Fondamenti di bioingegneria

Laurea in

Ingegneria Informatica, Biomedica e delle Telecomunicazioni

Fabio Baselice

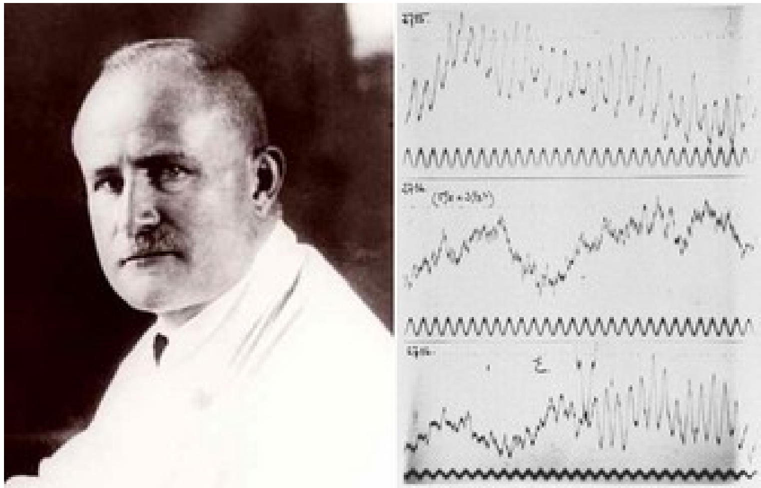
Argomenti

- Il sistema nervoso centrale (CNS)
- Elettroencefalogramma (EEG)
- Magnetoencefalogramma (MEG)

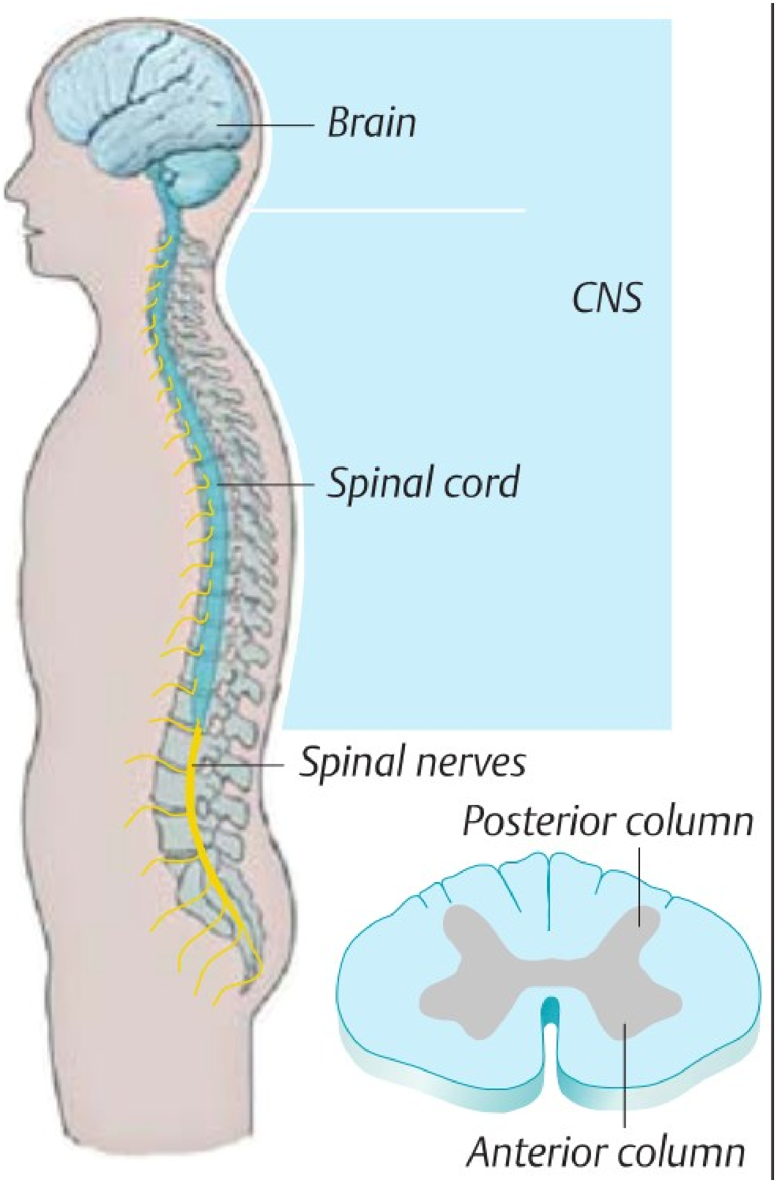
Cenni storici

Richard Caton (1875) – Pubblicazione dei primi risultati sulla registrazione dell’attività bioelettrica cerebrale di animali.

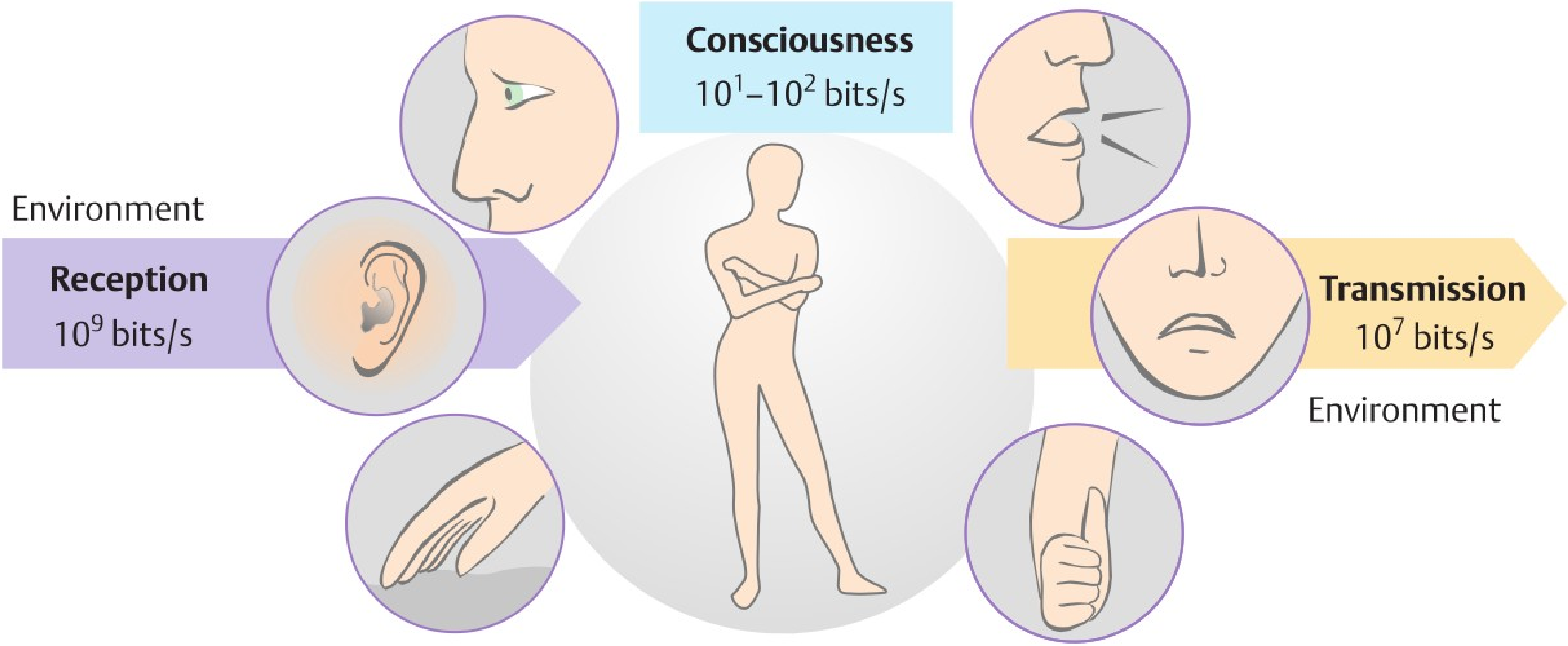
Hans Berger (1924) – Prima registrazione dei segnali elettrici cerebrali sull’uomo.



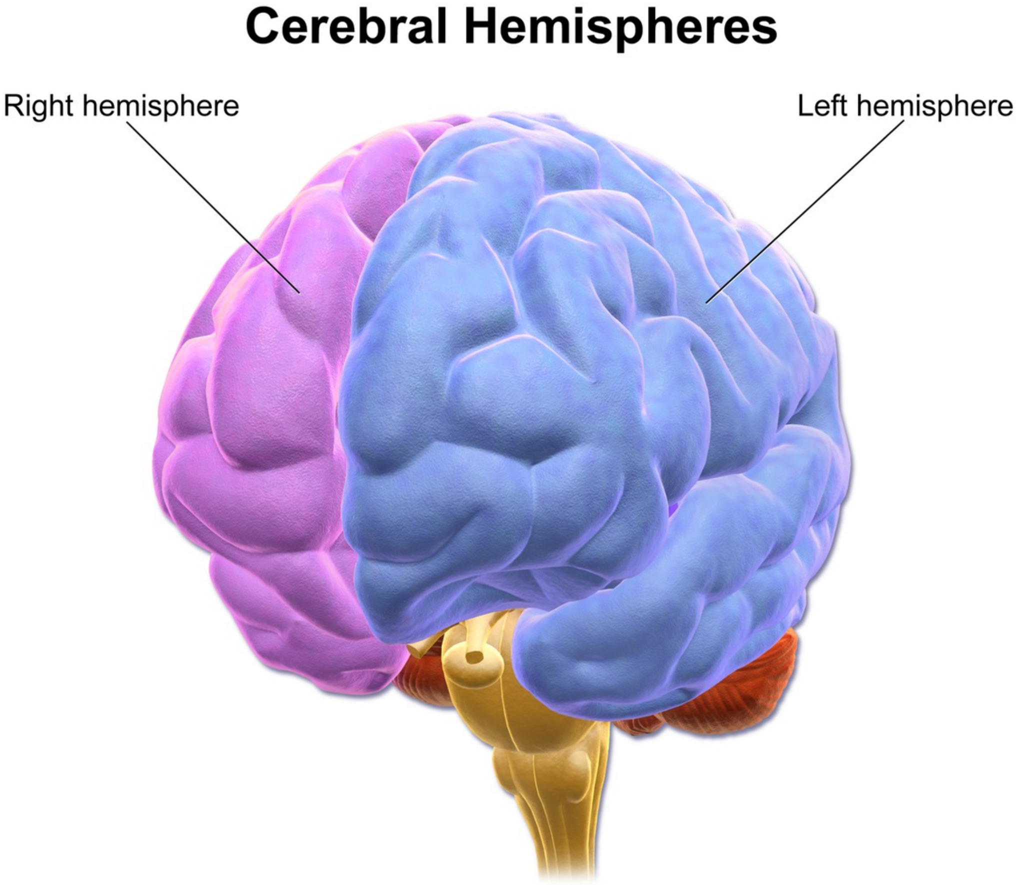
Cenni di anatomia


Brain
CNS
Spinal cord
Spinal nerves
Posterior column
Anterior column

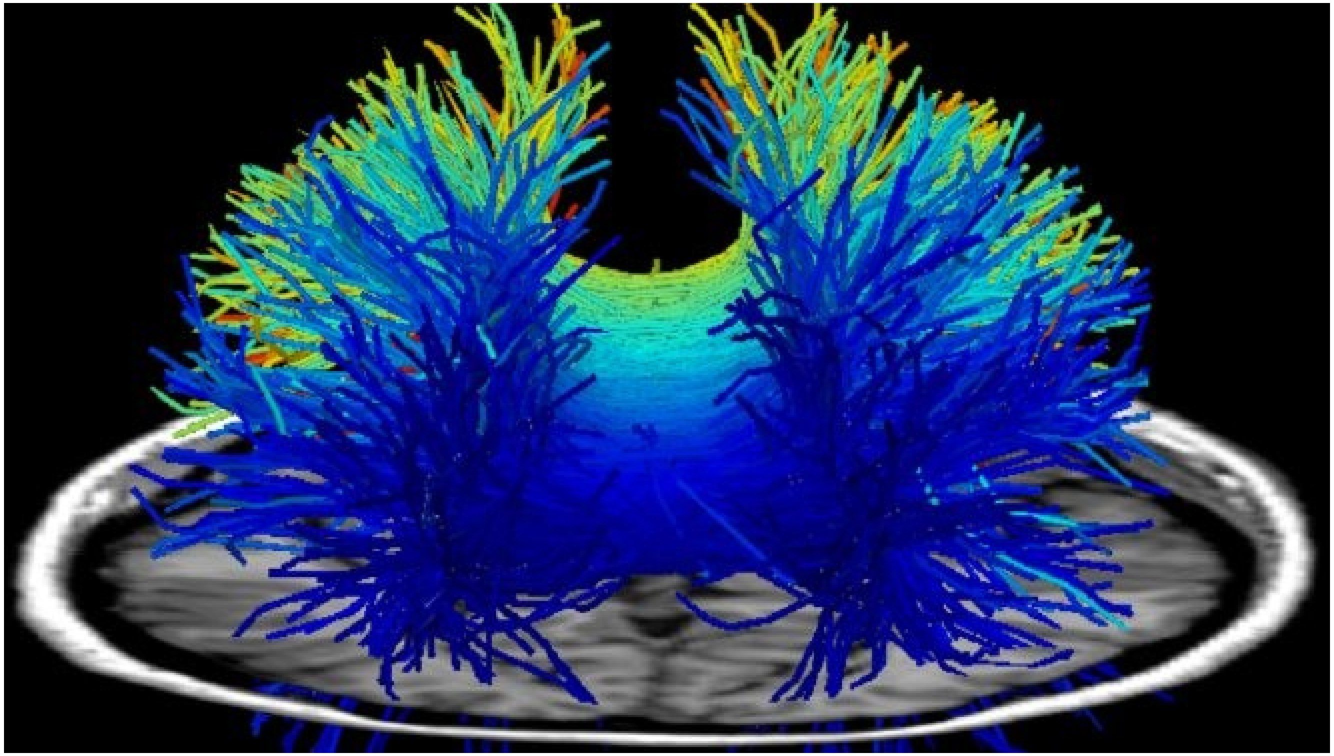
Cenni di anatomia


Consciousness
10^1–10^2 bits/s
Environment
Reception
10^9 bits/s
Transmission
10^7 bits/s
Environment

Cenni di anatomia

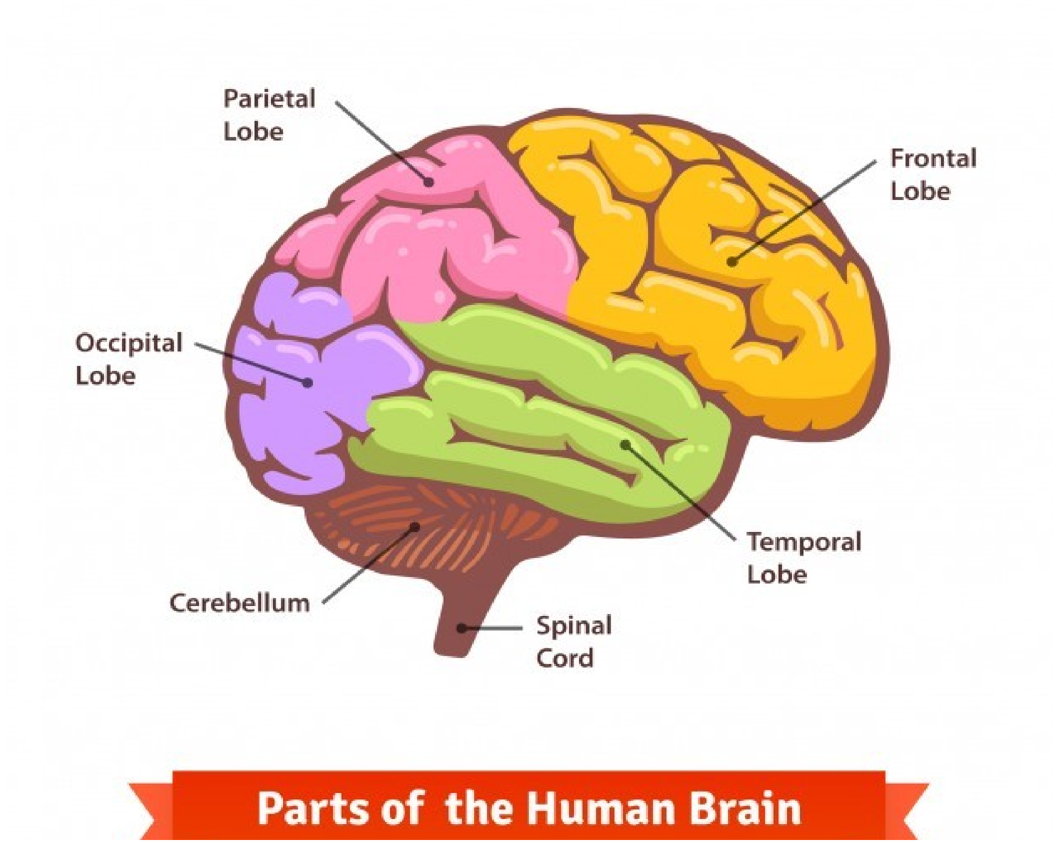

Cerebral Hemispheres
Right hemisphere
Left hemisphere

Cenni di anatomia



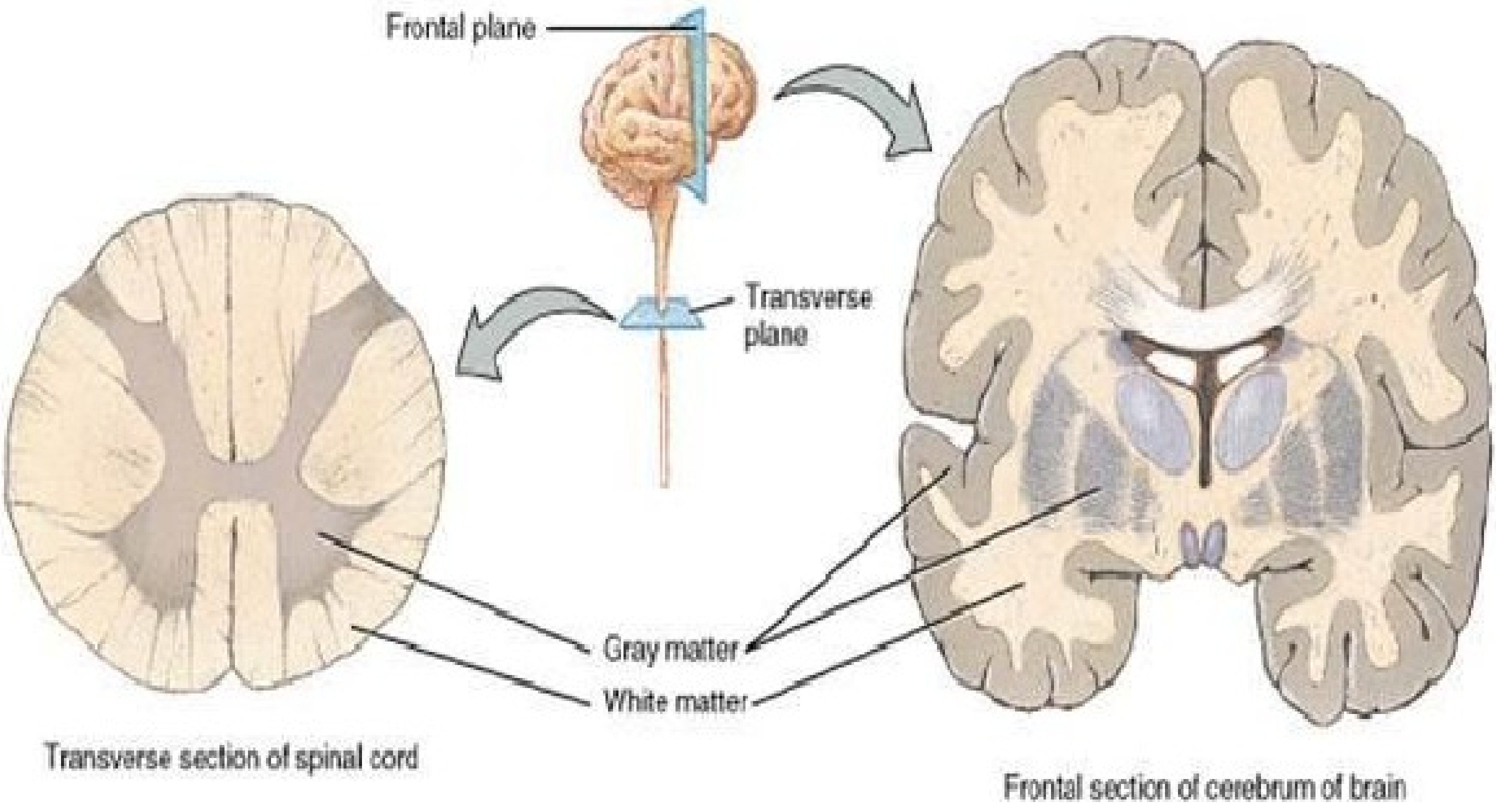
Corpo calloso

Cenni di anatomia

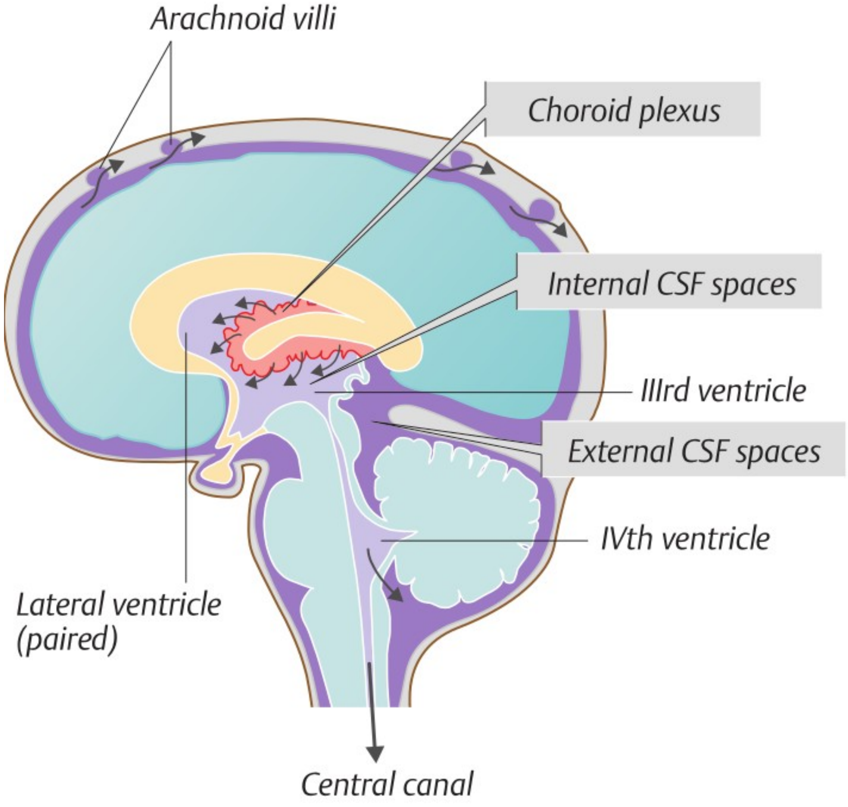

Parietal Lobe
Frontal Lobe
Occipital Lobe
Temporal Lobe
Cerebellum
Spinal Cord
Parts of the Human Brain

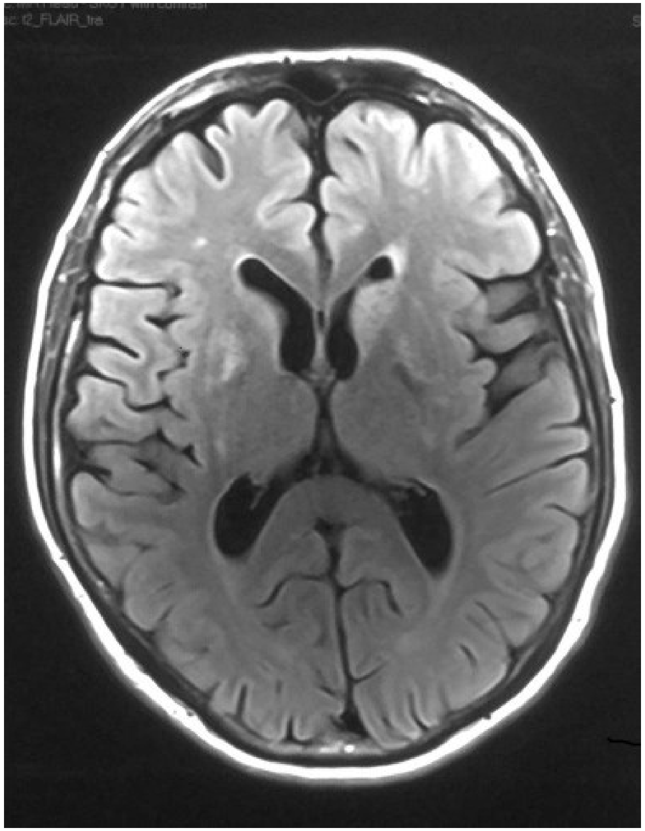
Encefalo: cervello, cervelletto e tronco encefalico.
Sistema talamo-corticale e nuclei della base

Cenni di anatomia


Frontal plane
Transverse plane
Gray matter
White matter
Transverse section of spinal cord
Frontal section of cerebrum of brain

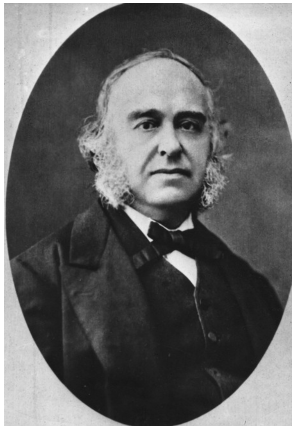
Cenni di anatomia


Arachnoid villi
Choroid plexus
Internal CSF spaces
IIIrd ventricle
External CSF spaces
IVth ventricle
Lateral ventricle (paired)
Central canal



Funzionamento cerebrale

Localizzazione

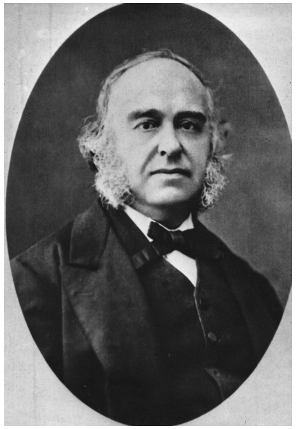


Paul Broca

Area del linguaggio

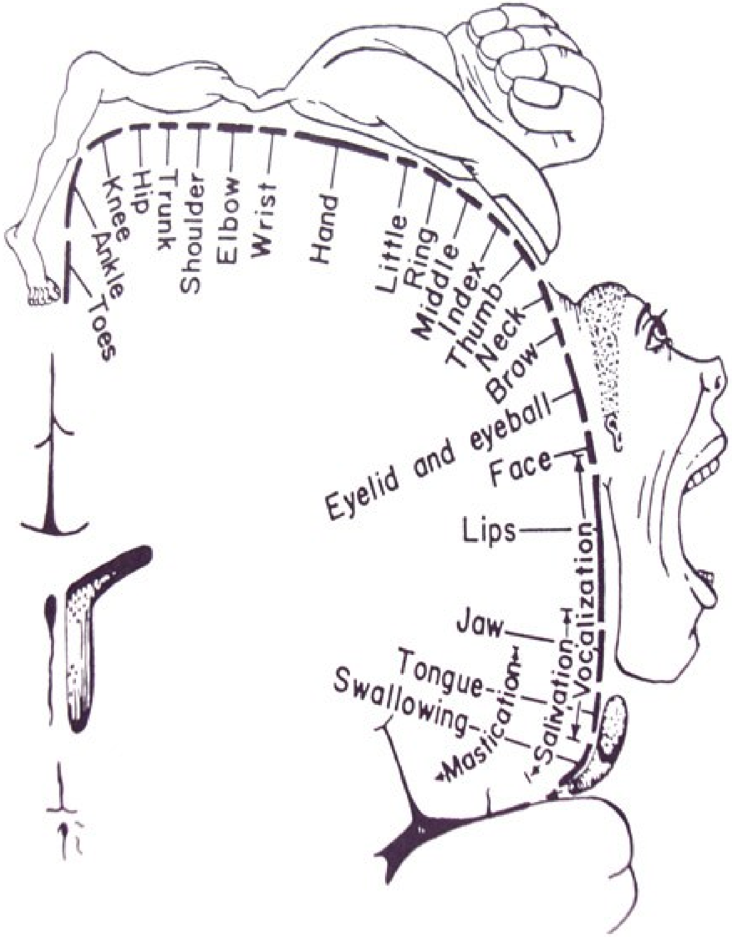
Funzionamento cerebrale

Localizzazione



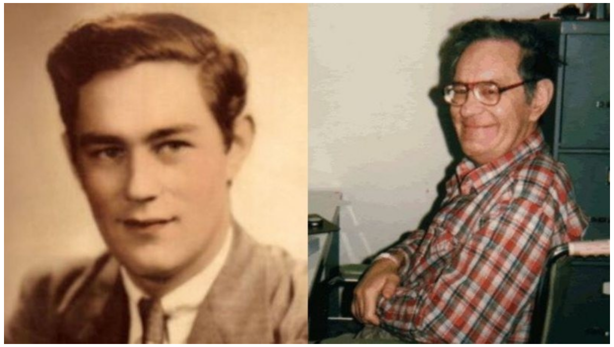
Paul Broca

Area del linguaggio


Toes
Ankle
Knee
Hip
Trunk
Shoulder
Elbow
Wrist
Hand
Little
Ring
Middle
Index
Thumb
Neck
Brow
Eyelid and eyeball
Face
Lips
Jaw
Tongue
Swallowing
Mastication
Salivation
Vocalization

Funzionamento cerebrale

Rete



Henry Molaison

USA, 1953

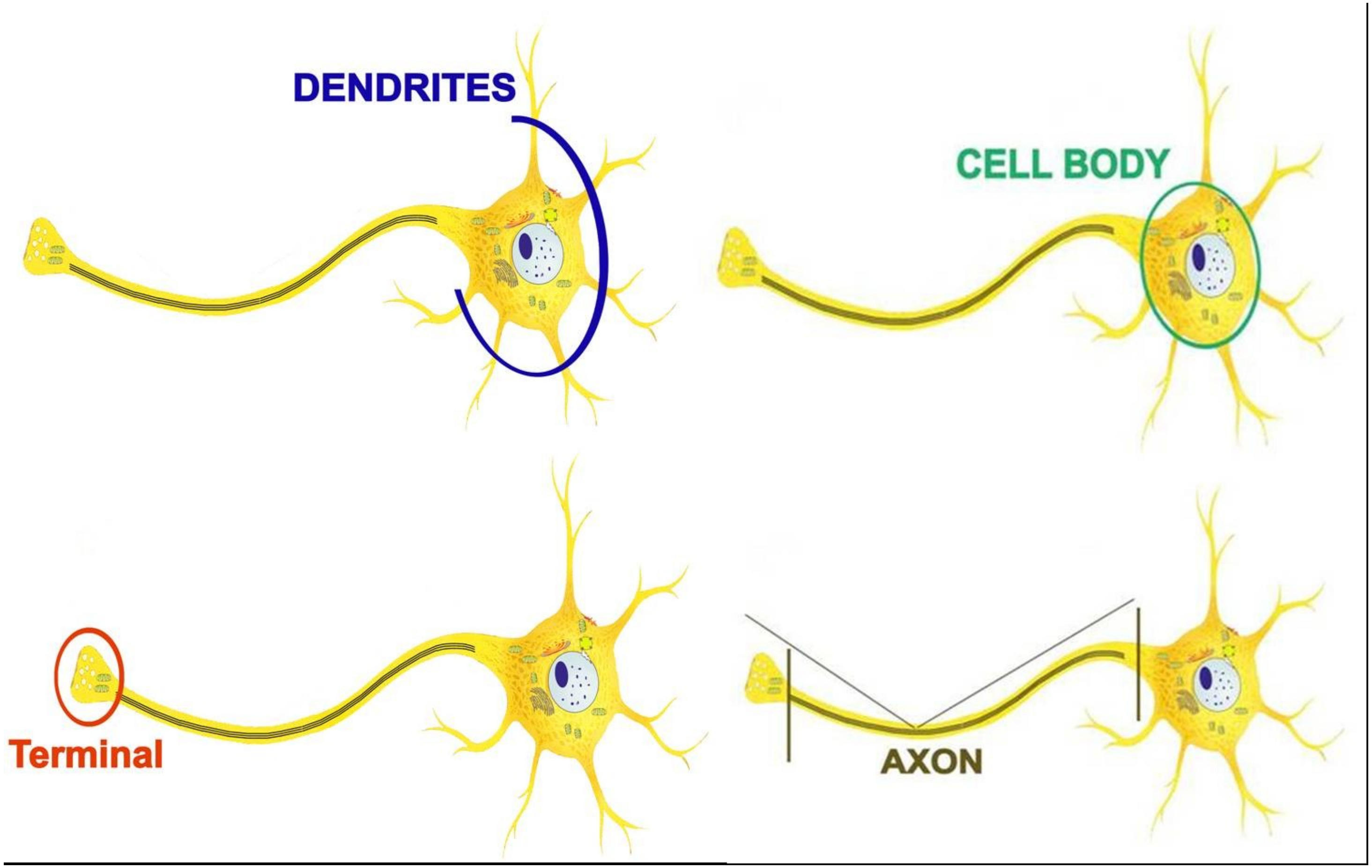
nature
THE INTERNATIONAL WEEKLY JOURNAL OF SCIENCE
THE WORM-WIDE WEB
Complete nervous systems mapped for both sexes of C. elegans
PAGES 40 & 63
ENGINEERING
ARTIFICIAL CIRCULATION
Synthetic vascular system powers robot fish
PAGE 51
DEVELOPMENT
UNSCRAMBLED EGGS
Unpicking the evolutionary history of insect ova
PAGES 24 & 58
MACHINE LEARNING
ON THE PAPER TRAIL
Text mining spots hidden properties of materials
PAGES 42 & 95
NATURE.COM
4 July 2019
Vol. 571, No. 7763

2019

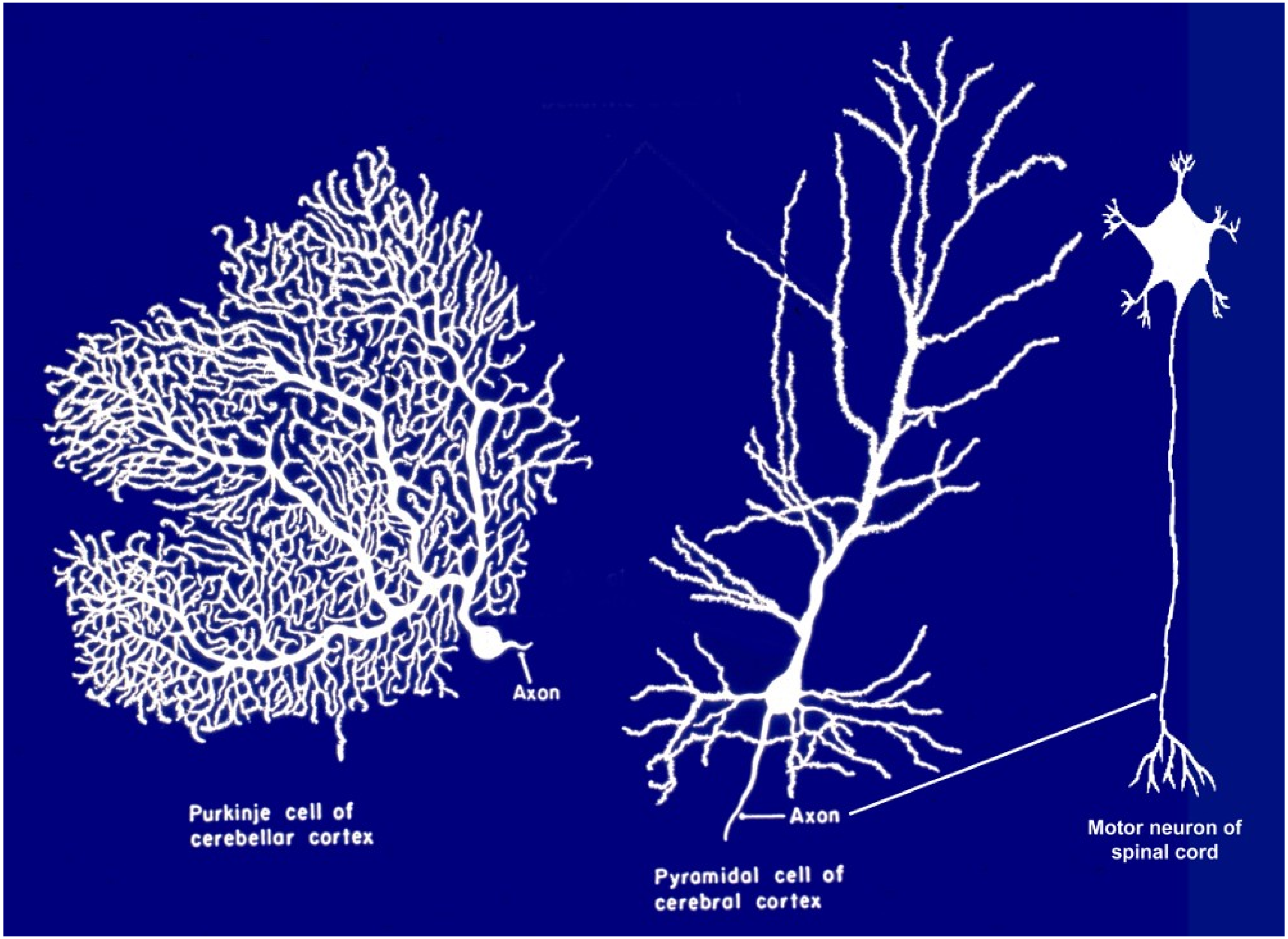
Caenorhabditis elegans.

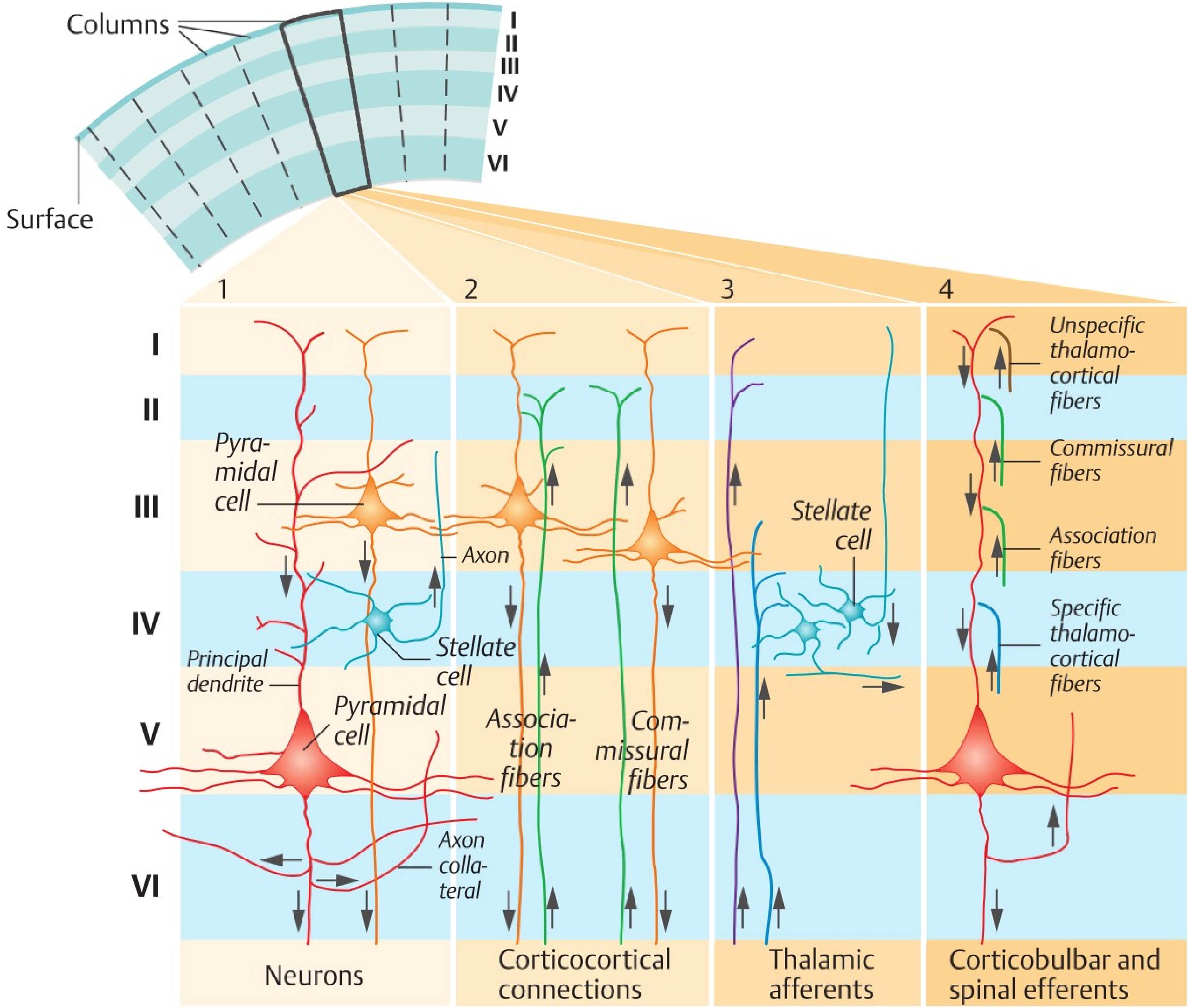
302 neuroni, 8000 sinapsi

Cenni di anatomia


DENDRITES
CELL BODY
Terminal
AXON

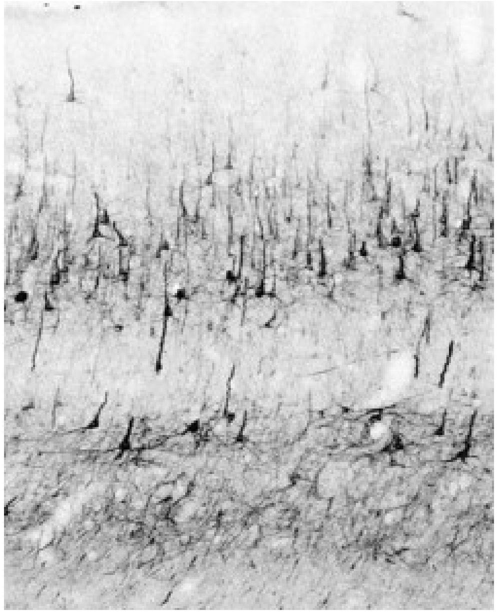
Cenni di anatomia


Axon
Purkinje cell of
cerebellar cortex
Axon
Pyramidal cell of
cerebral cortex
Motor neuron of
spinal cord

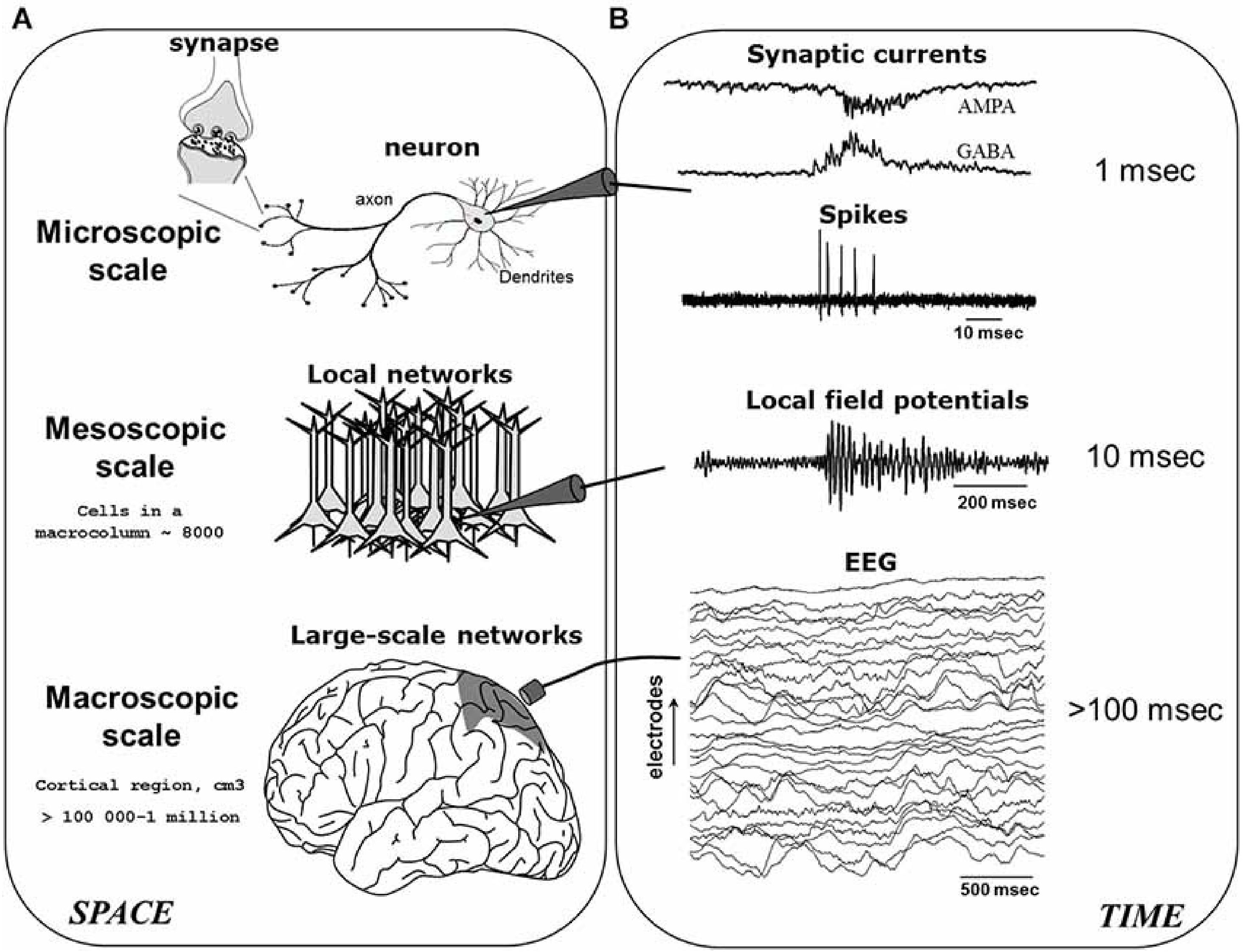

Columns
I
II
III
IV
V
VI
Surface
1
2
3
4
I
II
III
IV
V
VI
Pyra-
midal
cell
Axon
Stellate
cell
Principal
dendrite
Pyramidal
cell
Axon
colla-
teral
Associa-
tion
fibers
Com-
missural
fibers
Stellate
cell
Unspecific
thalamo-
cortical
fibers
Commissural
fibers
Association
fibers
Specific
thalamo-
cortical
fibers
Neurons
Corticocortical
connections
Thalamic
afferents
Corticobulbar and
spinal efferents

EEG

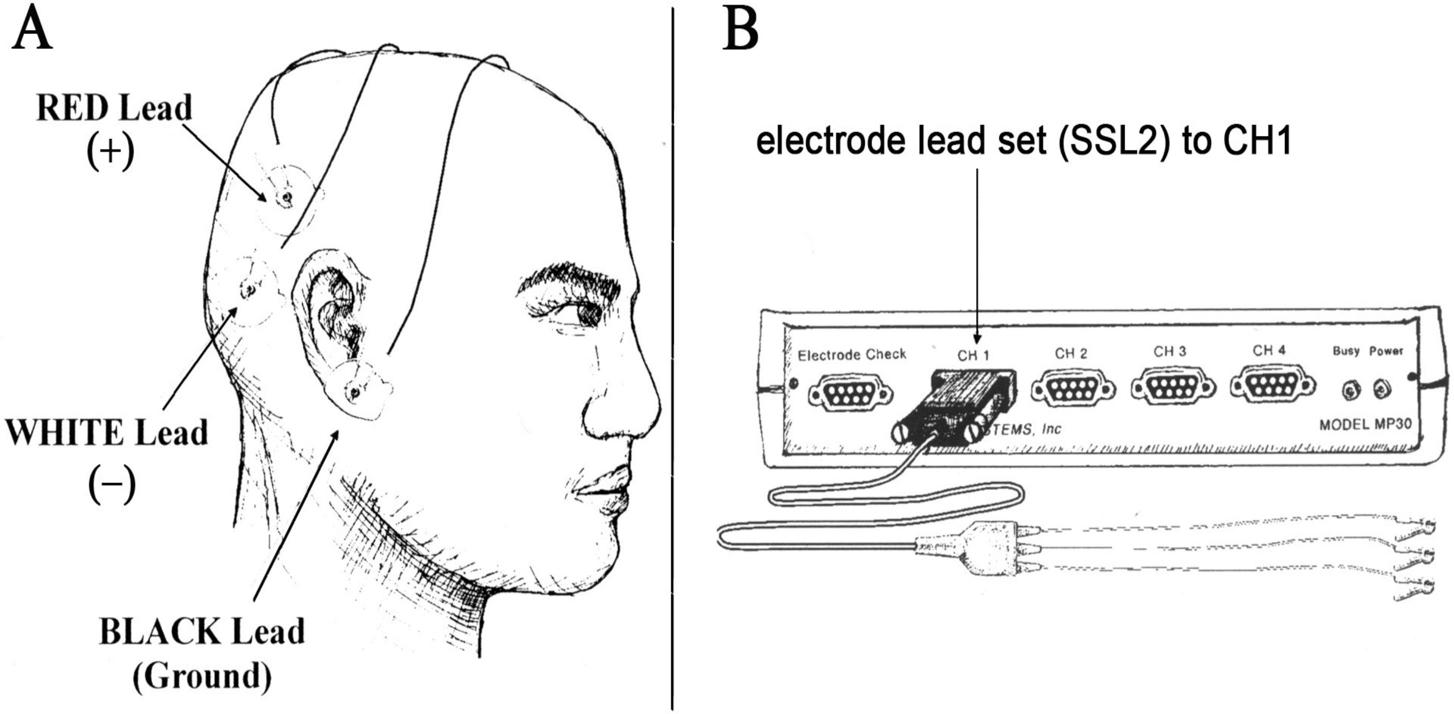
L’elettroencefalogramma (EEG) rileva l’attività elettrica spontanea della corteccia cerebrale data dalla somma dell’attività sincrona di migliaia di milioni di neuroni piramidali che presentano un orientamento simile nello spazio.



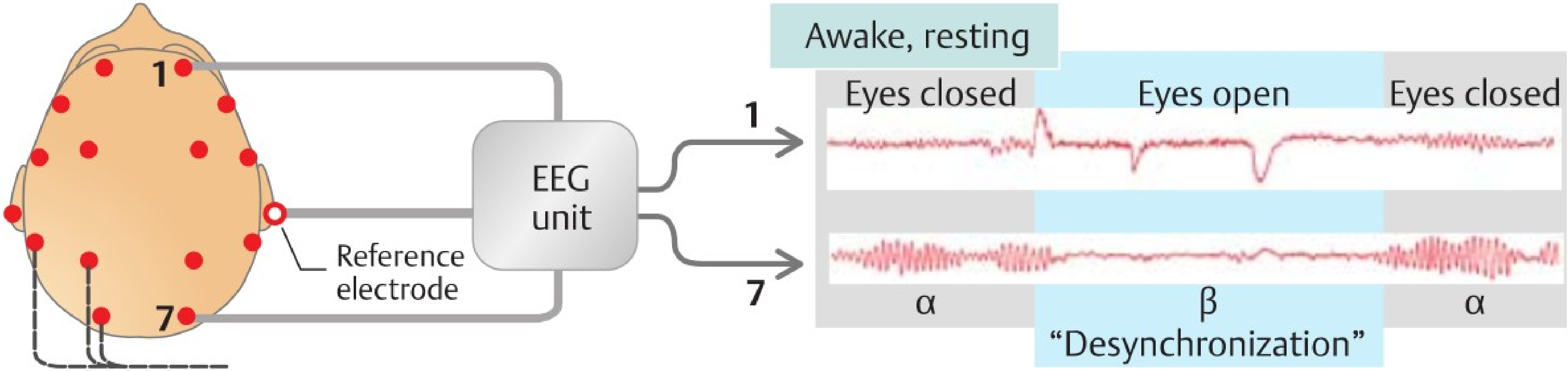
EEG


A
synapse
neuron
axon
Microscopic scale
Dendrites
Local networks
Mesoscopic scale
Cells in a macrocolumn ~ 8000
Large-scale networks
Macroscopic scale
Cortical region, cm3
> 100 000-1 million
SPACE
B
Synaptic currents
AMPA
GABA
1 msec
Spikes
10 msec
Local field potentials
10 msec
200 msec
EEG
electrodes
>100 msec
500 msec
TIME

EEG

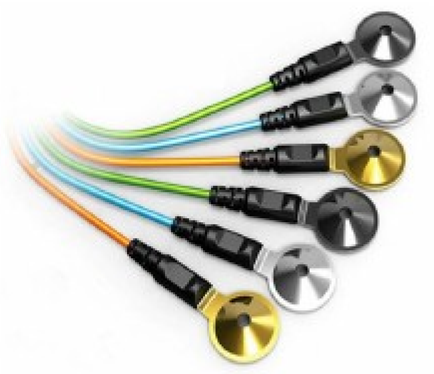

A
RED Lead
(+)
WHITE Lead
(−)
BLACK Lead
(Ground)
B
electrode lead set (SSL2) to CH1
Electrode Check
CH 1
CH 2
CH 3
CH 4
Busy
Power
STEMS, Inc
MODEL MP30

EEG

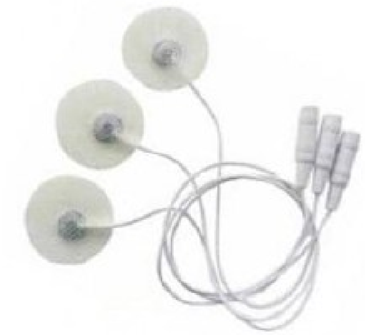

1
7
Reference electrode
EEG unit
1
7
Awake, resting
Eyes closed
Eyes open
Eyes closed
α
β
"Desynchronization"
α

EEG

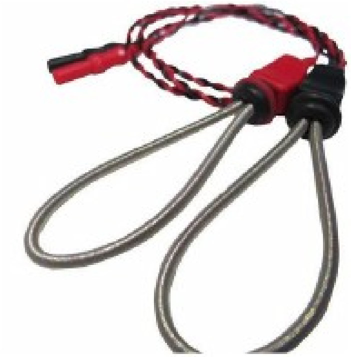
Il sistema di registrazione dei segnali EEG è chiamato Elettroencefalo, ed è costituito da una unità di acquisizione (elettrodi) di segnali misurati sullo scalpo, da una unità di elaborazione dei segnali e da una unità di visualizzazione e memorizzazione dei dati.



Elettrodi a coppetta

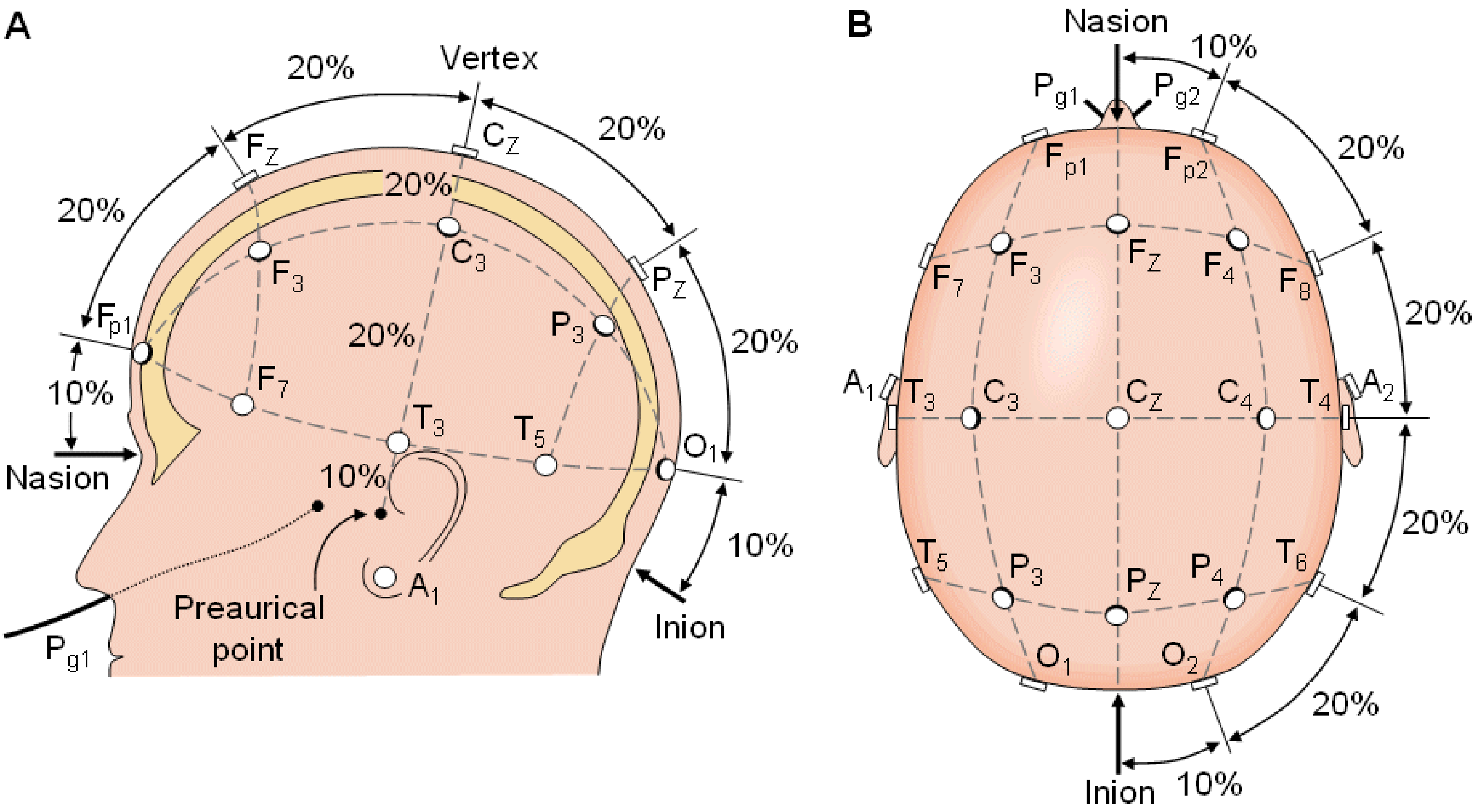


Elettrodi monouso



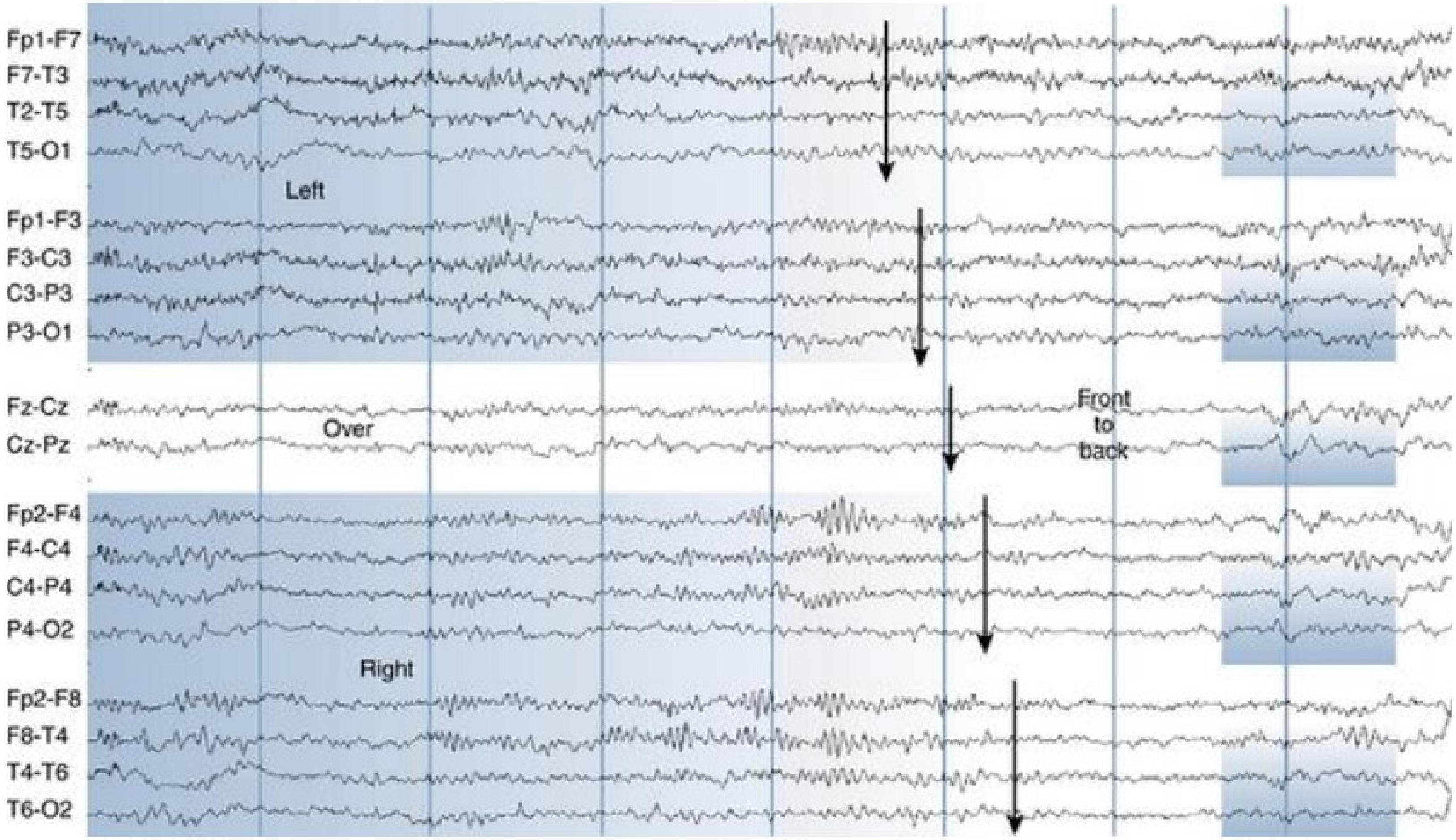
Elettrodi ad anello

Sistema internazionale 10/20


A
Vertex
20%
20%
20%
20%
20%
20%
10%
10%
10%
F_Z
C_Z
P_Z
F_{p1}
F_3
C_3
P_3
F_7
T_3
T_5
O_1
A_1
Nasion
Inion
Preaurical point
P_{g1}
B
Nasion
10%
P_{g1}
P_{g2}
F_{p1}
F_{p2}
20%
F_7
F_3
F_Z
F_4
F_8
20%
A_1
T_3
C_3
C_Z
C_4
T_4
A_2
20%
T_5
P_3
P_Z
P_4
T_6
O_1
O_2
20%
Inion
10%

Sistema internazionale 10/20

Esempio di segnale registrato


Fp1-F7
F7-T3
T2-T5
T5-O1
Left
Fp1-F3
F3-C3
C3-P3
P3-O1
Fz-Cz
Cz-Pz
Over
Front
to
back
Fp2-F4
F4-C4
C4-P4
P4-O2
Right
Fp2-F8
F8-T4
T4-T6
T6-O2

Configurazione referenziale

Ogni canale misura ed amplifica la differenza tra un elettrodo applicato sullo scalpo del paziente (sito elettricamente attivo) e l'elettrodo di riferimento (sito elettricamente neutro, es. punta del naso, lobo dell'orecchio, ...)

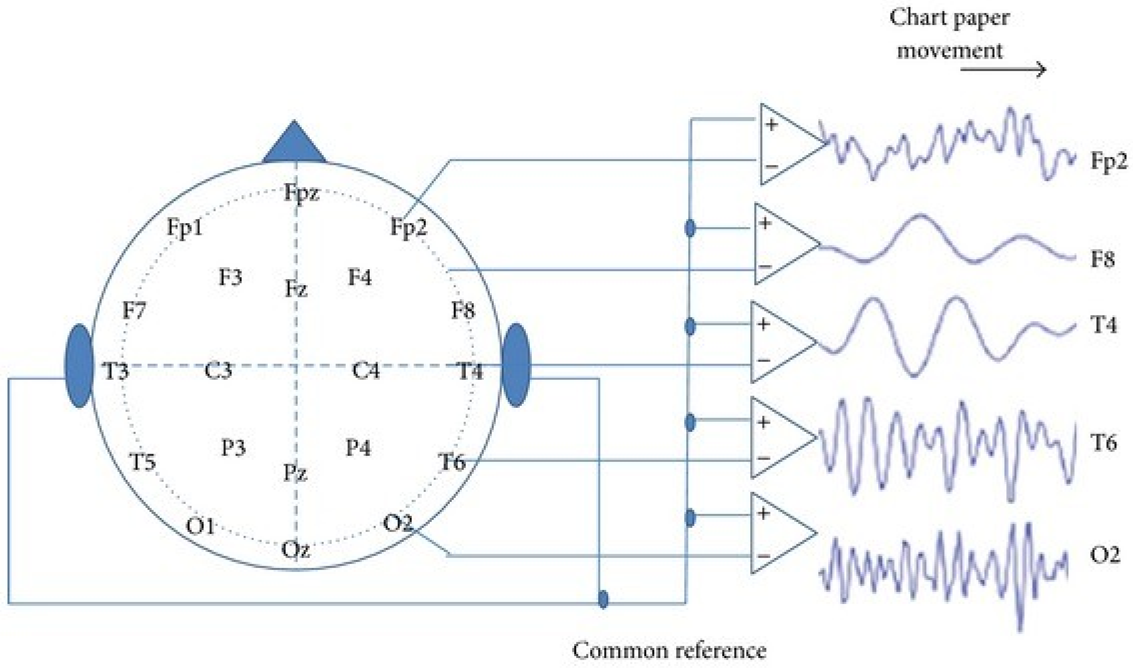
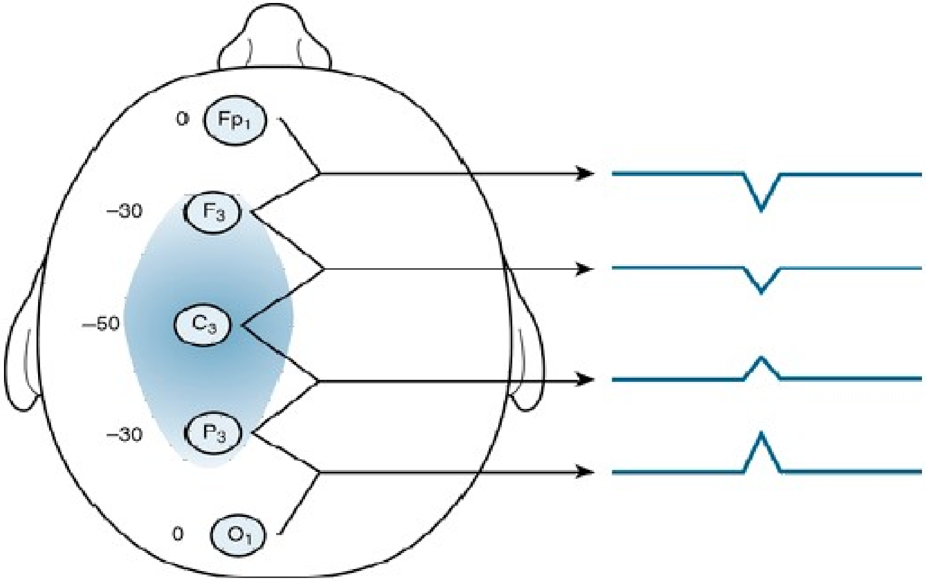


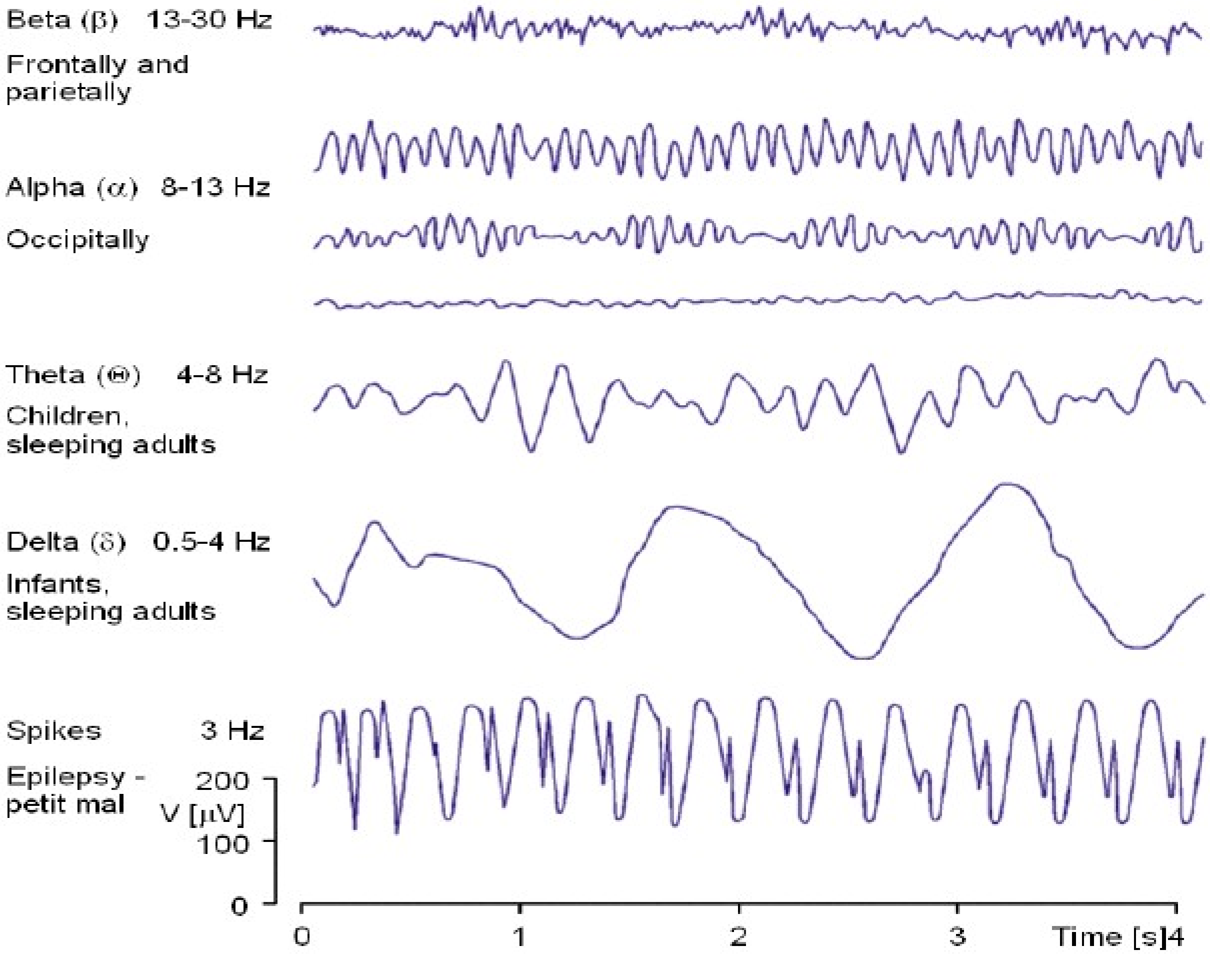
Chart paper movement
Fpz
Fp1
Fp2
F3
Fz
F4
F7
F8
T3
C3
C4
T4
T5
P3
Pz
P4
T6
O1
Oz
O2
+
–
Fp2
F8
T4
T6
O2
Common reference

Configurazione bipolare

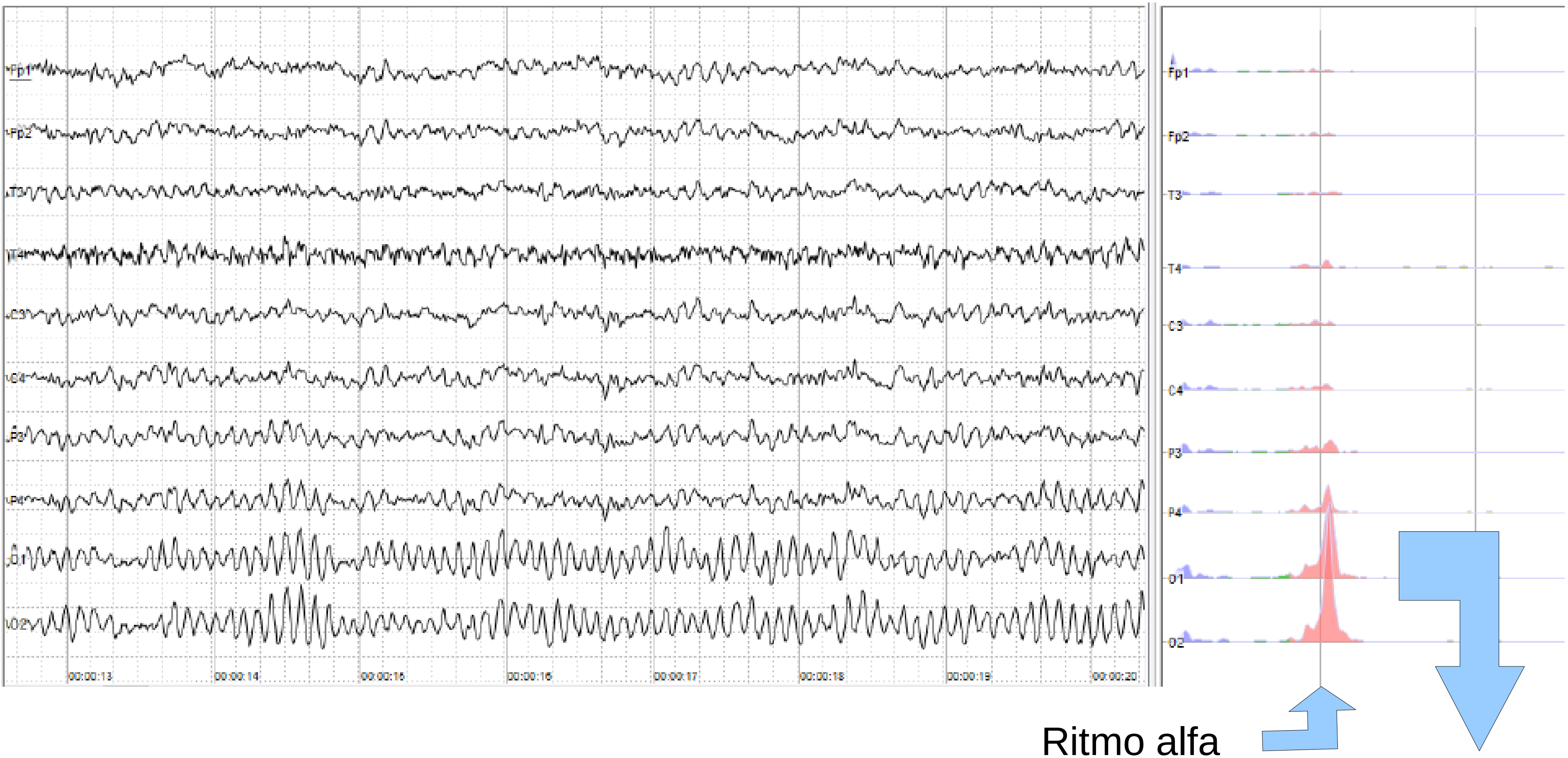
Ogni canale misura ed amplifica la differenza tra elettrodi adiacenti, entrambi applicati sullo scalpo del paziente (su siti elettricamente attivi).



Ritmi elettroencefalografici



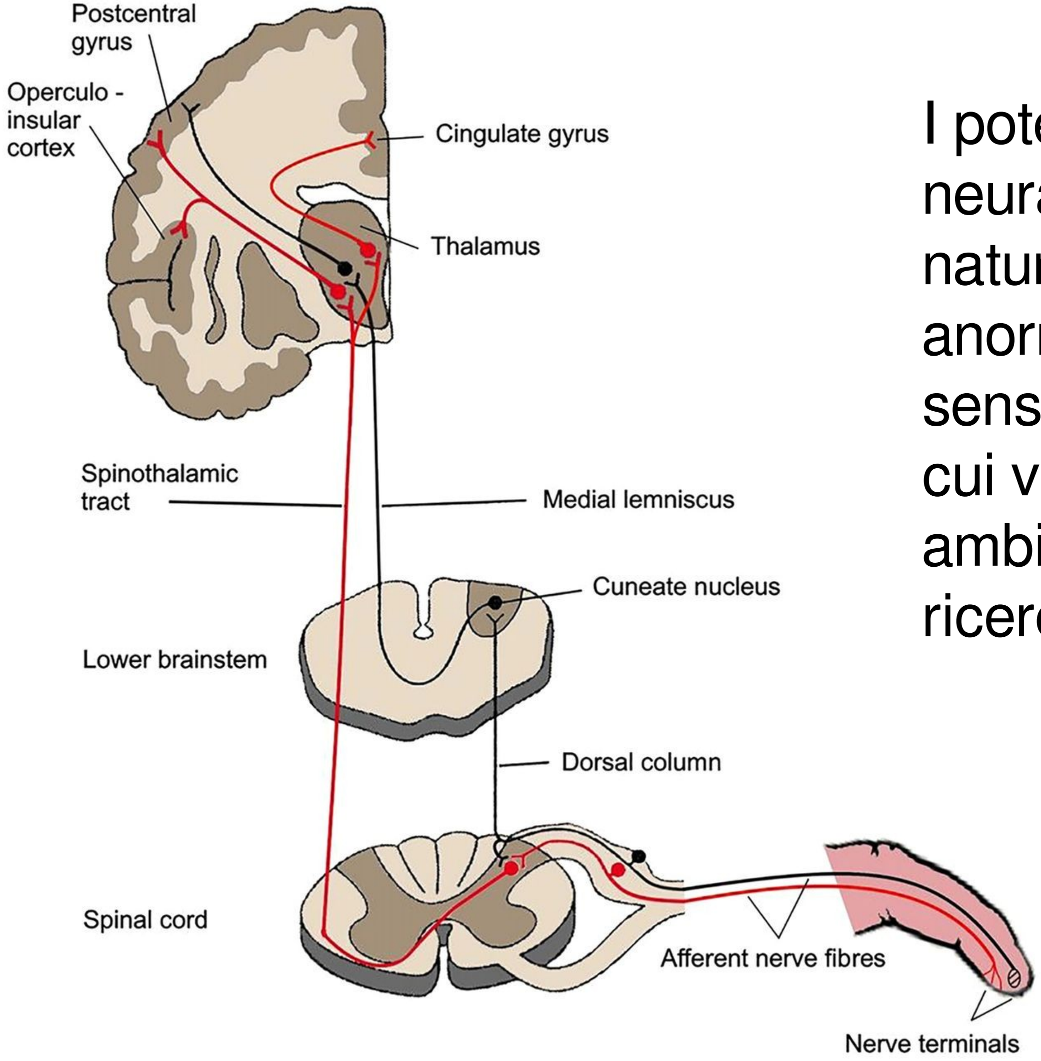
Ritmi elettroencefalografici


Fp1
Fp2
T3
T4
C3
C4
P3
P4
O1
O2
00:00:13
00:00:14
00:00:15
00:00:16
00:00:17
00:00:18
00:00:19
00:00:20

Ritmo alfa

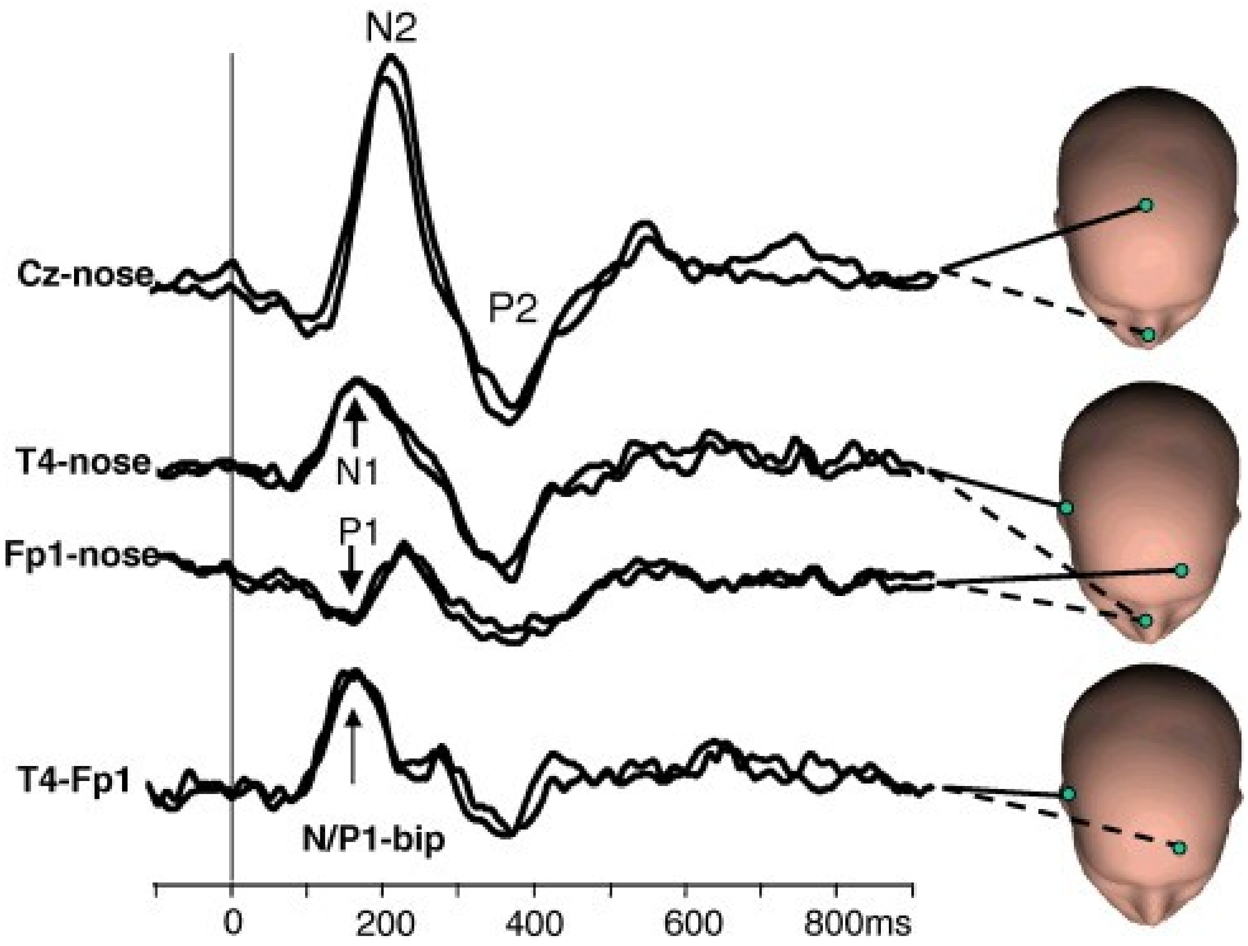
Regione occipitale destra

Potenziale evocato

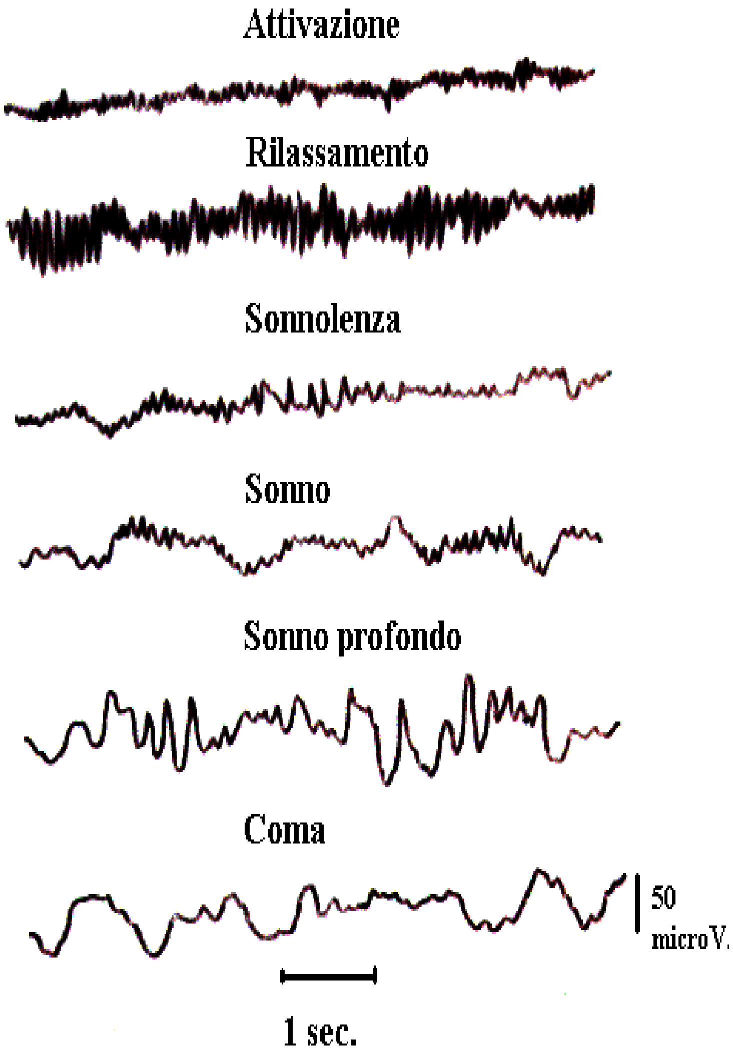

Postcentral gyrus
Operculo - insular cortex
Cingulate gyrus
Thalamus
Spinothalamic tract
Medial lemniscus
Cuneate nucleus
Lower brainstem
Dorsal column
Spinal cord
Afferent nerve fibres
Nerve terminals

I potenziali evocati sono risposte neurali legati a stimoli di varia natura. Sono degli indicatori di anormalità nel sensore sensoriale e motorio, motivo per cui vengono utilizzate sia in ambito clinico che in ambito di ricerca.

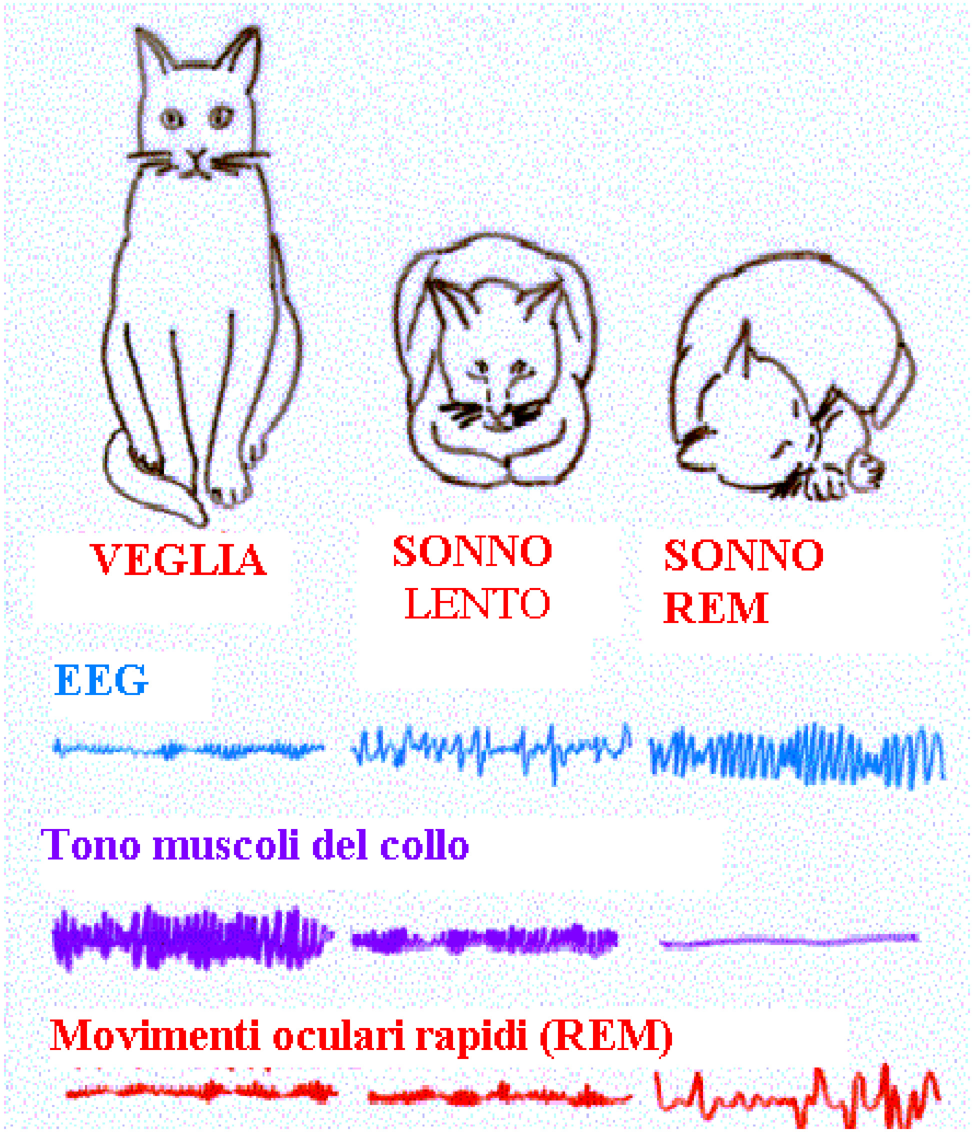
Potenziale evocato



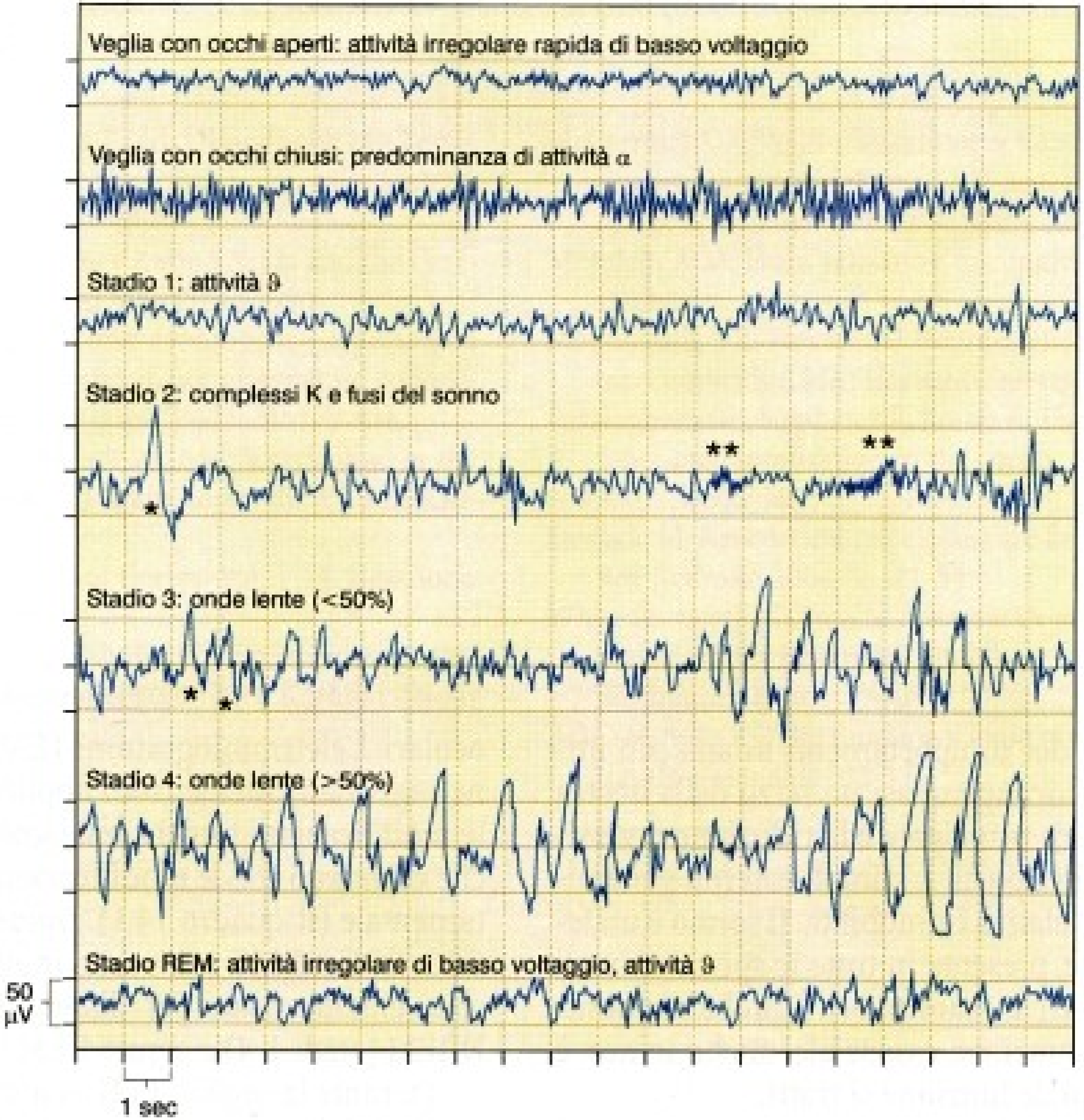
Sonno


Attivazione
Rilassamento
Sonnolenza
Sonno
Sonno profondo
Coma
50 microV.
1 sec.

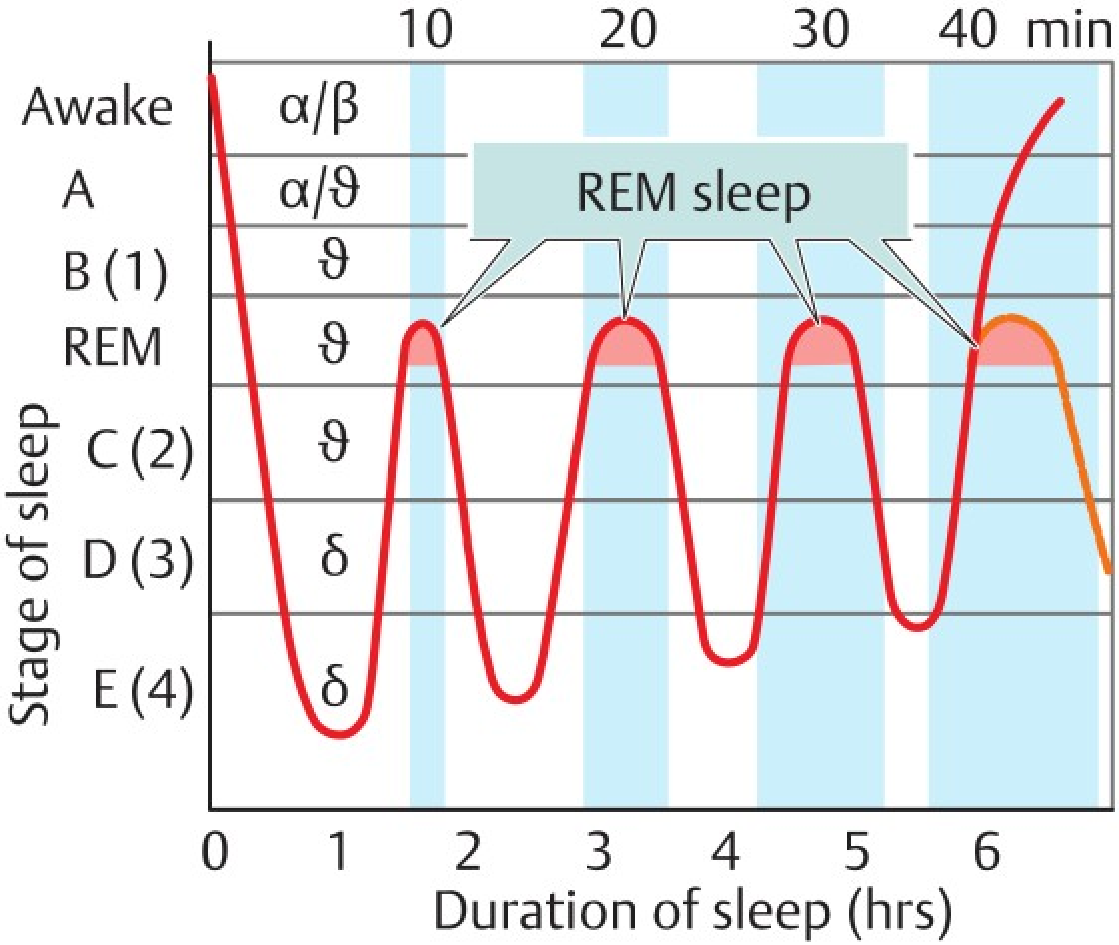
Sonno


VEGLIA
SONNO LENTO
SONNO REM
EEG
Tono muscoli del collo
Movimenti oculari rapidi (REM)

Sonno

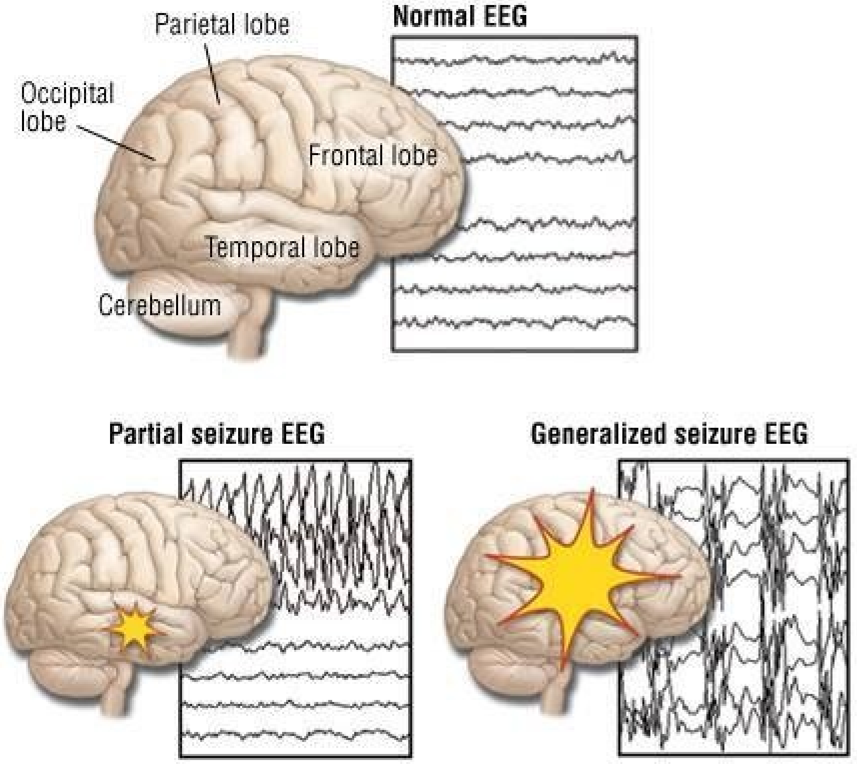

Veglia con occhi aperti: attività irregolare rapida di basso voltaggio
Veglia con occhi chiusi: predominanza di attività α
Stadio 1: attività ϑ
Stadio 2: complessi K e fusi del sonno
*
**
**
Stadio 3: onde lente (<50%)
*
*
Stadio 4: onde lente (>50%)
Stadio REM: attività irregolare di basso voltaggio, attività ϑ
50 µV
1 sec

Sonno

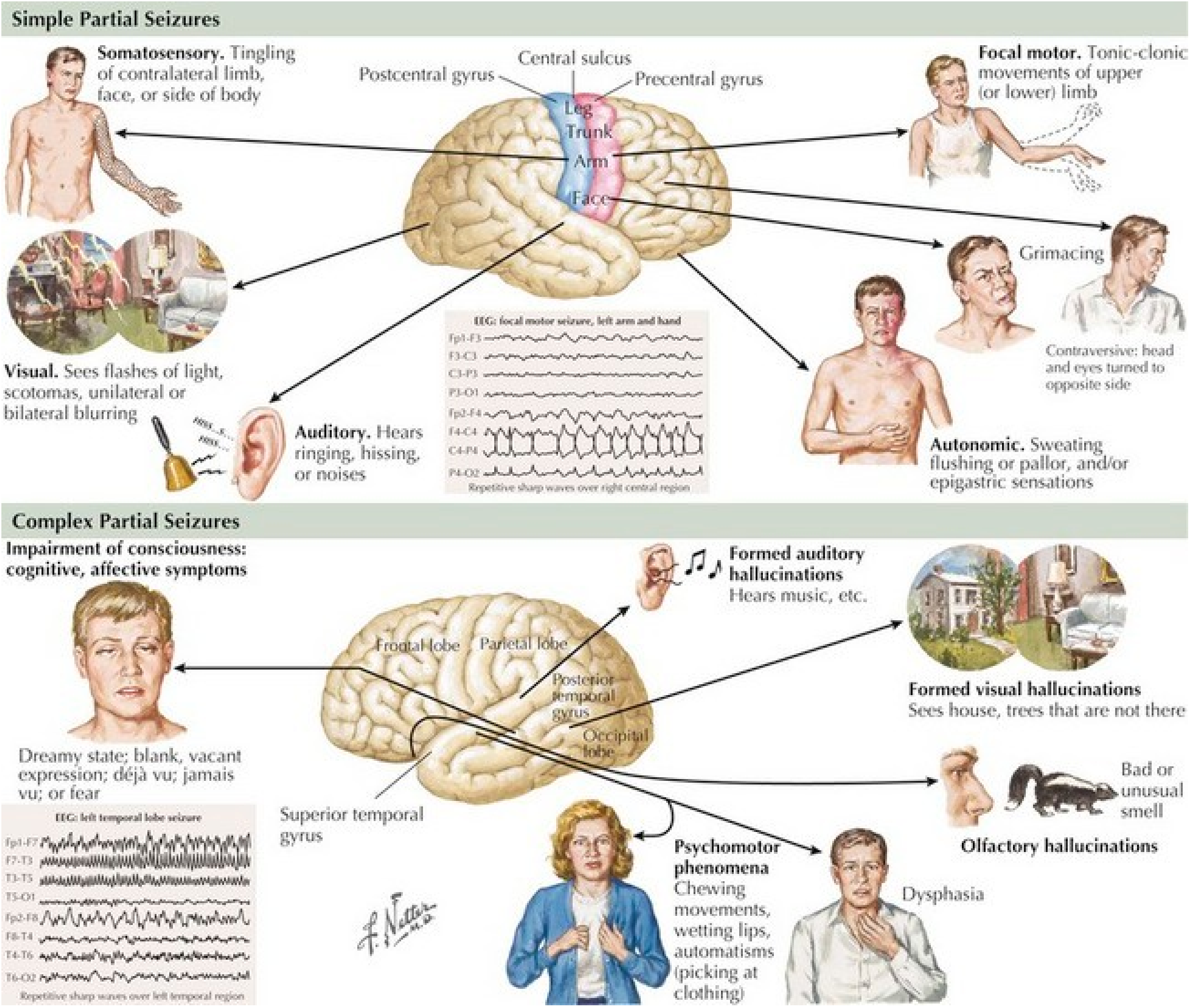

10
20
30
40 min
Awake
α/β
A
α/ϑ
B (1)
ϑ
REM
ϑ
C (2)
ϑ
D (3)
δ
E (4)
δ
Stage of sleep
REM sleep
0
1
2
3
4
5
6
Duration of sleep (hrs)

Epilessia

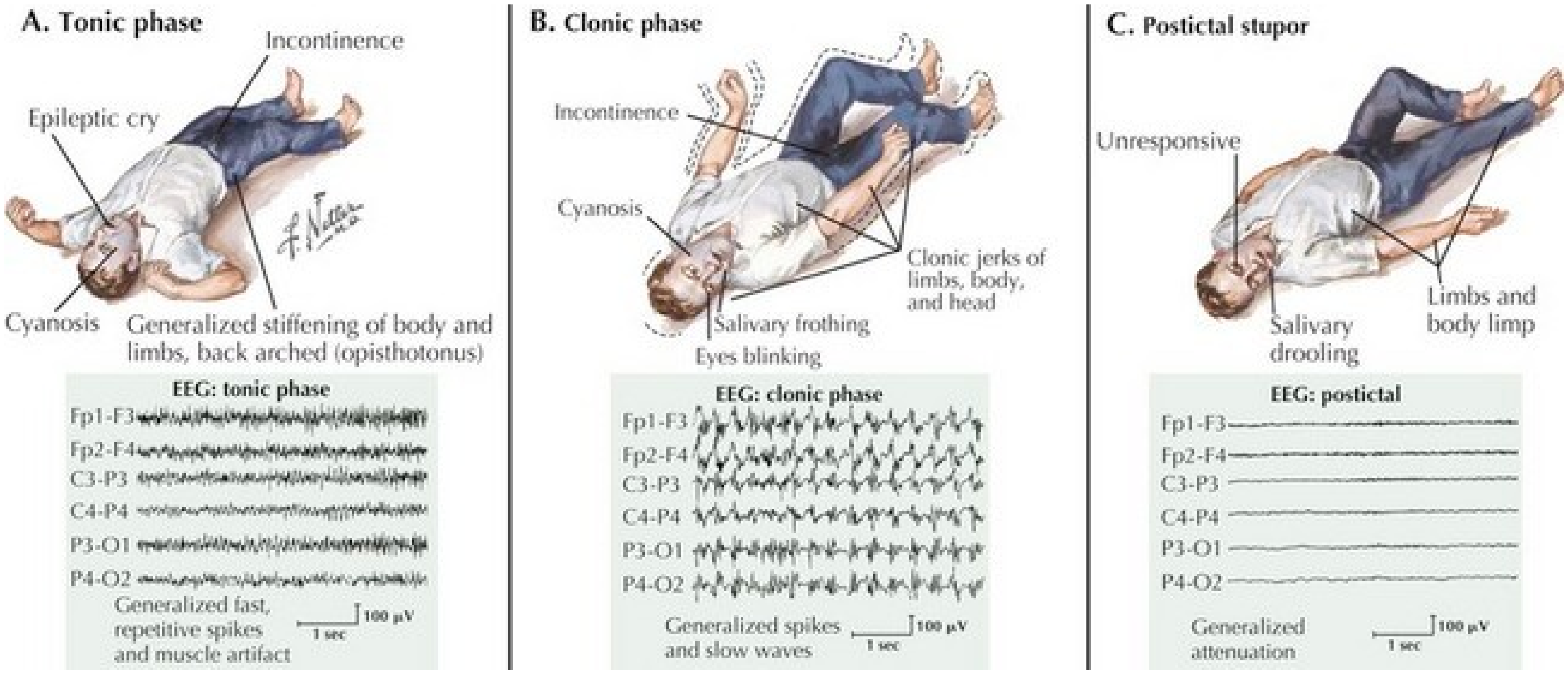
L’epilessia è caratterizzata da un’eccessiva attività incontrollata di una parte o dell’intero cervello. In questo caso, si parla di epilessia parziale o di epilessia generalizzata, rispettivamente.


Parietal lobe
Normal EEG
Occipital lobe
Frontal lobe
Temporal lobe
Cerebellum
Partial seizure EEG
Generalized seizure EEG

Epilessia – crisi parziale


Simple Partial Seizures
Somatosensory. Tingling of contralateral limb, face, or side of body
Postcentral gyrus
Central sulcus
Precentral gyrus
Leg
Trunk
Arm
Face
Focal motor. Tonic-clonic movements of upper (or lower) limb
Grimacing
Contraversive: head and eyes turned to opposite side
Visual. Sees flashes of light, scotomas, unilateral or bilateral blurring
Auditory. Hears ringing, hissing, or noises
EEG: focal motor seizure, left arm and hand
Fp1-F3
F3-C3
C3-P3
P3-O1
Fp2-F4
F4-C4
C4-P4
P4-O2
Repetitive sharp waves over right central region
Autonomic. Sweating flushing or pallor, and/or epigastric sensations
Complex Partial Seizures
Impairment of consciousness: cognitive, affective symptoms
Formed auditory hallucinations Hears music, etc.
Frontal lobe
Parietal lobe
Posterior temporal gyrus
Occipital lobe
Formed visual hallucinations Sees house, trees that are not there
Dreamy state; blank, vacant expression; déjà vu; jamais vu; or fear
EEG: left temporal lobe seizure
Fp1-F7
F7-T3
T3-T5
T5-O1
Fp2-F8
F8-T4
T4-T6
T6-O2
Repetitive sharp waves over left temporal region
Superior temporal gyrus
F. Netter M.D.
Bad or unusual smell
Olfactory hallucinations
Psychomotor phenomena Chewing movements, wetting lips, automatisms (picking at clothing)
Dysphasia

Epilessia – crisi generalizzate


A. Tonic phase
Incontinence
Epileptic cry
Cyanosis
Generalized stiffening of body and limbs, back arched (opisthotonus)
EEG: tonic phase
Fp1-F3
Fp2-F4
C3-P3
C4-P4
P3-O1
P4-O2
Generalized fast, repetitive spikes and muscle artifact
100 µV
1 sec
B. Clonic phase
Incontinence
Cyanosis
Clonic jerks of limbs, body, and head
Salivary frothing
Eyes blinking
EEG: clonic phase
Fp1-F3
Fp2-F4
C3-P3
C4-P4
P3-O1
P4-O2
Generalized spikes and slow waves
100 µV
1 sec
C. Postictal stupor
Unresponsive
Salivary drooling
Limbs and body limp
EEG: postictal
Fp1-F3
Fp2-F4
C3-P3
C4-P4
P3-O1
P4-O2
Generalized attenuation
100 µV
1 sec

Grand mal (convulsiva), petit mal (non convulsiva)

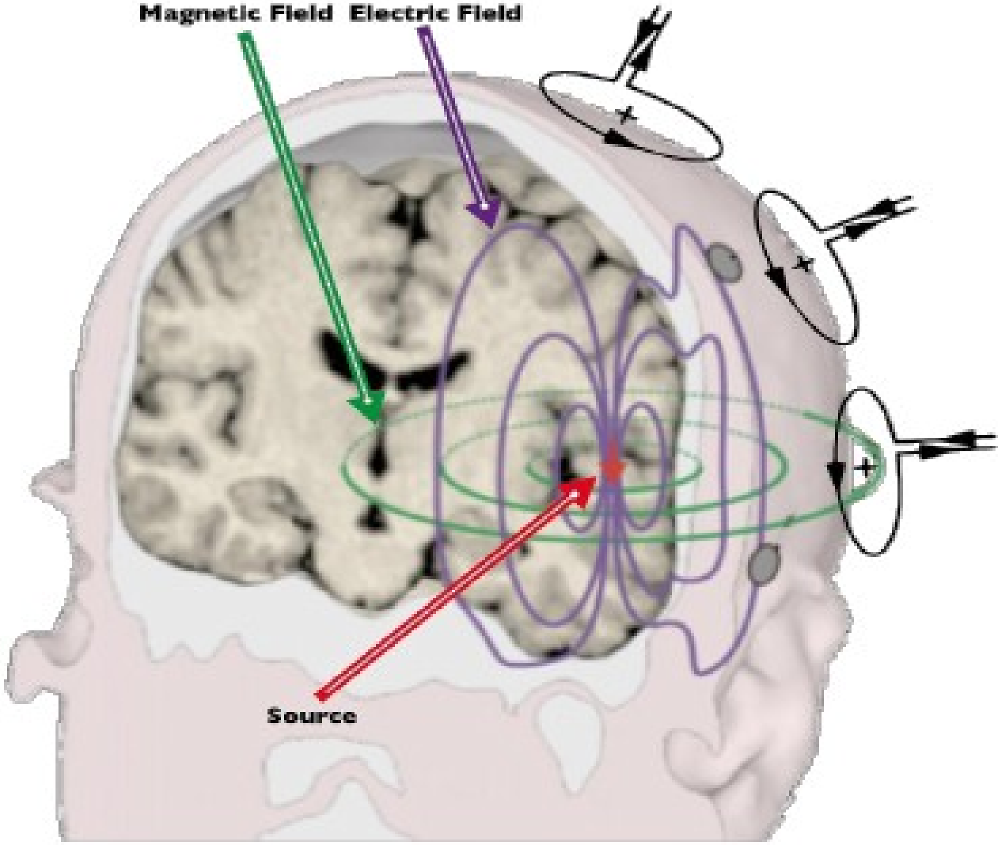
Magnetoencefalogramma (MEG)

Magnetoencefalogramma (MEG)

La magnetoencefalografia (MEG) è un sistema diagnostico di imaging che misura la variazioni temporali dei campi magnetici legati all'attività cerebrale.

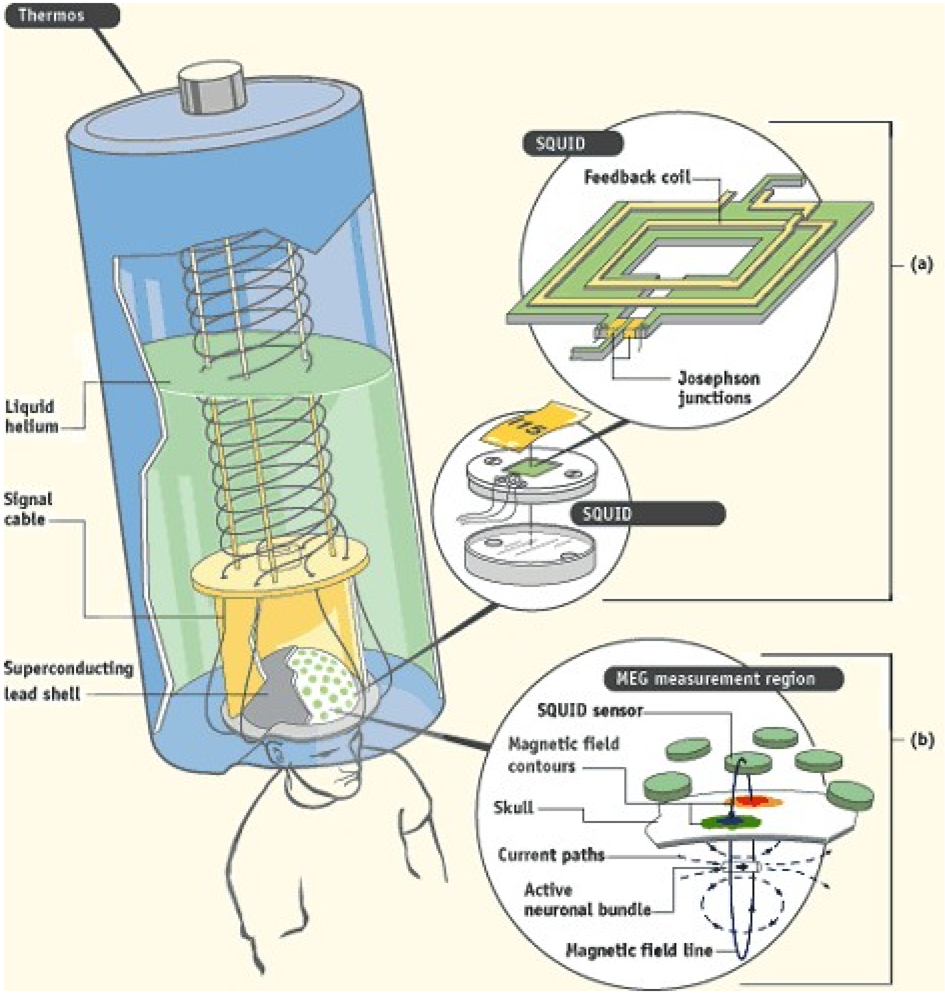
Magnetoencefalogramma (MEG)

Magnetoencefalogramma (MEG)

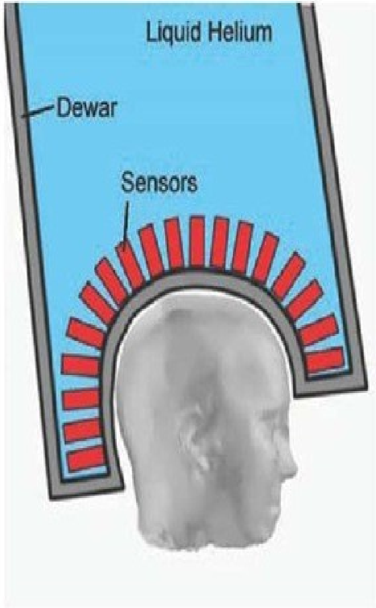

Magnetic Field
Electric Field
Source

Sorgenti

Magnetoencefalogramma (MEG)

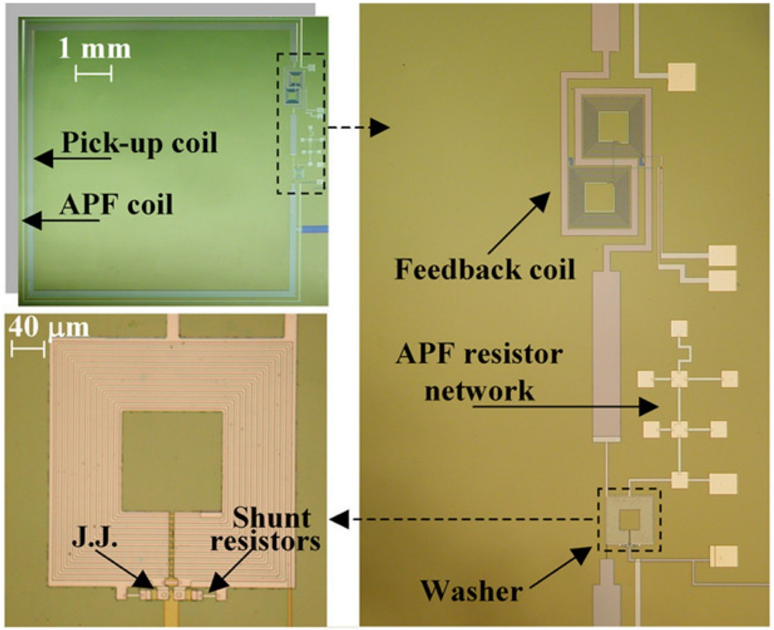

Thermos
SQUID
Feedback coil
(a)
Josephson junctions
Liquid helium
Signal cable
SQUID
Superconducting lead shell
MEG measurement region
SQUID sensor
Magnetic field contours
Skull
Current paths
Active neuronal bundle
Magnetic field line
(b)

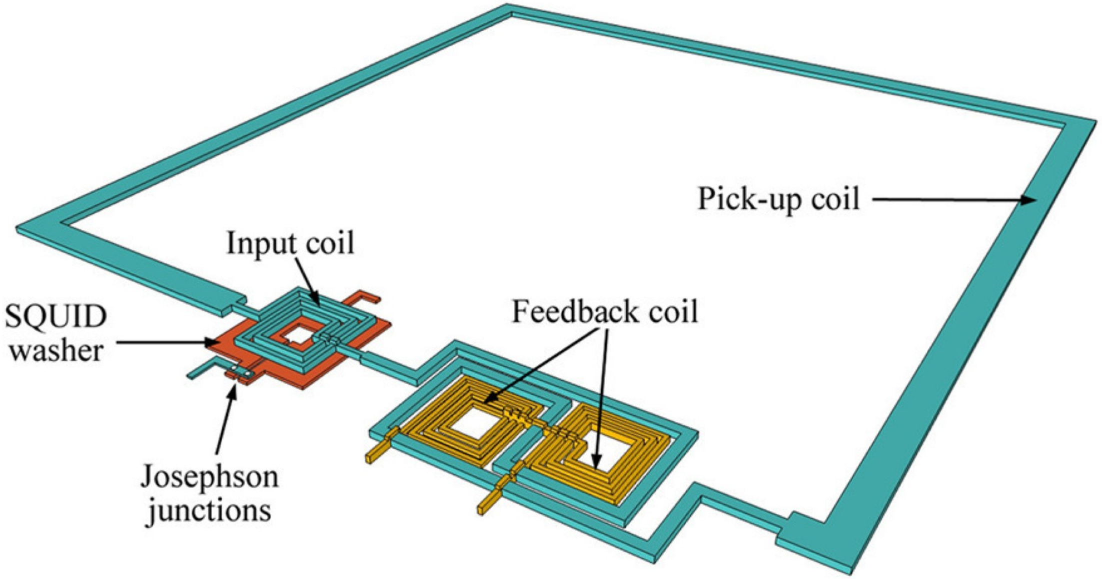
Magnetoencefalogramma (MEG)


Liquid Helium
Dewar
Sensors

Per funzionare il sistema richiede temperature molto basse.
Per questo motivo si riempie il dewar di elio liquido (t<-269°C).

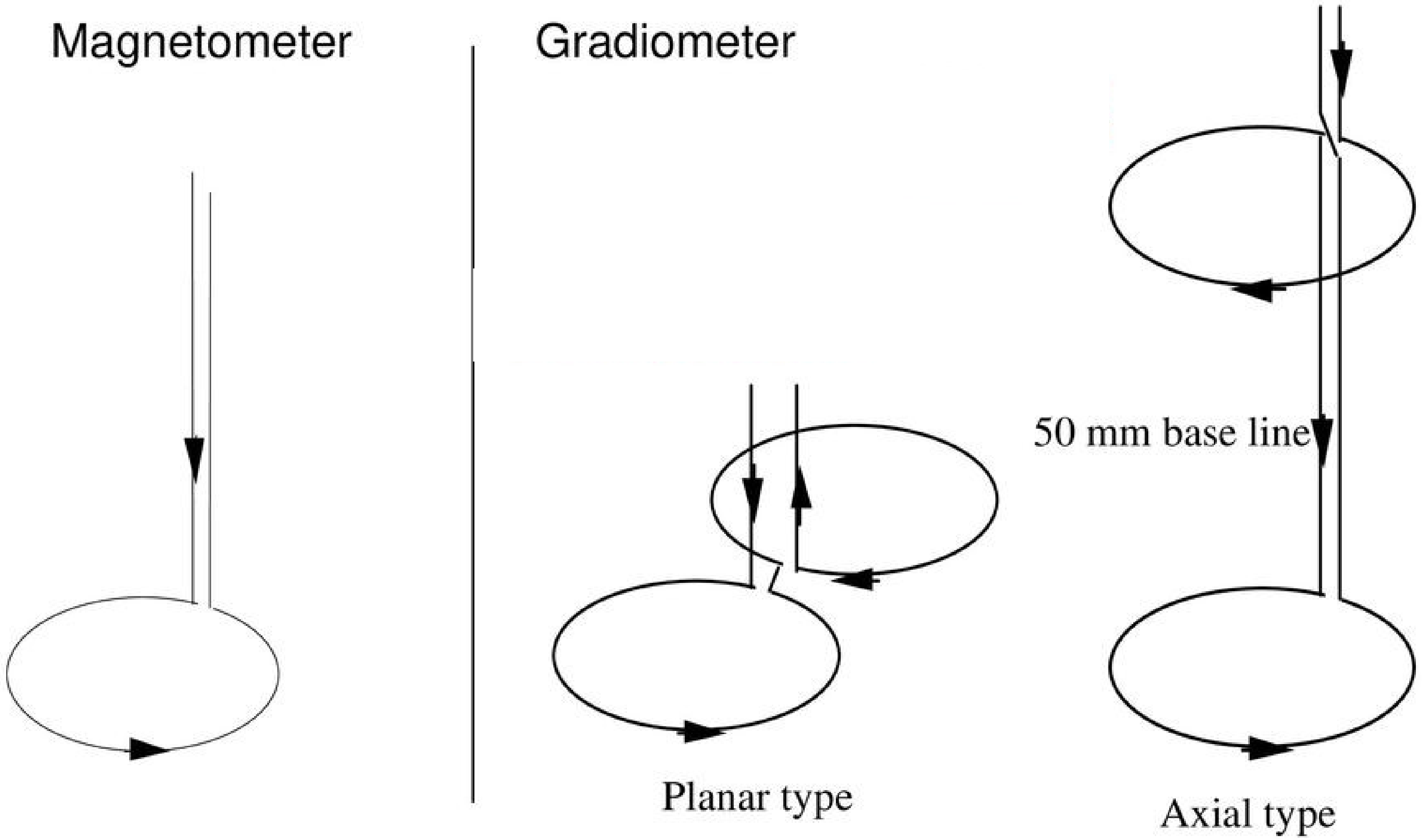
Sensori


1 mm
Pick-up coil
APF coil
40 µm
J.J.
Shunt resistors
Feedback coil
APF resistor network
Washer

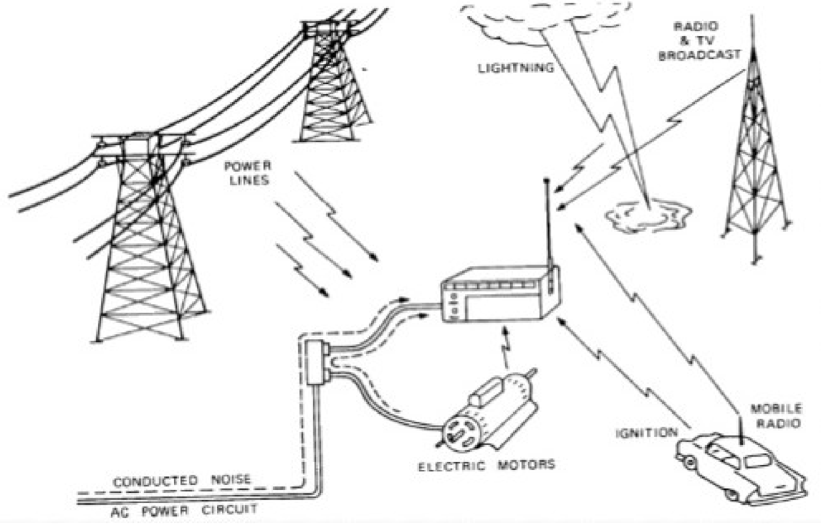

Pick-up coil
Input coil
SQUID washer
Feedback coil
Josephson junctions

SQUID - Superconductor Quantum Interference Devices

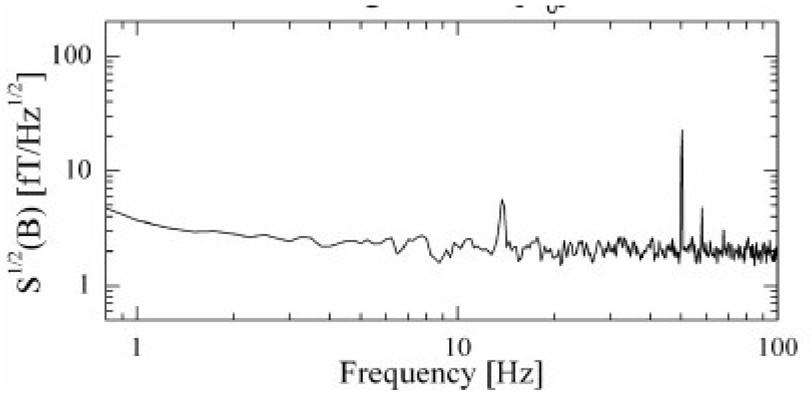
Sensori


Magnetometer
Gradiometer
50 mm base line
Planar type
Axial type

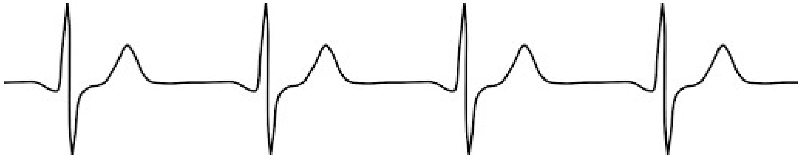
Rumore


RADIO
& TV
BROADCAST
LIGHTNING
POWER
LINES
MOBILE
RADIO
IGNITION
ELECTRIC MOTORS
CONDUCTED NOISE
AC POWER CIRCUIT

Ambientale

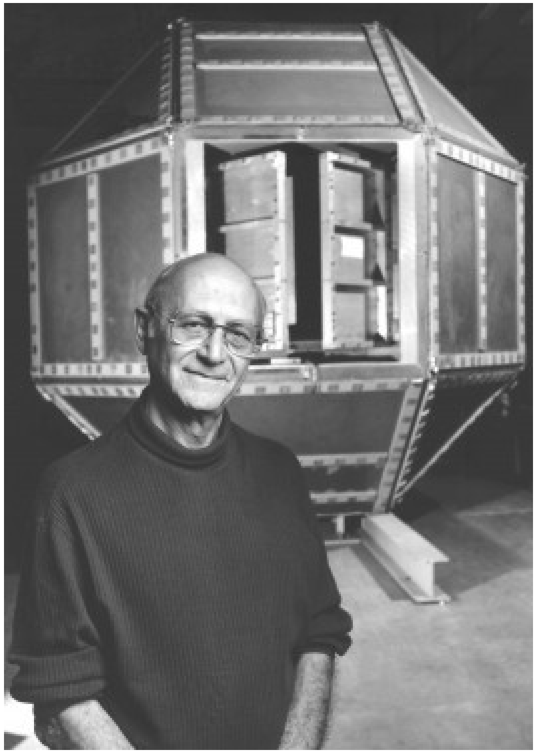


Sensori



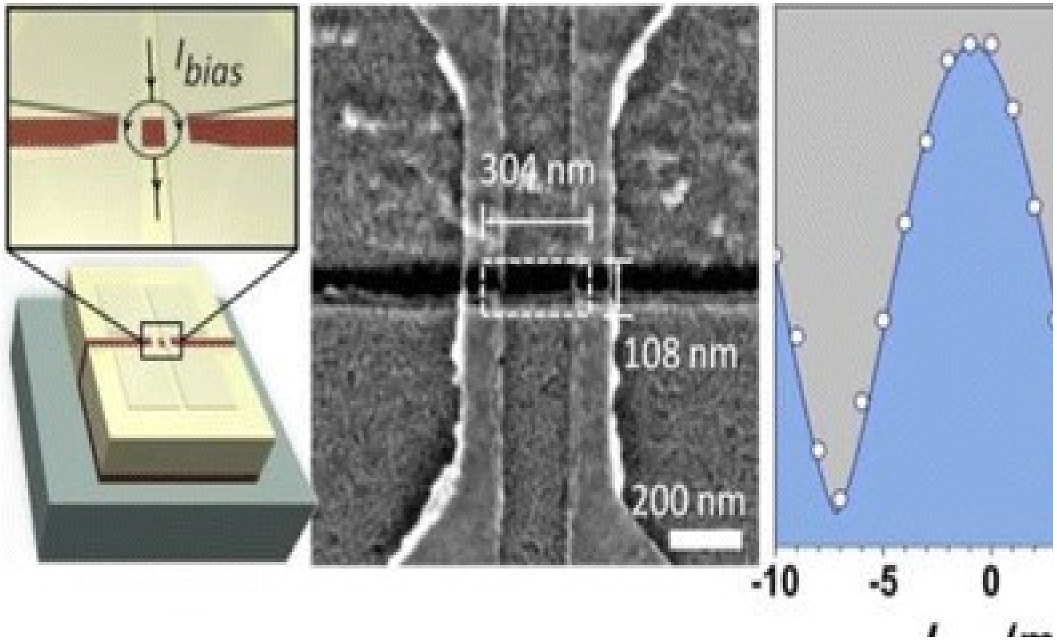
Fisiologico

Rumore ambientale - Schermaggio



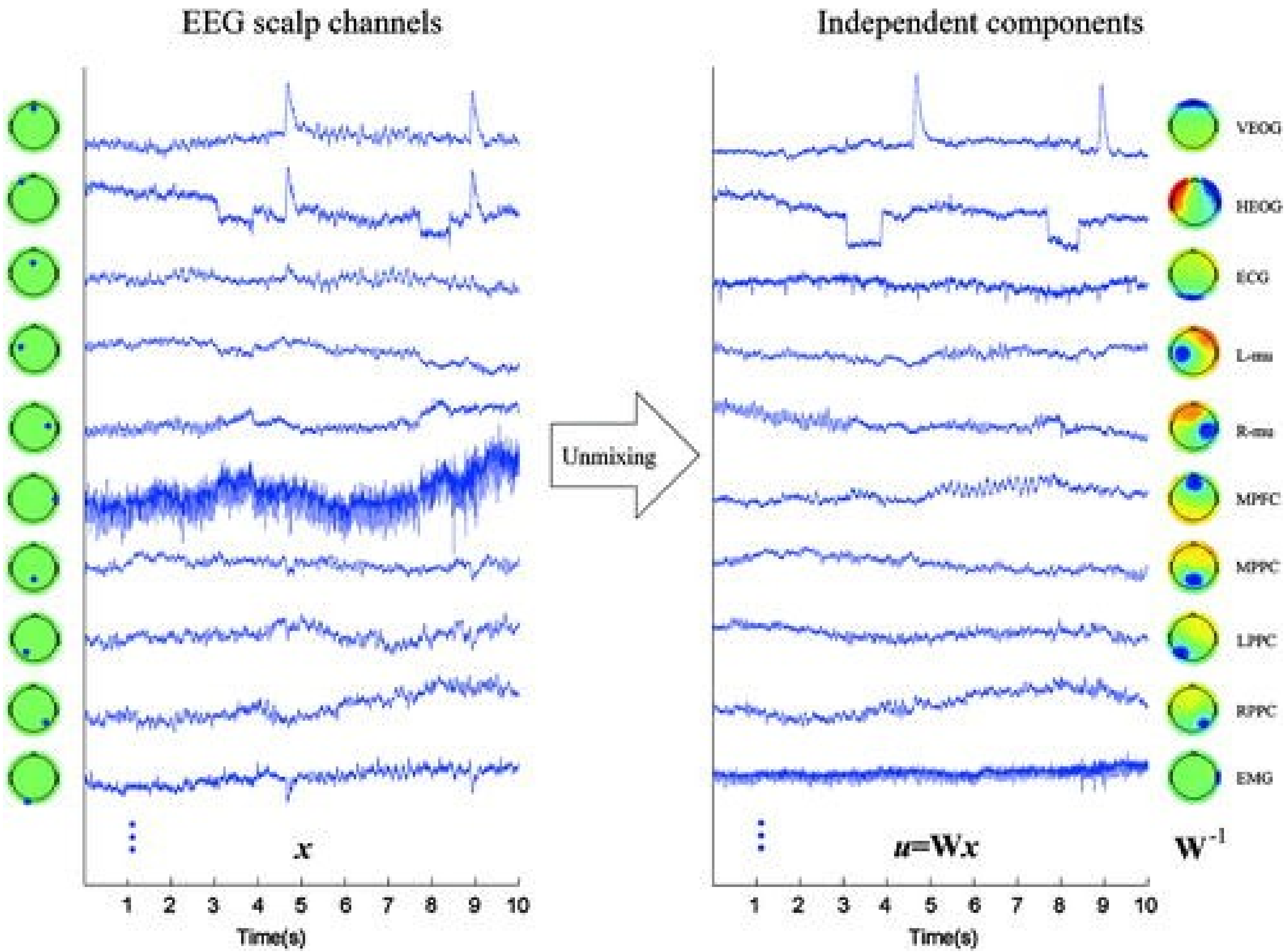
David Cohen,
MIT, 1969.

Rumore dei sensori

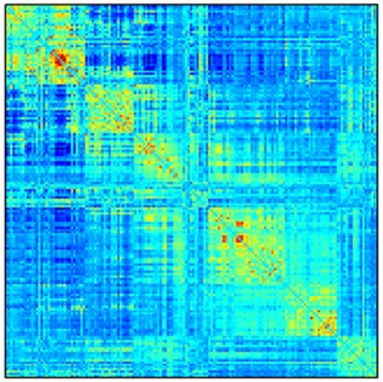

I_{bias}
304 nm
108 nm
200 nm
-10
-5
0

SQUID di nuova generazione (es. 3D).

Rumore fisiologico - Algoritmi



Catena di elaborazione

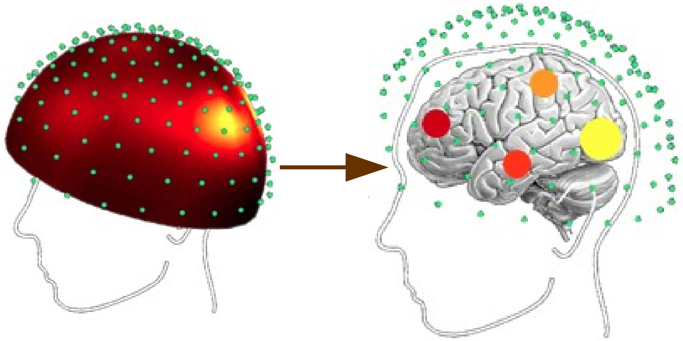


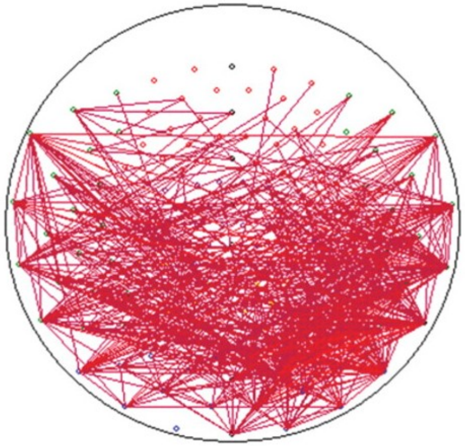
Data
Acquisition

Focusing

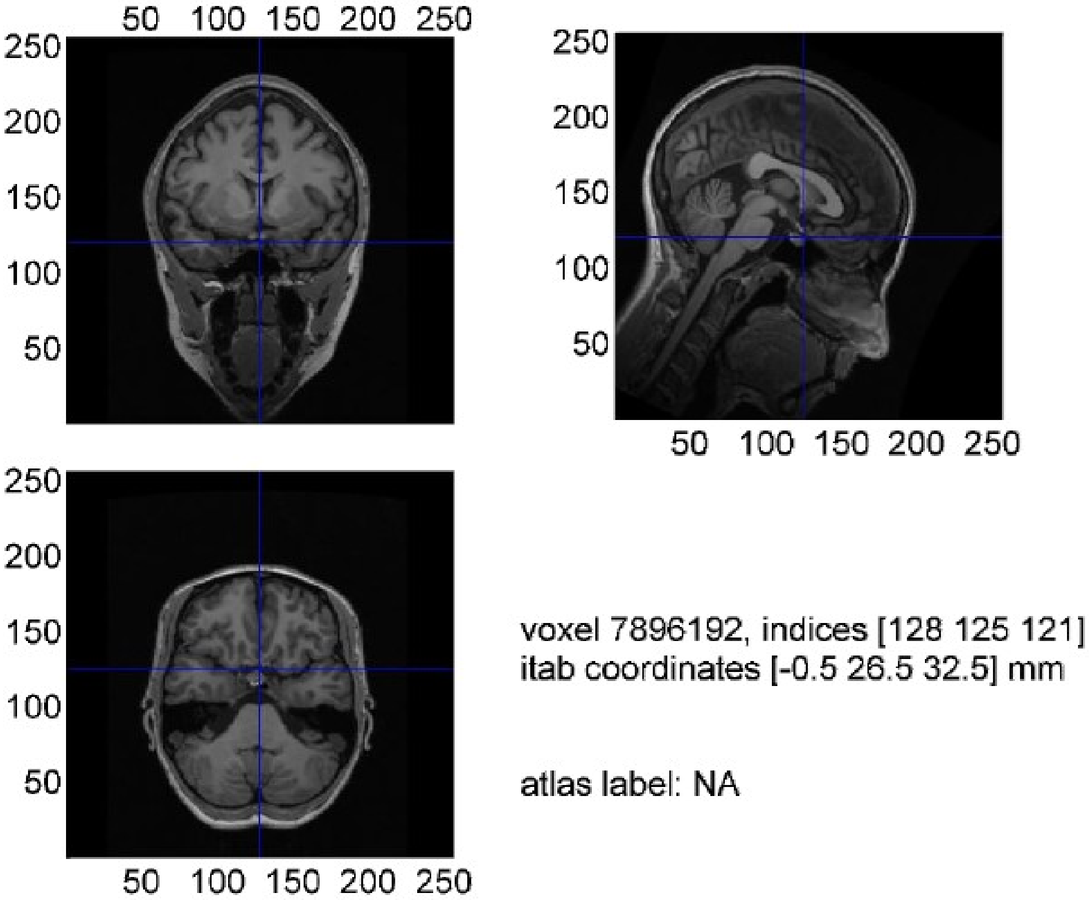
Connectivity
measurement

Graph
analysis



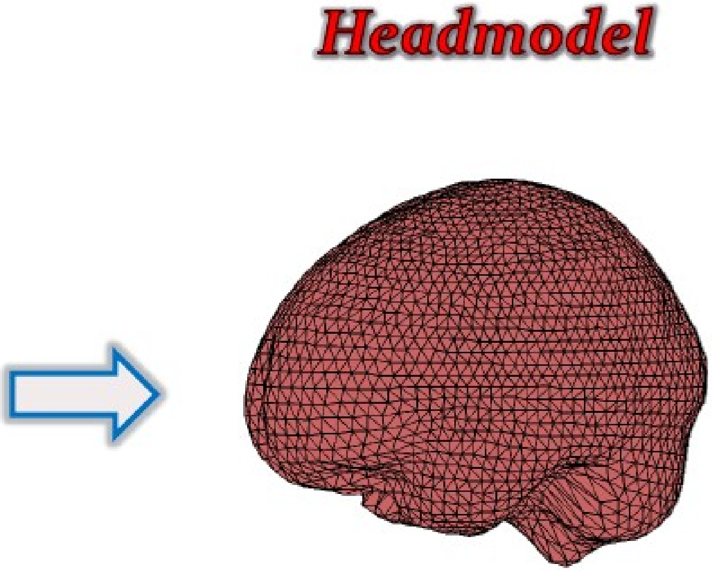


Catena di elaborazione

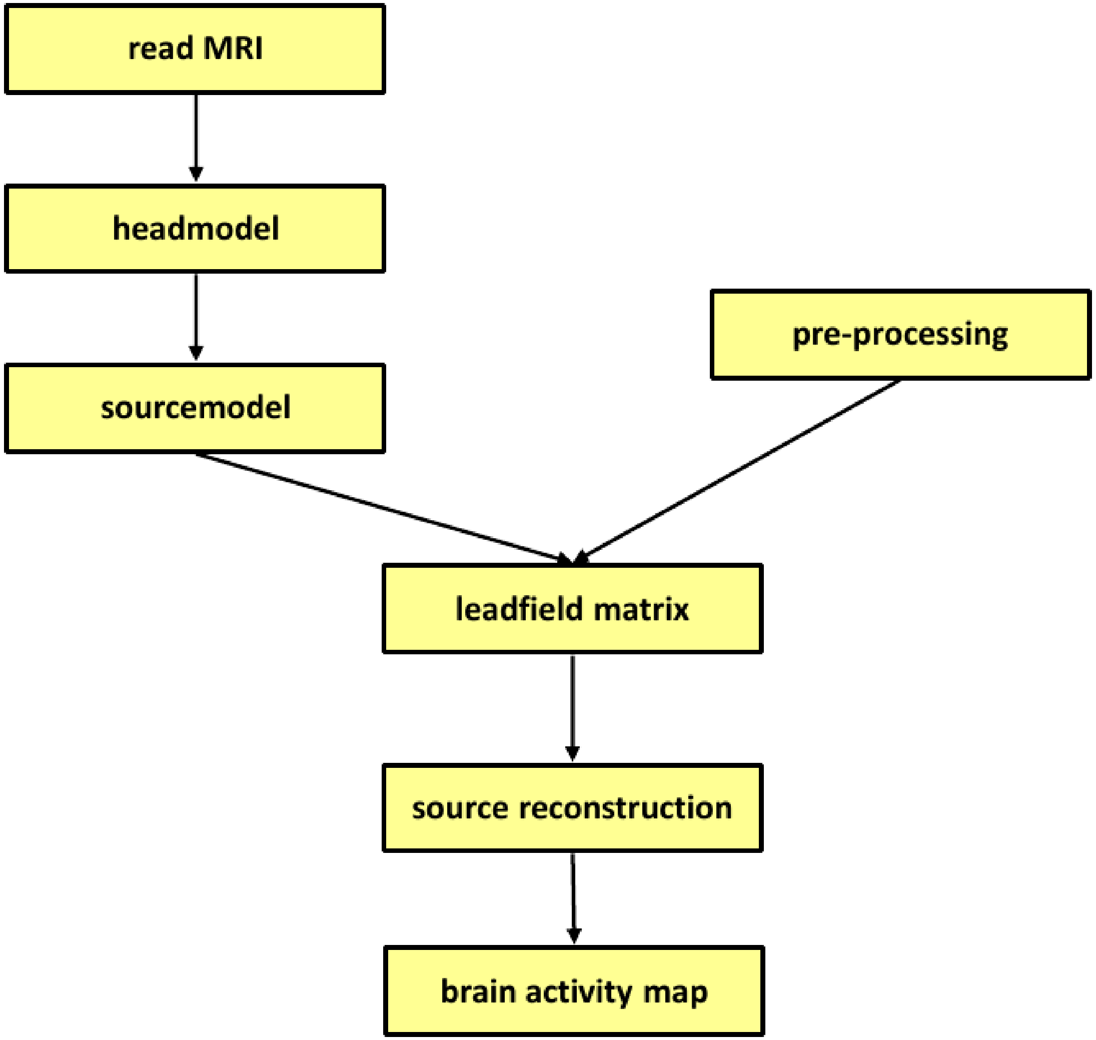

50 100 150 200 250
250
200
150
100
50

voxel 7896192, indices [128 125 121]
itab coordinates [-0.5 26.5 32.5] mm

atlas label: NA



Catena di elaborazione



read MRI

headmodel

sourcemodel

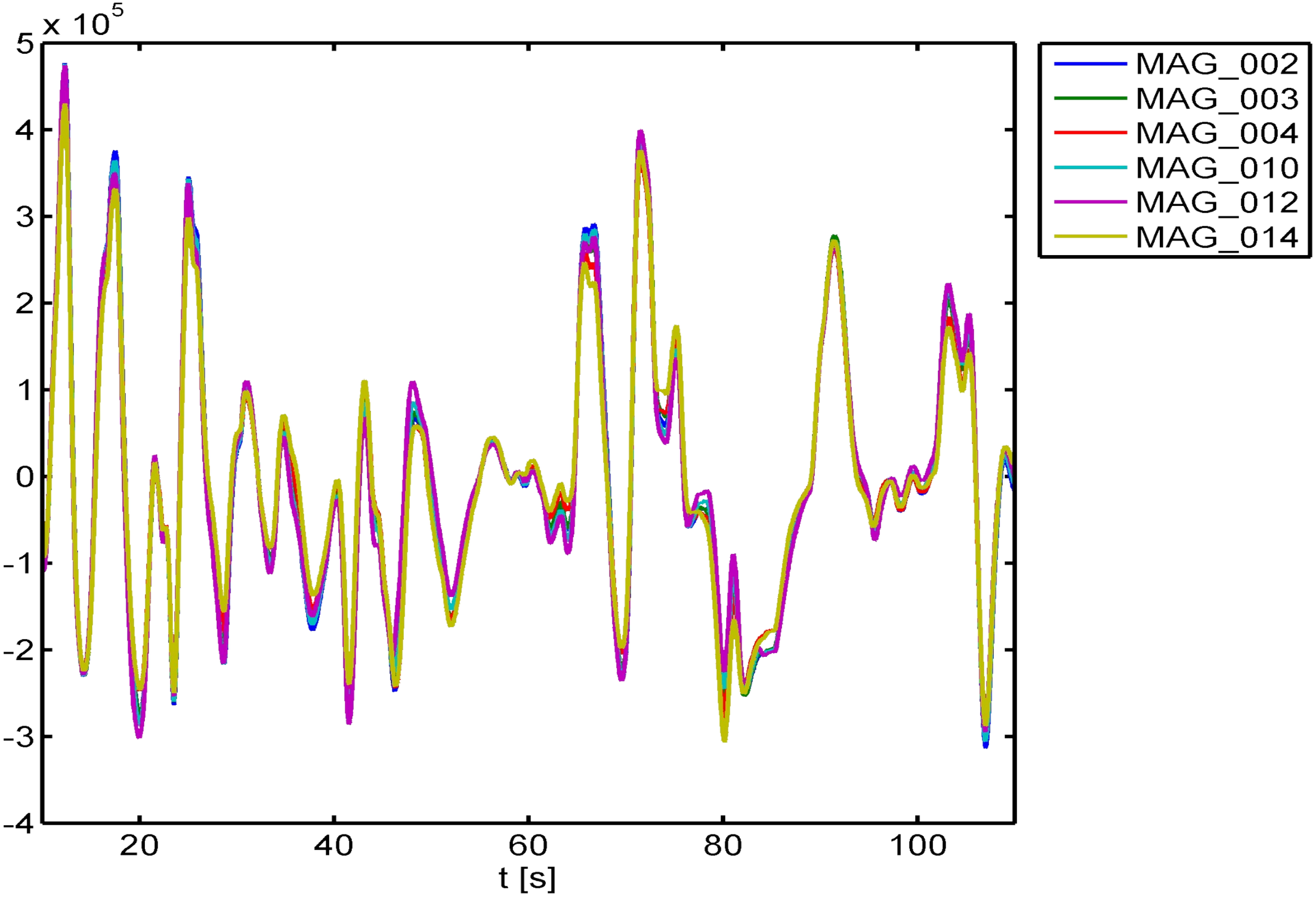
pre-processing

leadfield matrix

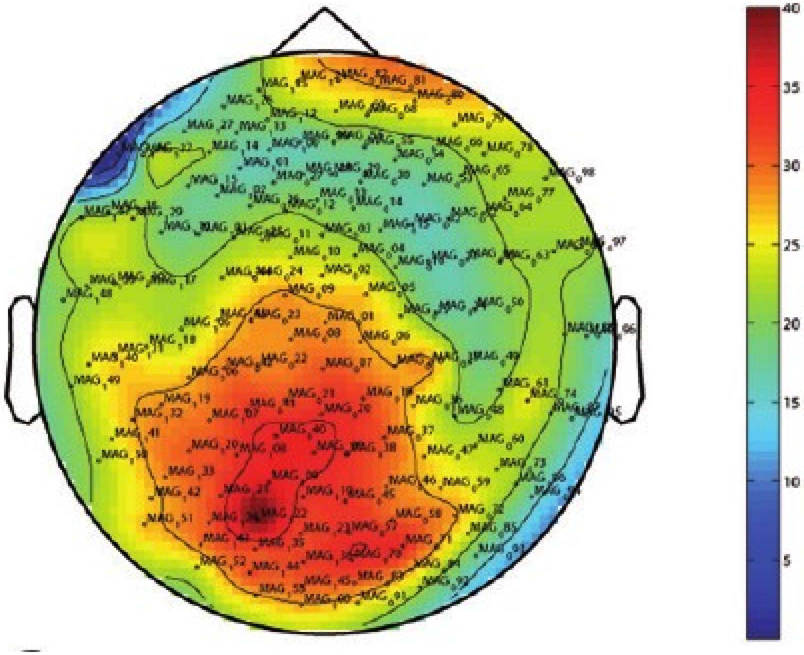
source reconstruction

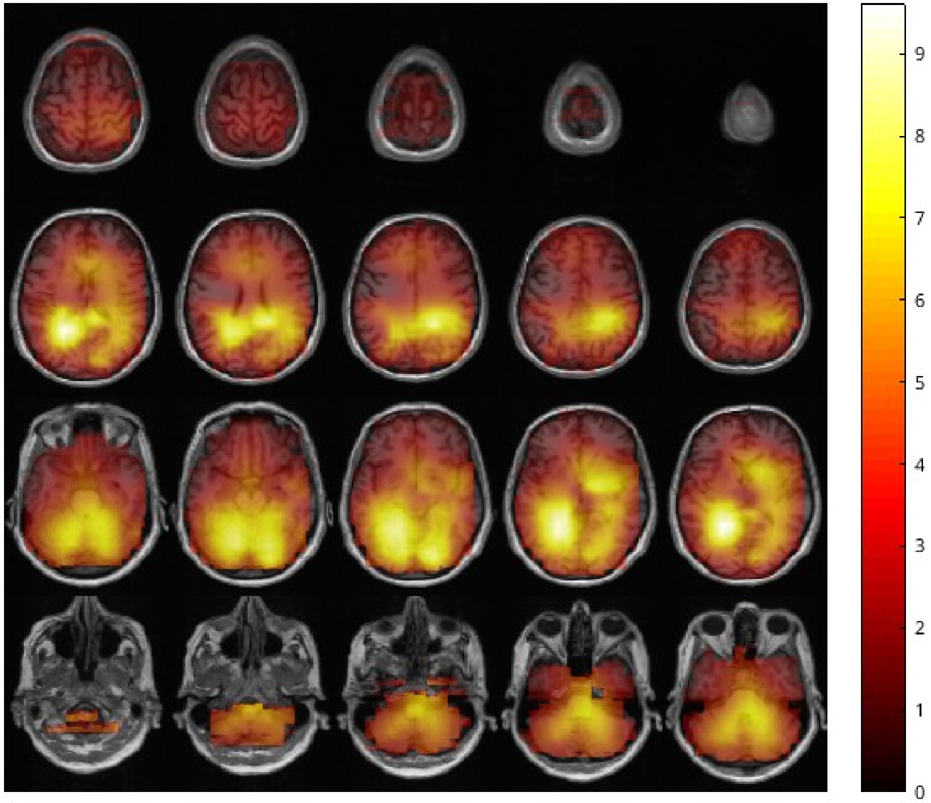
brain activity map

Catena di elaborazione

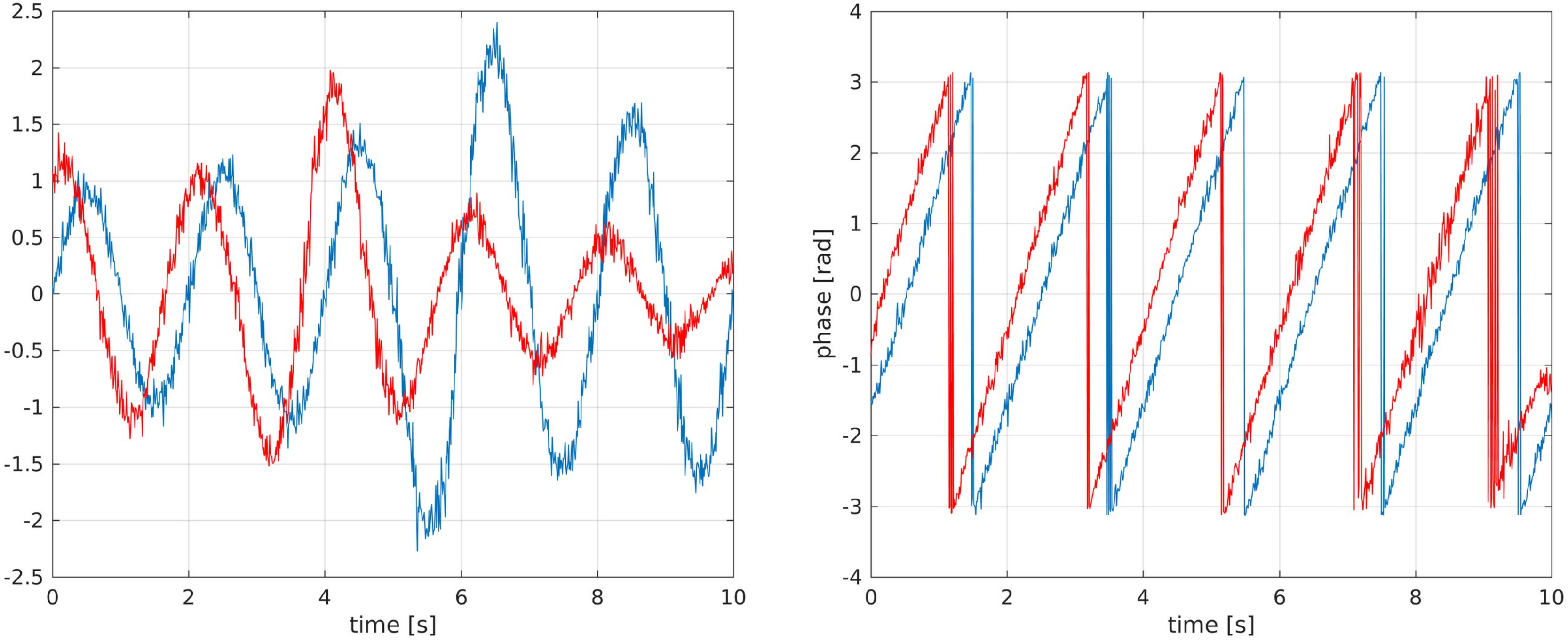


Catena di elaborazione

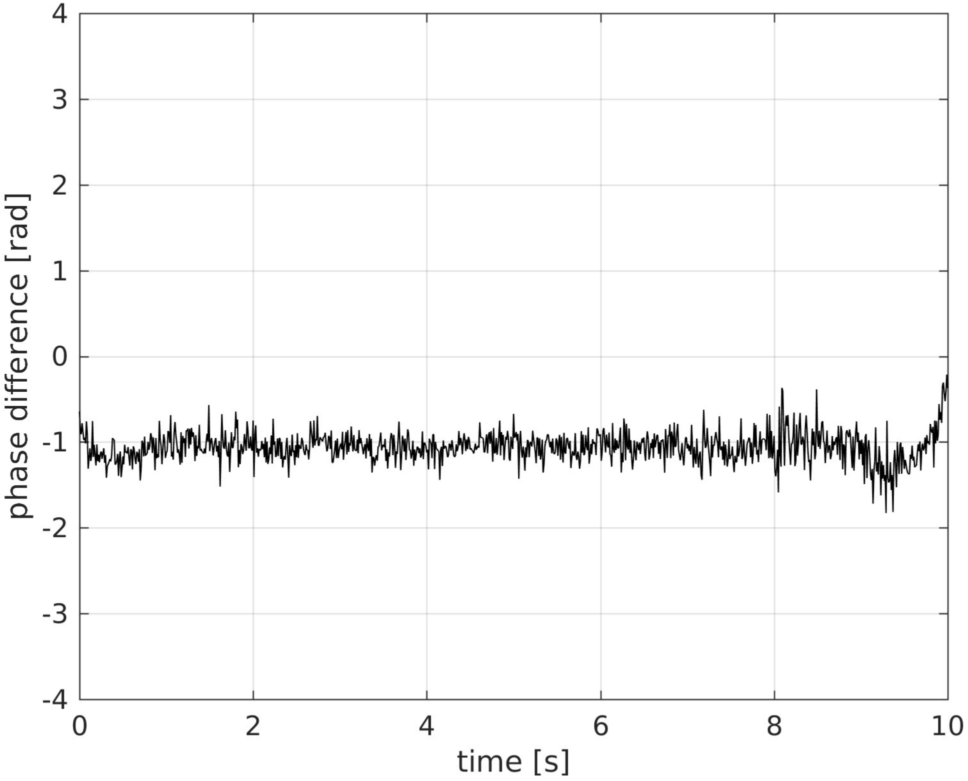



9
8
7
6
5
4
3
2
1
0

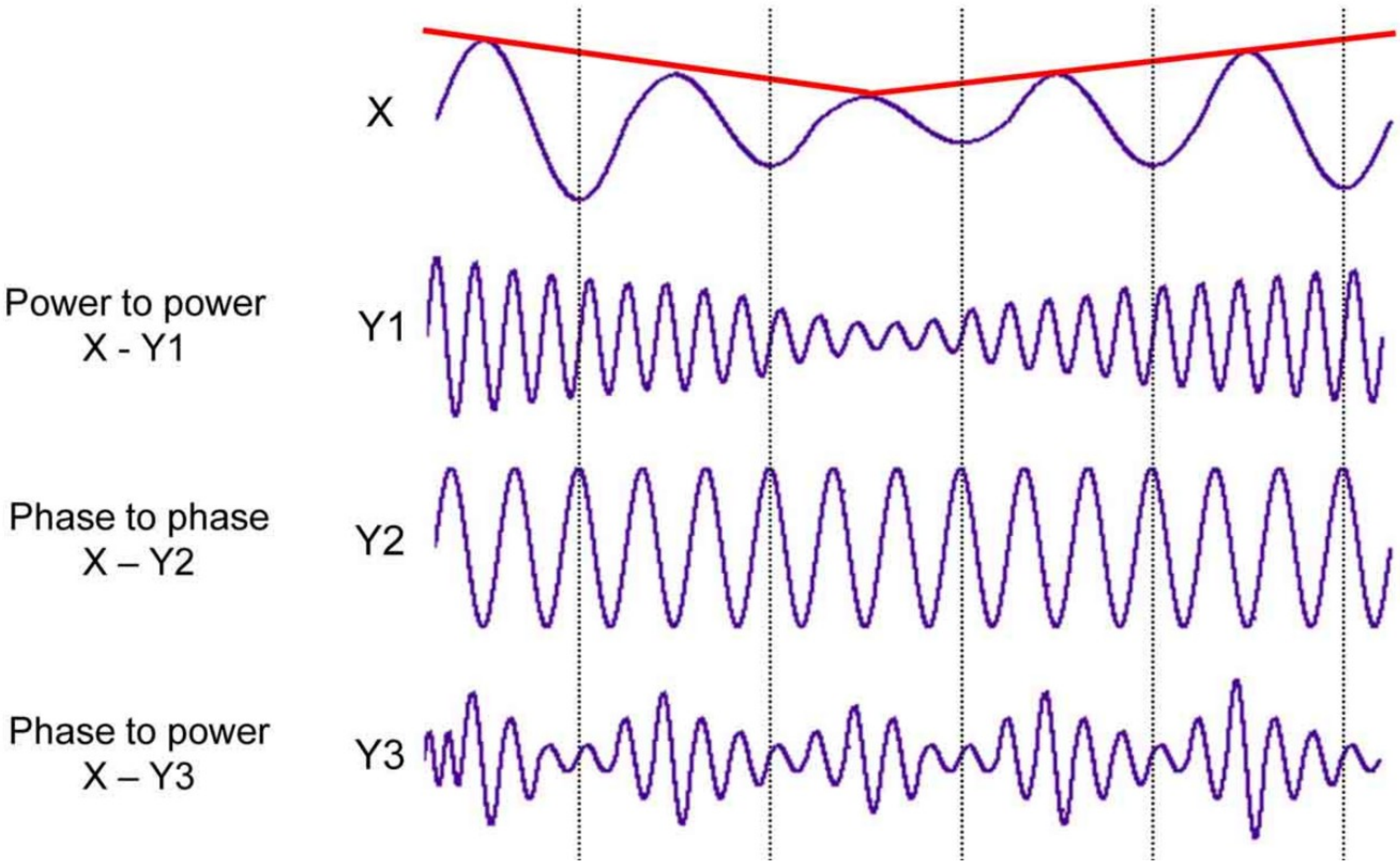
Accoppiamento



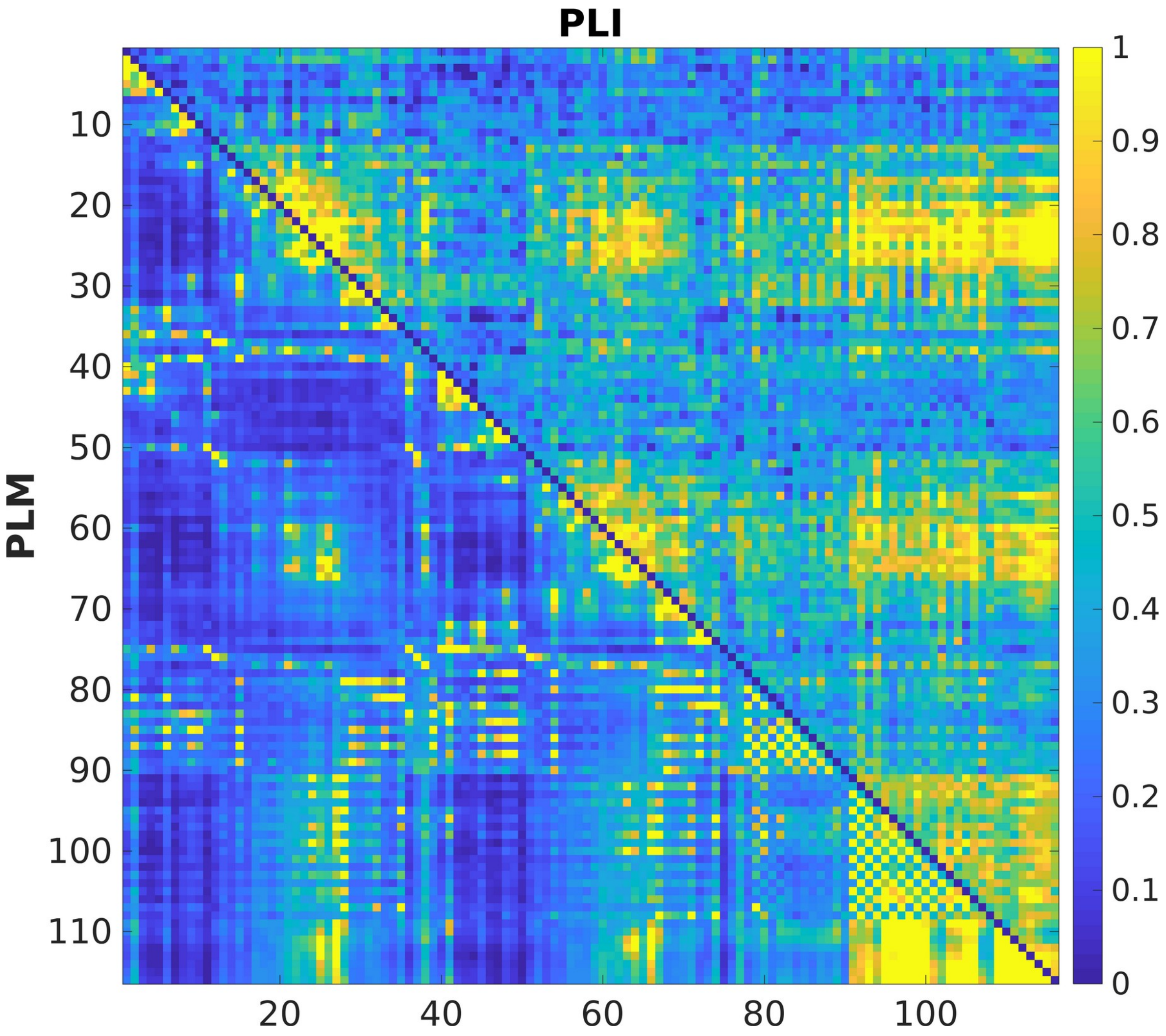
Accoppiamento



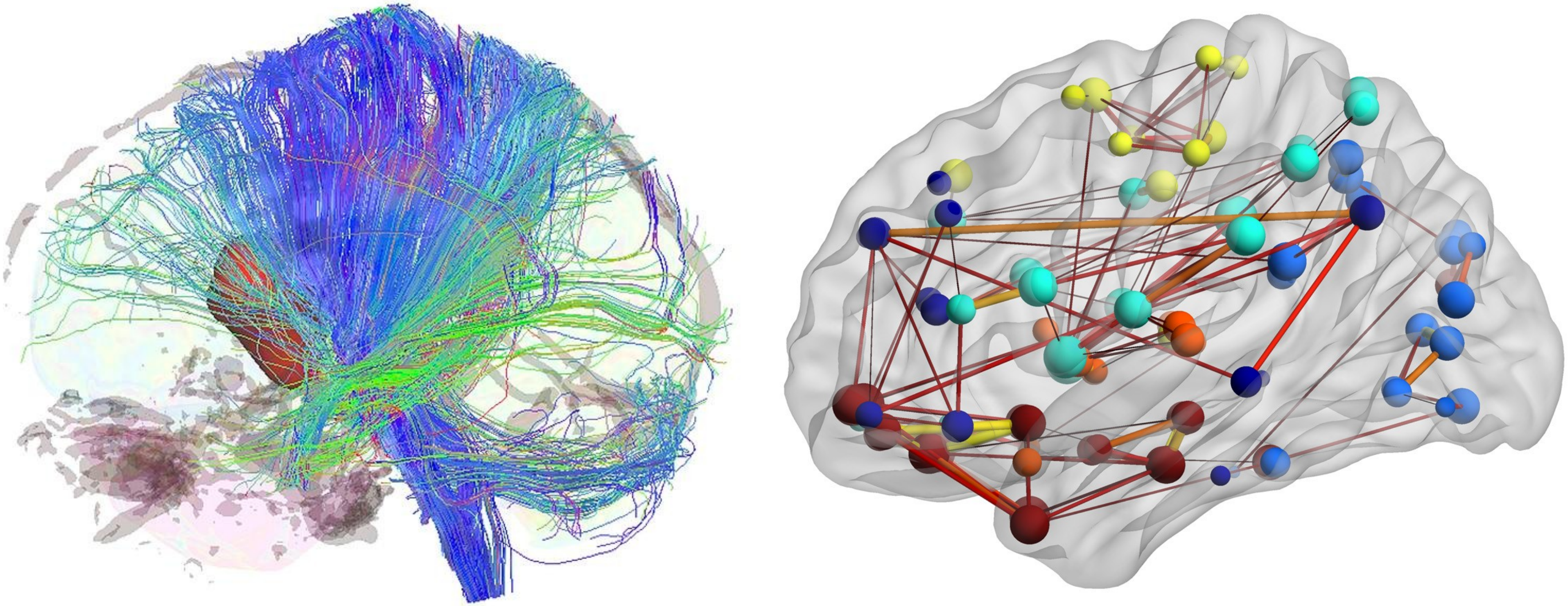
Accoppiamento



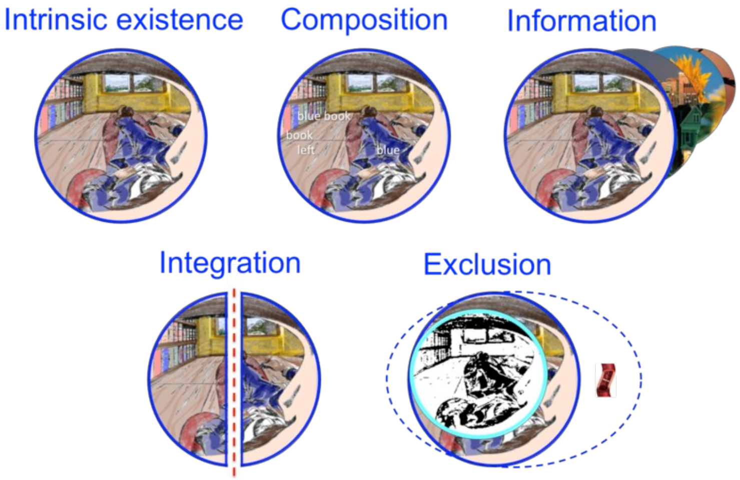
Connettività



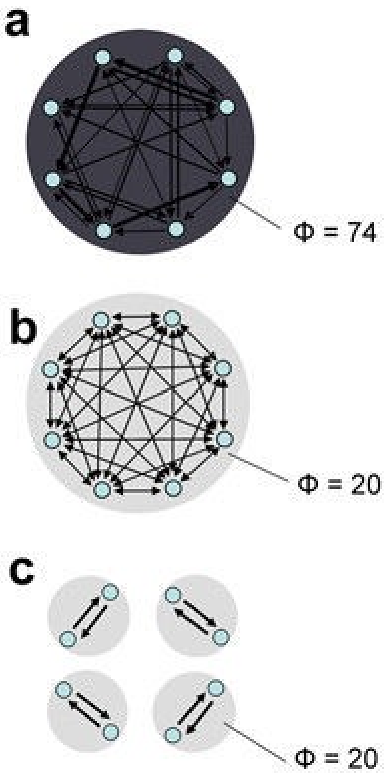
Rete di connettività cerebrale

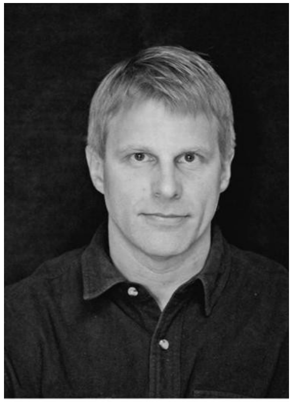


Coscienza


Intrinsic existence
Composition
Information
blue book
book
left
blue
Integration
Exclusion

Integrated Information Theory


a
Φ = 74
b
Φ = 20
c
Φ = 20



Giulio Tononi
Credit: Courtesy of the Author