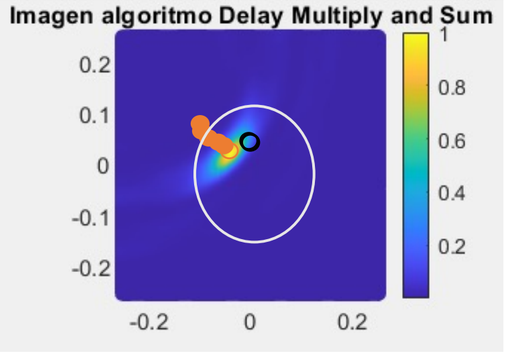
Pos 6-Pos 5



Pos 7-Pos 6



Pos 8-Pos 7



RESULTADOS BRAIN SHITH
1.5cm EN ANTENA 9 (180º)

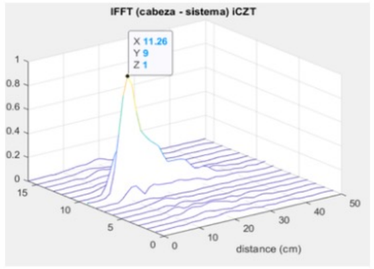
a) Detección de brain-shift a partir de la Transformada Inversa Chirp

b) Detección de brain-shift a partir de la Transformada Inversa de Fourier

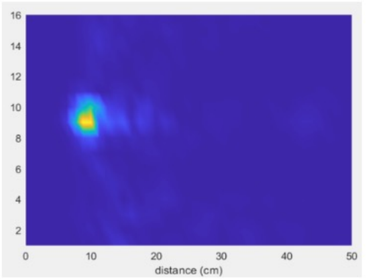
c) Representación en intensidad de los algoritmos DAS, DMAS and Coherence para brain-shift en altura 3

d) Representación en intensidad de las distintas alturas evaluadas con el algoritmo DAS

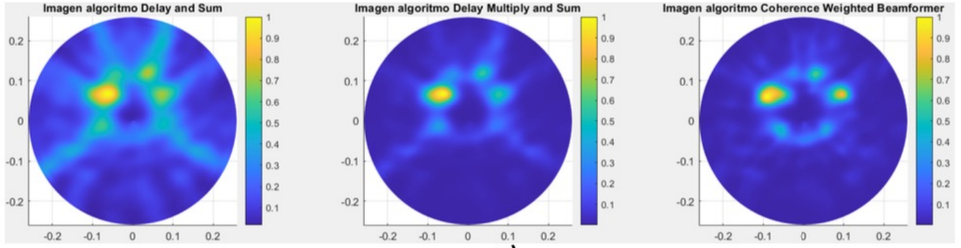
d) Representación algoritmo DAS para las distintas alturas evaluadas. Se marcan los bordes de cráneo, brain antes y brain después.
Se marca el desplazamiento observado



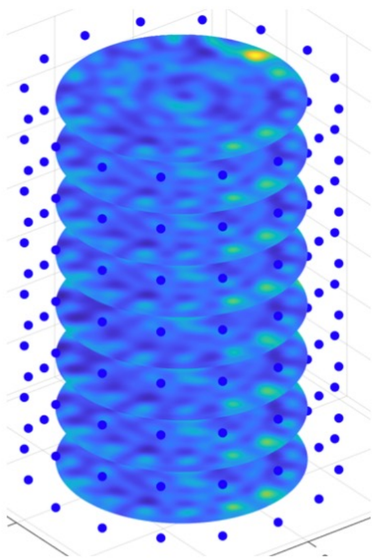
a)



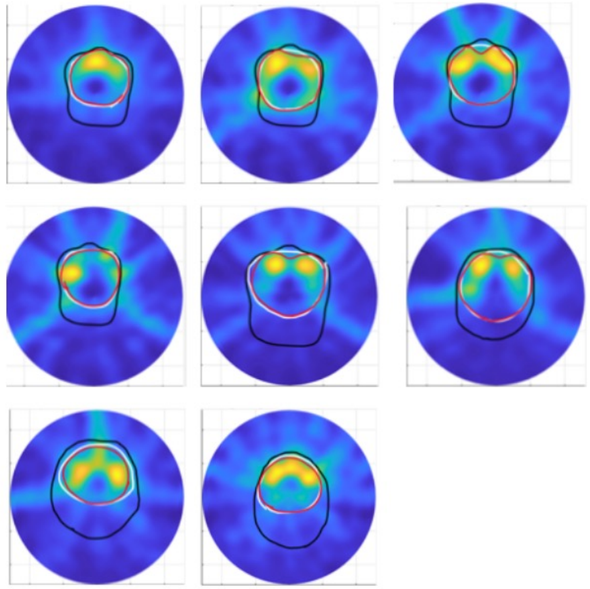
b)



c)



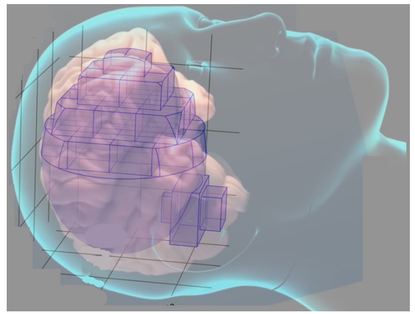
d)

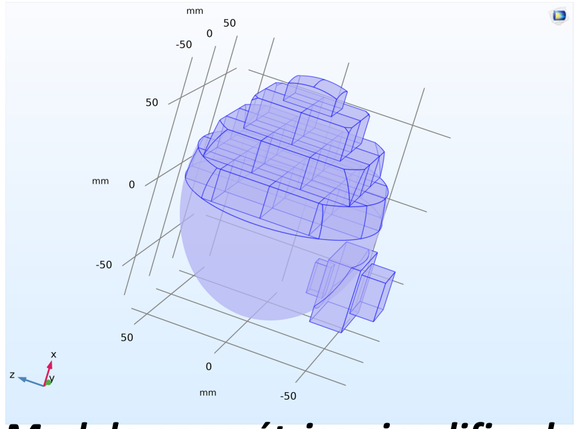


e)

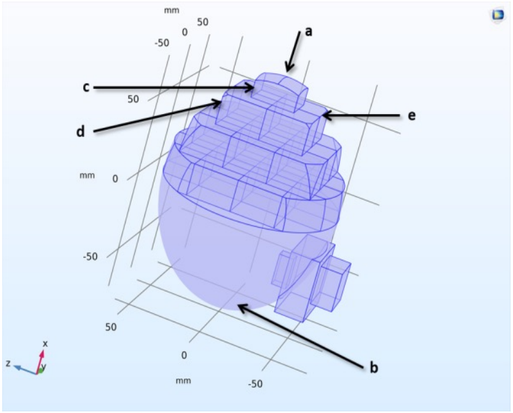
RESULTADOS EN SIMULACION

Cálculo del *brain shift* utilizando medidas prefabricadas de distancias en la superficie cerebral.

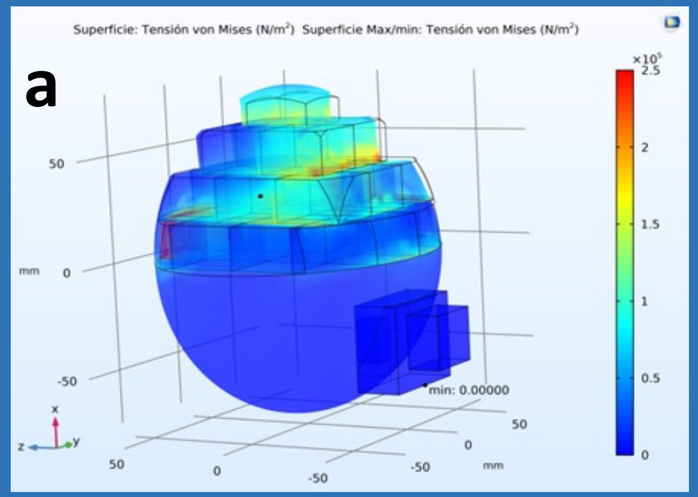


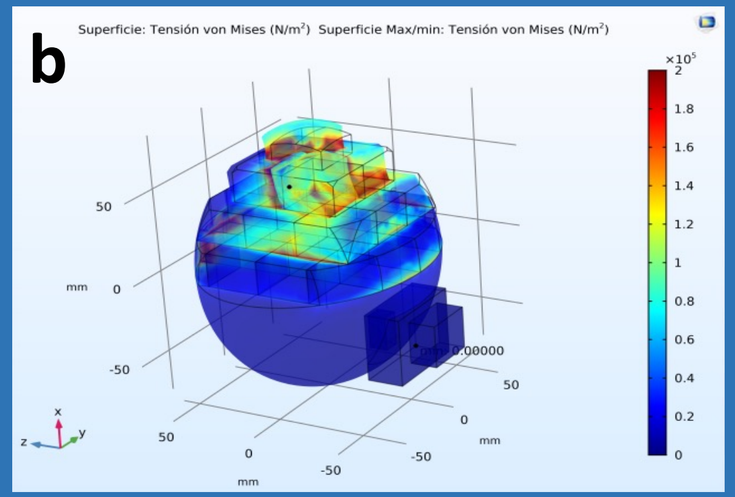


Modelo geométrico simplificado del cerebro.



Zonas de carga y restricción de movilidad en el tejido cerebral.

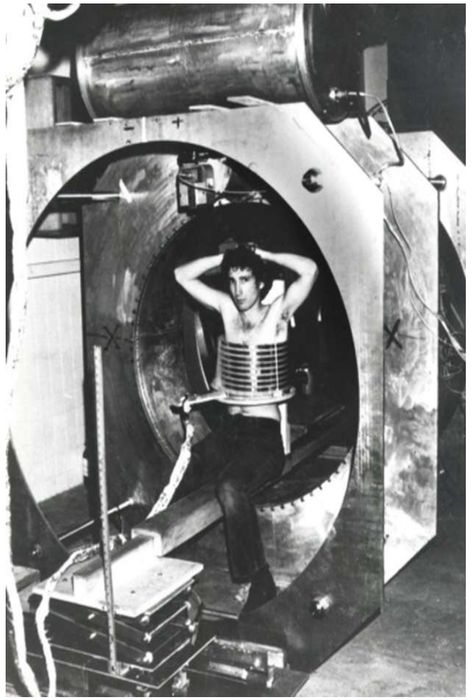


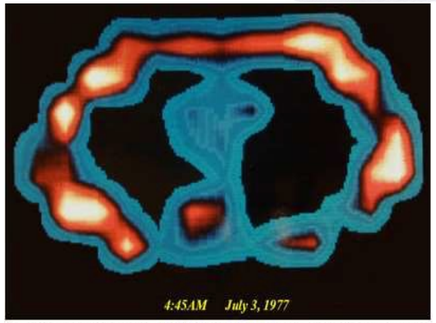


Deformación y* stress *calculado sobre el tejido cerebral. a) Antes de la resección. b) Después de la resección.

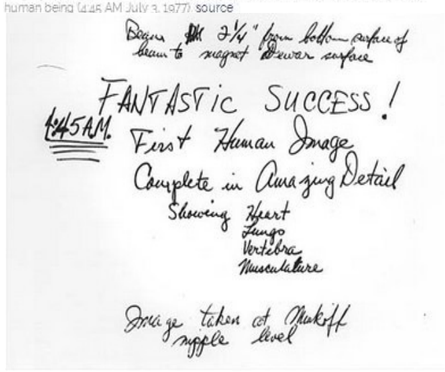
Mapa Juan de la Cosa, 1500

MRI, 1977

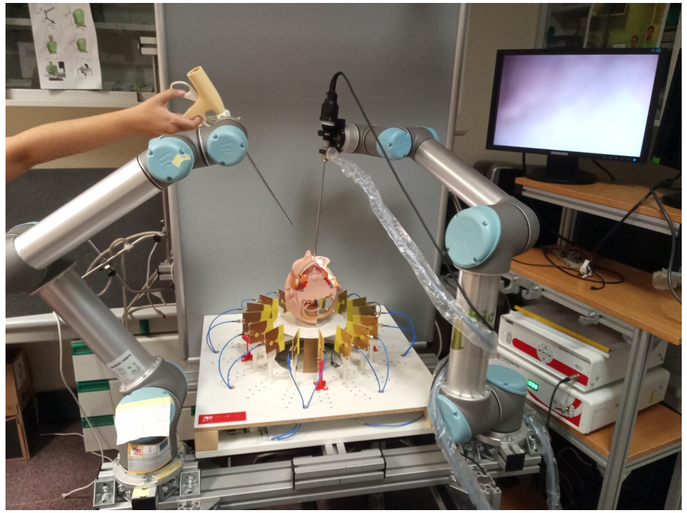


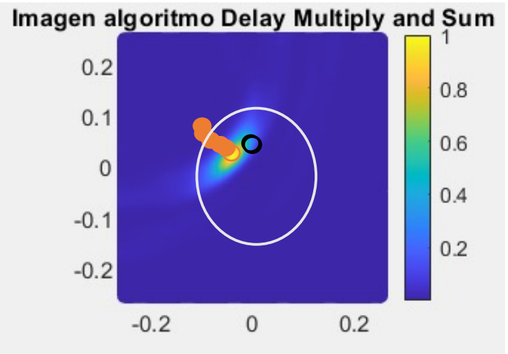


The interpolated image of the Minkoff scan and the first ever MRI scan of a live human being (4:45 AM July 3, 1977) source

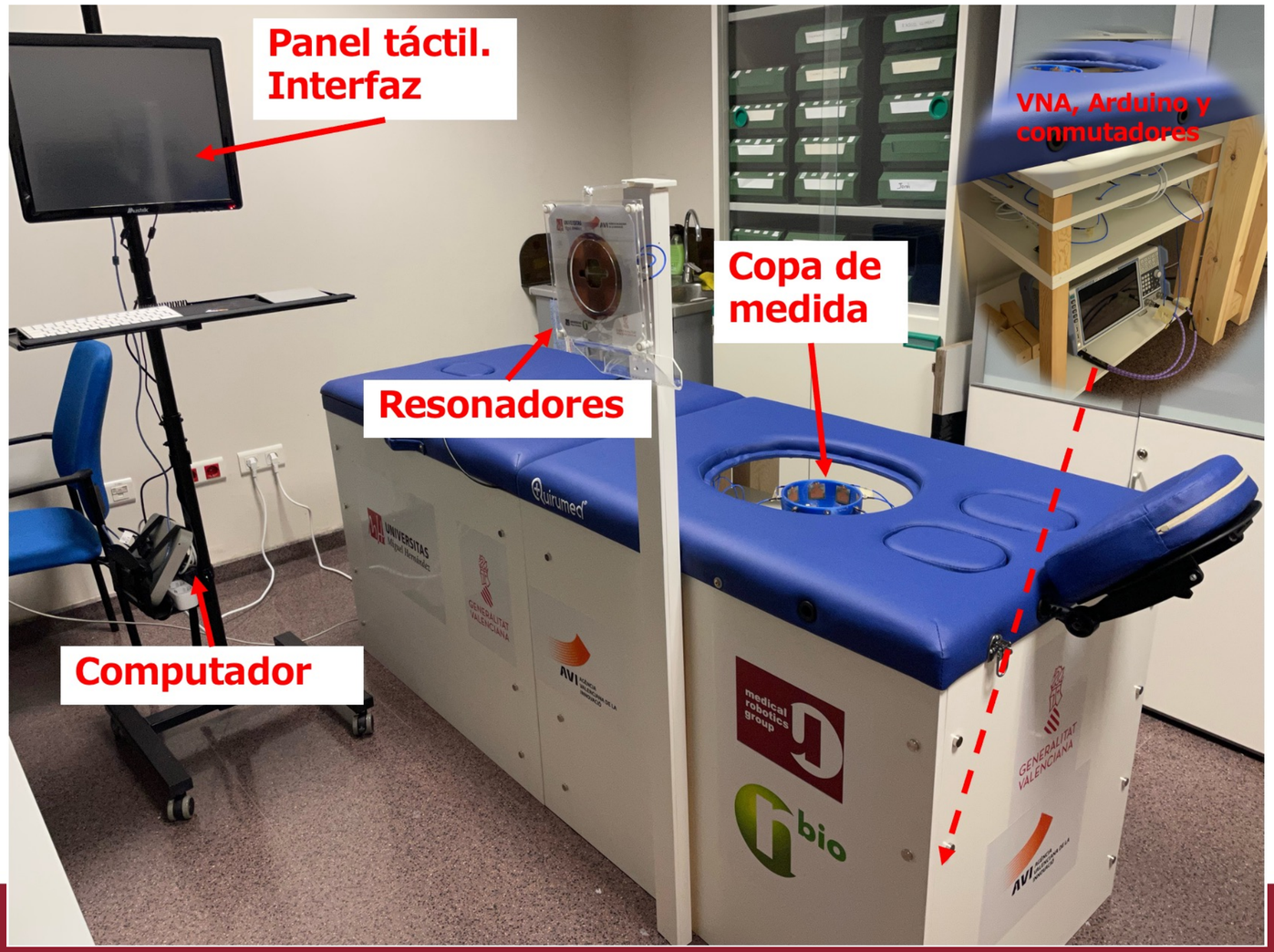


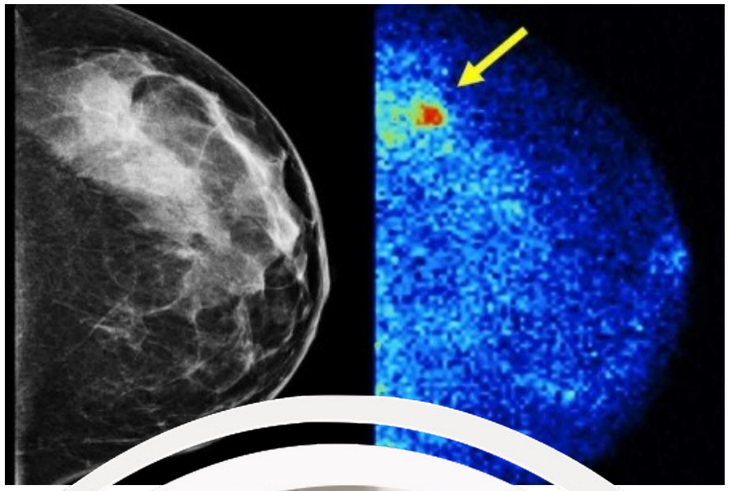
Craneeal, 202X





Microbio


Panel táctil.
Interfaz
VNA, Arduino y
conmutadores
Copa de
medida
Resonadores
Computador




Gracias
Merci
Hvala
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Xié
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Dankon
Maraba
Moltes
Maketai
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Paldies
olun
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Thanks
Tack
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pai
dimo
Kommol
Shokrán
Dannaba
Mwebare
Kaigai
Dekoju
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Trugarez
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