Designing a Brain-Machine Interface for Direct Communication with Visual Cortex Neurons

CORTIVIS
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Neuro-IT.net Workshop

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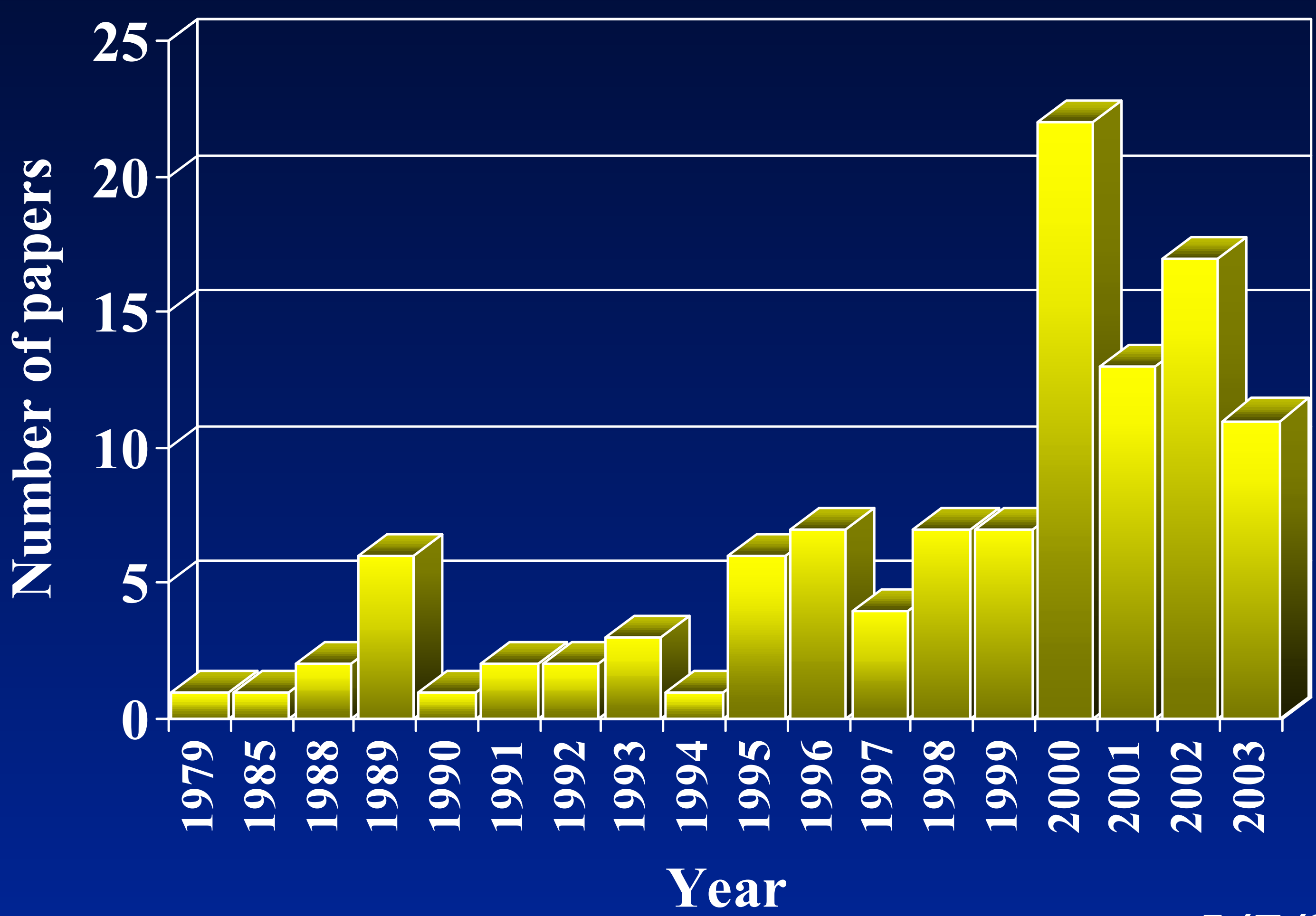
UNIVERSITAS Miguel Hernández

PubMed: Papers referring to “brain-machine interfaces”, “brain-computer interfaces” or “neuroprostheses”



5/7/2003

EIGHTEENTH CENTURY

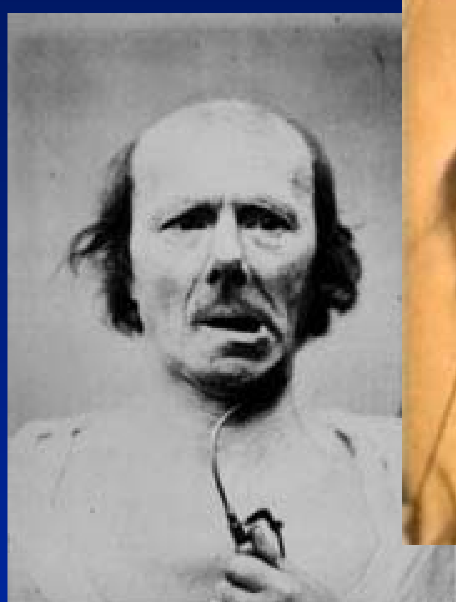
Fig. 331. — Larrey provoque, par le galvanisme, des contractions musculaires, sur un membre récemment amputé (page 643).

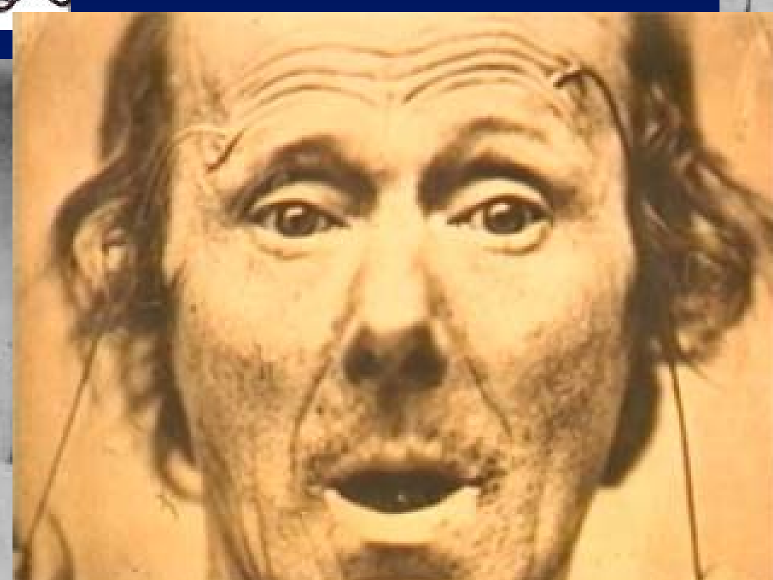
NINETEENTH CENTURY

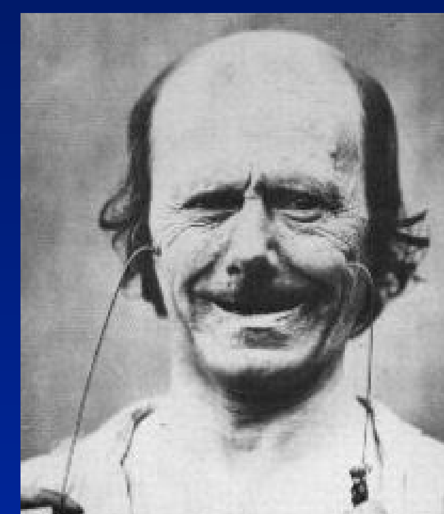
Alessandro Volta 1745-1827

I have only one work to say about hearing. I had tried without success to ecite this sense with two single metallic plates, although they were the most active among all the movers of electricity, namely, one of silver or gold and the other of zinc, but I finally managed to affect it with my new apparatus, made up of 30 or 40 couples of these metals. I introduced two probes of metallic rods with rounded ends quite forward into the two ears, and I immediately connected them to the two ends of the apparatus. At the moment the circuit was completed in this way, I received a shock in the head, and a few moments later (the circuit operating continuosly without any interruption), I began to be conscious of a sound, or rather a noise, in my ears that I cannot define clearly; it was a kind of jerky crackling or bubbling, as though some paste or tenacious matter was boiling. This noise continued without stopping and without increasing all the time the circuit was complete. Because of the disagreeable, and I feared, dangerous sensation of the jolt in the brain, I did not repeat this experiment several times.

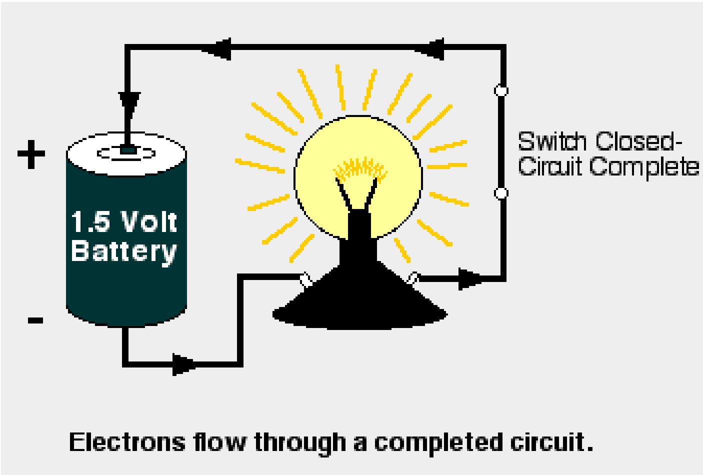
Mechanism of Human Facial Expression
Guillaume Duchenne, 1862

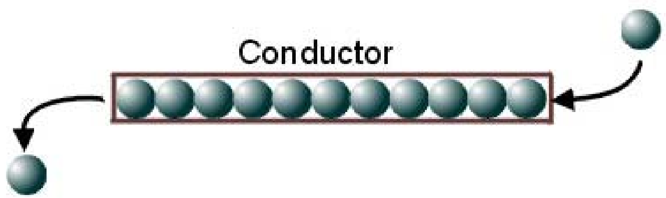


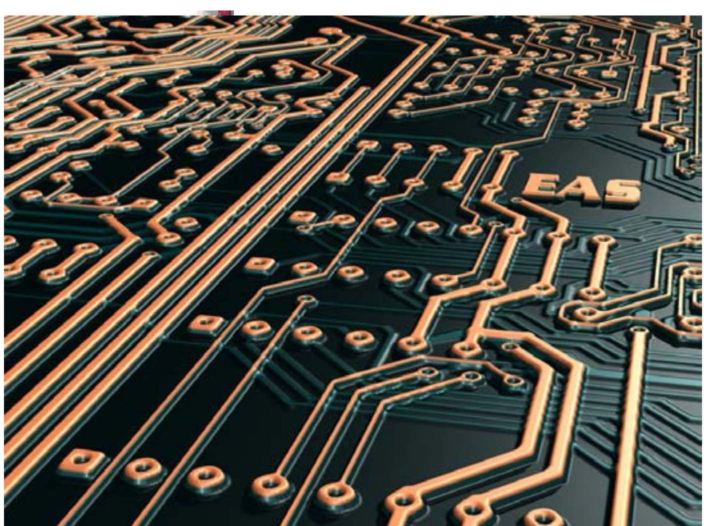


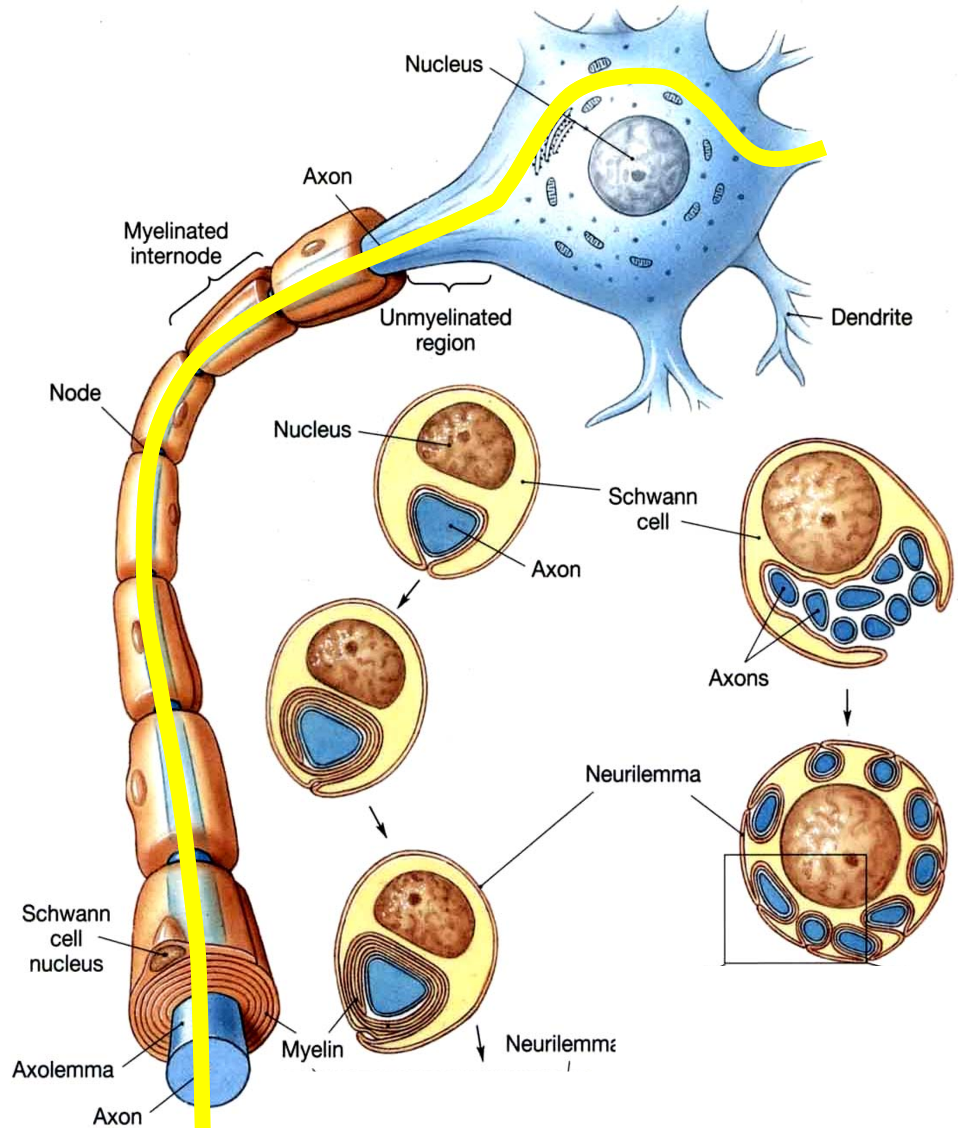


Stimulus

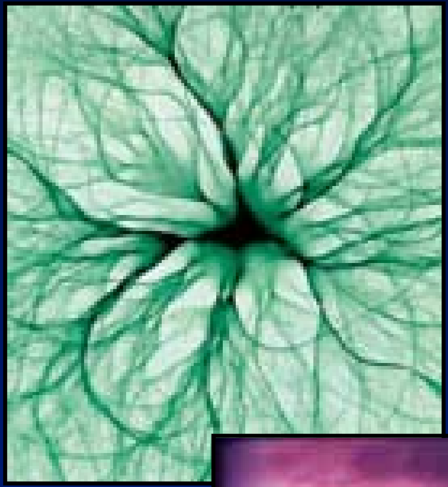

+
1.5 Volt Battery
-
Switch Closed-
Circuit Complete
Electrons flow through a completed circuit.

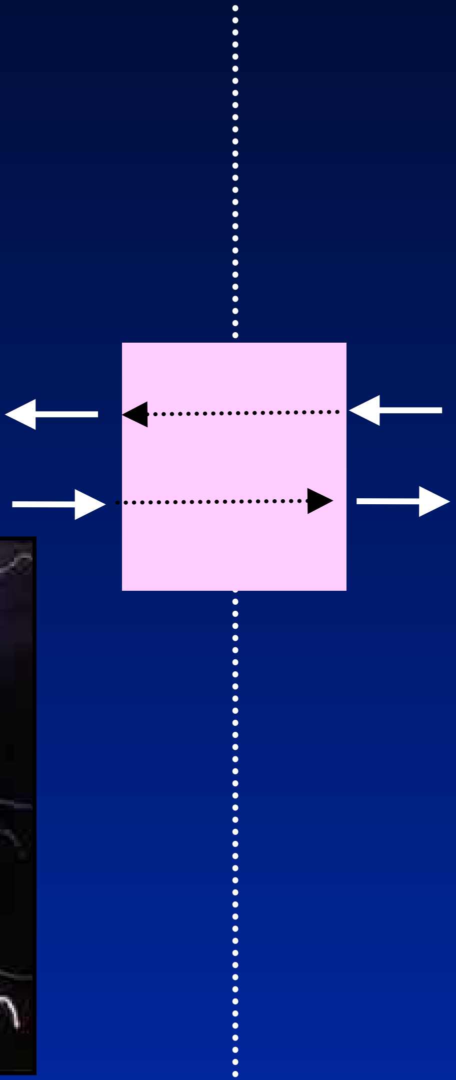

Conductor


EAS

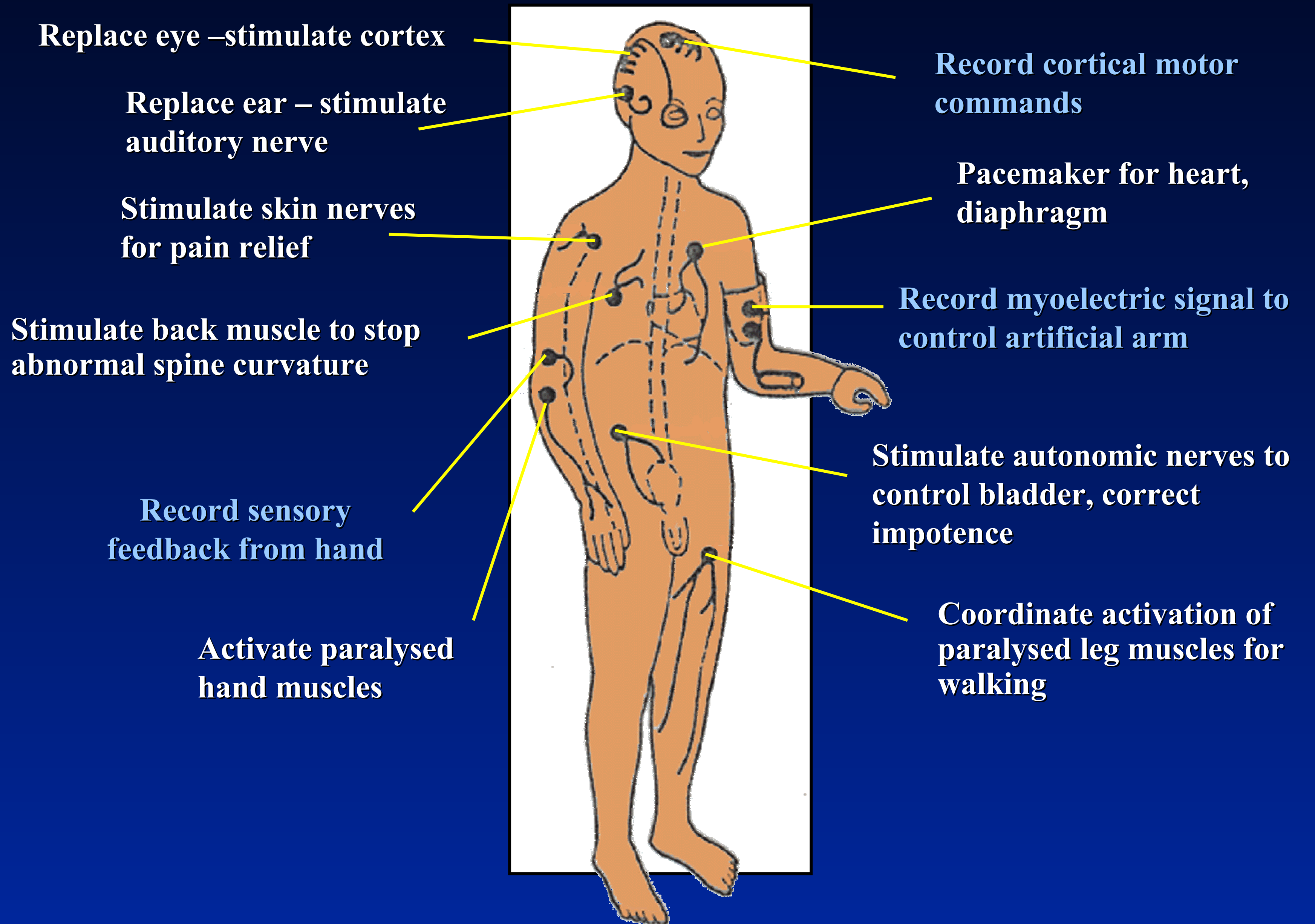

Nucleus
Axon
Myelinated internode
Unmyelinated region
Dendrite
Node
Nucleus
Schwann cell
Axon
Axons
Neurilemma
Schwann cell nucleus
Myelin
Neurilemma
Axolemma
Axon

The goals of Neural Interfaces are to obtain control signals directly from the electrical activity of neurons and convey sensory information and/or motor commands directly to the nervous system.





Neuroprosthetic interfaces with the nervous system

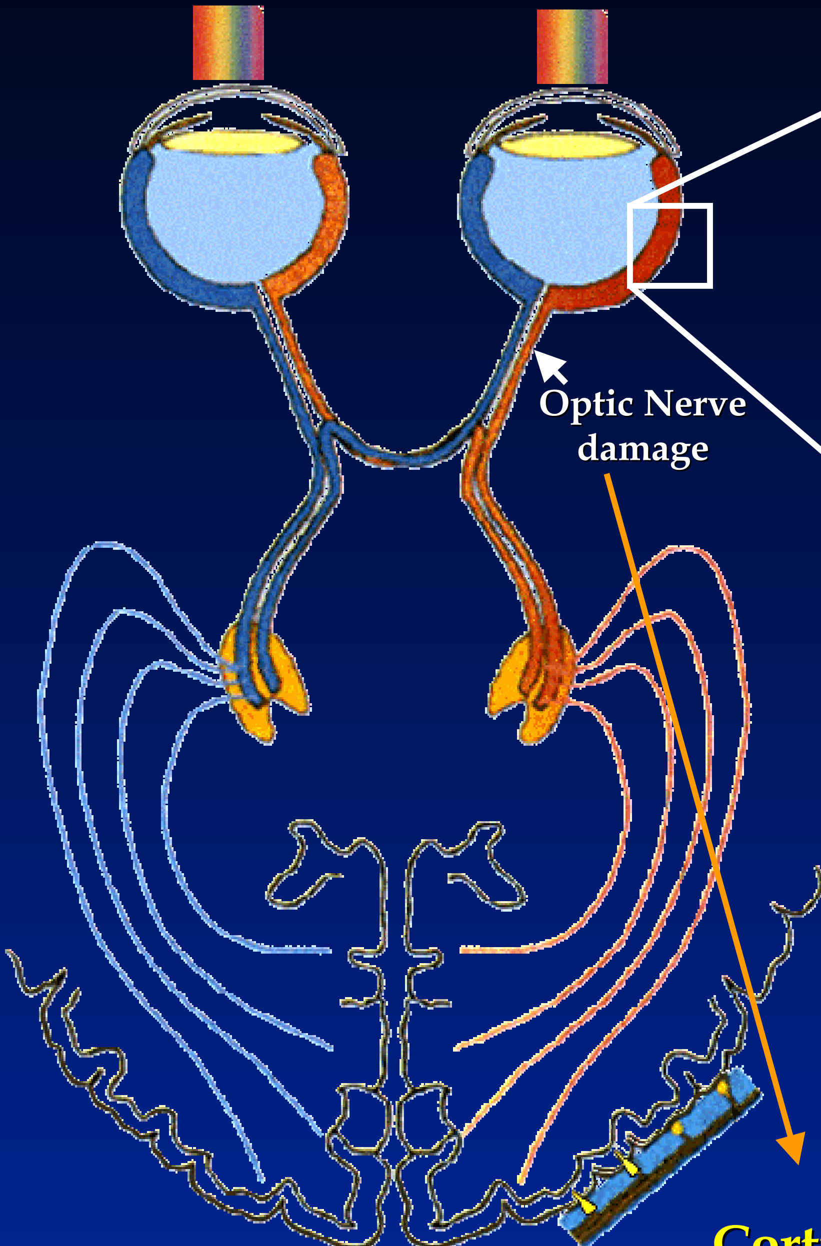


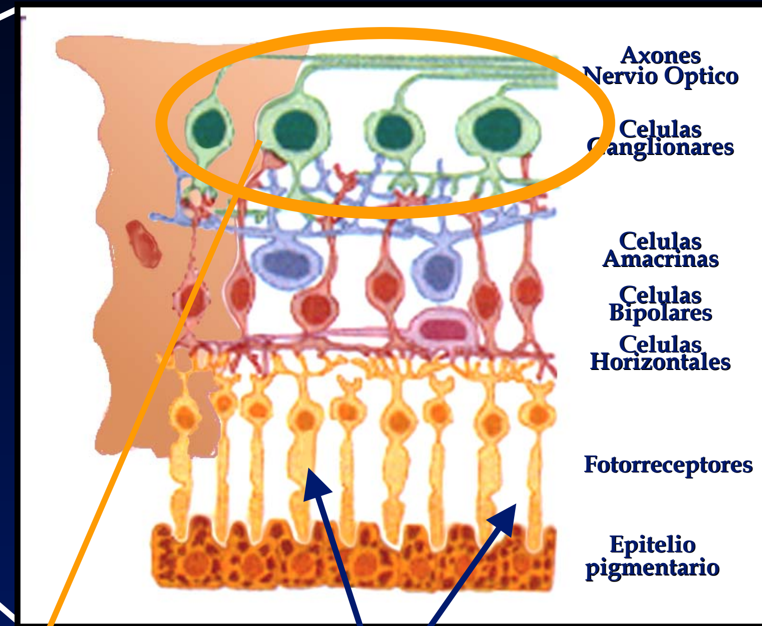
The Problem:

- Damage to Peripheral Nervous System
- Injury to Spinal Cord
- Disorders of Sensory Organs

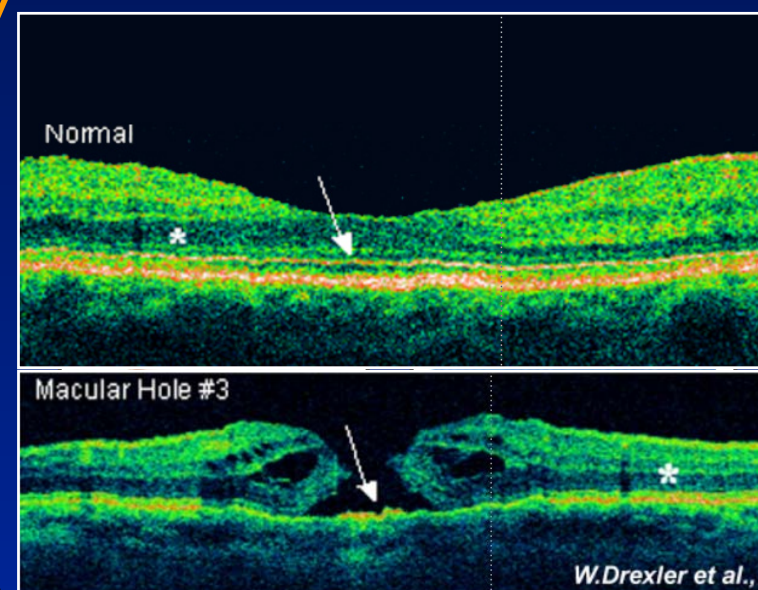
…However, the brain is usually perfectly functional in spite of these injuries.

… the solution: Communicate directly with the brain

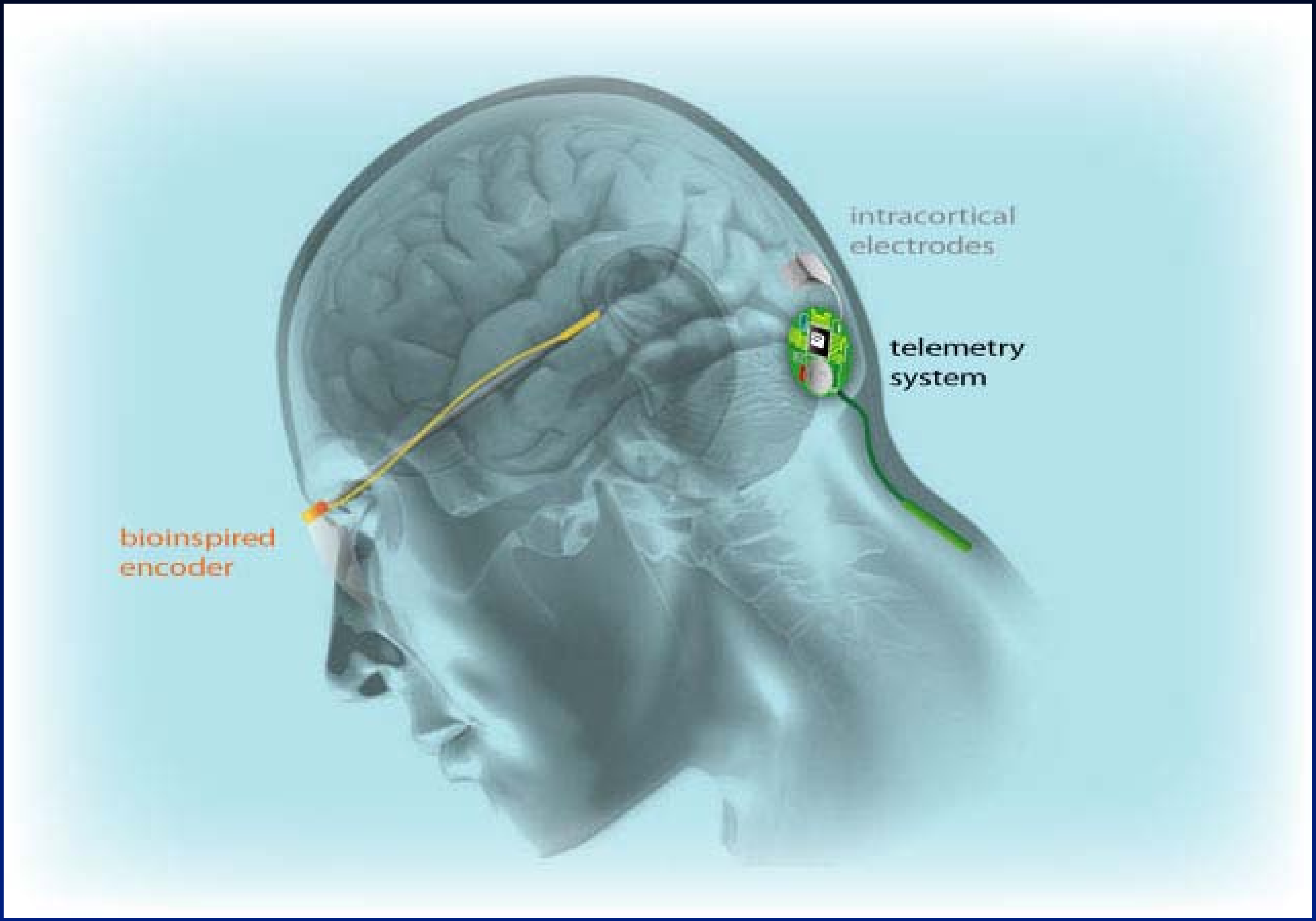




Degeneration (RP, DM)



Cortical Neuroprostheses

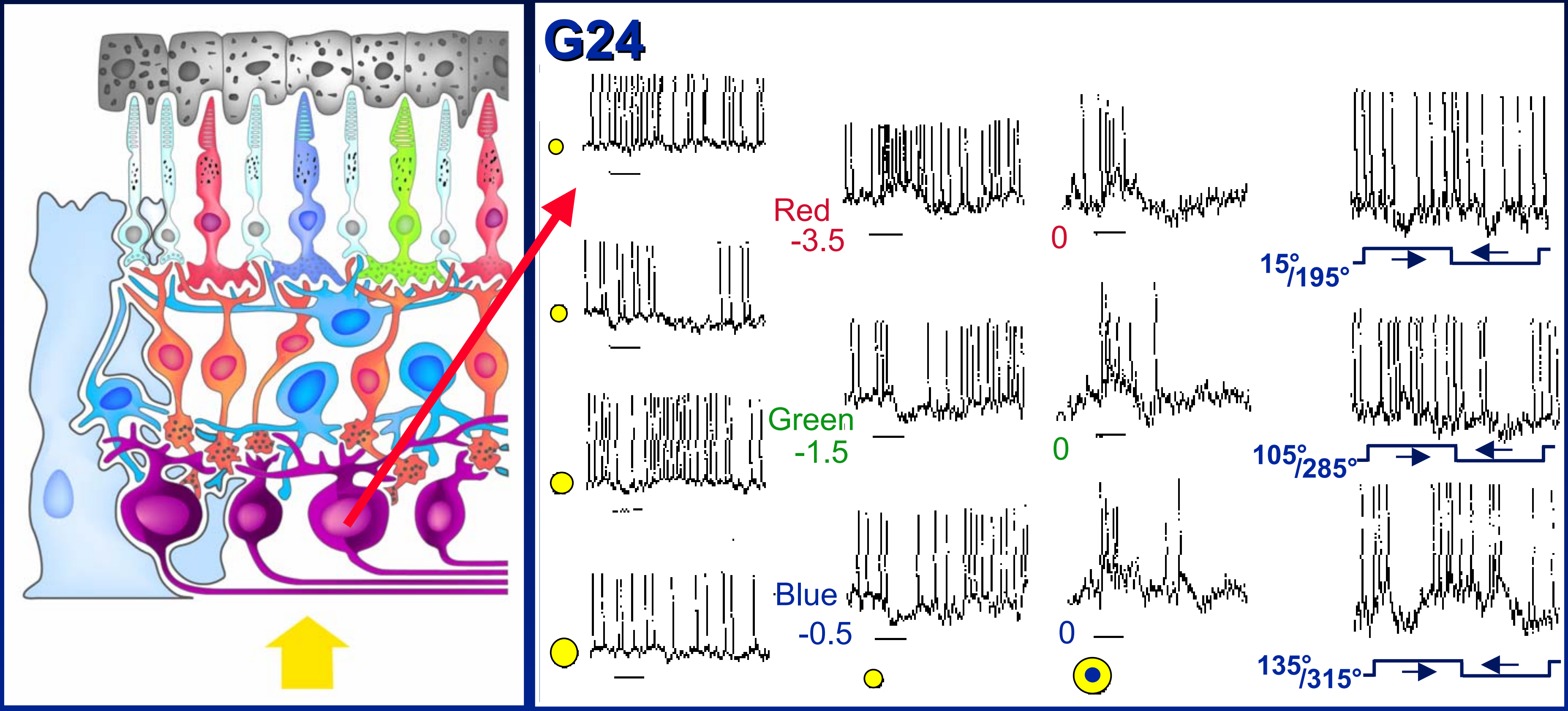


External processing

The problem is not to transmit a image with a high resolution, but to send useful information to the right locations inside the SNC.

- ✓ **It is important to know how the visual information is encoded in the retina.**

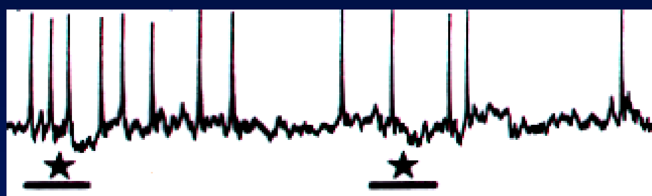
Ganglion cell spike trains are the result of extensive signal processing in the retinal network



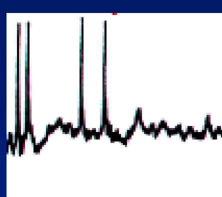
Ammermüller et al.

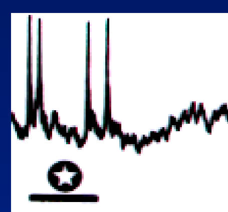
Individual ganglion cells are unreliable stimulus encoders due to response variability and ambiguity

Variability



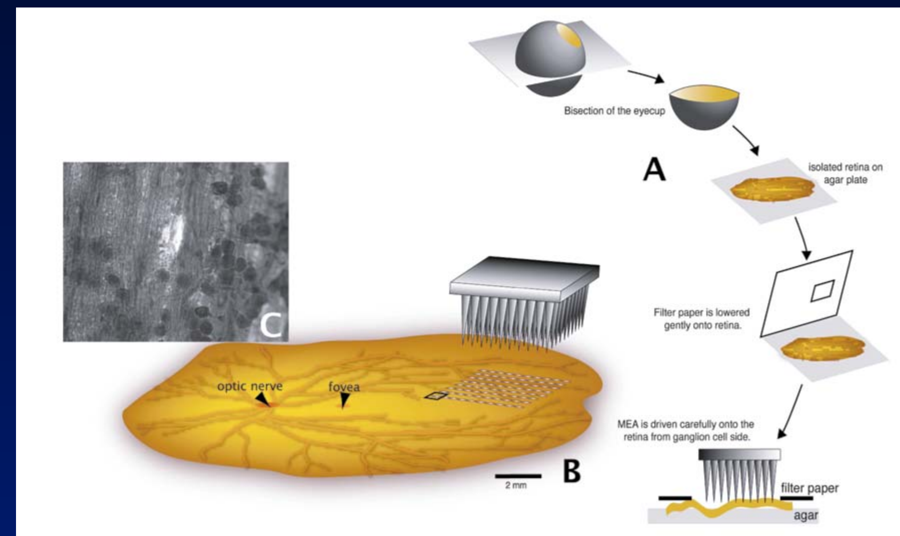
Ambiguity

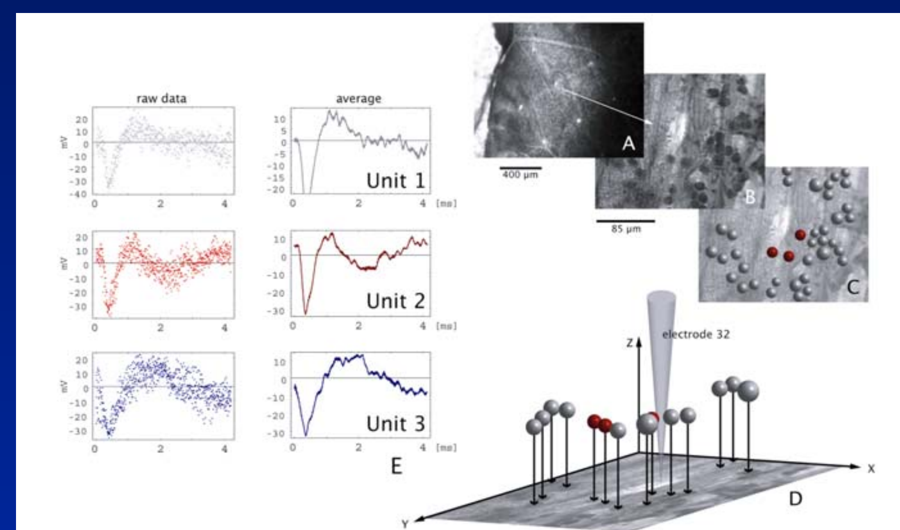




Ratecode?
Timecode?

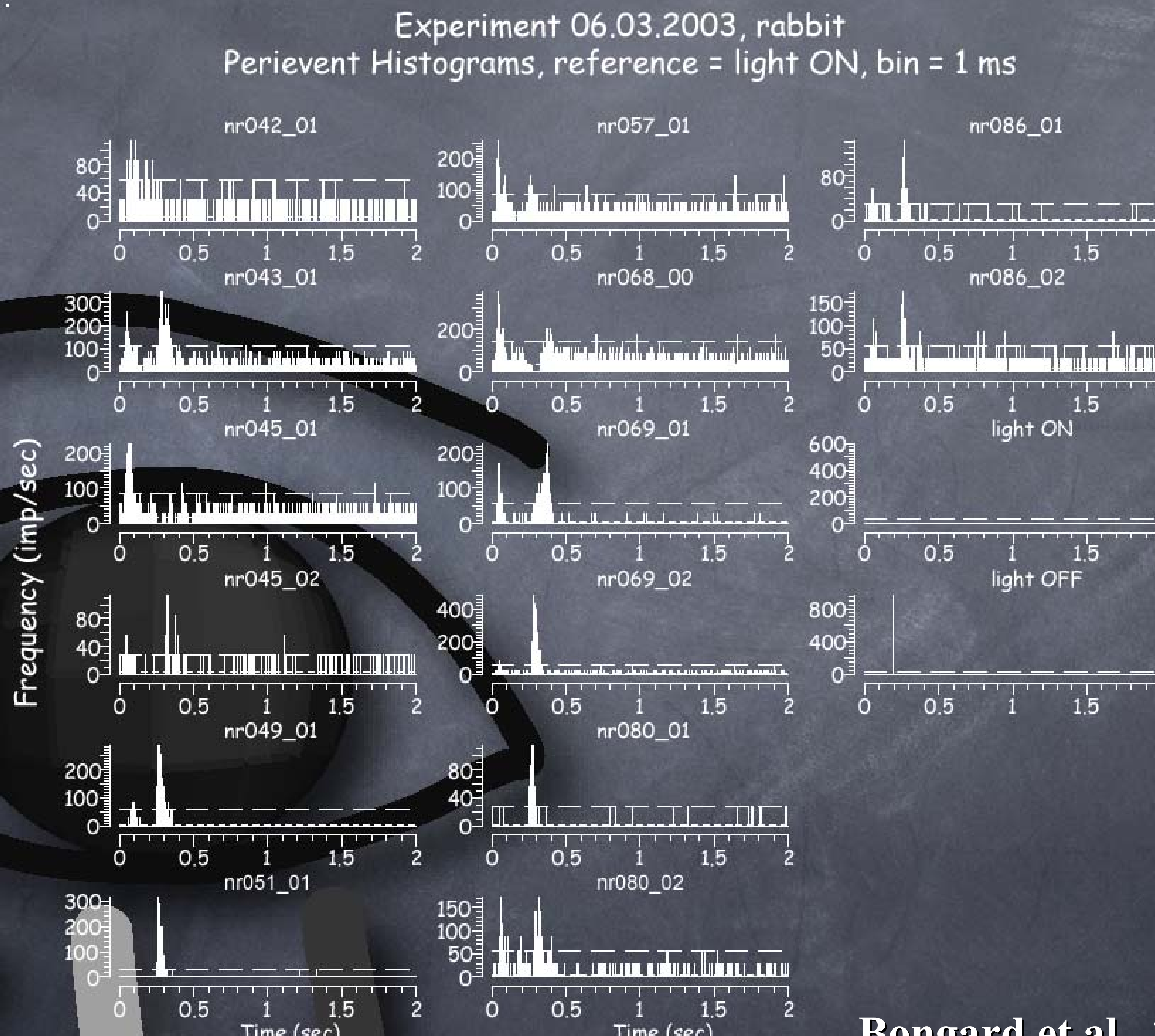
local versus distributed representation





in vivo recordings of retinal ganglion cells

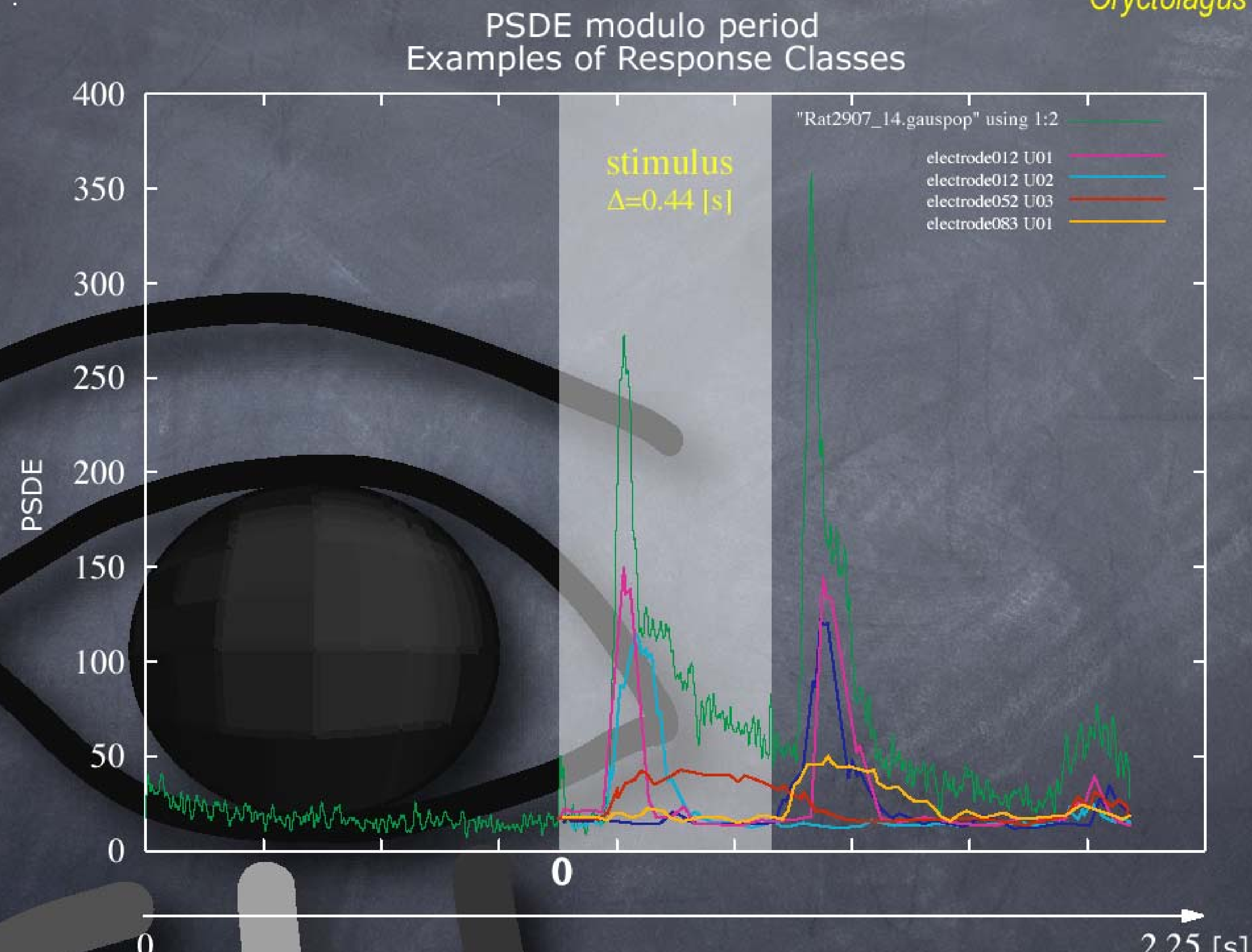
Oryctolagus cuniculus



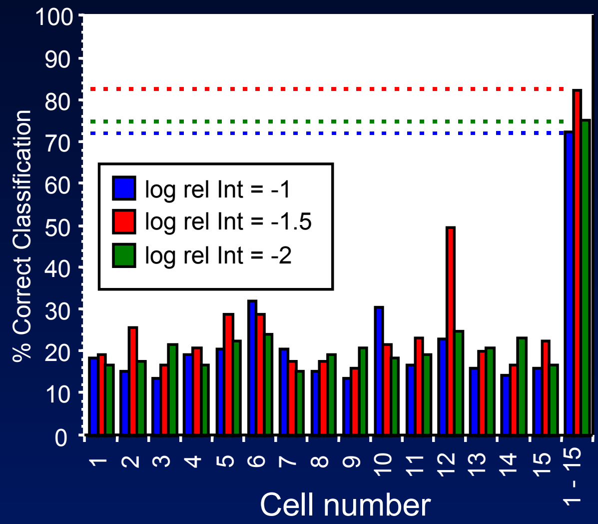
Bongard et al., 2003

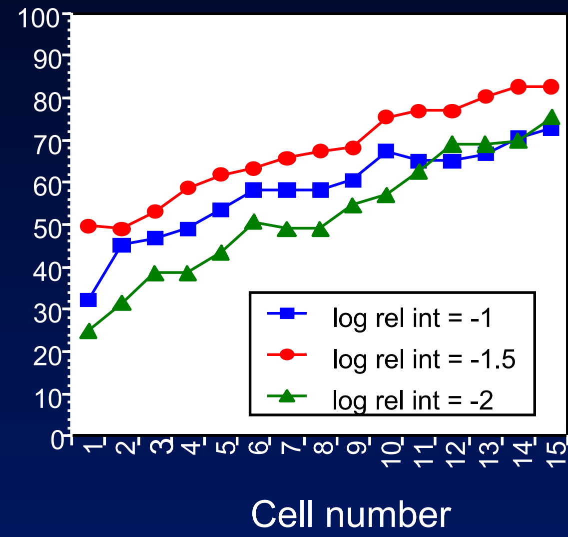
in vivo recordings of retinal ganglion cells

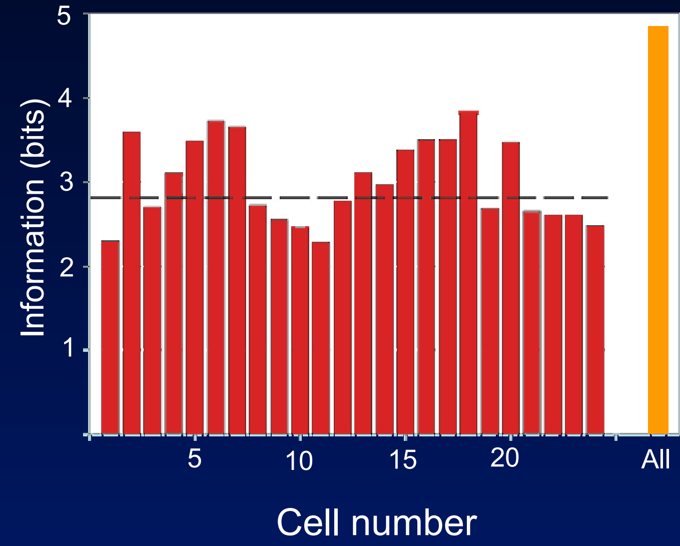
Oryctolagus cuniculus

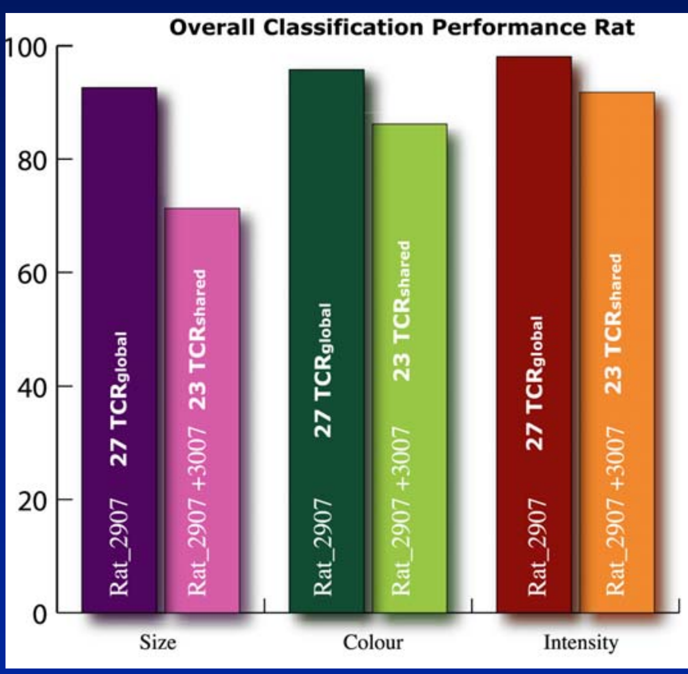


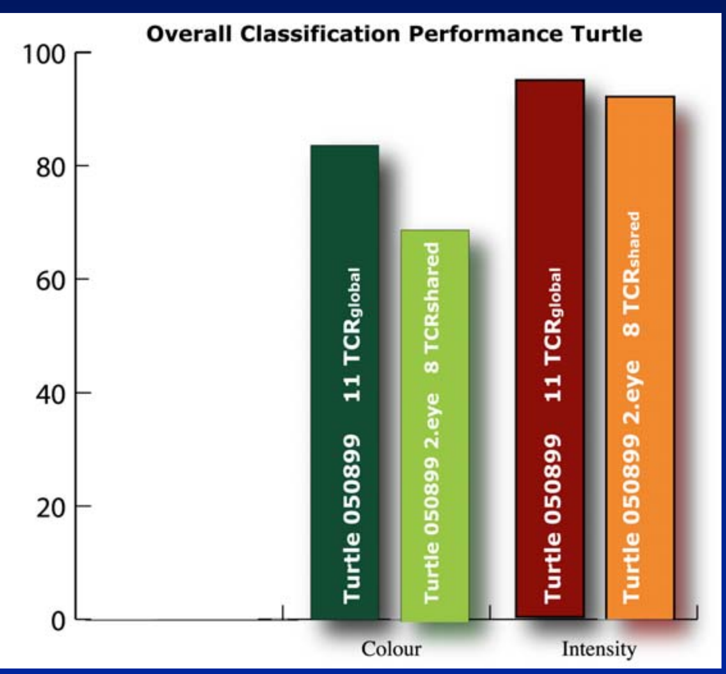
The brain can potentially deduce reliable information about stimulus features from response patterns of retinal ganglion cell populations



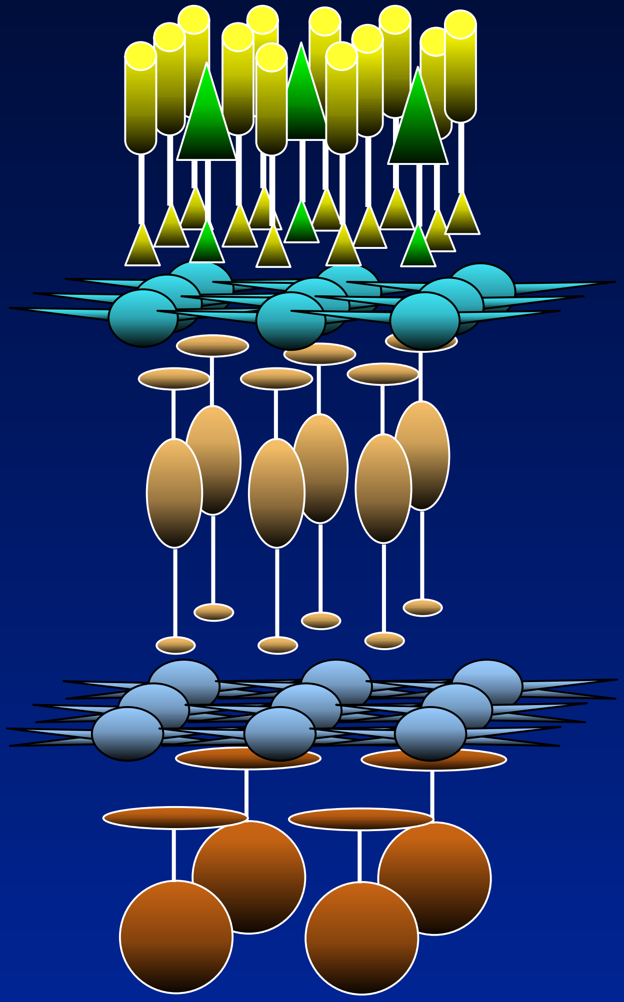




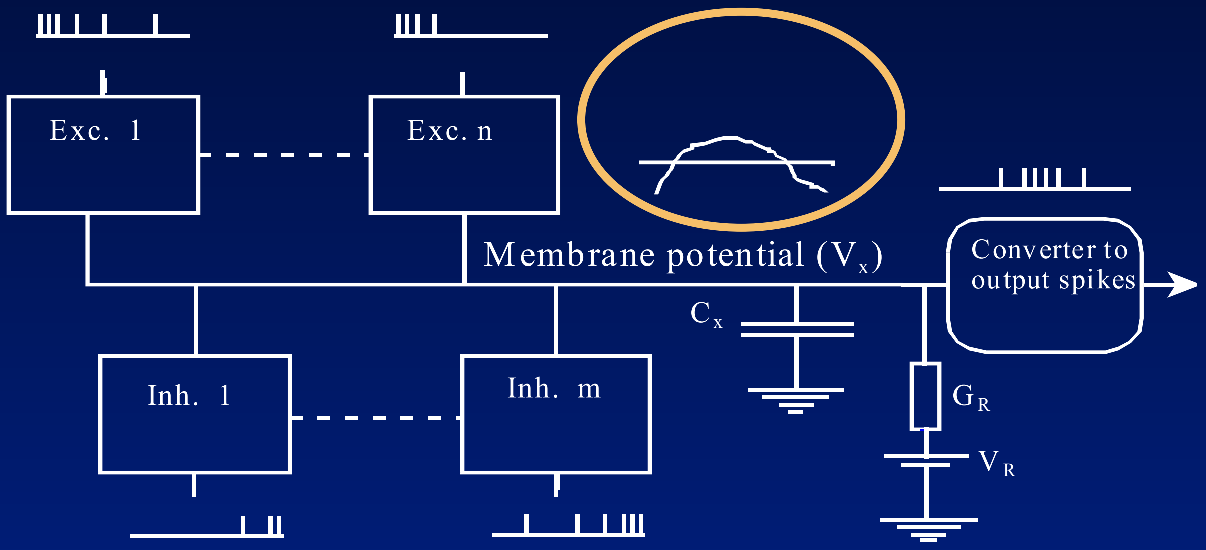




Development of a reconfigurable bioinspired visual processing front-end (artificial retina)



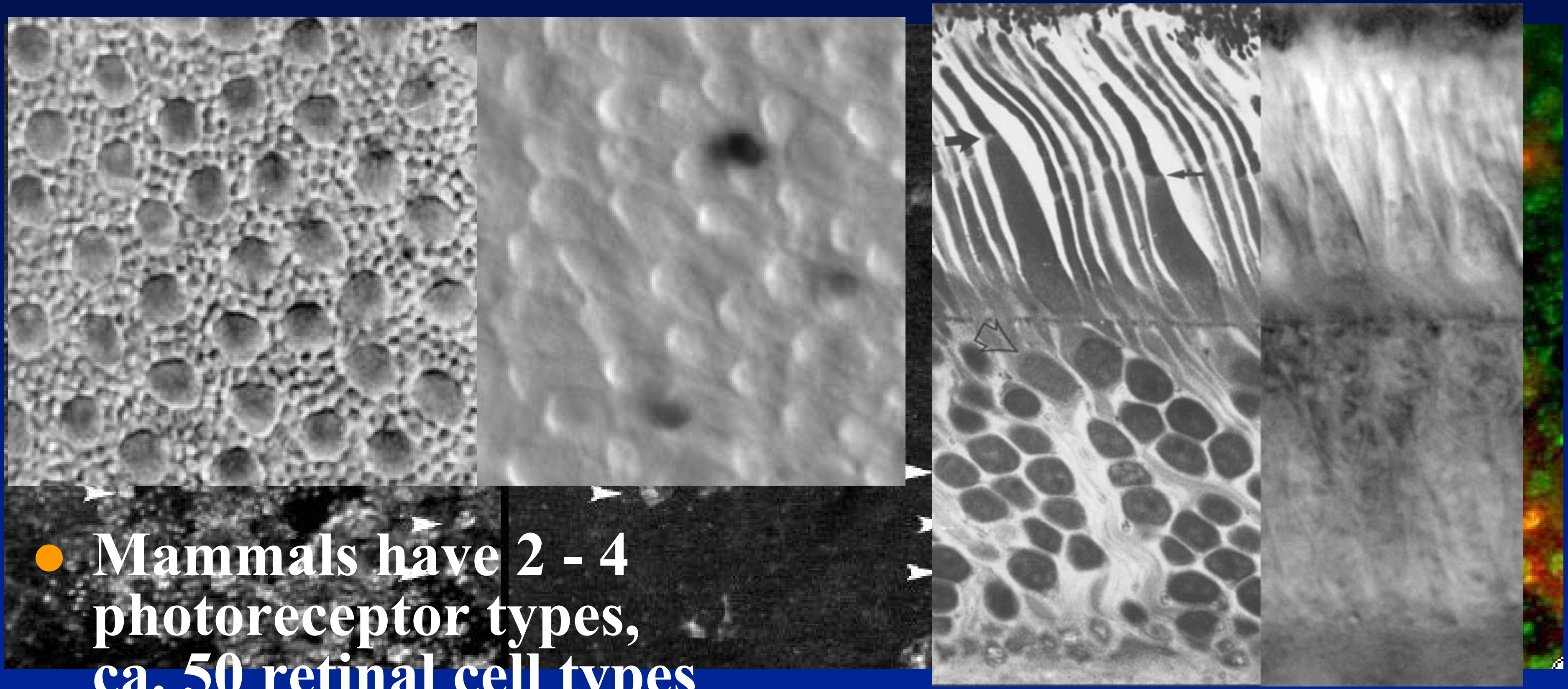
Generation of output spikes



Different approaches:

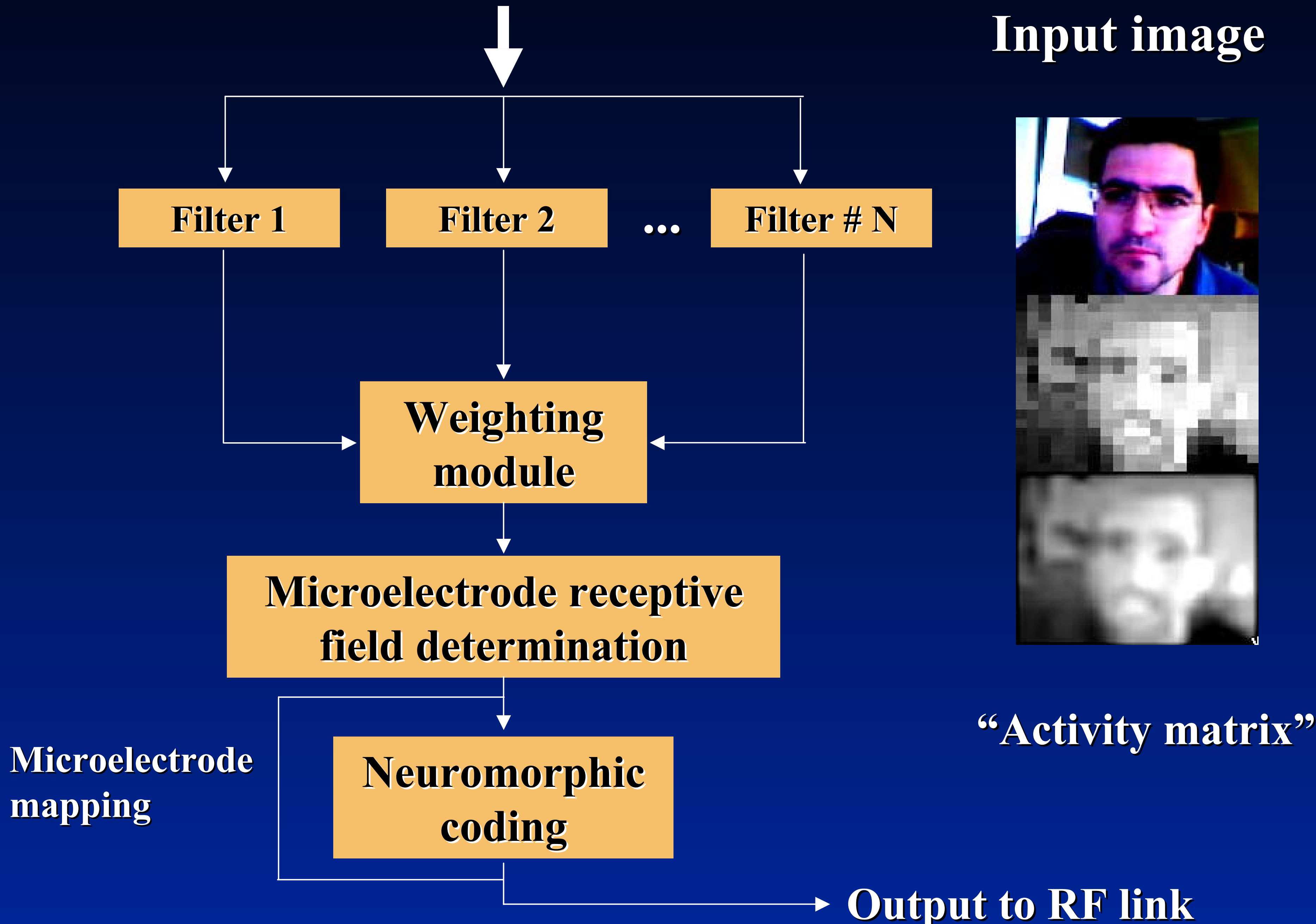
- **Phase coding (firing-time): $t_d(V_x)$**
- **Spike frequency coding (firing-rate): $F(V_x)$**

What animal model?

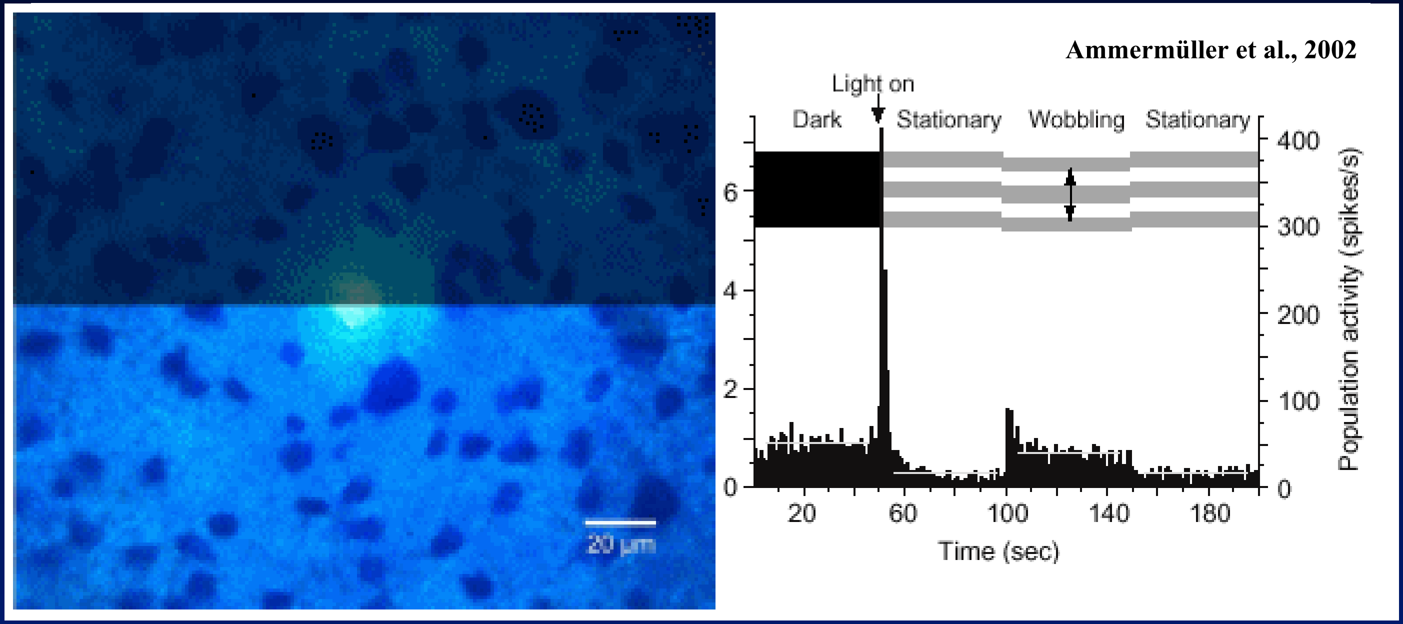


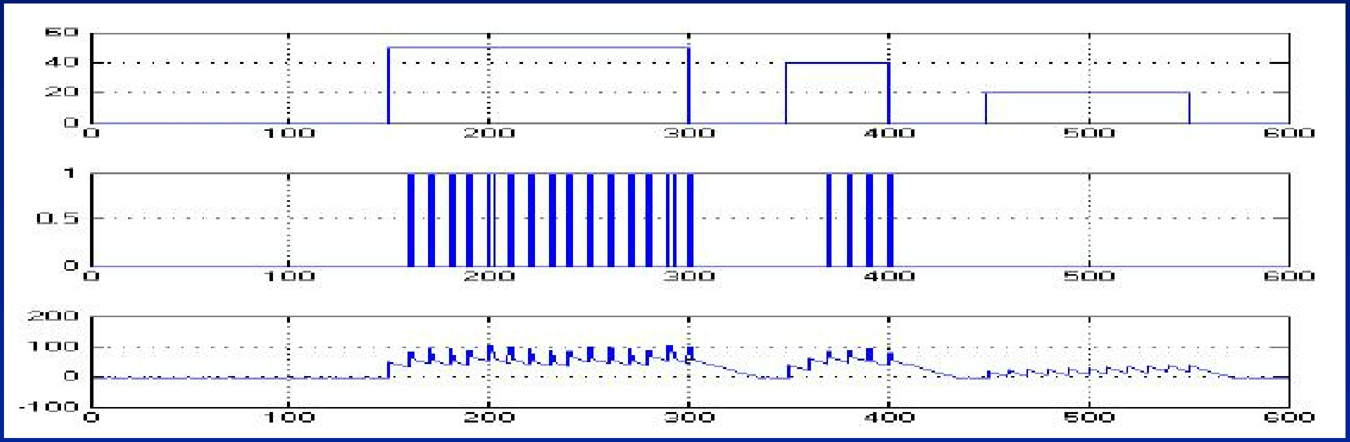
- Mammals have 2 - 4 photoreceptor types, ca. 50 retinal cell types

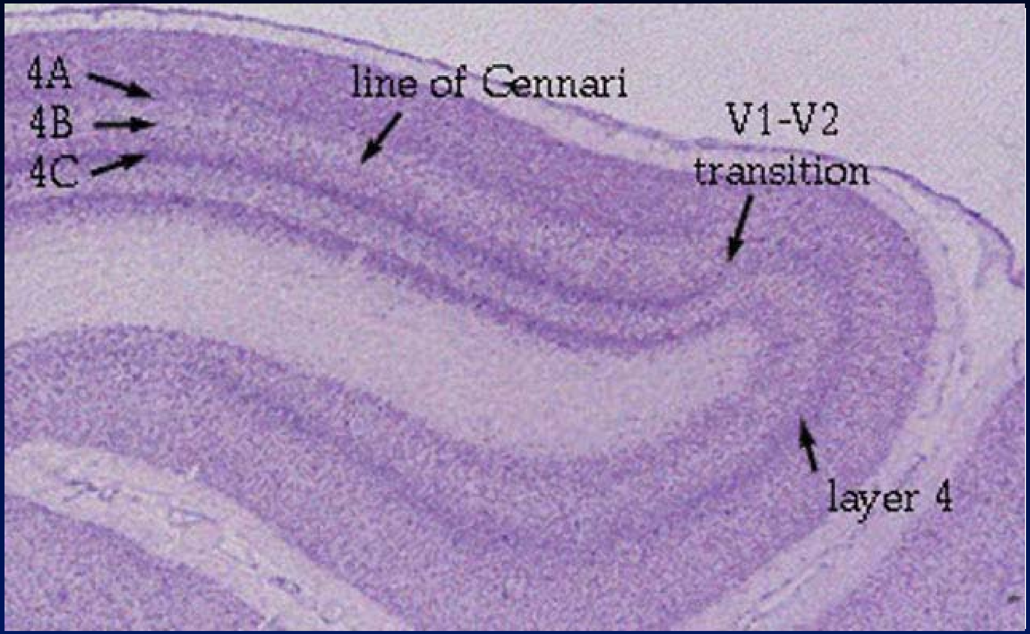
Ahnelt et al. 2003

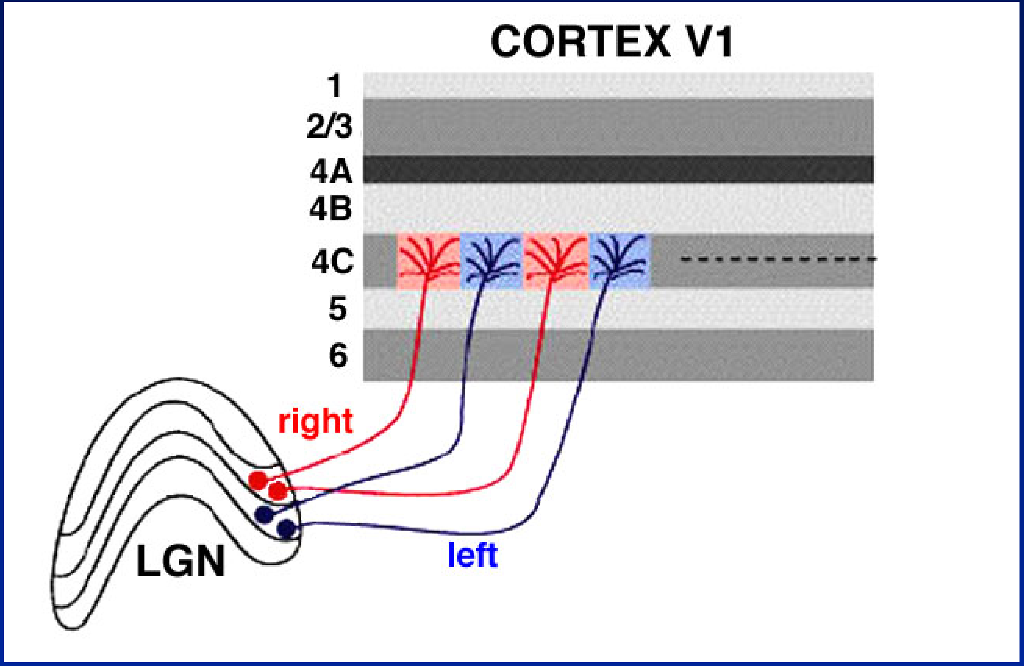

Input image
Filter 1
Filter 2
...
Filter # N
Weighting module
Microelectrode receptive field determination
Neuromorphic coding
Microelectrode mapping
"Activity matrix"
Output to RF link

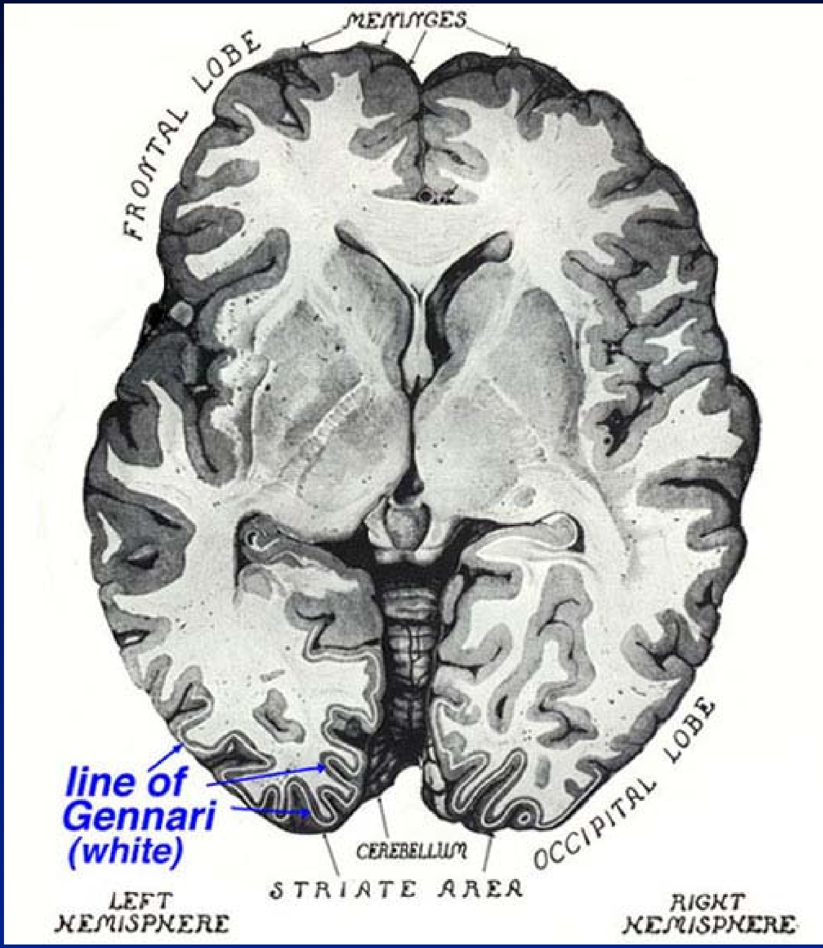
Single spike neuron (Xilinx block set for Simulink) and simulation results for flashes of different duration and intensity






4A
4B
4C
line of Gennari
V1-V2
transition
layer 4


CORTEX V1
1
2/3
4A
4B
4C
5
6
right
left
LGN

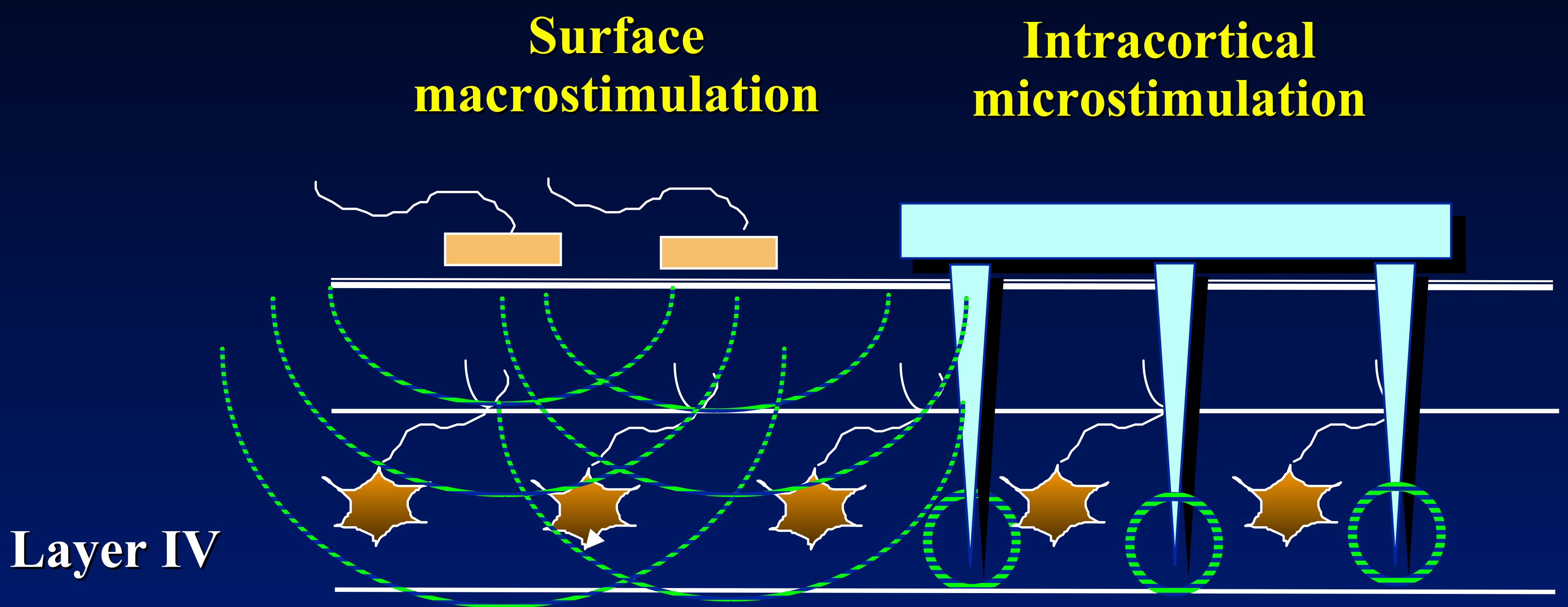

MENINGES
FRONTAL LOBE
line of
Gennari
(white)
CEREBELLUM
OCCIPITAL LOBE
STRIATE AREA
LEFT
HEMISPHERE
RIGHT
HEMISPHERE

" . . . the cerebral cortex is similar to a garden filled with trees, the pyramidal cells, which,

thanks to intelligent culture, can multiply their branches, sending their roots deeper and

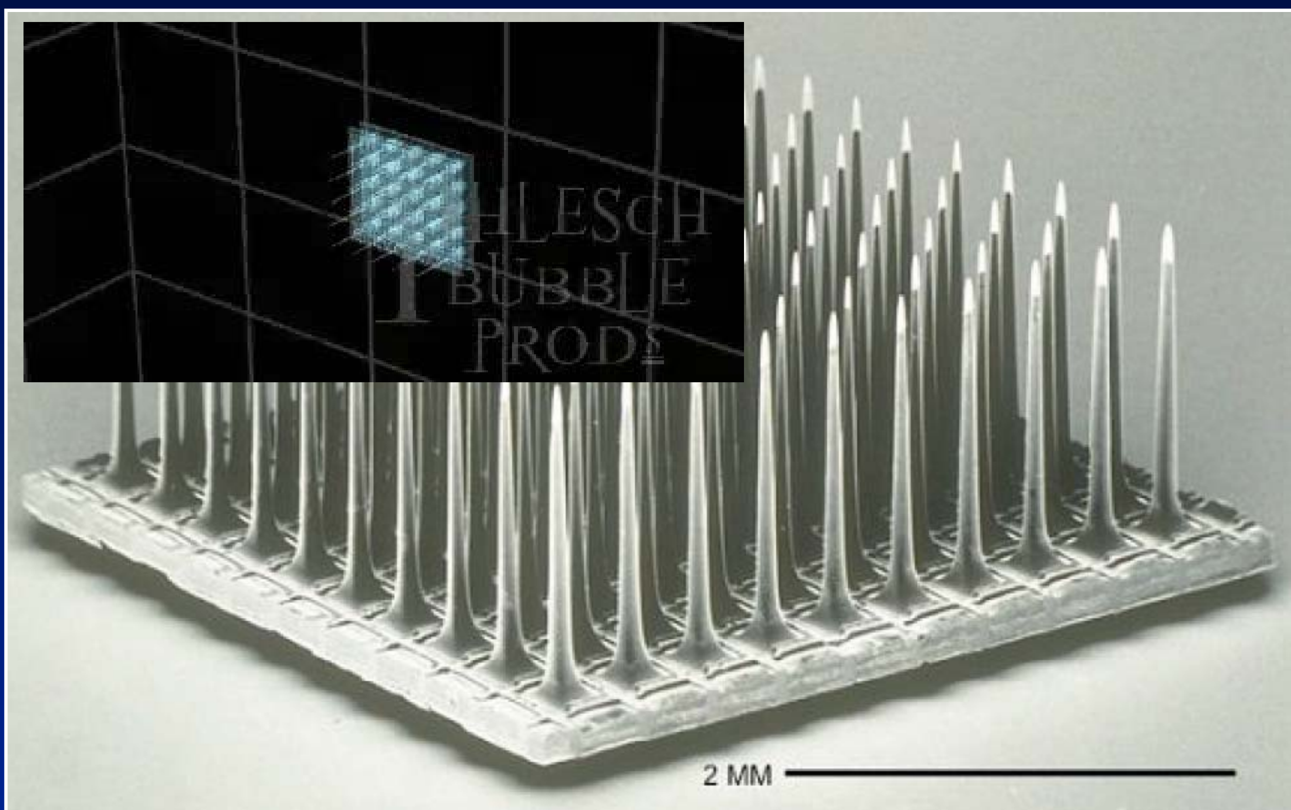
producing more and more varied and exquisite flowers and fruits."

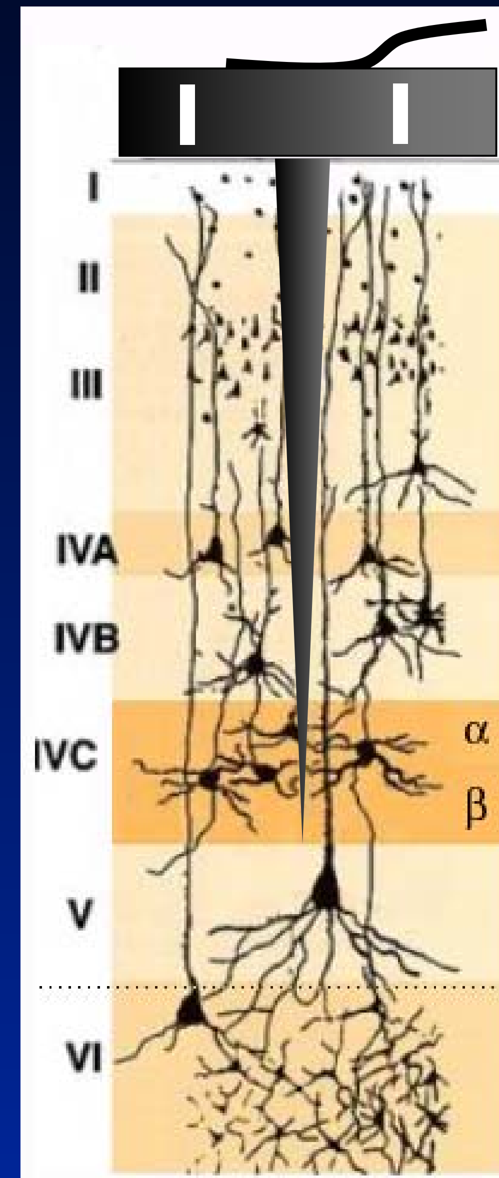
Santiago Ramon y Cajal

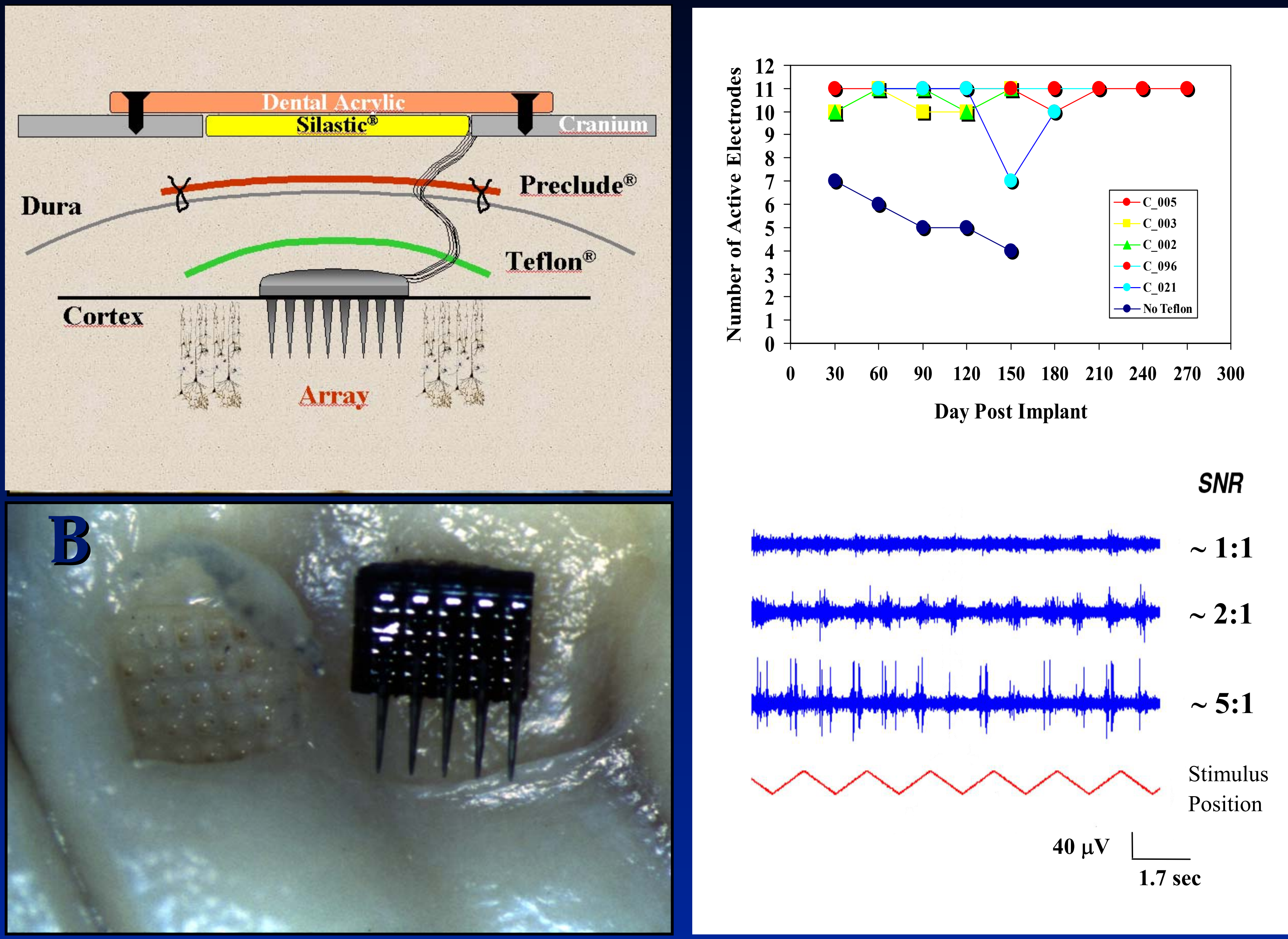


	Surface macrostimulation	Intracortical microstimulation
Contact area	1 mm^2	0.001 mm^2
Impedance	10 kΩ	100 kΩ
Current	1 mA	0.01 mA
Charge density	10 μC/cm^2	100 μC/cm^2
Mean power	20 μW/channel	0.02 μW/channel

Design of electrodes for cortical stimulation

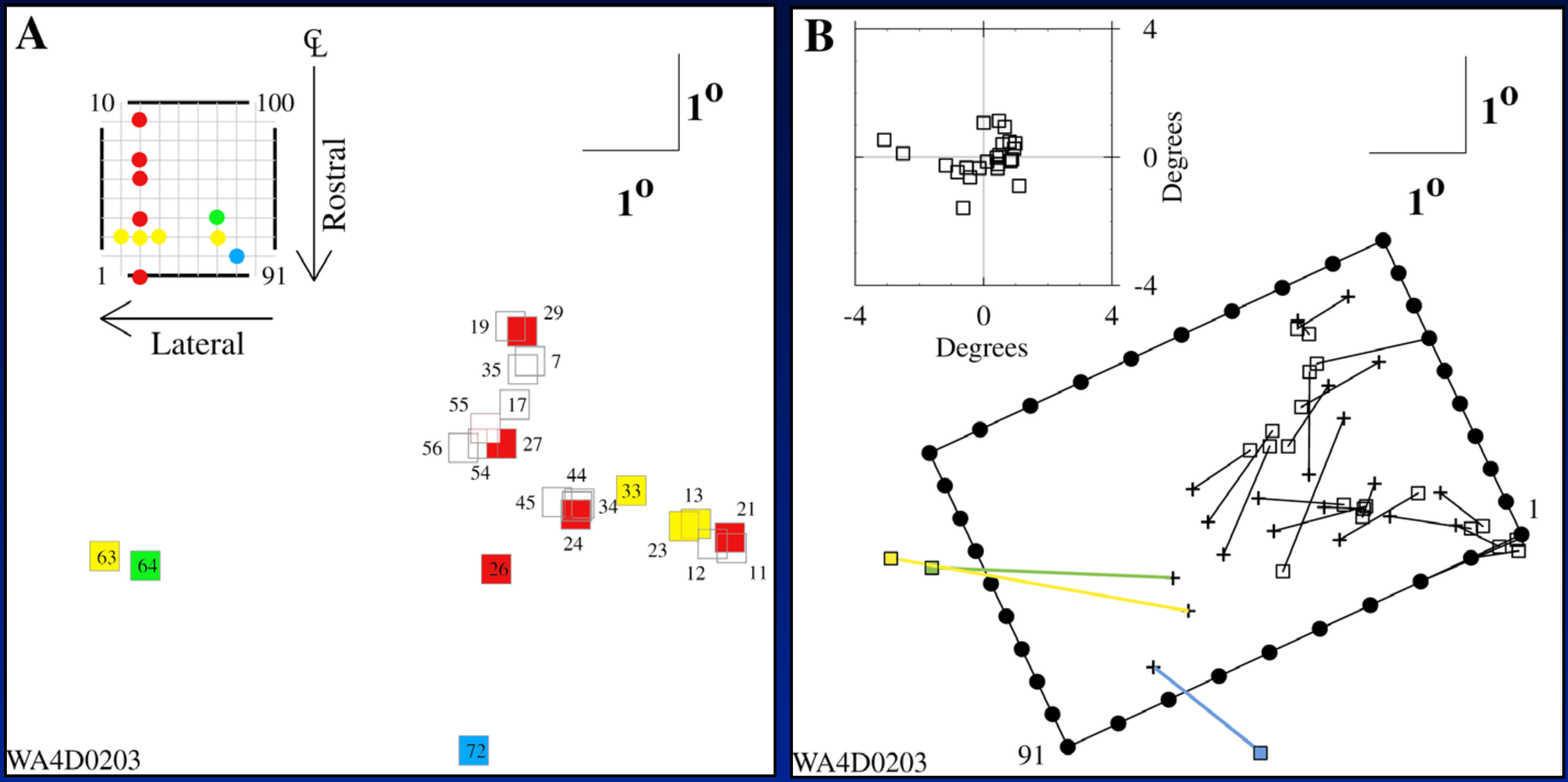






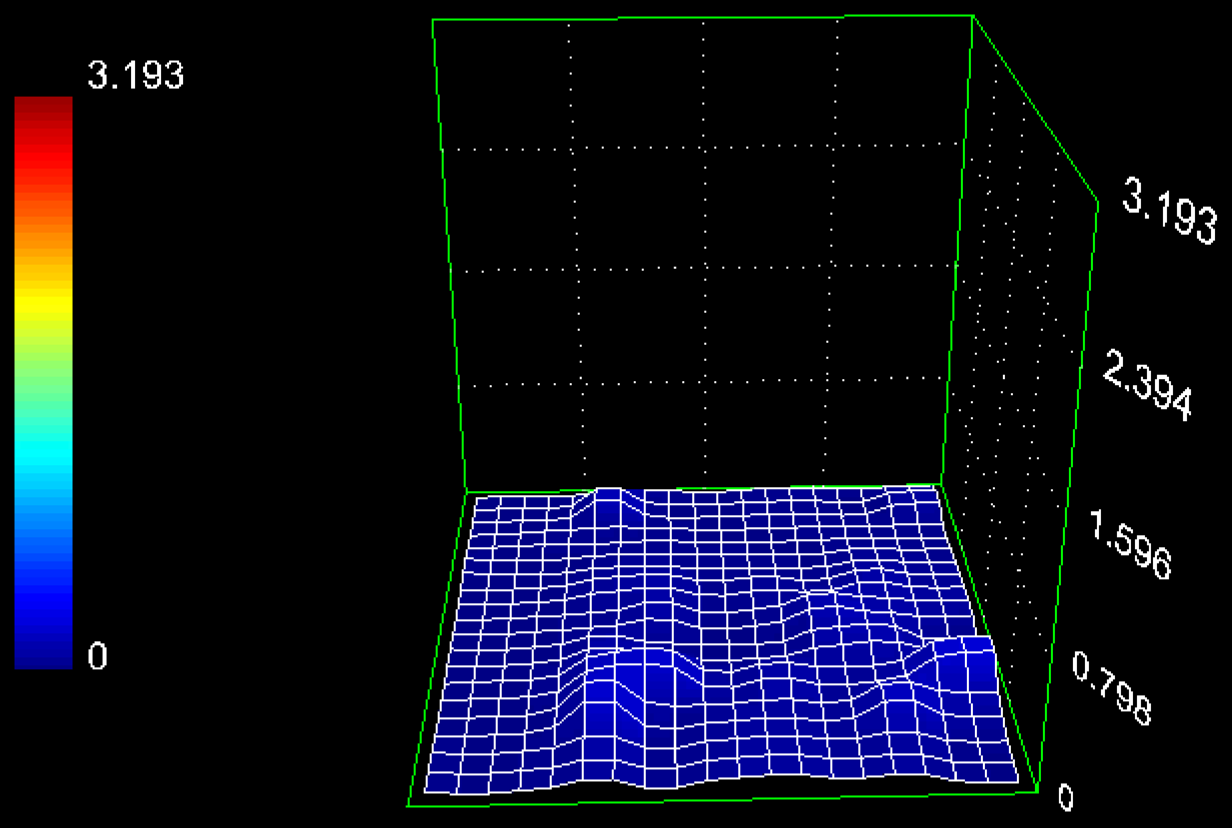
Dental Acrylic
Silastic®
Cranium
Preclude®
Dura
Teflon®
Cortex
Array
B
Number of Active Electrodes
Day Post Implant
C_005
C_003
C_002
C_096
C_021
No Teflon
SNR
~ 1:1
~ 2:1
~ 5:1
Stimulus Position
40 µV
1.7 sec

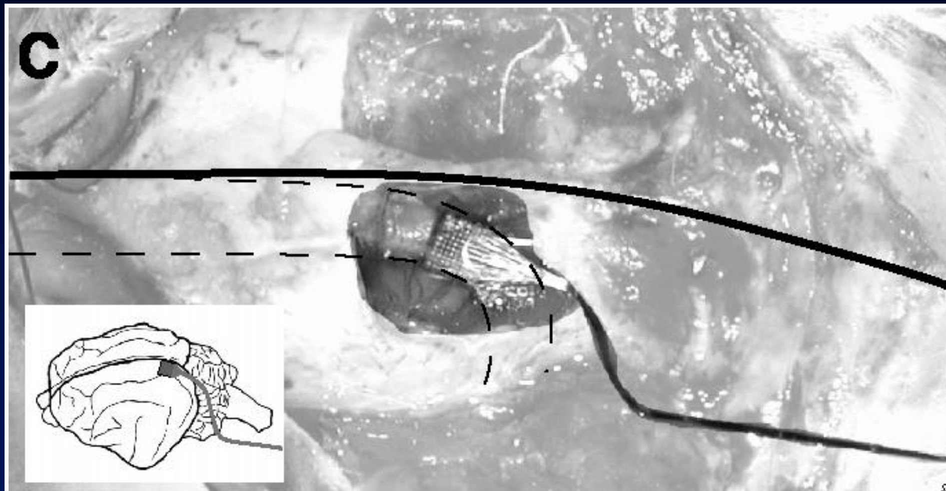
Receptive field map of cat visual cortex obtained with simultaneous recordings using intracortical microelectrodes

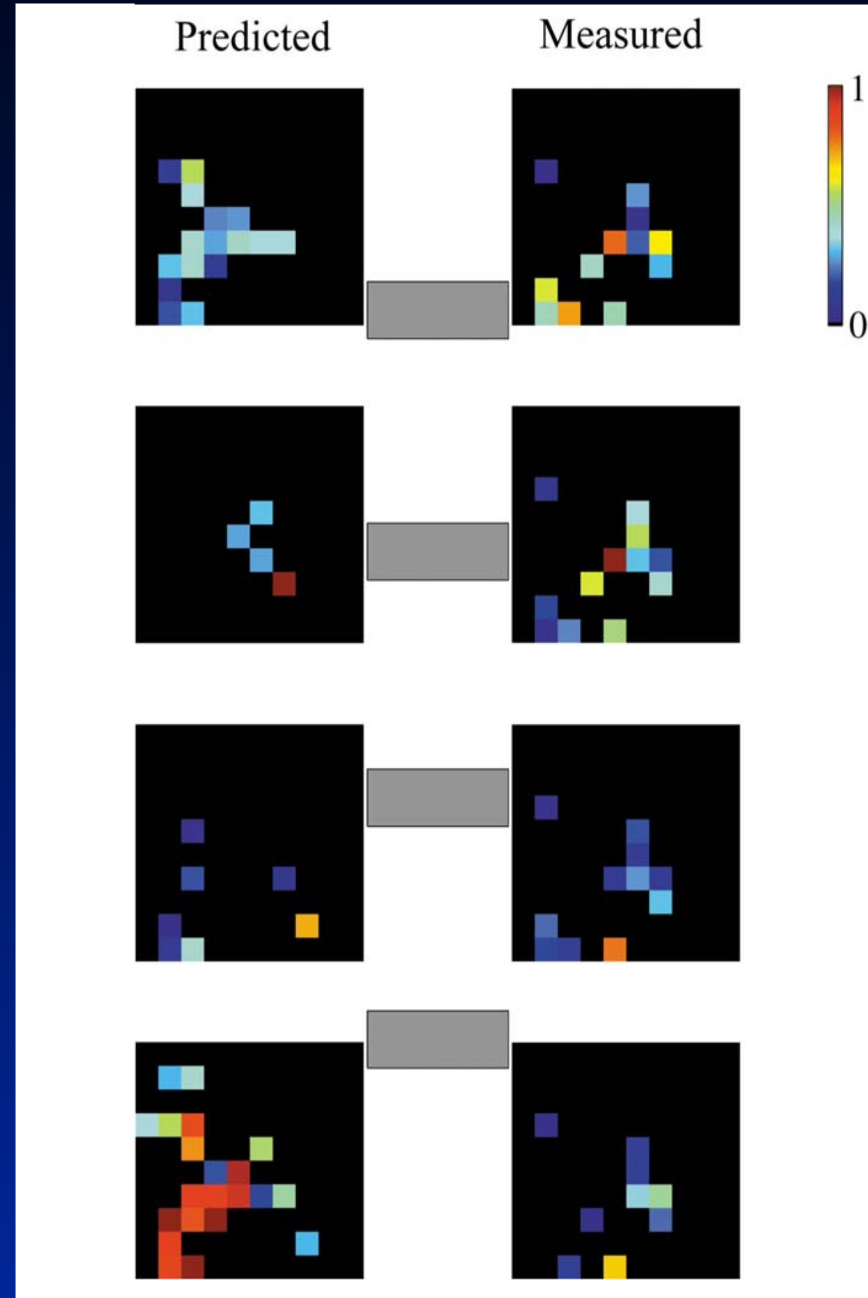


Neuronal Activity, Ack1543g.nex

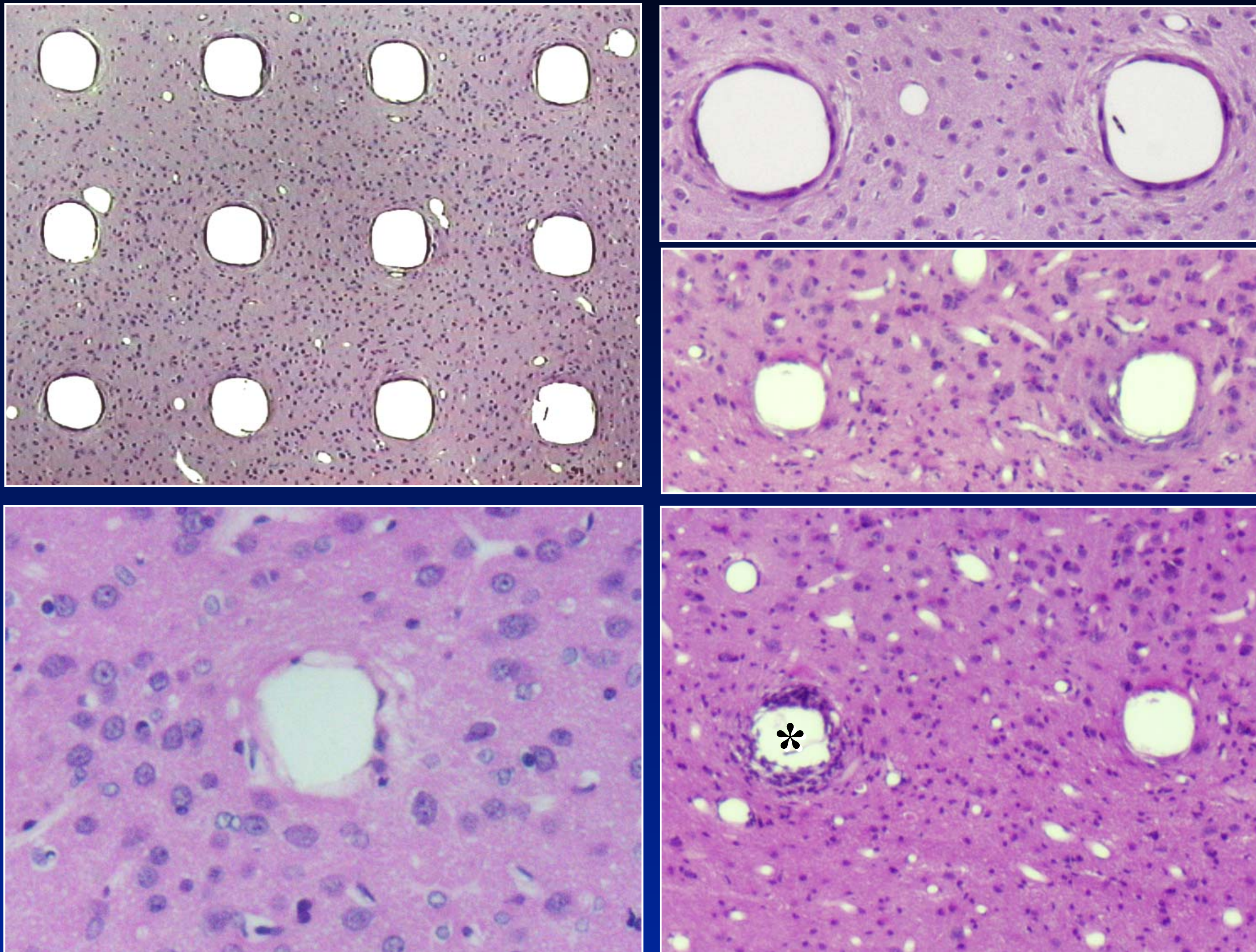
0.545 sec



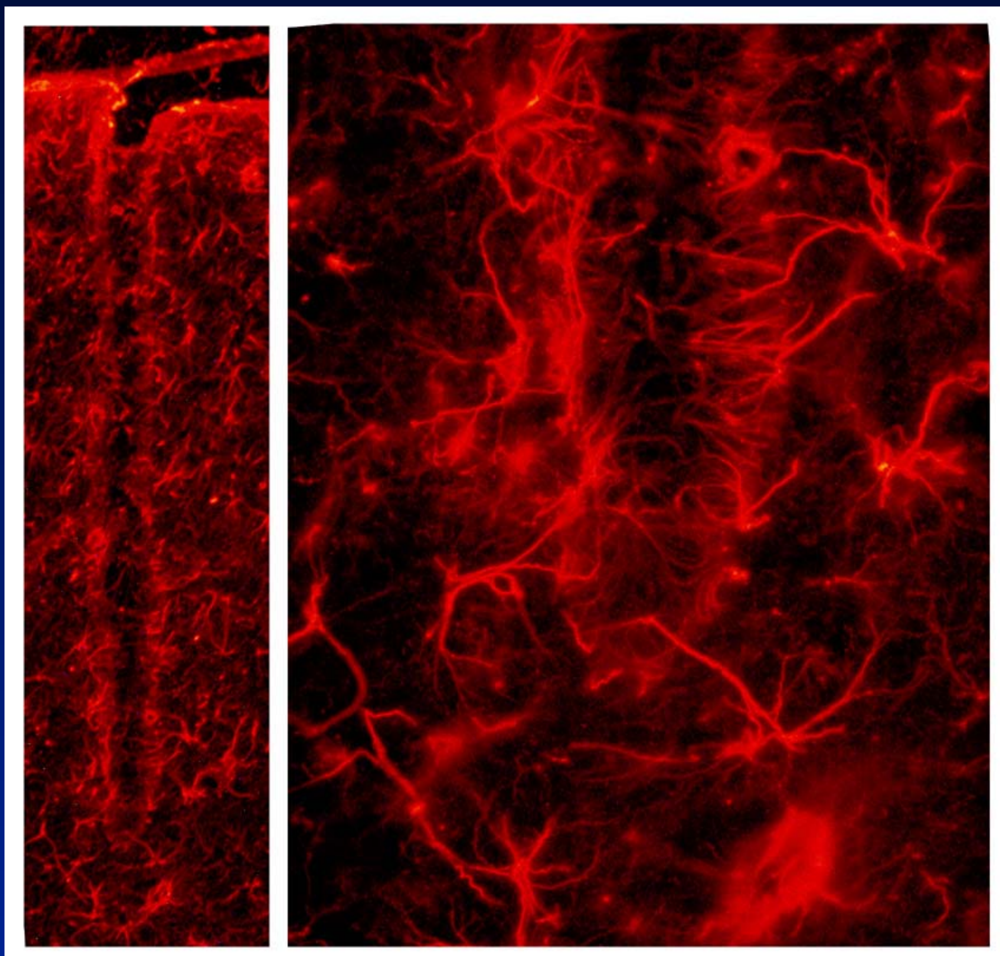


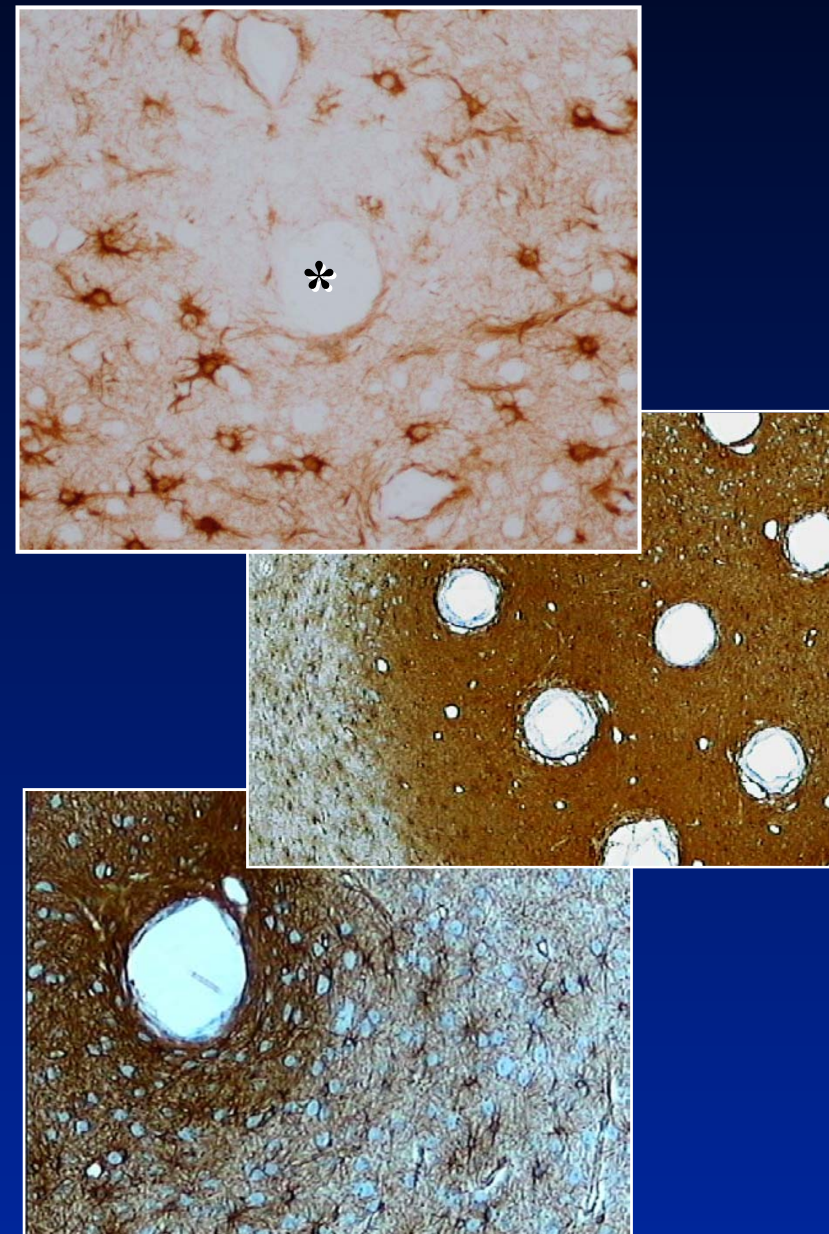


Predicted and measured responses of cat area 17 cell ensemble to upwardly moving horizontal bar

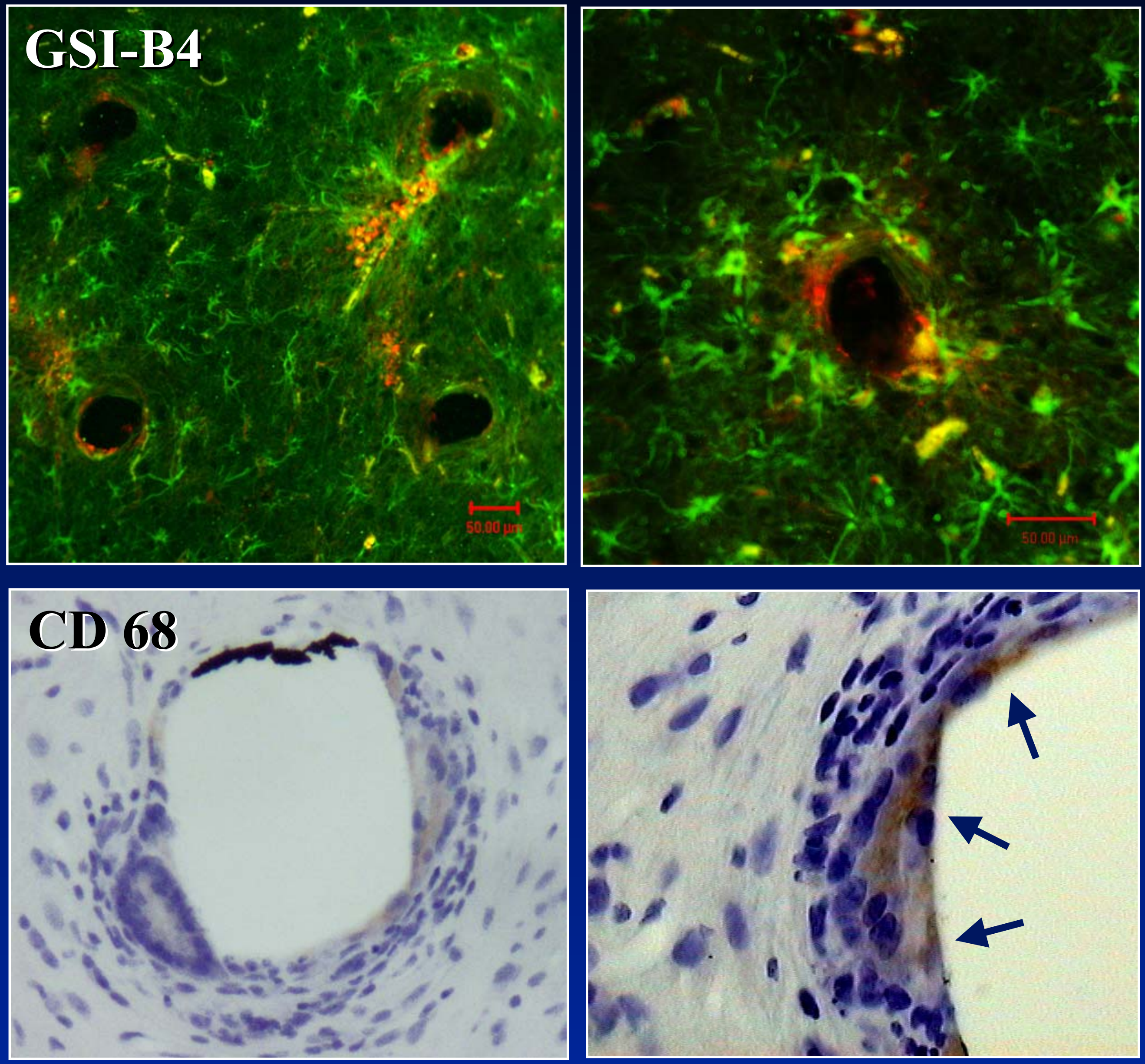


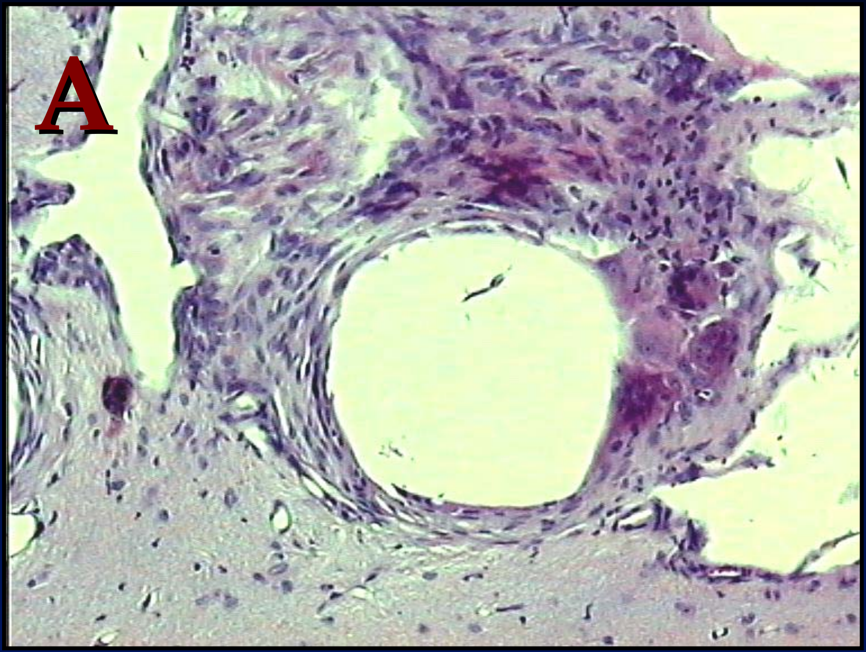
Proliferation of reactive astrocytes (GFAP stain)

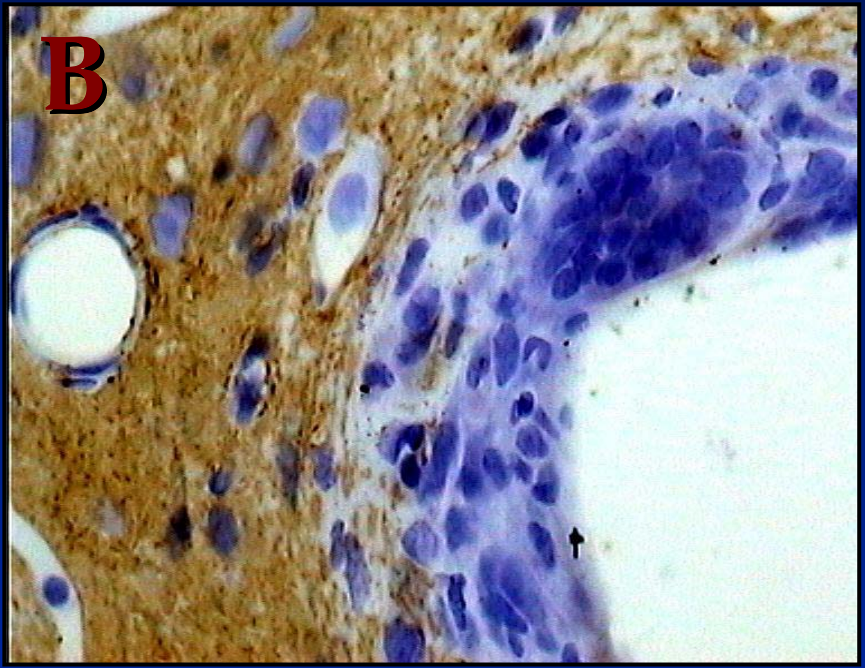


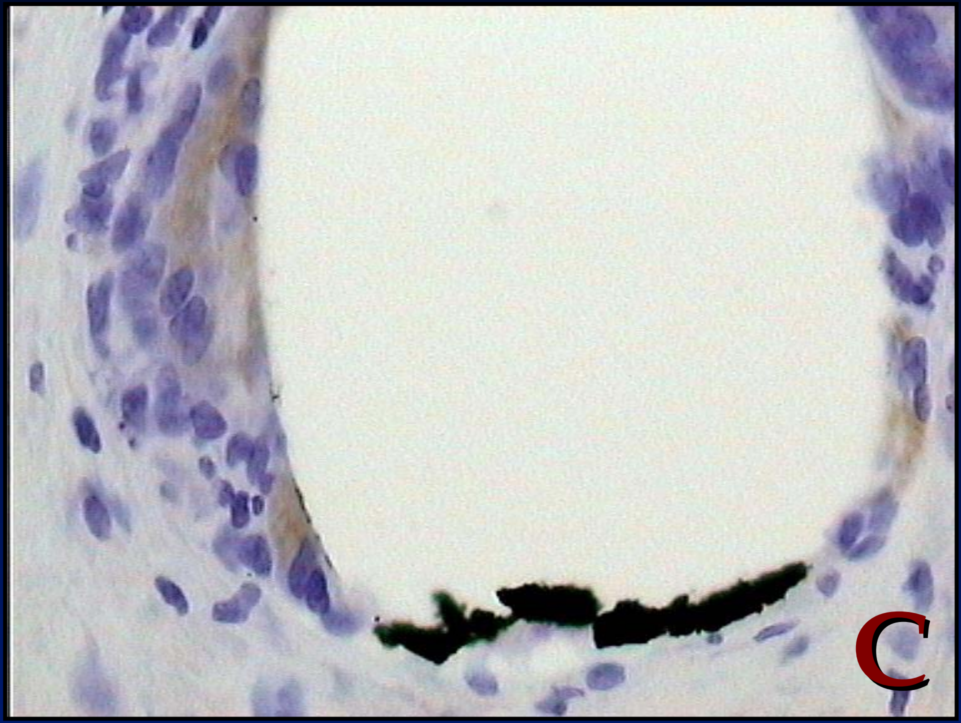


Proliferation of microglia and macrophages



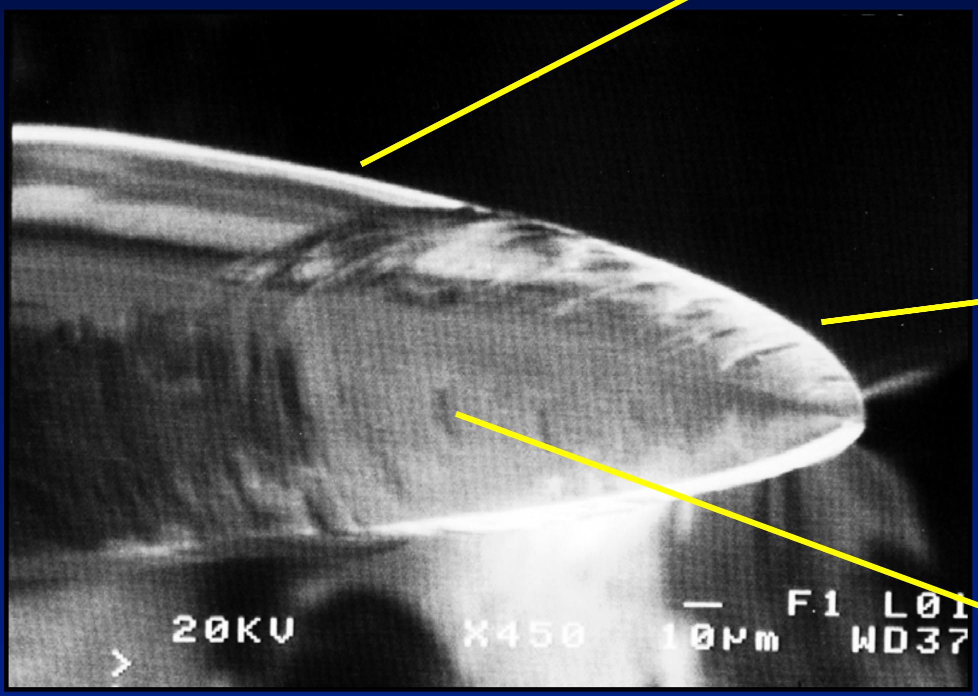


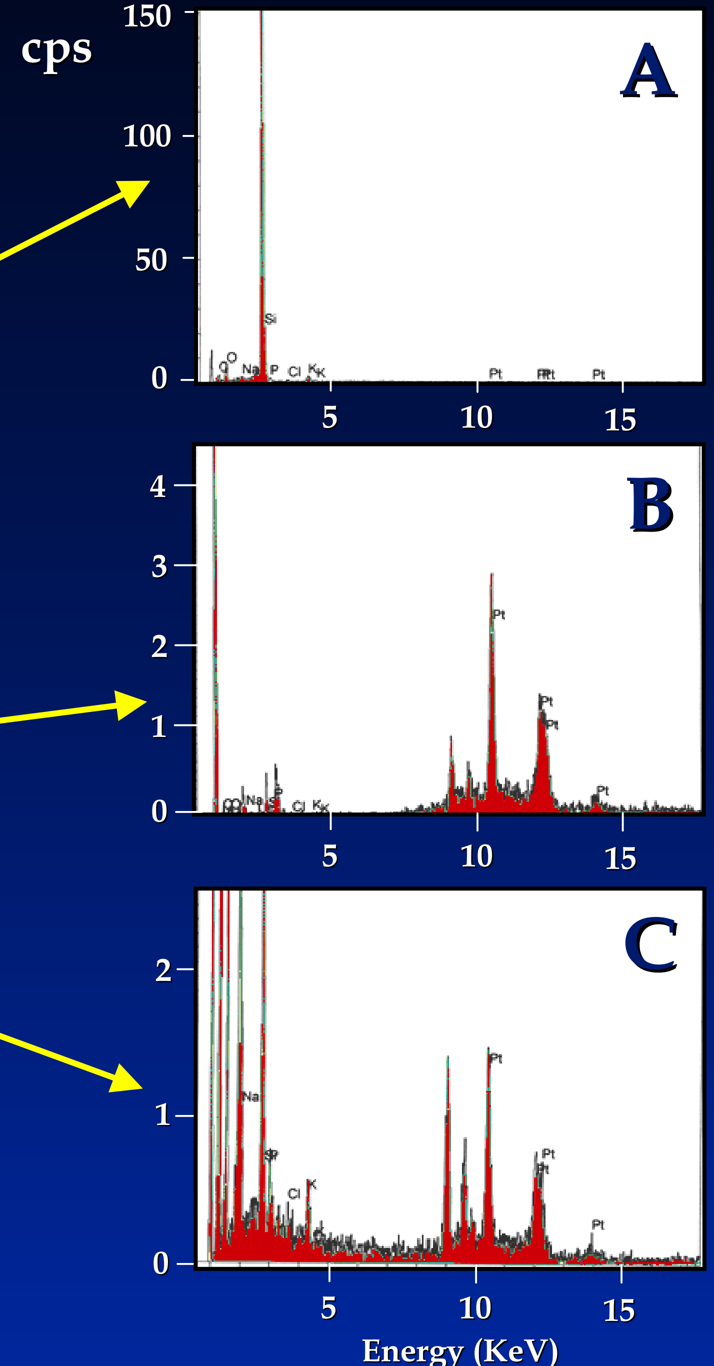




Deposit of metallic-matter in some of the microelectrode tracks

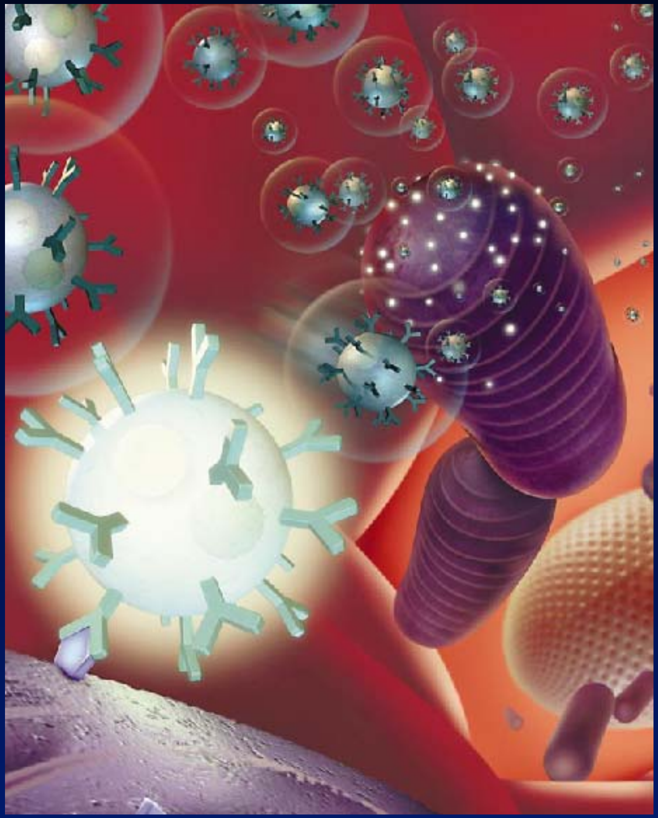
Microanalysis

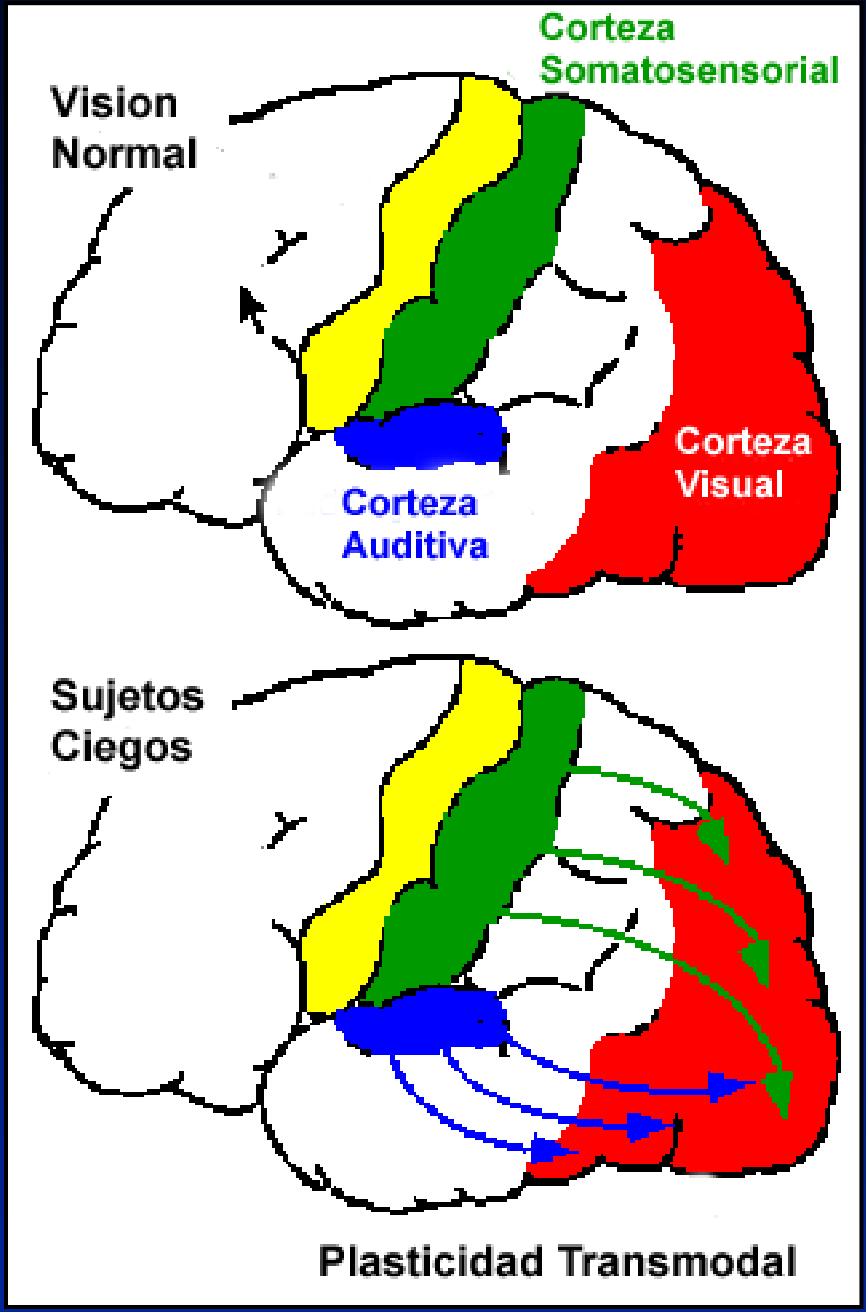




Because the initial response is stereotypic across a wide variety of injuries, it may be possible to understand the signals that lead to the neuroglial activation and …

- To control the response.
- Reduce the adverse nature of the response.
- Maintain and ideal environment for the brain-electrode interface.



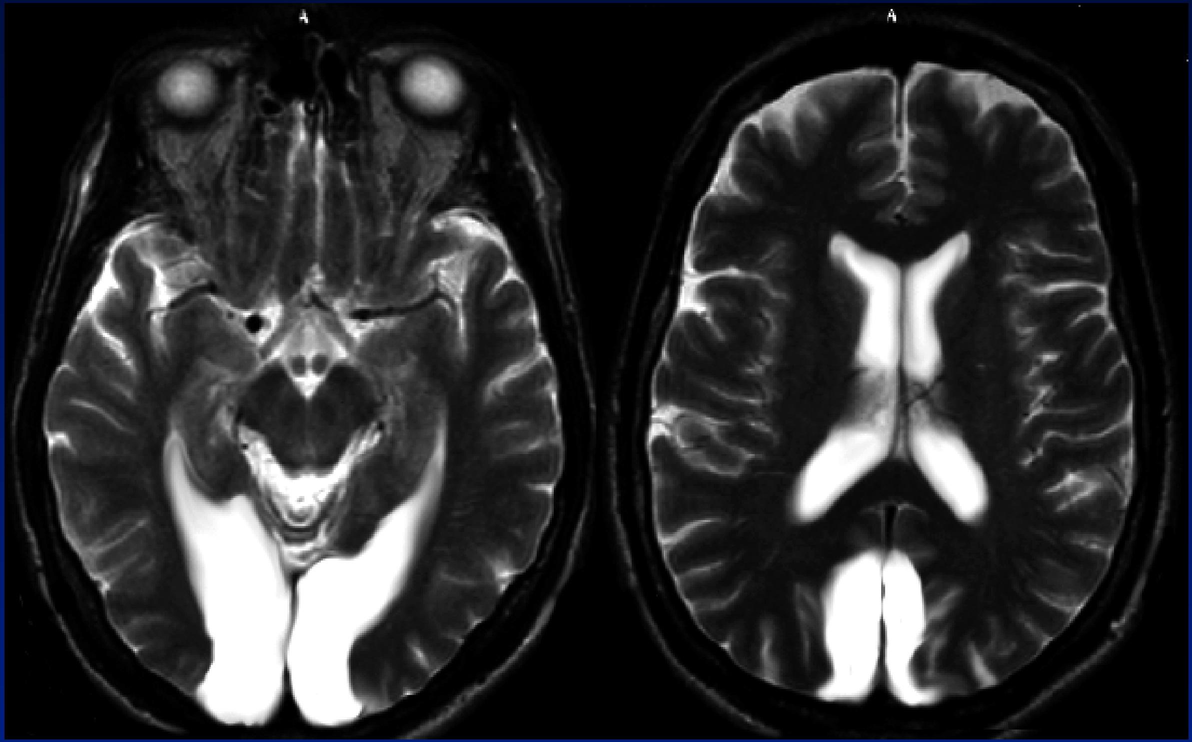


Is the occipital cortex of blind subjects able to process visual information?

Braille alexia

Lesion study

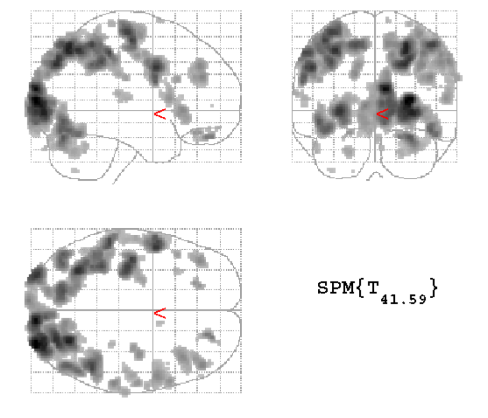
- 54 y/o woman
- Blind “since birth”
- Braille since age 7
- Braille 4-6 h/d
- Unable to read Braille after transient coma
- Normal neurological exam

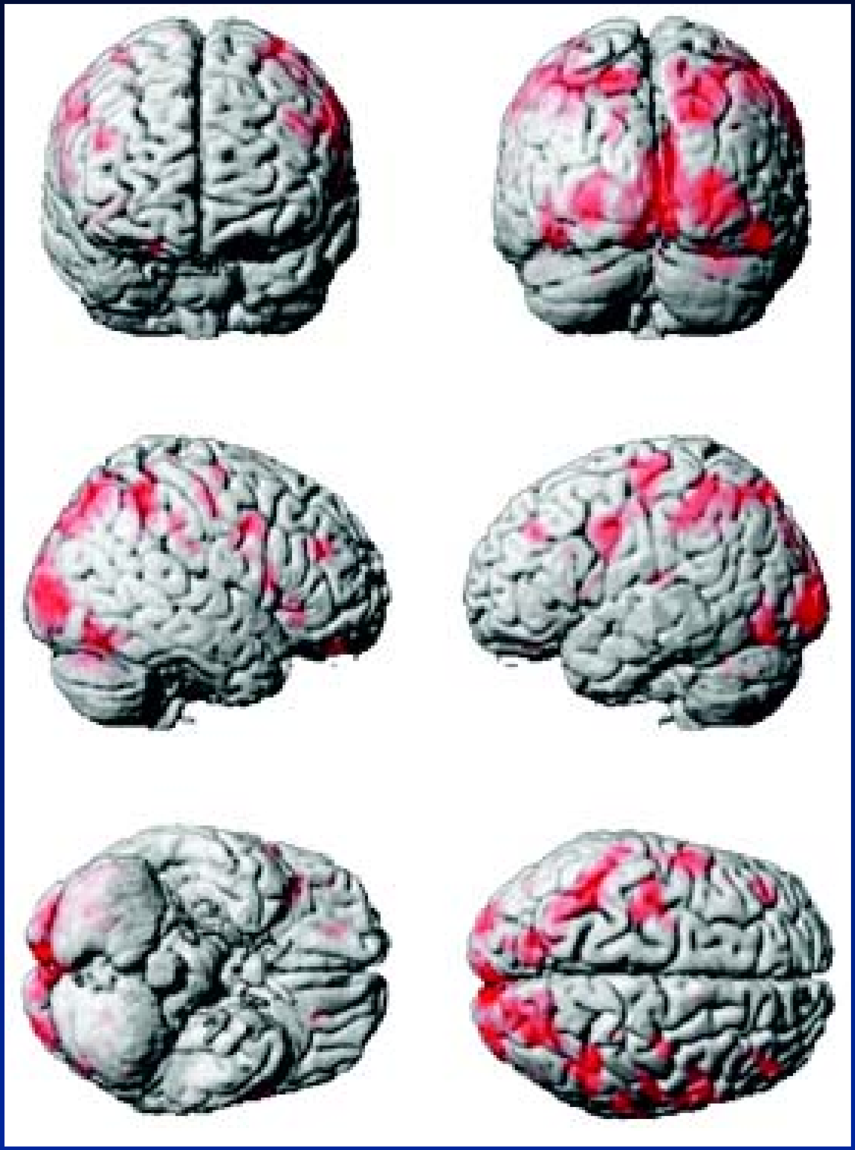


Pascual Leone et al. 1999

Braille reading in blind subjects

- **Main activation areas:**
  - Somatosensory cortex (contralateral to the side of stimulation)
  - Primary and associative visual cortex (mainly contralateral to the side of stimulation) (p<0’05)
- **Less significant activation:**
  - Motor areas
  - Left prefrontal cortex

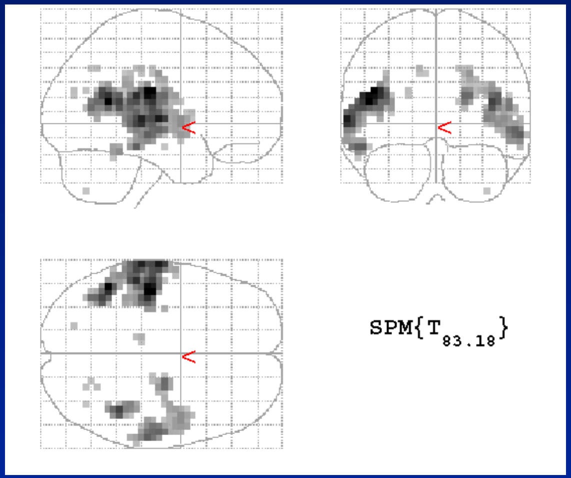


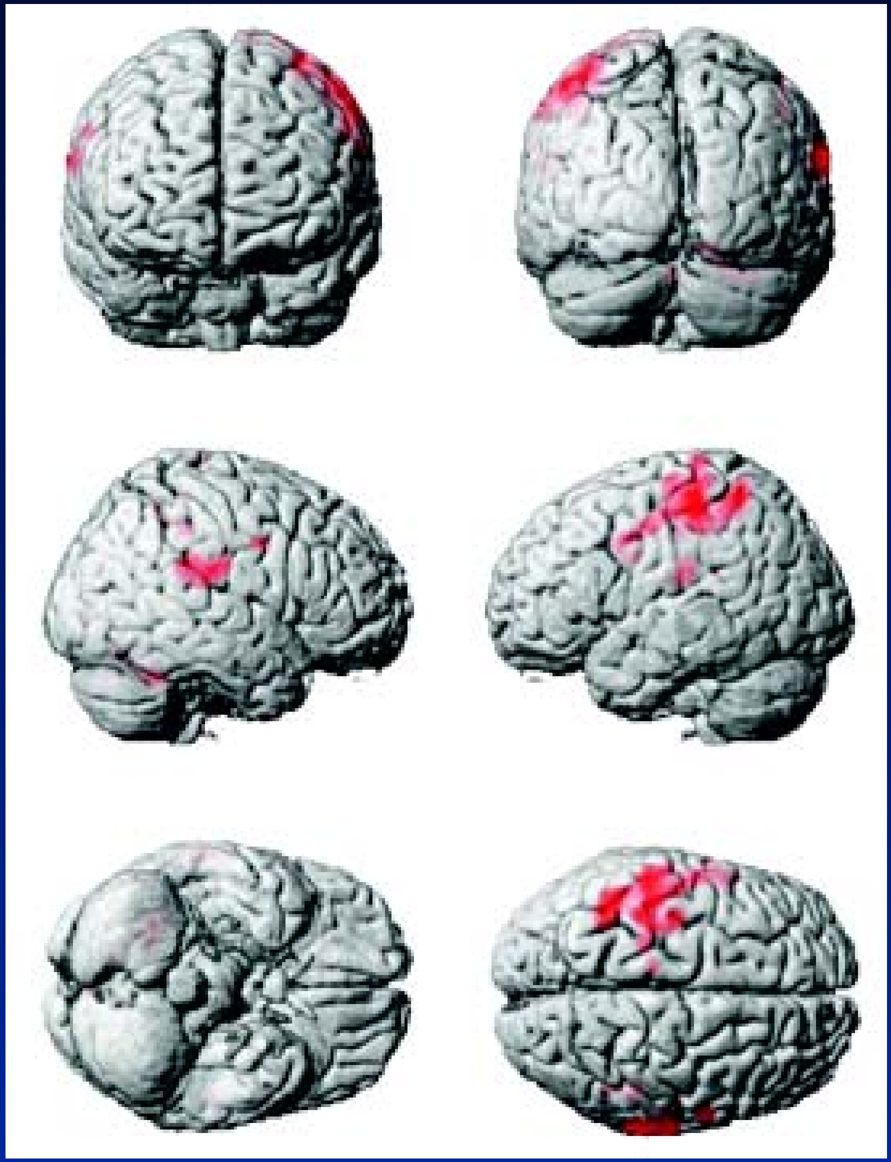


Sensory discrimination of Braille characters by sighted subjects

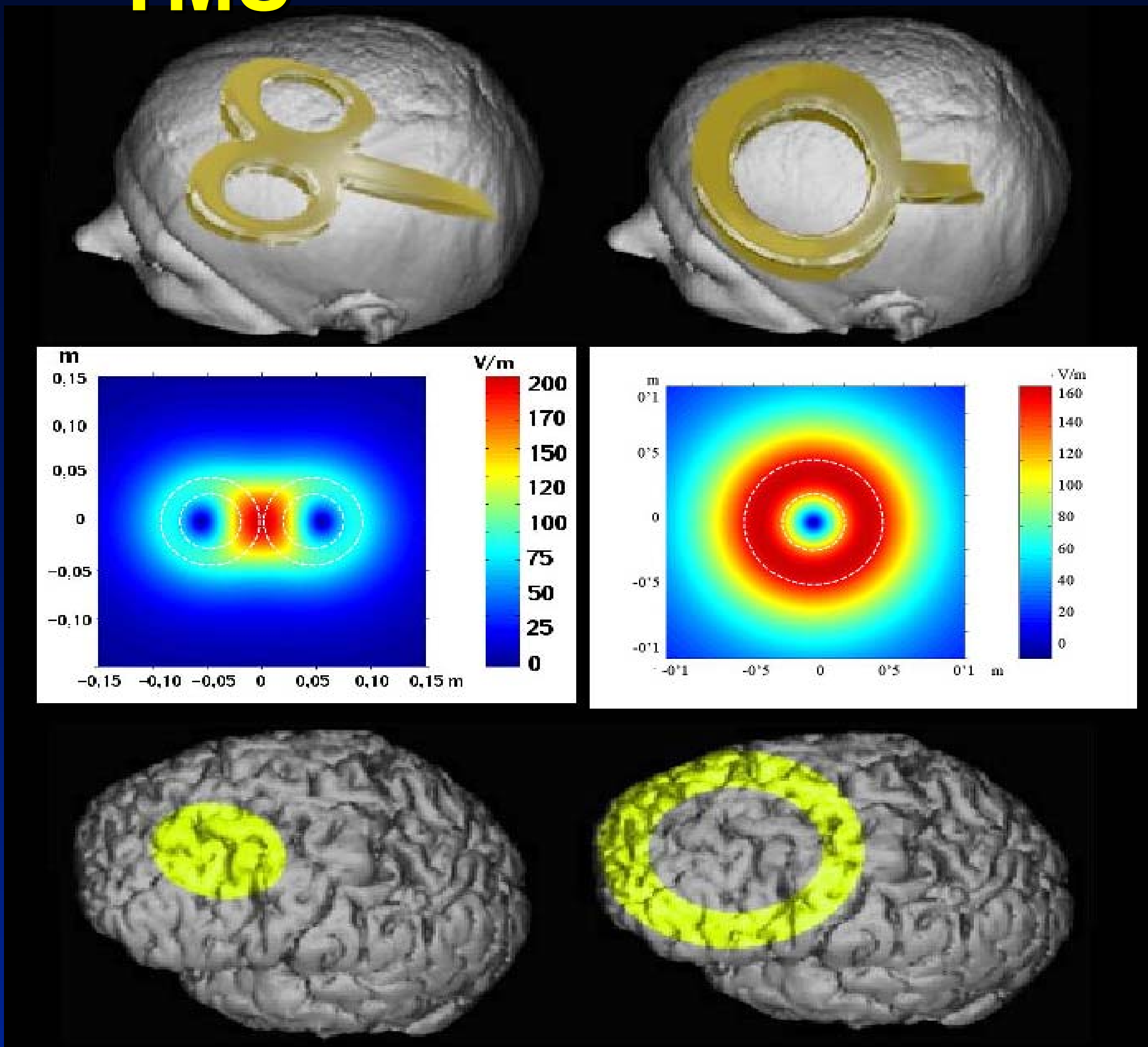
- Posterocentral sulcus (contralateral to the side of stimulation)

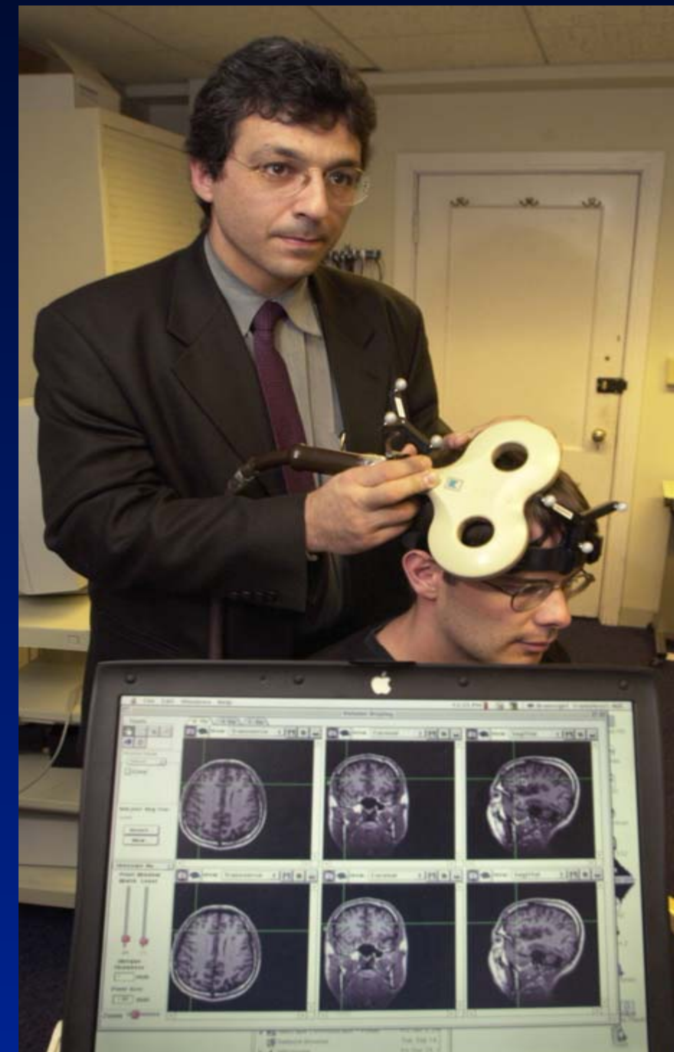
(p<0'05)





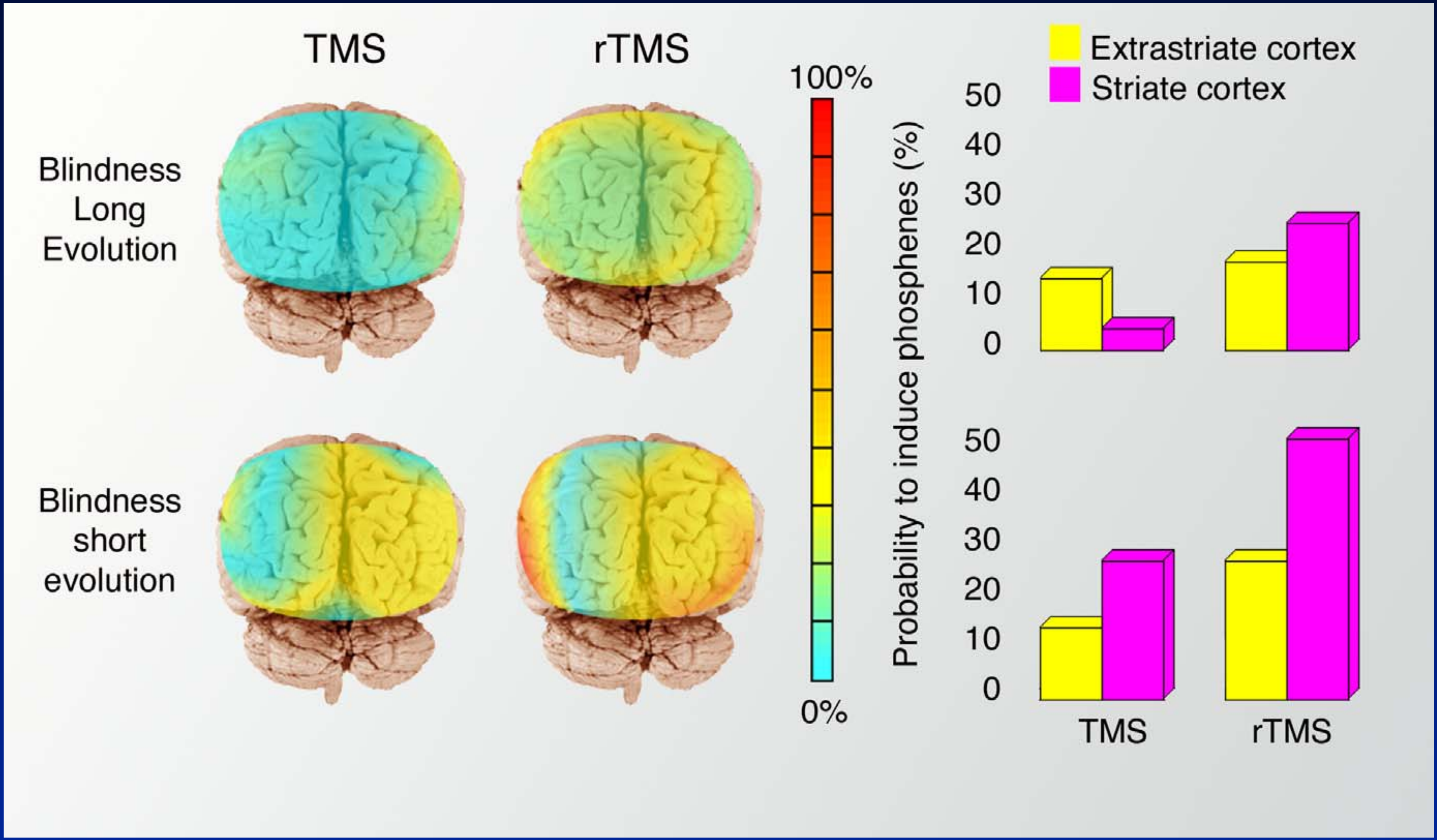
Mapping the human visual cortex using TMS



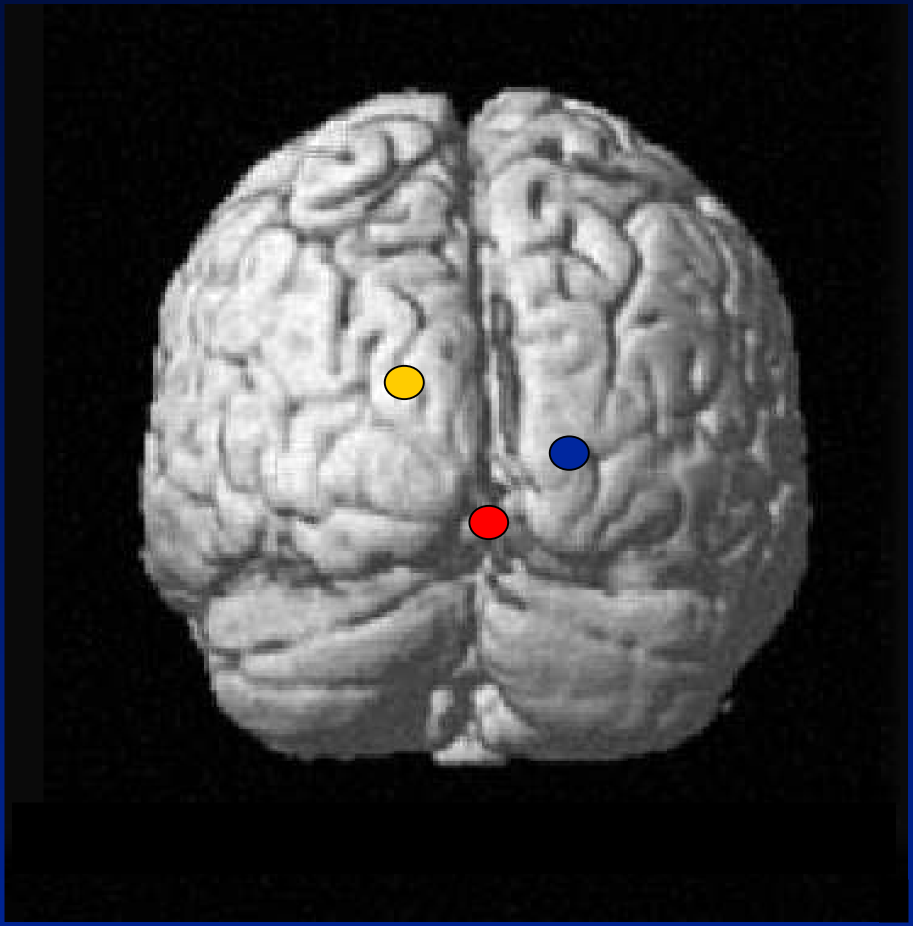


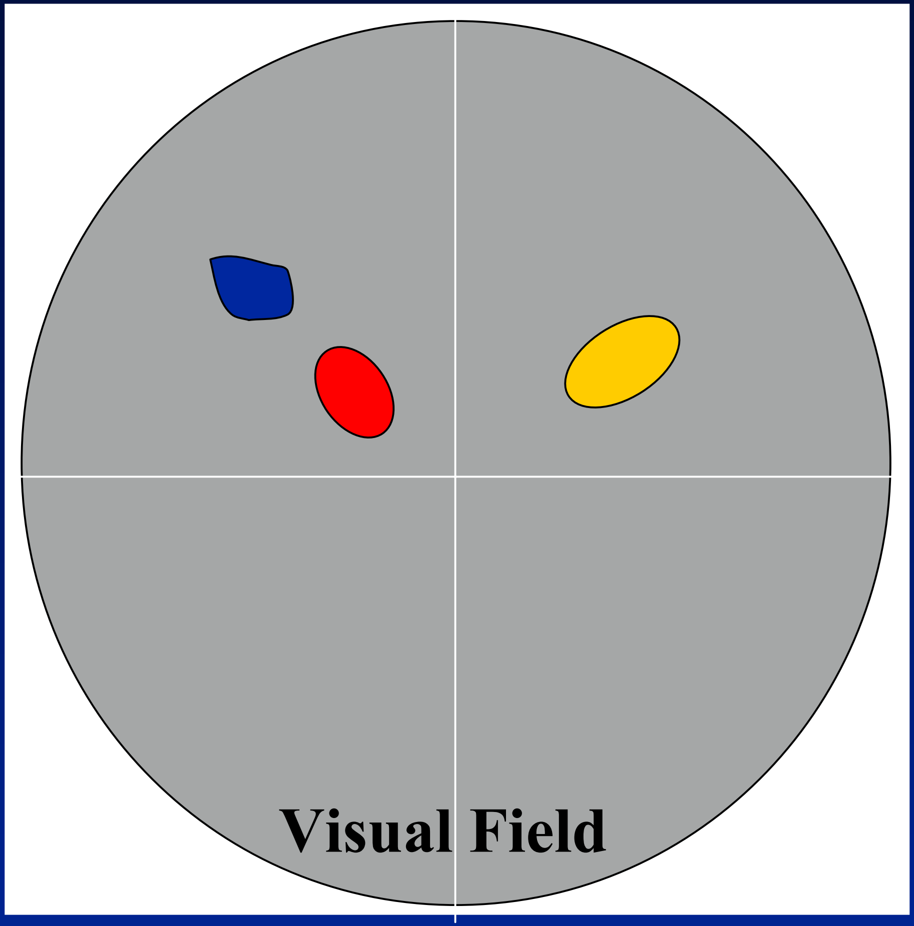
Fernández et al, 2002

Perception of phosphenes in blind subjects



Examples of retinotopic mapping of TMS induced phosphenes in blind subject #8





- **How many electrodes are required to produce a useful visual sense?**
- **How stable are the phosphene thresholds on a day by day basis?**
- **How far apart can a pair of electrodes be positioned and still produced contiguous phosphenes?**
- **Does patterned stimulation produce patterned percepts?**

Conclusions:

- ✓ If we can understand more about the fundamental mechanism of neuronal coding, and to safely stimulate nervous system, there will real potential to apply this knowledge clinically.
- ✓ Our results show that intracortical microelectrodes could be safely used in long-term applications, although more studies regarding safety and preservation of neuronal tissues as well as optimizations of stimulating parameters are needed preceding any clinical trial.

Never in the history have been so many new findings concerning neural prosthesis as have been achieved in the recent 10 years. Still there may be a long way to application of such findings in patients. However, it can be expected that, at least for some patients, effective therapies will be developed during the upcoming years.

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