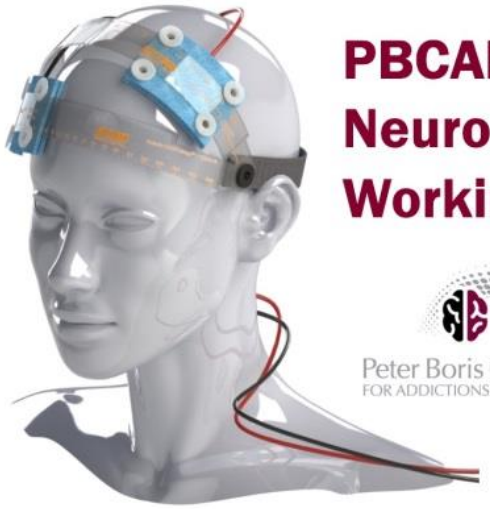

PBCAR
Neuromodulation
Working Group

Peter Boris Centre
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Cognitive
Neuroscience
of
Addictions
LABoratory

Basic Principles of Transcranial Electrical Stimulation

Dr. Michael Amlung

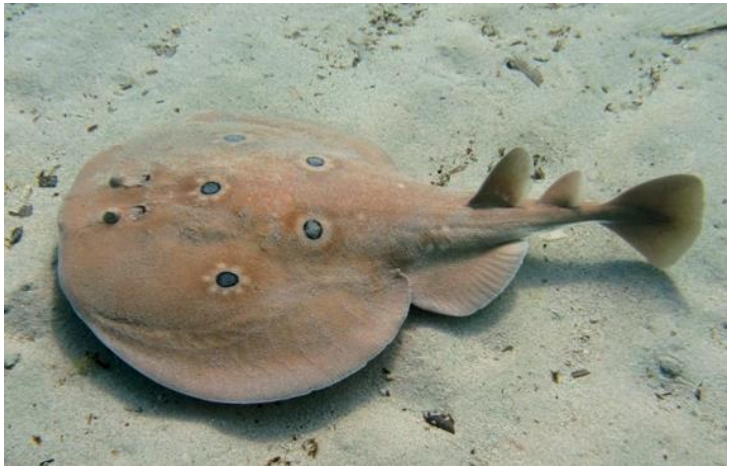
11/24/2017

Outline

- Brief history of transcranial electrical stimulation
- Neuromodulation vs. neurostimulation
- Transcranial direct current stimulation
  - Neurophysiology
  - Current intensity
  - Electrode position / configuration
  - Duration / intervals
- Intro to transcranial alternating current stimulation

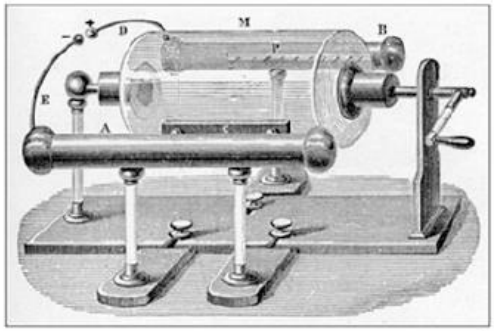
Brief History

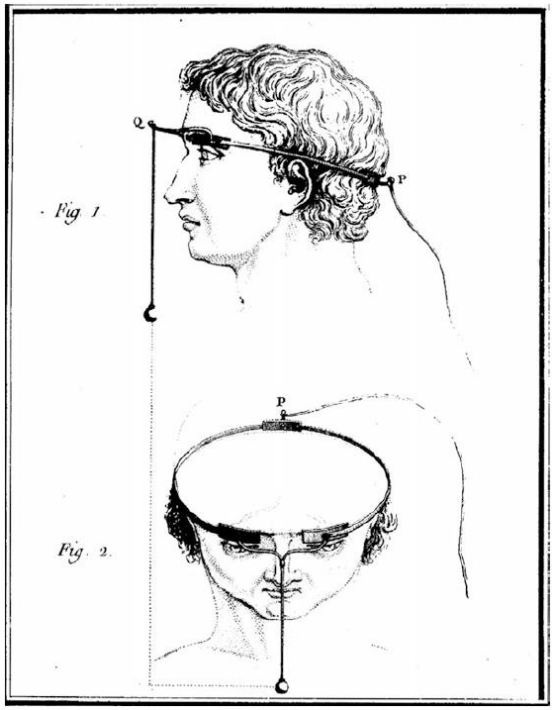
- Greco-Roman period: Torpedo electric fish
  - Scribonious Largus (c.1-c.50 AD)
  - Galen (131-140 AD)



Brief History

- Charles Georges Le Roy (France, 1755)
  - Cure for hysterical or psychogenic blindness
  - Placed conducting wires around the patient's head and led one wire to his leg. The wires were connected to an array of Leyden jars and three shocks were administered in the hope that sight would be restored.





Brief History

- Volta invented battery in 1799
- Geovanni Aldini (Volta's nephew)
  - Melancholia / depressoin

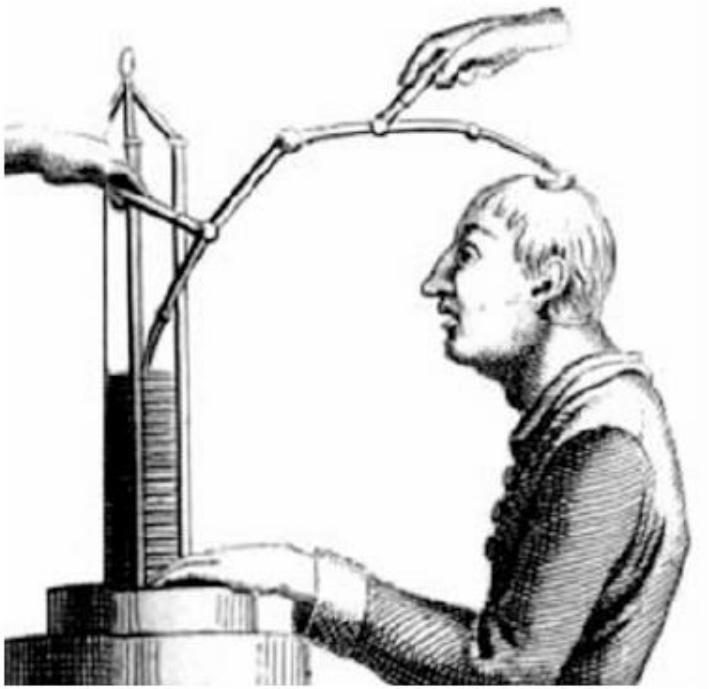
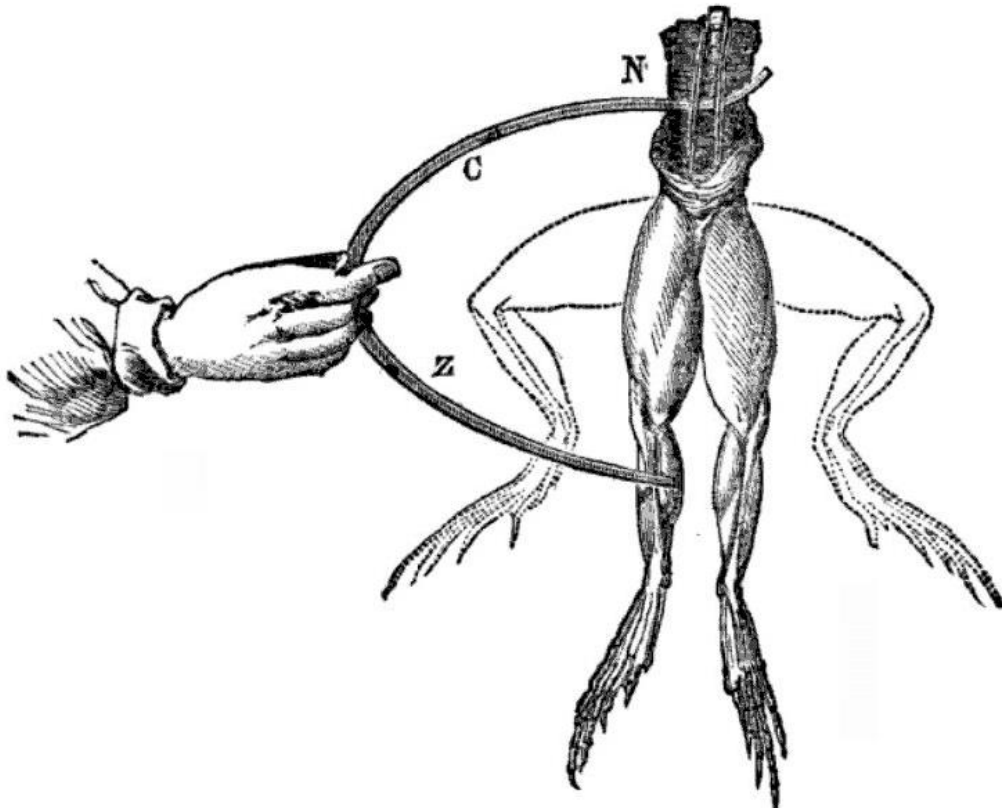


Fig. 1.6 Aldini's patient Luigi Lanzarini suffers from melancholia to whom galvanism is being applied in the head

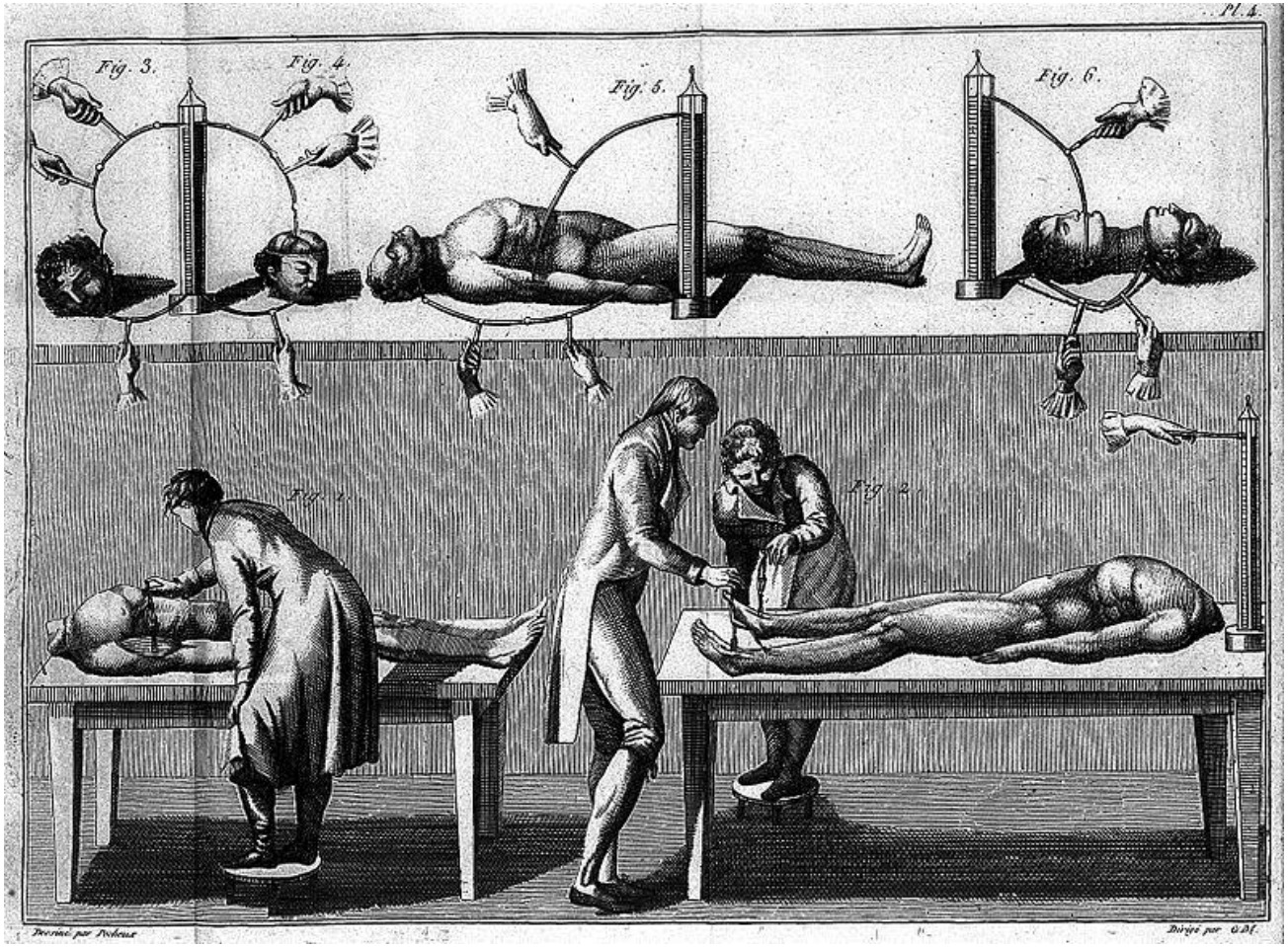
Brief History

- Galvinism



Brief History

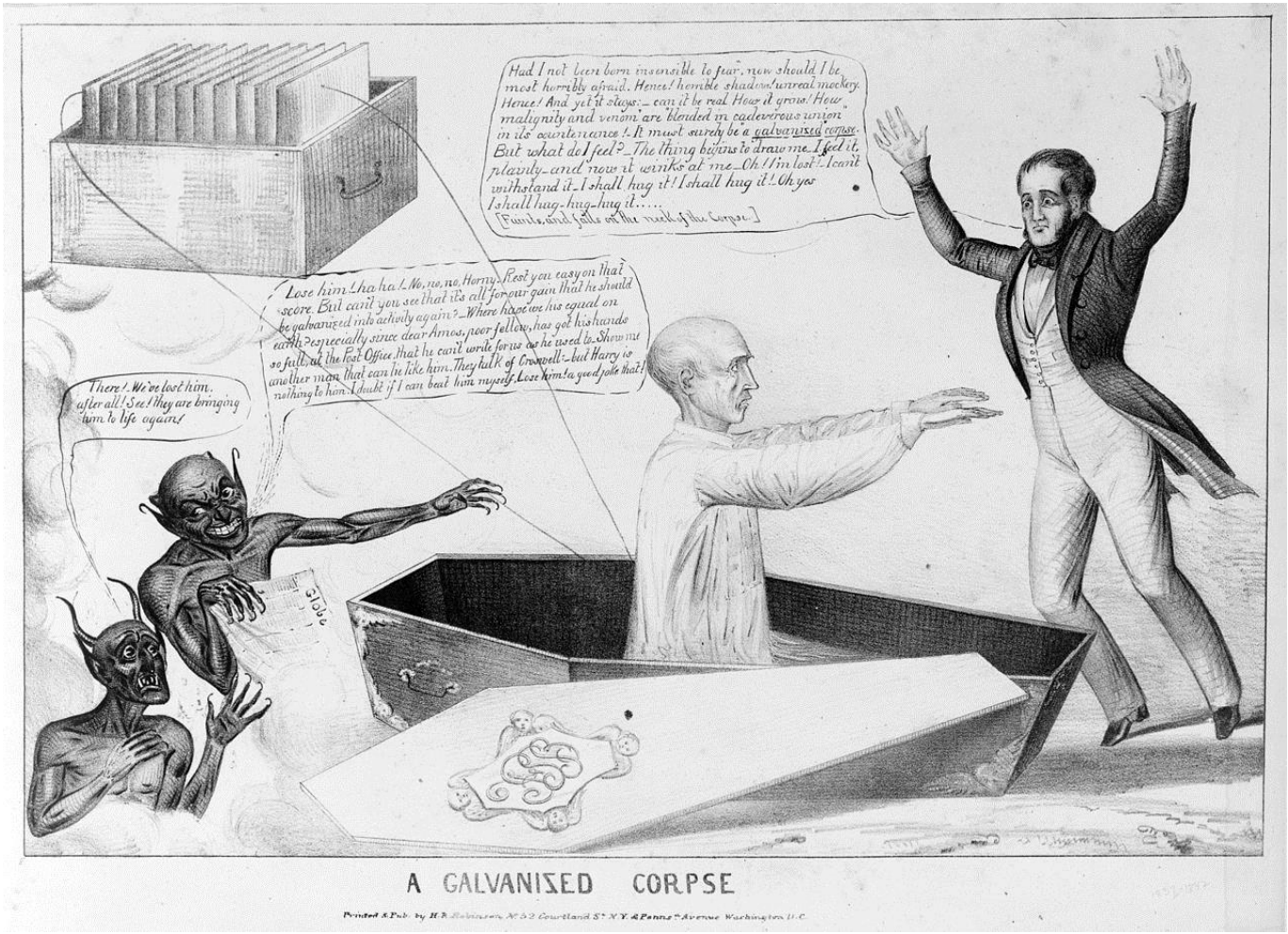
- Galvinism



On the first application of the process to the face, the jaws of the deceased criminal began to quiver, and the adjoining muscles were horribly contorted, and one eye was actually opened. In the subsequent part of the process the right hand was raised and clenched, and the legs and thighs were set in motion.

Brief History

- Galvinism



Brief History

- Cerletti & Bini (1938)
- Electroconvulsive therapy (ECT)

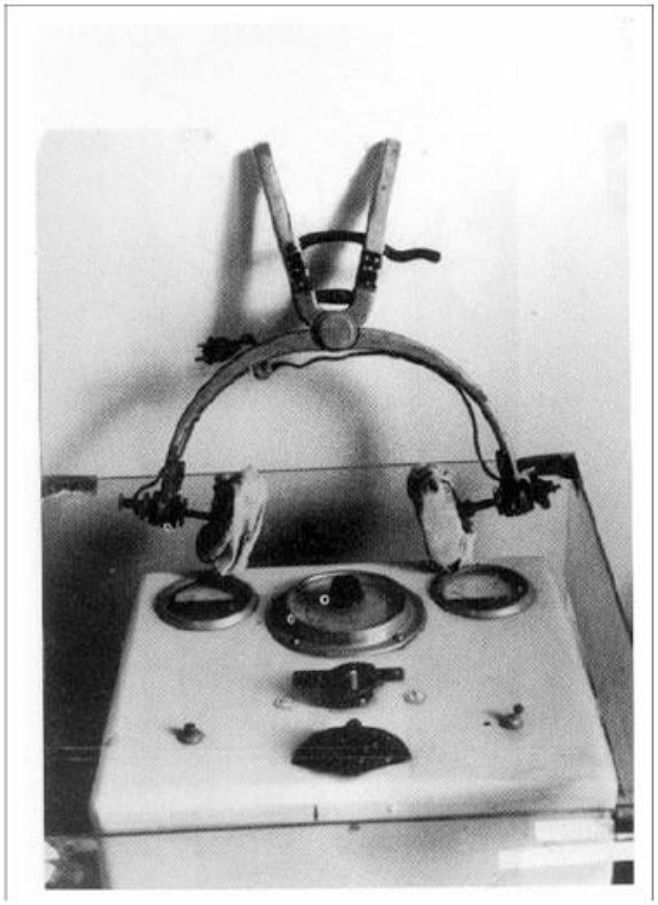
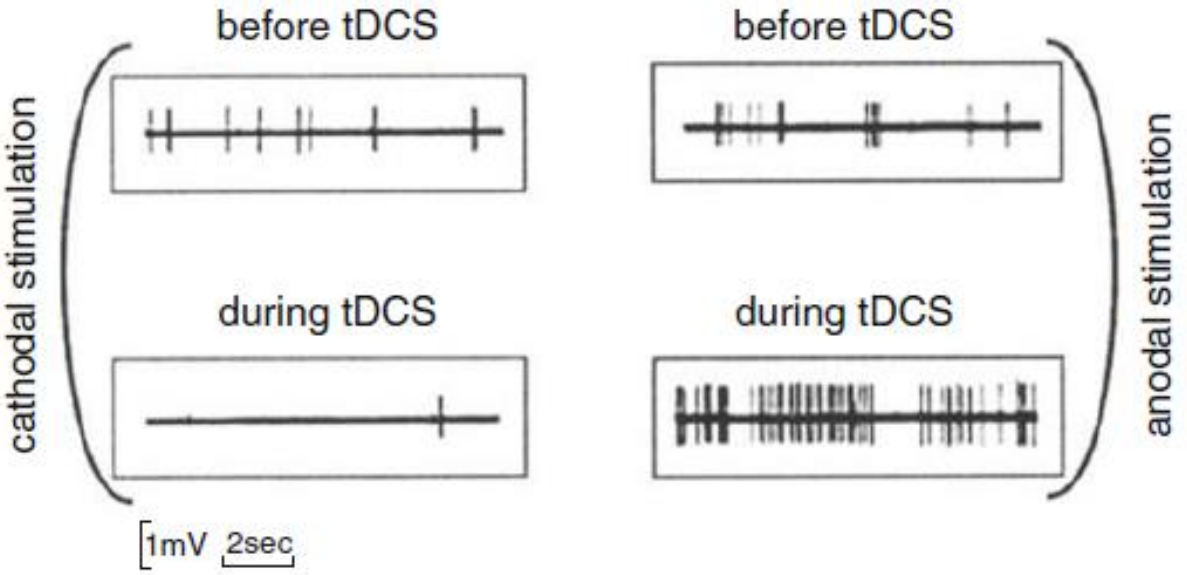


Fig. 1.9 Apparatus used by Cerletti and Bini in their first electroconvulsive experience

Brief History

- Bindman et al 1964
- Weak currents applied to pial surface of rat brain could influence spontaneous activity for hours following minutes of stimulation



Brief History

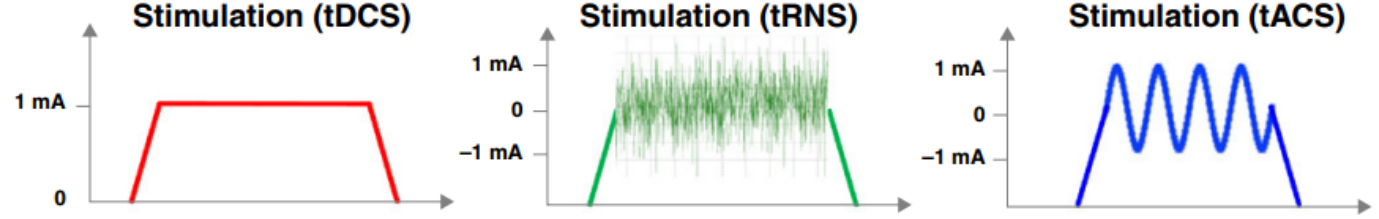
- Lippold and Readfearn (1964)
  - 32 normal subjects → anodal currents induced increase in mood, alertness, motor activity; cathodal currents induced quietness and apathy

- Readfearn et al (1964)
  - Direct anodal scalp current improved in depressed patients

- Herjanic et al (1967)
  - First application to schizophrenia

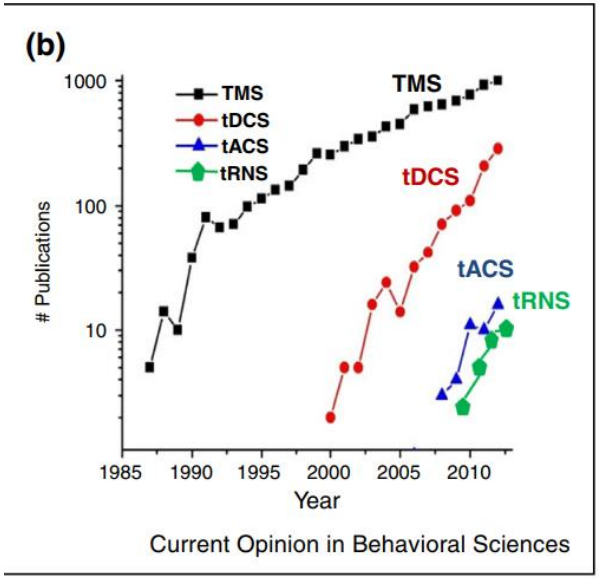
Modern TES

(a)

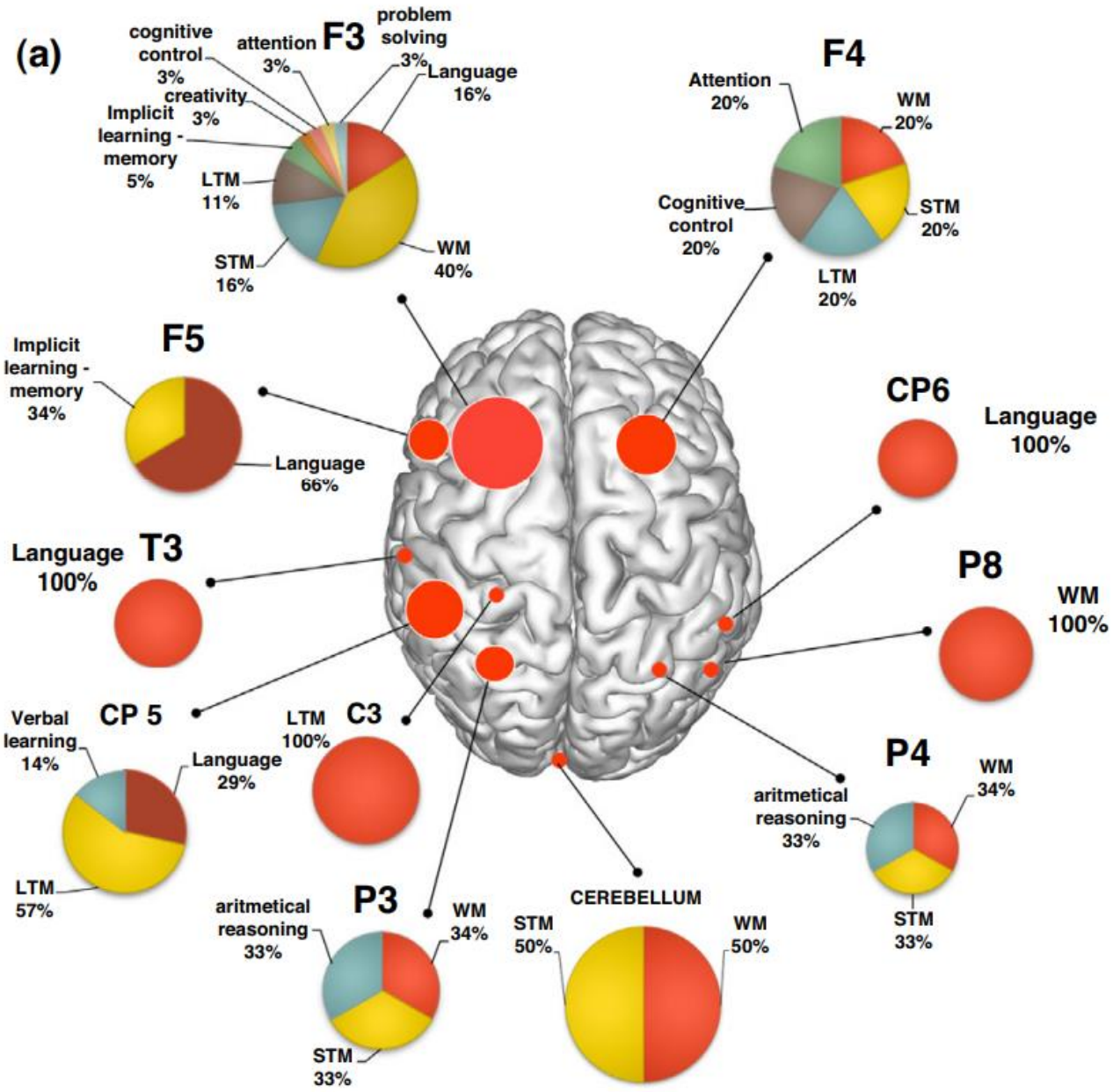


Current	Constant/Direct	Oscillatory/Alternating	Oscillatory/Alternating
Stimulation parameters	Anode: excitatory Cathode: inhibitory	1-640 Hz (random) 100-640 Hz: excitatory	Frequency (Hz) Phase (Degrees)
Mechanism	Membrane polarization	Stochastic resonance	Entrainment
Effect on	Cortical excitability	Cortical excitability	- Brain oscillations (power, phase) - Cortical excitability (>100Hz)
Neuronal effect	During and After	During and After	During and After

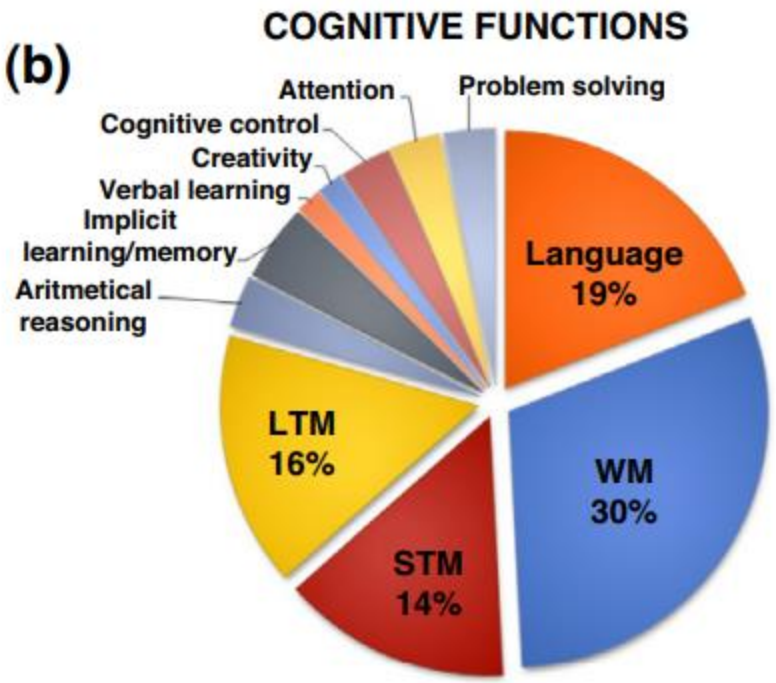
(b)

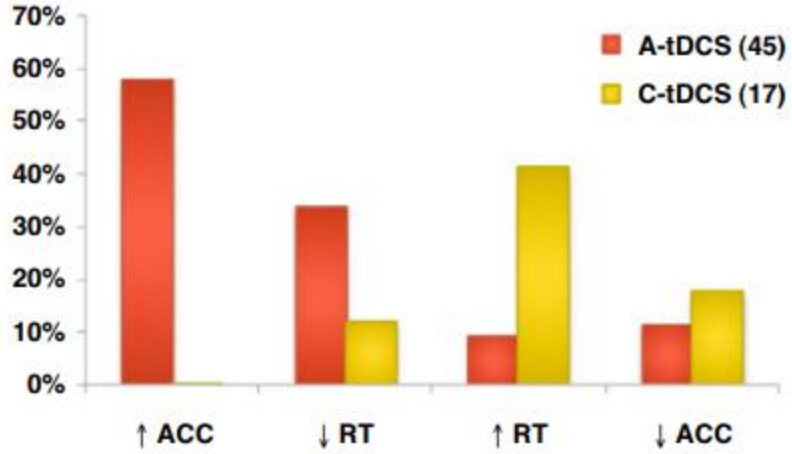


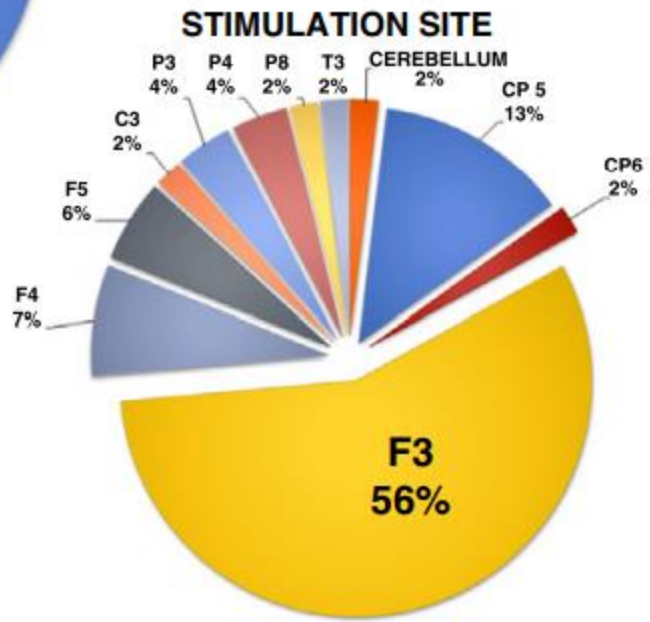
Santarnecchi et al. 2015 Curr Opin Behav Sci



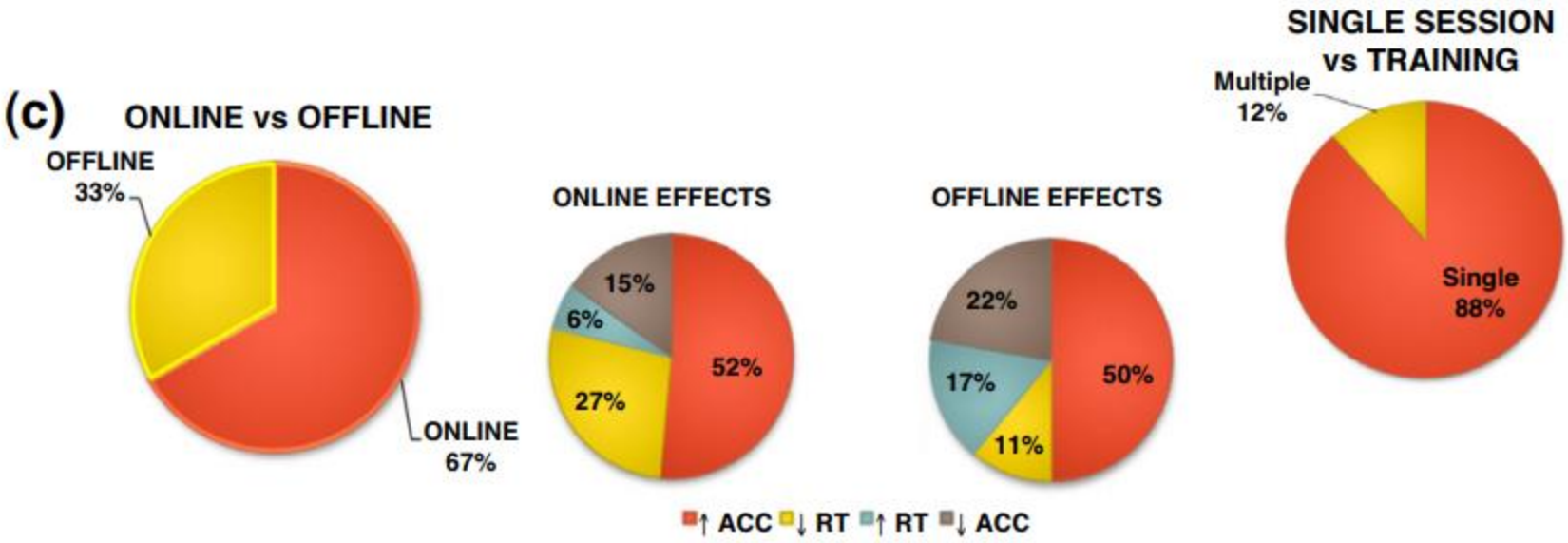
Santarnecchi et al. 2015 Curr Opin Behav Sci





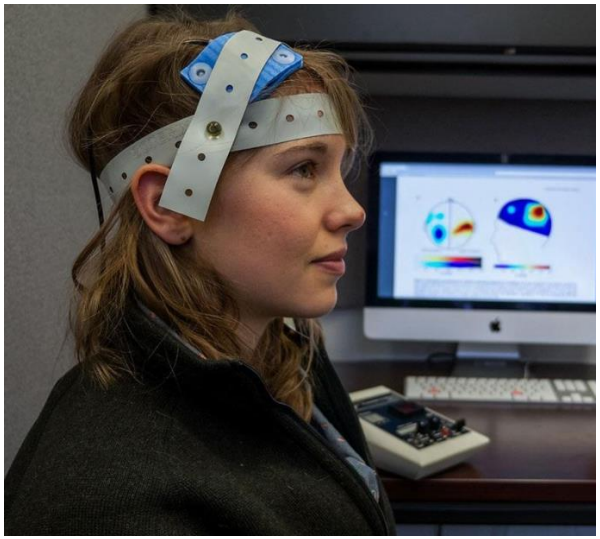


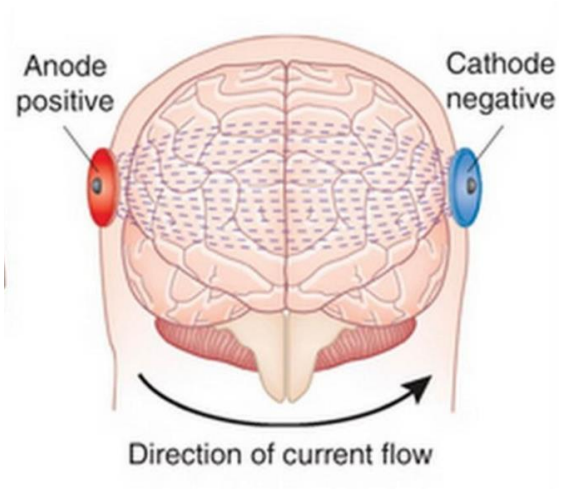
Santarnecchi et al. 2015 Curr Opin Behav Sci


(c)
ONLINE vs OFFLINE
OFFLINE
33%
ONLINE
67%
ONLINE EFFECTS
15%
6%
27%
52%
OFFLINE EFFECTS
22%
17%
11%
50%
↑ ACC
↓ RT
↑ RT
↓ ACC
SINGLE SESSION
vs TRAINING
Multiple
12%
Single
88%

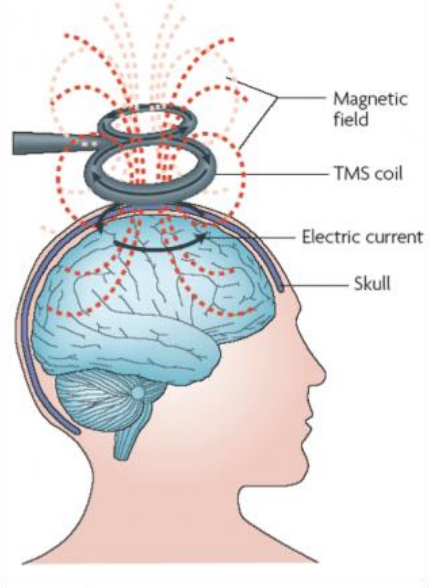
Neuromodulation vs Neurostimulation

Transcranial electrical stimulation





Transcranial magnetic stimulation



Terminology & Equipment

Terminology & Equipment

Cathodal
(-) in tDCS

Anodal
(+) in tDCS

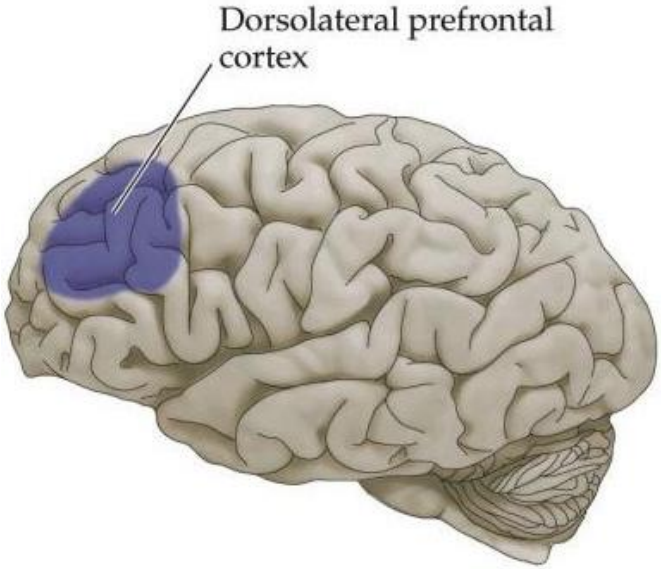
NeuroConn
DC Stimulator Plus

Terminology & Equipment

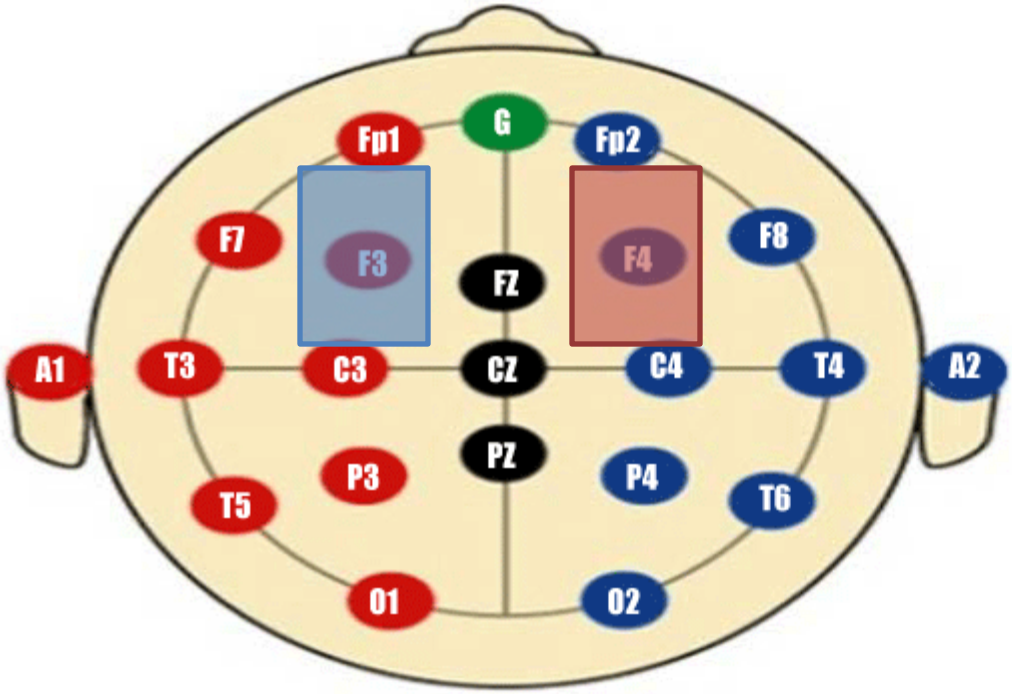
0.9% Sodium Chloride (Saline) solution

Terminology & Equipment

Electrode Placement



International 10-20 EEG placement system



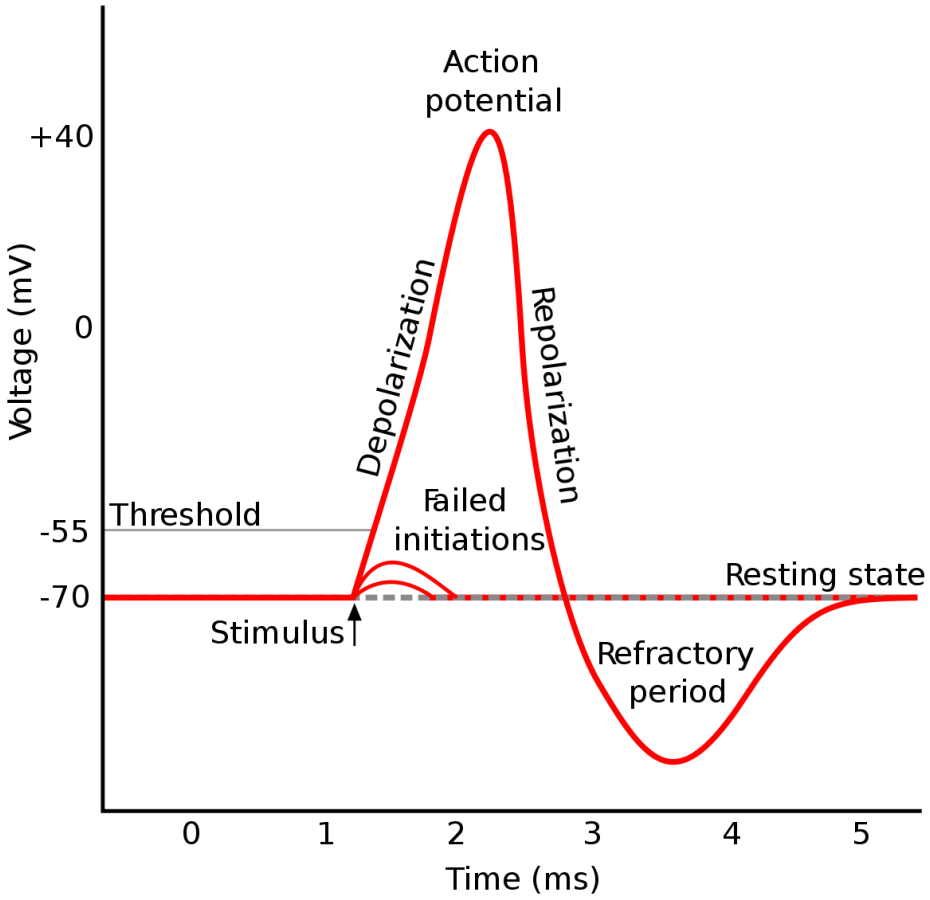
The letters used are:

F - Frontal lobe
T - Temporal lobe
C - Central lobe
P - parietal lobe
O - Occipital lobe

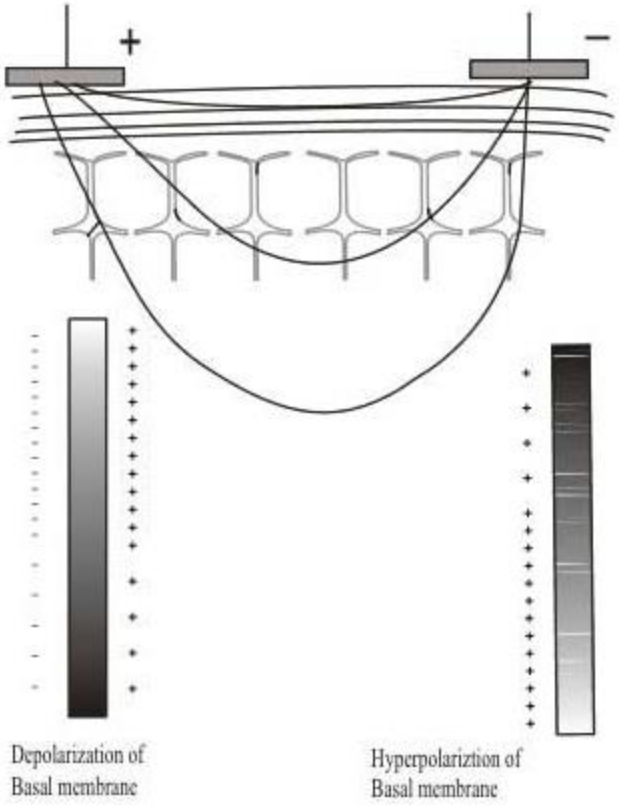
"Z" refers to an electrode placed on the min-line

Mechanisms of tDCS

- This content presented on white board.



Electrophysiology of polarization induced by direct current



- Two electrodes (positive and negative) on the scalp produce an electric current.
- A part of the electric current passes through the cortex.
- The current under the anode electrode induces a lack of positive ions at the basal part of neuronal membrane. This induces depolarization of this part of the membrane. The excitability of the neuron increases and the frequency of the background activity increases. The net effect is **anodal activation of neurons**.
- Vice versa, the current under the cathode electrode induces an excess of positive ions near the external part of the basal membrane. This induces hyperpolarization of this part of the membrane. The excitability of the neuron decreases and the frequency of the background activity decreases. The net effect is **cathodal suppression of neurons**.
- Hyperpolarization inactivates Ca and Na channels. Depolarization activates these channels.

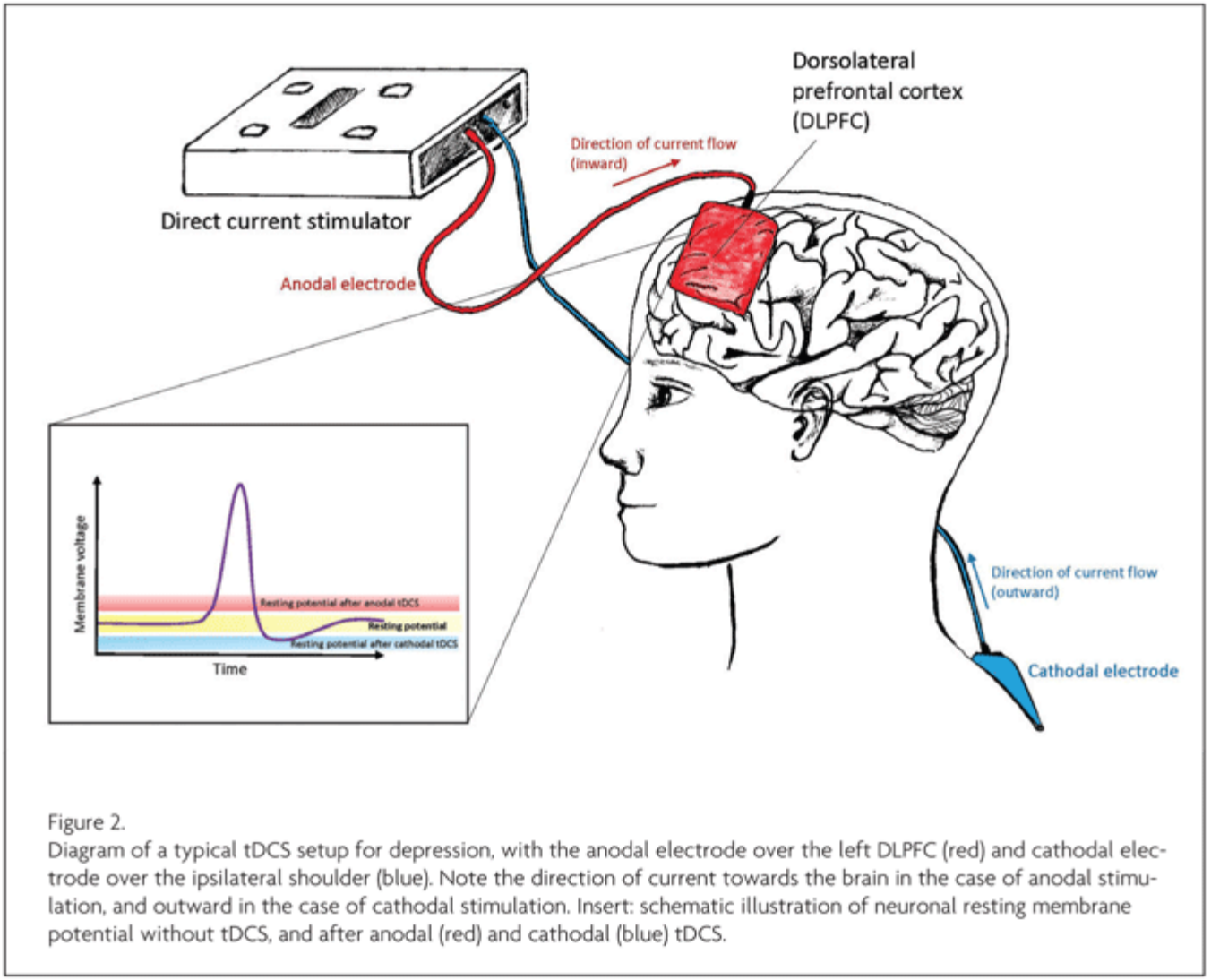
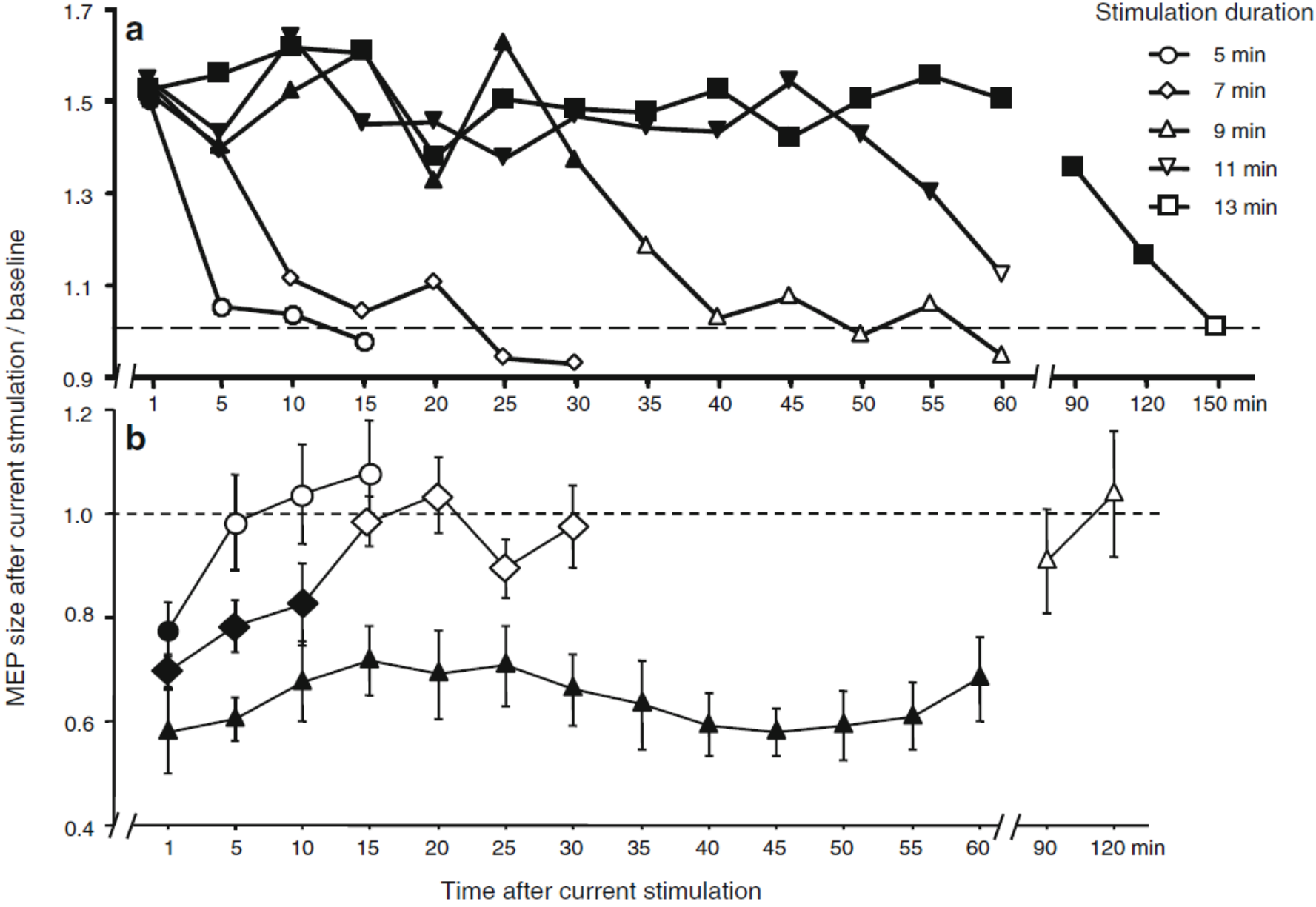
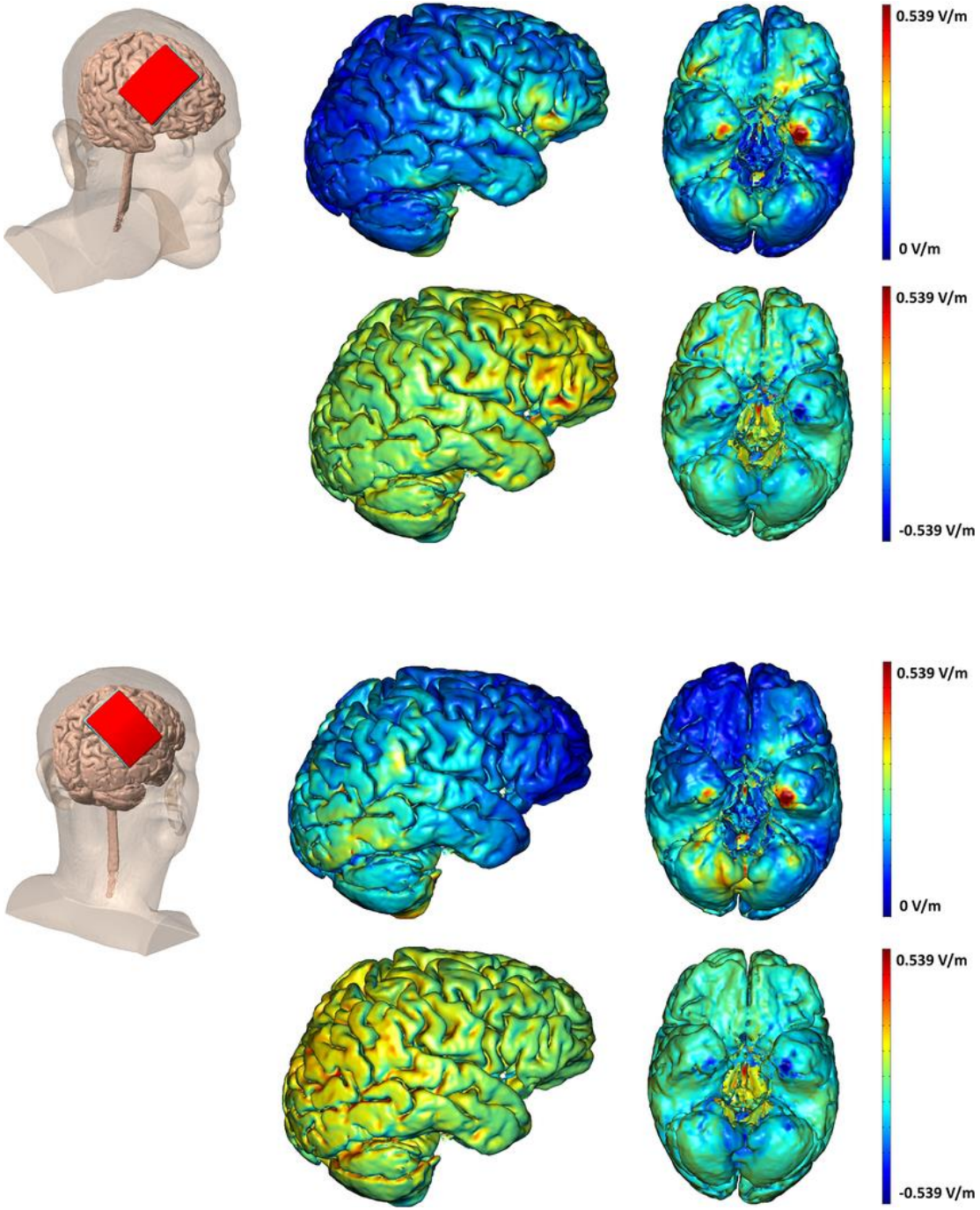
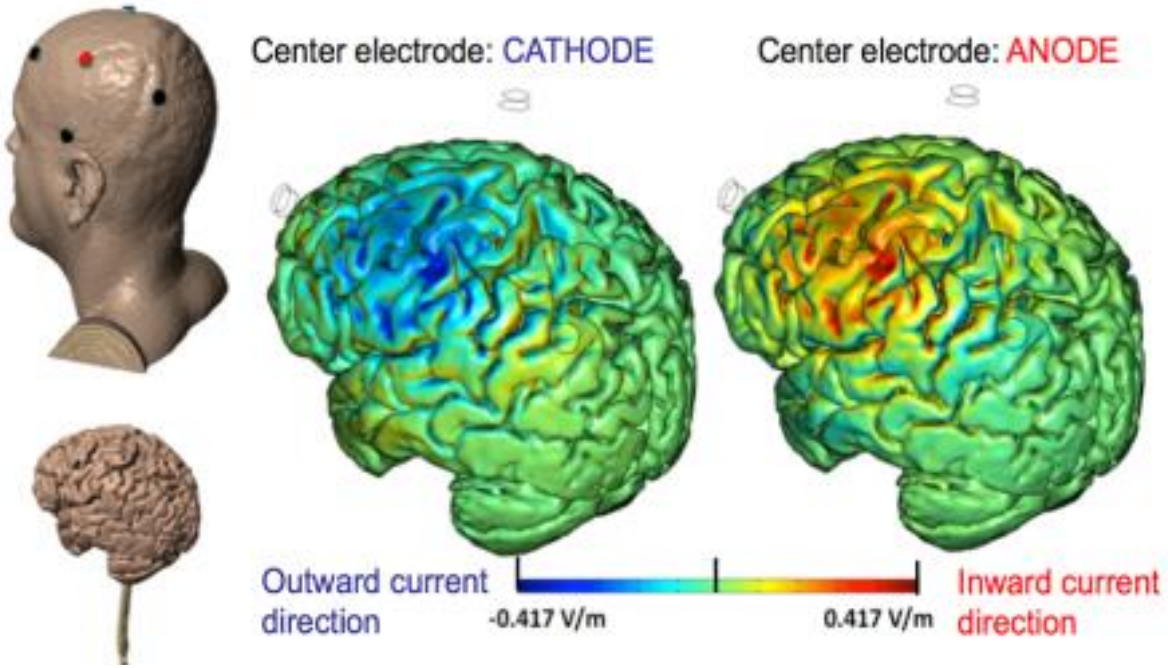


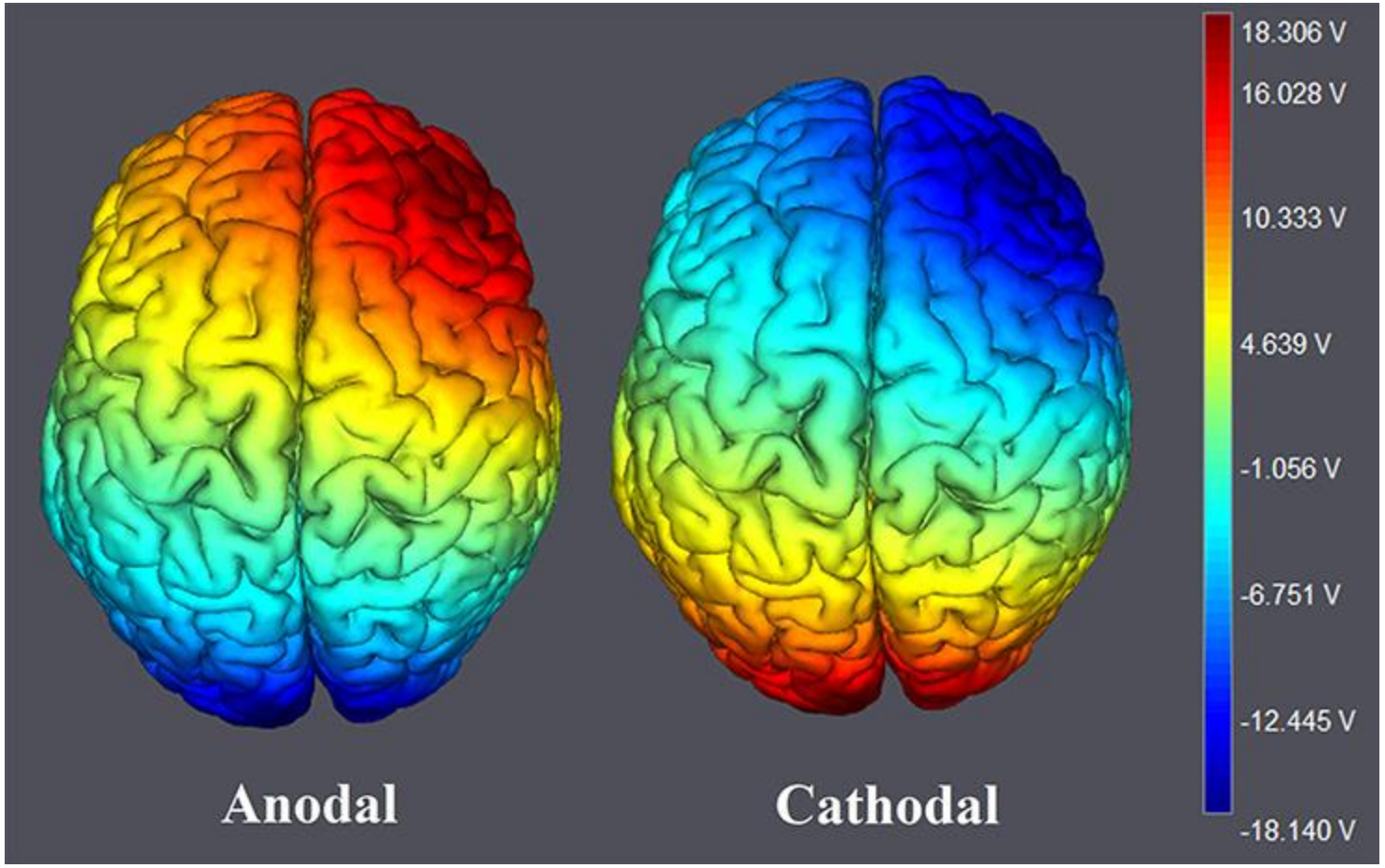
Figure 2.
Diagram of a typical tDCS setup for depression, with the anodal electrode over the left DLPFC (red) and cathodal electrode over the ipsilateral shoulder (blue). Note the direction of current towards the brain in the case of anodal stimulation, and outward in the case of cathodal stimulation. Insert: schematic illustration of neuronal resting membrane potential without tDCS, and after anodal (red) and cathodal (blue) tDCS.



Nitsche MA, Paulus W. Sustained excitability elevations induced by transcranial DC motor cortex stimulation in humans. Neurology. 2001;57(10):1899–901.


0.539 V/m
0 V/m
0.539 V/m
-0.539 V/m
0.539 V/m
0 V/m
0.539 V/m
-0.539 V/m


Center electrode: CATHODE
Center electrode: ANODE
Outward current direction
-0.417 V/m
0.417 V/m
Inward current direction


18.306 V
16.028 V
10.333 V
4.639 V
-1.056 V
-6.751 V
-12.445 V
-18.140 V
Anodal
Cathodal

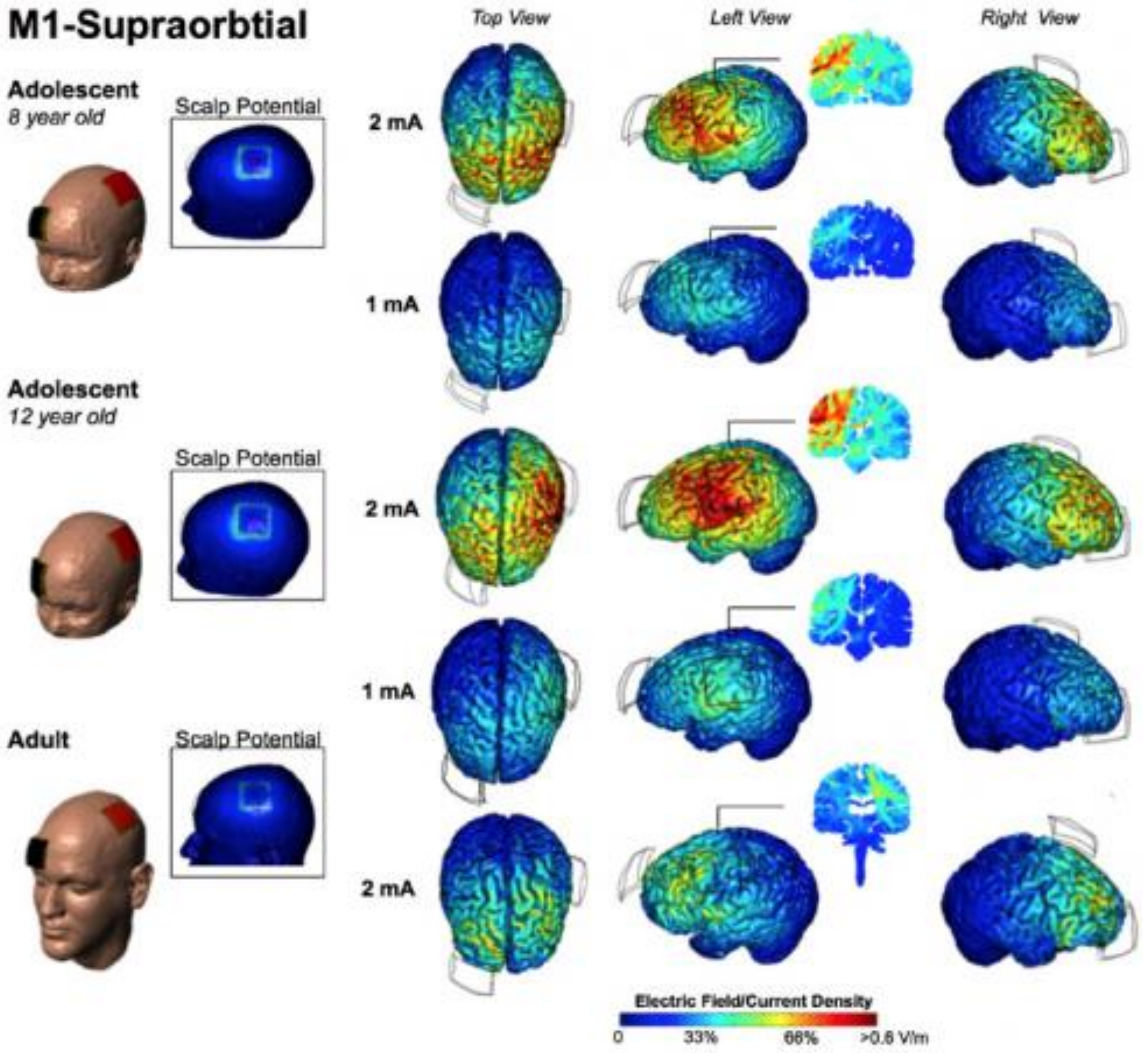
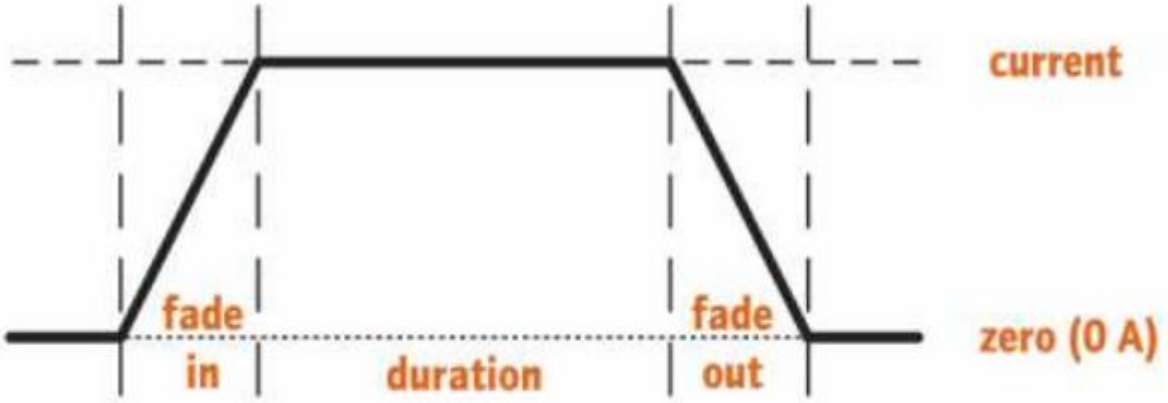


Figure 4. Computerized modeling of tDCS-induced current flow in adult and children subjects. For example, the smaller head size of children relative to adults results in a higher brain current intensity with the same applied scalp current.
tDCS, transcranial direct current stimulation
Courtesy Marom Bikson, PhD.



total stimulation time = fade in + duration + fade out

Timing chart of current - sham stimulation

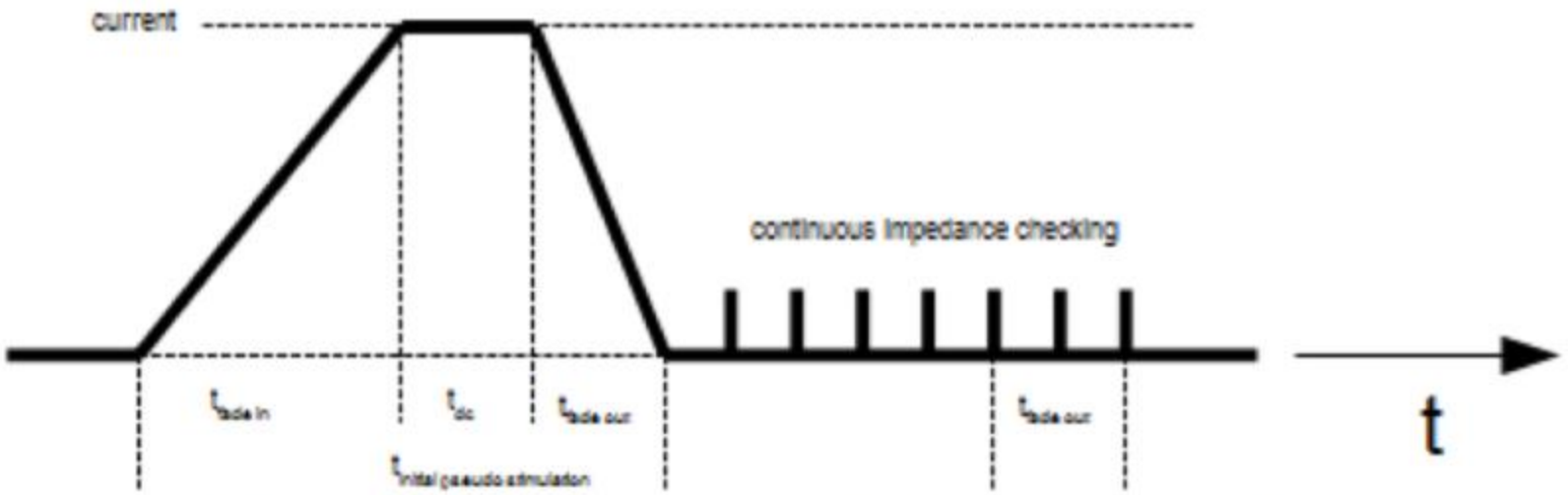
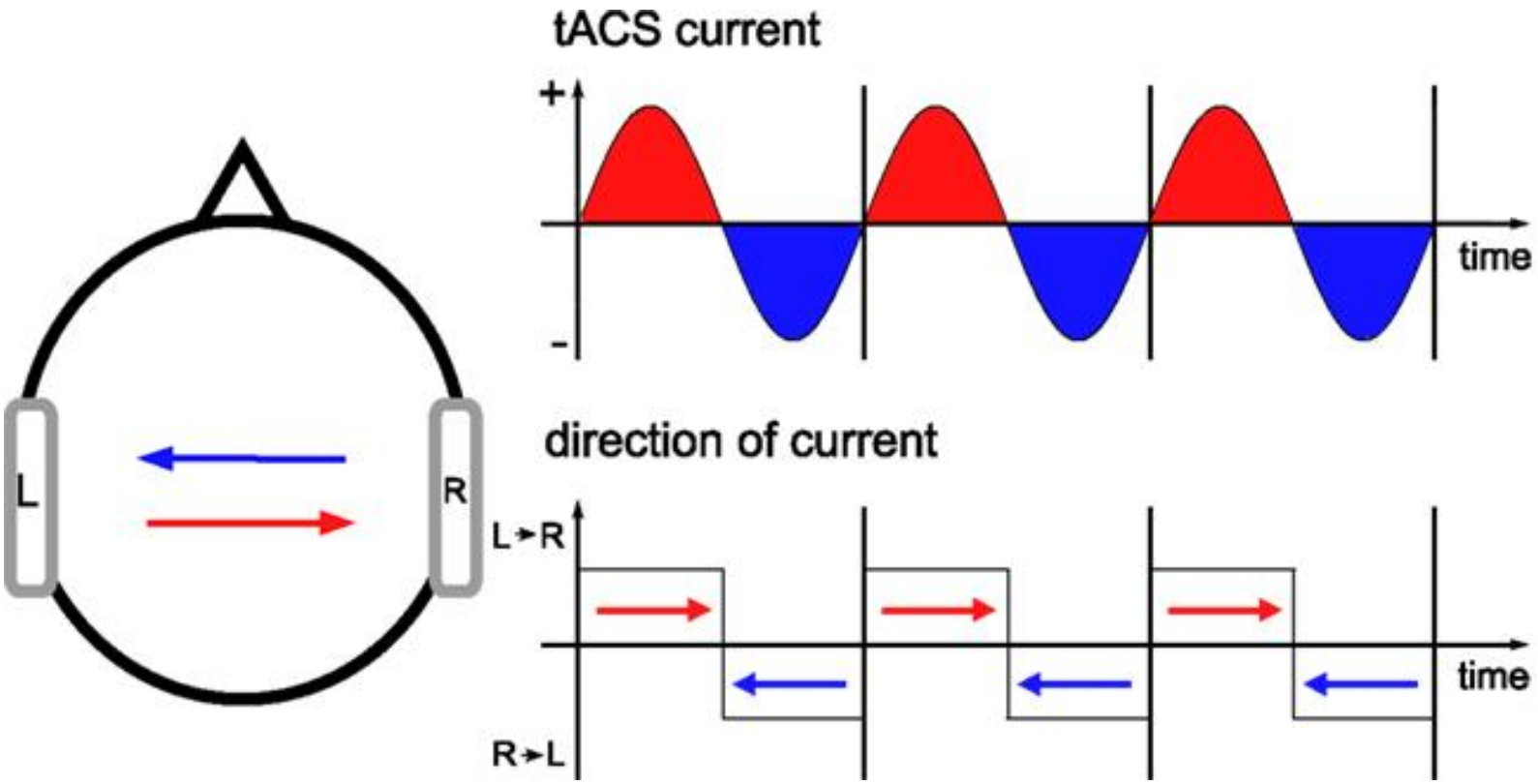
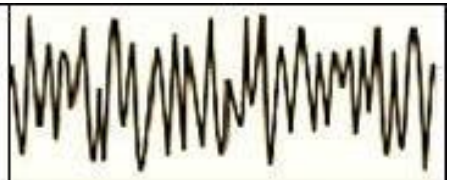
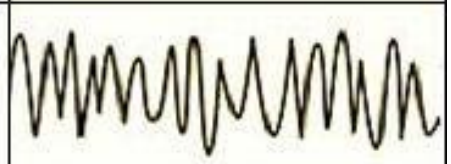
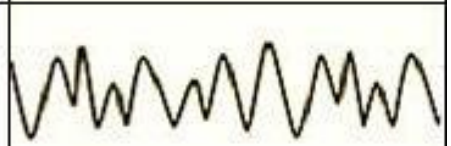
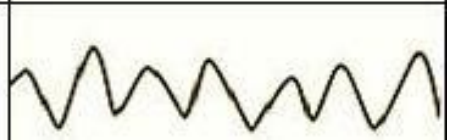
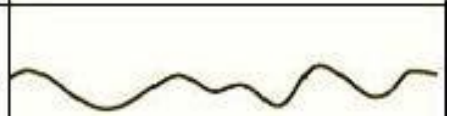


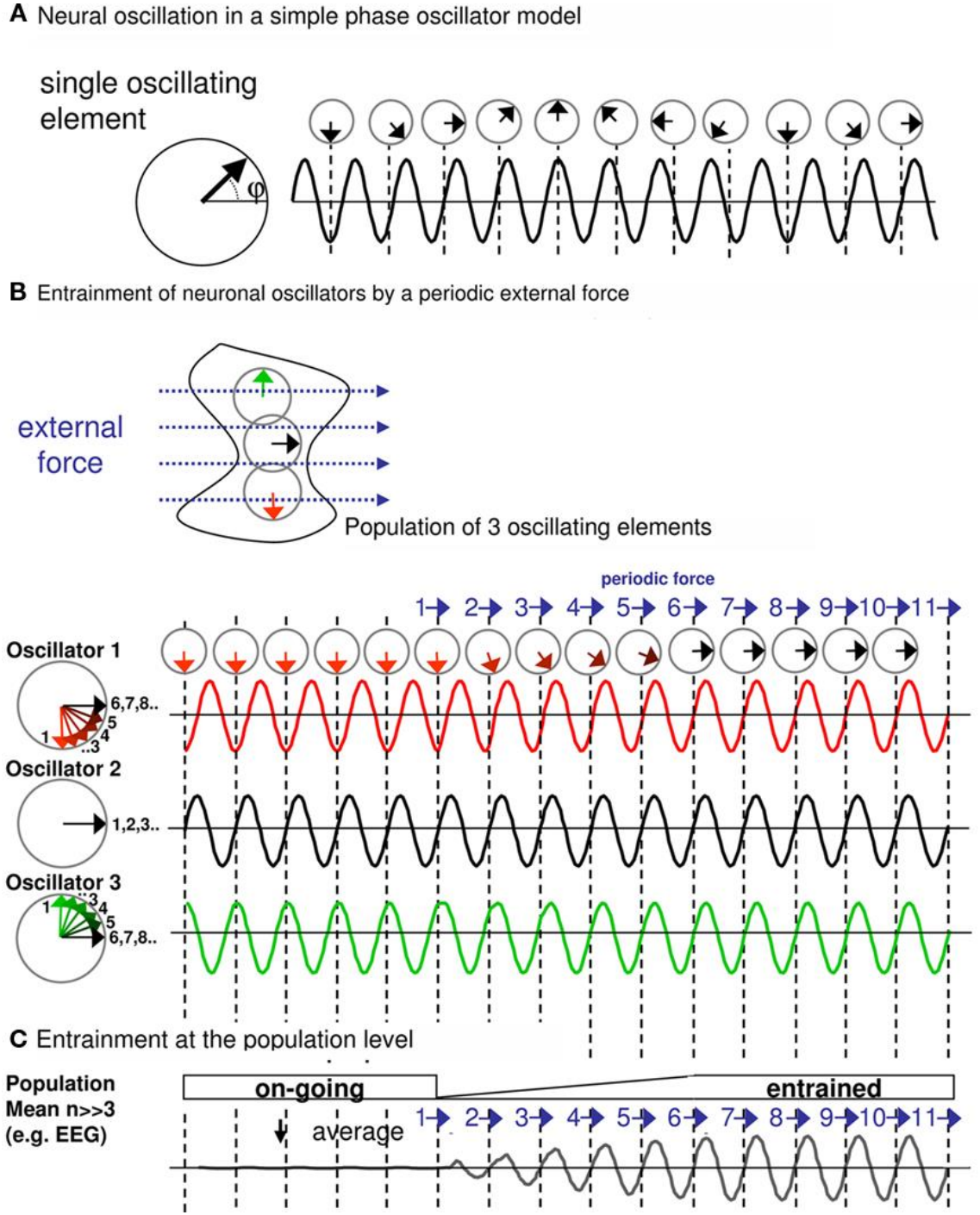
Illustration 61: Timing chart of current during sham stimulation (tDCS)

$t_{dc} = t_{duration}/30$

Example: $t_{fade\ in} = 8$ s; $t_{fade\ out} = 5$ s; $t_{duration} = 900$ s


tACS current
+
-
time
L
R
direction of current
L→R
R→L
time

Abstract mental activity, cognitive control, perceptual binding	**Gamma: 30-100+Hz** Peak performance, flow	
Mainly motor activity	**Beta: 12-30Hz** Awake, normal alert consciousness	
Active inhibition of task-irrelevant areas	**Alpha: 8-12Hz** Relaxed, calm, lucid, not thinking	
Memory, emotional regulation, creativity	**Theta: 4-7Hz** Deep relaxation and meditation, mental imagery	
Sleep, learning, motivational processing	**Delta: .1-4Hz** Deep, dreamless sleep	


A Neural oscillation in a simple phase oscillator model
single oscillating element
φ
B Entrainment of neuronal oscillators by a periodic external force
external force
Population of 3 oscillating elements
periodic force
1 2 3 4 5 6 7 8 9 10 11
Oscillator 1
6,7,8..
5
4
1
3
Oscillator 2
1,2,3..
Oscillator 3
1
3
4
5
6,7,8..
C Entrainment at the population level
Population
Mean n>>3
(e.g. EEG)
on-going
entrained
average
1 2 3 4 5 6 7 8 9 10 11

Endogenous Electric Fields May Guide Neocortical Network Activity

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DOI 10.1016/j.neuron.2010.06.005