Starlab Neuroscience

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THE LUMINOUS PROJECT

EU H2020 FET Open Project

G.Ruffini, Starlab / Neuroelectrics

The Science of Consciousness, Tucson 2016

Horizon 2020

This project has received funding from the European Union's Horizon 2020 research and innovation programme Euratom research and training programme 2014-2018 under grant agreement Number 686764

aim for the stars ….

Overview

A slide about the FET Open framerwork

High level overview of Luminous

Science and technology

Some scenarios in the project

About EU FET Open

The Future and Emerging Technologies Open Scheme - FET-Open - is a roots-up approach for exploring promising visionary ideas that can contribute to challenges of long term importance for Europe.

The purpose of FET Open is to enable a range of ideas for future and emerging technologies to be explored and realised.

An open scheme:

The widest possible spectrum of research opportunities

Bold ideas that would involve high risks

Longer term research with sound objectives

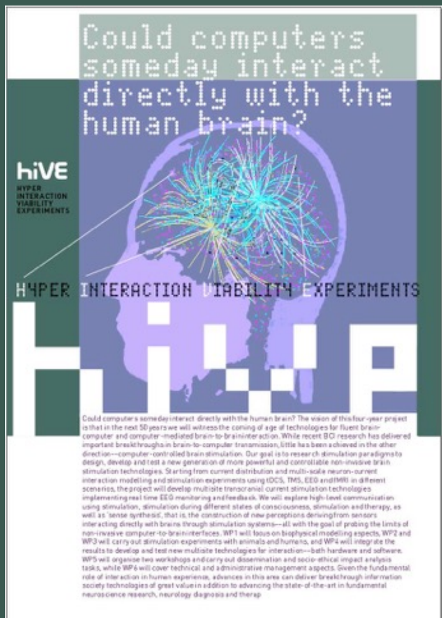
Some history

Studying consciousness
in the electrical brain

LUMINOUS®

hiVE
HYPER
INTERACTION
VIABILITY
EXPERIMENTS

Vision and Mission

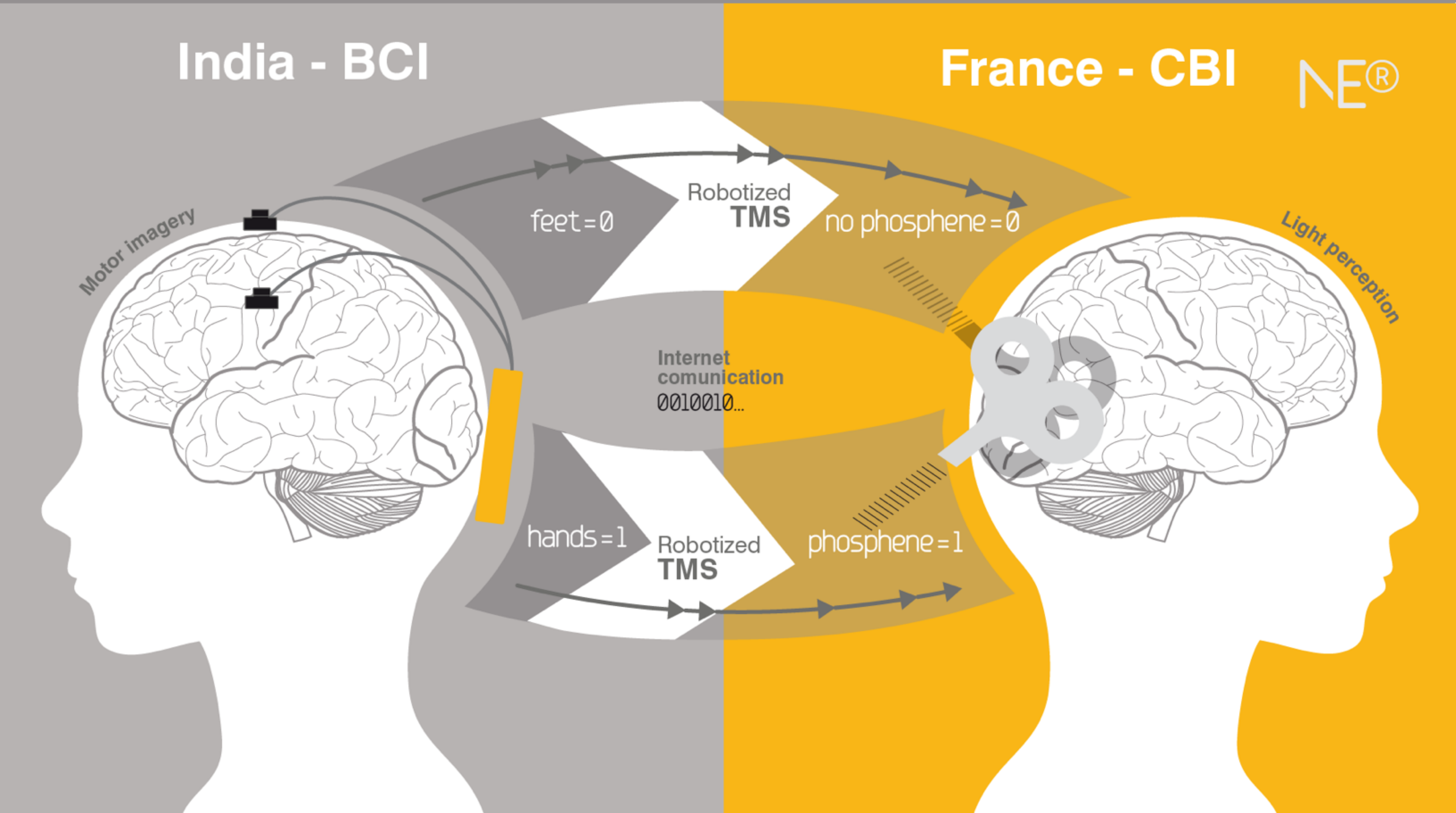


2008-2012

Grand Vision: in the next 50 years we will witness the coming of age of technologies for fluent brain-computer and computer-mediated brain-to-brain interaction—which we call *hyper-interaction*.

Our question: are **non-invasive** brain stimulation technologies a viable option for hyper-interaction?

The overall **mission** of this project is to probe the limits of non-invasive computer-to-brain interfaces by carrying out research using improved brain stimulation paradigms to explore fundamental neuroscience questions and applications, and by designing and testing more powerful, controllable and safe non-invasive brain stimulation technologies.



Conscious Brain-to-Brain Communication in Humans Using Non-Invasive Technologies

Carles Grau, Romuald Ginhoux, Alejandro Riera, Thanh Lam Nguyen, Hubert Chauvat, Michel Berg, Julià L. Amengual, Alvaro Pascual-Leone, Giulio Ruffini

Published: August 19, 2014 • DOI: 10.1371/journal.pone.0105225

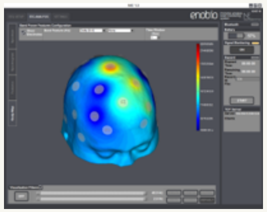
http://hive-eu.org

From projects to products!

neuroelectrics®

NUBE EEG

neurosurfer



EEG Monitoring

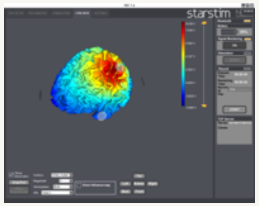
enobio

ROBUST
PRECISE
WIRELESS
EEG

8, 20 & 32 channel versions

NIC Home

stimweaver



tCS Stimulation+EEG

starstim

NONINVASIVE
WIRELESS tCS
NEUROSTIMULATOR

tCS research, clinic and home research versions
8, 20 & 32 channel versions

Luminous overview

Studying consciousness
in the electrical brain

luminous®

Luminous project (2016-2020)

vision

Consciousness will someday be electromagnetically measured and altered. Likewise the associated needed insights will prove crucial to the development of cognitive sciences.

our questions

What is consciousness?
Can it be measured?
Can it be altered through electromagnetic brain stimulation?

LUMINOUS project: consortium

Instituts thématiques Inserm
Institut national de la santé et de la recherche médicale

UNIVERSITY OF OXFORD

IfADo

EBERHARD KARLS UNIVERSITÄT TÜBINGEN

Starlab® Living Science

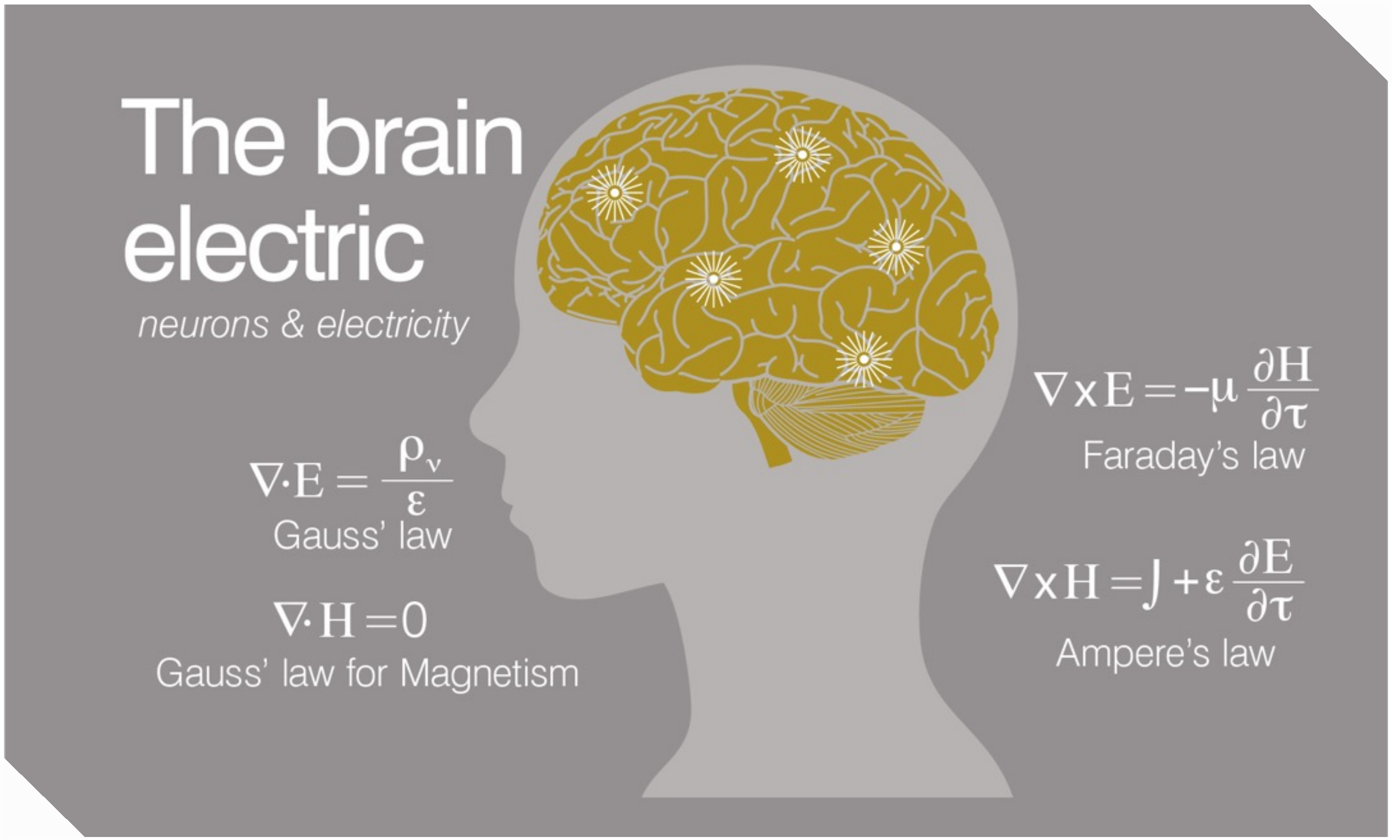
Coordinator

UNIVERSITAS STUDIORUM MEDIOLANENSIS

COMA SCIENCE GROUP

We aim to measure and interact with

The electric brain



Luminous project

Targeted Breakthroughs

Breakthrough 1

The creation of a new class of consciousness-probing technologies that bypass or minimize the use of sensory, motor or executive functions

Breakthrough 2

The electric alteration of consciousness

Science & Technology Objectives

O1. Provide a **scientific, theoretical framework of consciousness for modelling, definition of metrics, and planning of experiments**.

O2. Develop a **physiologically validated computational neuroscience model to guide experimental plans, connecting NIBS and EEG with theoretical models of consciousness.**

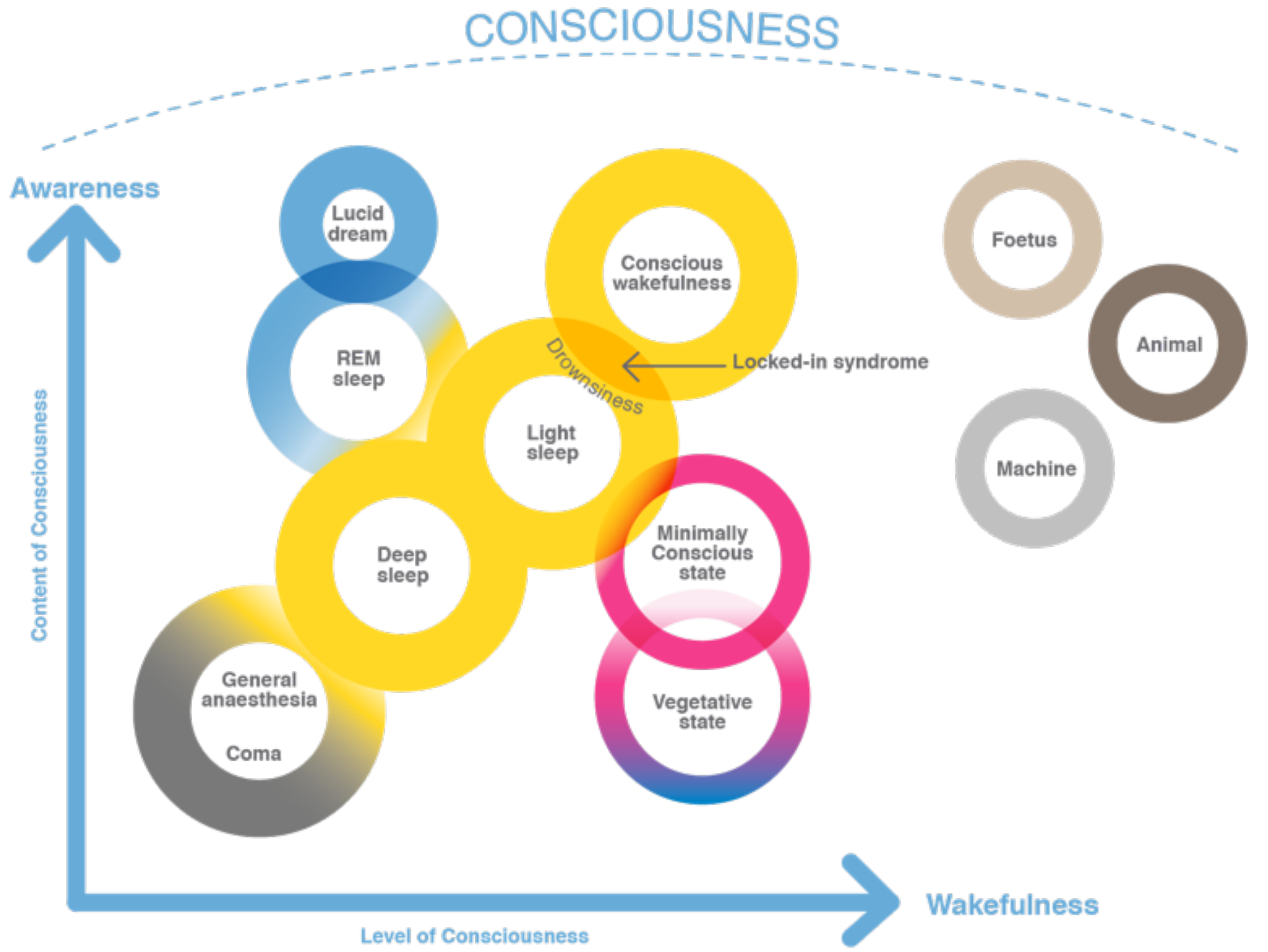
O3. Guided by information theory and modelling, **develop consciousness metrics** from the measurement of brain activity combined with stimulation.

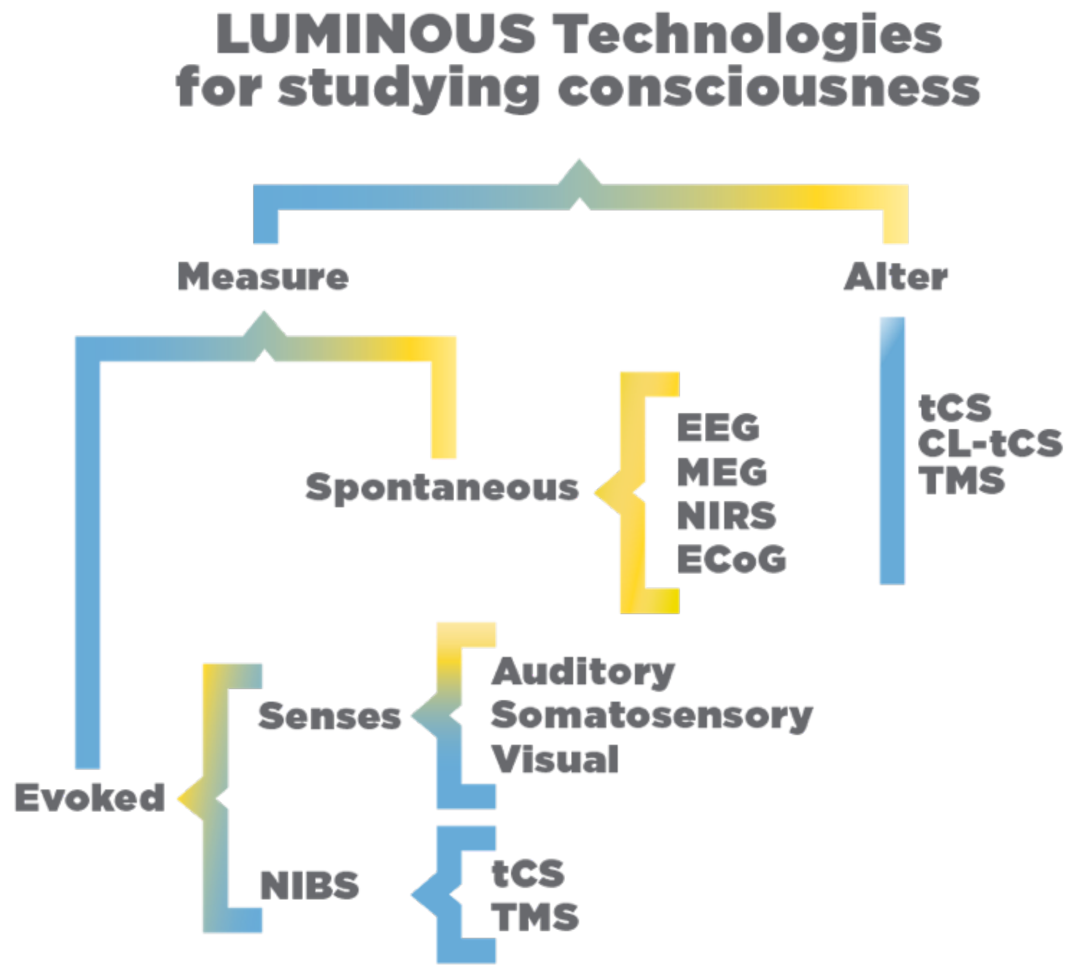
O4. Develop **open** and **closed-loop non-invasive technology to monitor and alter consciousness** in research and medical applications.

O5. Validate and refine the methodology in different **clinical scenarios**.

Explore

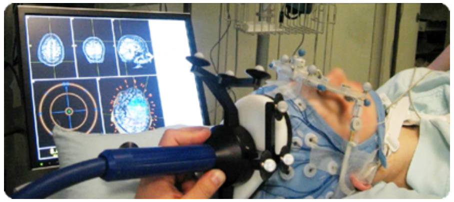
Consciousness landscape




LUMINOUS Technologies
for studying consciousness
Measure
Alter
Spontaneous
EEG
MEG
NIRS
ECoG
tCS
CL-tCS
TMS
Evoked
Senses
Auditory
Somatosensory
Visual
NIBS
tCS
TMS

Develop, refine, validate

Experimental Scenarios



1. In Utero (passive sensing using MEG)
2. Locked in Syndrome
3. Anesthesia
4. Sleep (lucidity enhancement)
5. Diseases of consciouness

6. In-silico

Scenario/Methods	Passive probing	PNS probing (ERPs)	NIBS probing	NIBS alteration	Consc. State Ground truth
in-utero	fMEG	Auditory, somatosensory	none	none	Nijuis criteria
Sleep/lucidity	EEG, connectivity	Somatosensory, auditory, visual	tCS, TMS	tCS, CL-MtCS	Sleep stages
Anaesthesia	EEG, fMRI	Auditory, somatosensory	tCS	tCS, CL-MtCS	Percp. Awareness metrics
LIS	EEG, MEG, NIRS, ECoG	Auditory, somatosensory	tCS, TMS	tCS, CL-MtCS	BCI performance
DOC	EEG connectivity	somatosensory, auditory, visual	tCS, TMS	tCS, CL-MtCS	Consc. Scales (CRS/GRS)
healthy	EEG, source space, connectivity	3 visual perception conditions	tCS, TMS	tCS, CL-MtCS, TMS	Expected perception
in-silico / computer model	EEG, source space, connectivity	yes: MMN and P300 model	tCS, TMS	tCS, CL-MtCS, TMS	EEG data

Information
(mathematics)

Studying consciousness
in the electrical brain

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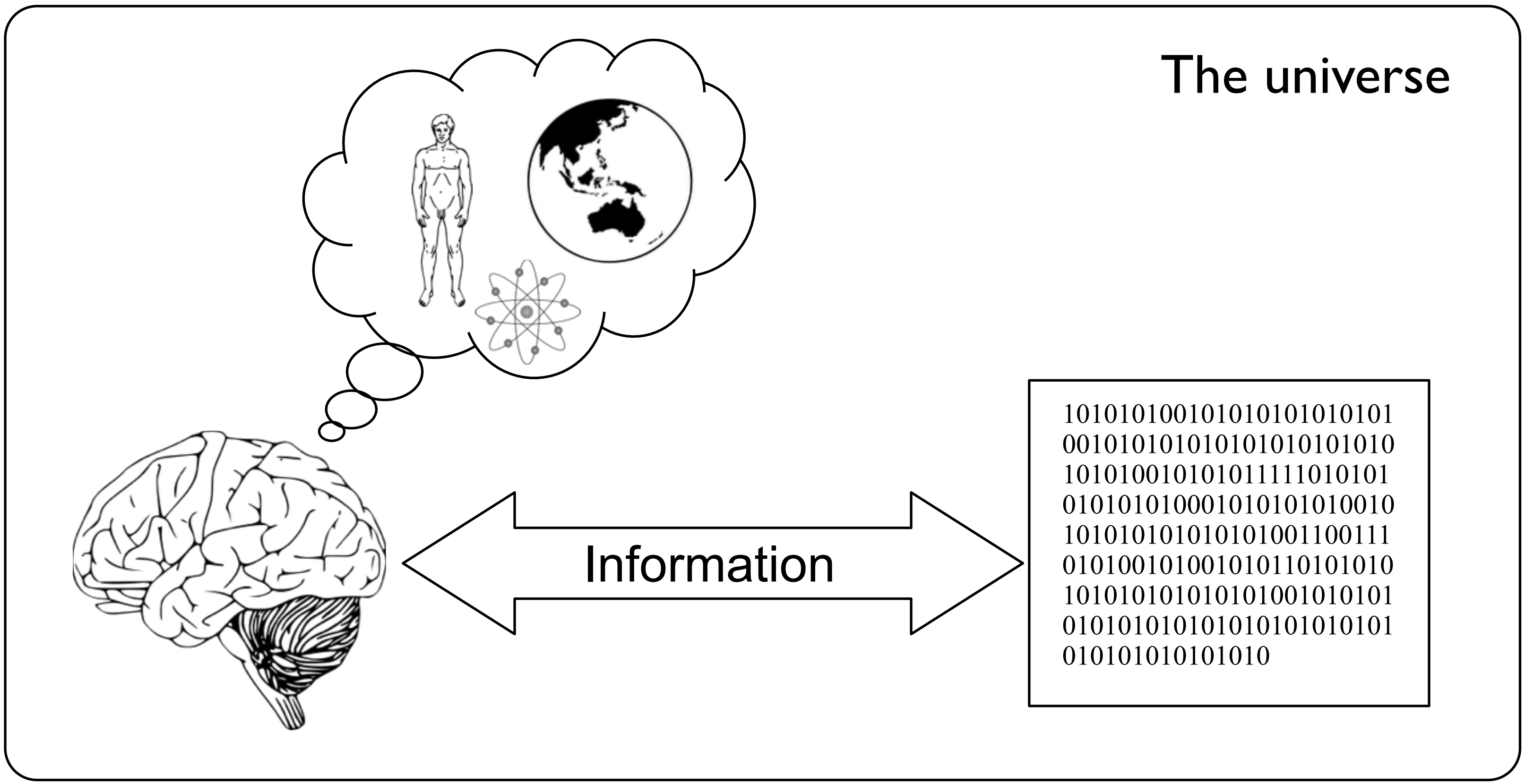
Luminous project

Information



Theoretical background: information theory and complexity

Information and consciousness: "RAS"

There are several approaches to consciosness that rely on information.

E.g., **Information Integration Theory (**IIT, Tononi et al) states that *the level of consciousness of a physical system is related to the repertoire of causal states (**information**) available to the system as a whole (**integration**)*.

Here we explore the idea that *the level of consciousness of a physical system is related to its capability (and practice) to model its input/ output (complex) information streams in an efficient manner (RAS)*.

We posit that conciousness is generated by brains (or other cognitive systems) running such compressive models.

Core mathematical concept: **Kolmogorov (or Algorithmic) Complexity**

Algorithmic complexity / simplicity

Complexity was first successfully formalized by the notion of **algorithmic complexity or Kolmogorov complexity** (also known as `algorithmic information', `algorithmic entropy', `Kolmogorov-Chaitin complexity', `descriptional complexity', `shortest program length' and `algorithmic randomness'.)

Co-discovered during the second half of the 20th century by Solomonoff, Kolmogorov and Chaitin . Provides a well-established albeit formal cornerstone to address the question of compression in brains---both natural or artificial.

We recall its definition: loosely, **the Kolmogorov complexity of a data set is the length of the shortest program capable of generating it.**

(in the oven)

About simplicity and conciousness (RAS*)

- What we call “reality” is a mental construct, a (mathematical) model. **Simplicity is a key aspect of the brain’s modeling strategy**
- Consciouness emerges as a result of the brain constructing and then running such compressive, efficient models

- In practice, **we propose to probe the brain using such an algorithmic complexity based framework,** studying the role of compression and simplicity in memory, prediction, brain state and responses to perturbation in different states of consciousness, delivering novel methodological tools in the electrical brain.

*Reality as Simplicity

arXiV papers:

Cornell University Library

arXiv.org > physics > arXiv:0704.1147

Physics > General Physics

Information, complexity, brains and reality (Kolmogorov Manifesto)

Giulio Ruffini

(Submitted on 9 Apr 2007)

I discuss several aspects of information theory and its relationship to physics and neuroscience. The unifying thread of this somewhat chaotic essay is the concept of Kolmogorov or algorithmic complexity (Kolmogorov Complexity, for short). I argue that it is natural to interpret cognition as the art of finding algorithms that apprach the Solomonoff-Kolmogorov-Chaitin (algorithmic) Complexity limit with appropriate tradeoffs. In addition, I claim that what we call the universe is an interpreted abstraction--a mental construct--based on the observed coherence between multiple sensory input streams and our own interactions. Hence, the notion of Universe is itself a model.

Comments: This is a live essay, kind of a mental log book on a series of topics under the theme of information and compression

Subjects: **General Physics (physics.gen-ph)**; Biological Physics (physics.bio-ph)

Report number: Starlab TN00054

Cite as: arXiv:0704.1147 **[physics.gen-ph]**
(or **arXiv:0704.1147v1 [physics.gen-ph]** for this version)

Submission history

From: Giulio Ruffini [view email]

[v1] Mon, 9 Apr 2007 20:17:39 GMT (308kb,D)

“RAS”

Cornell University Library

arXiv.org > physics > arXiv:0903.1193

Physics > General Physics

Reality as Simplicity

Giulio Ruffini

(Submitted on 6 Mar 2009 (v1), last revised 19 Jun 2009 (this version, v3))

The aim of this paper is to study the relevance of simplicity and its formal representation as Kolmogorov or algorithmic complexity in the cognitive sciences. The discussion is based on two premises: 1) all human experience is generated in the brain, 2) the brain has only access to information. Taken together, these two premises lead us to conclude that all the elements of what we call `reality' are derived mental constructs based on information and compression, i.e., algorithmic models derived from the search for simplicity in data. Naturally, these premises apply to humans in real or virtual environments as well as robots or other cognitive systems. Based on this, it is further hypothesized that there is a hierarchy of processing levels where simplicity and compression play a major role. As applications, I illustrate first the relevance of compression and simplicity in fundamental neuroscience with an analysis of the Mismatch Negativity paradigm. Then I discuss the applicability to Presence research, which studies how to produce real-feeling experiences in mediated interaction, and use Bayesian modeling to define in a formal way different aspects of the illusion of Presence. The idea is put forth that given alternative models (interpretations) for a given mediated interaction, a brain will select the simplest one it can construct weighted by prior models. In the final section the universality of these ideas and applications in robotics, machine learning, biology and education is discussed. I emphasize that there is a common conceptual thread based on the idea of simplicity, which suggests a common study approach.

Comments: Submitted to Brain Research Bulletin (special edition on VR, brain research and robotics). 42 pages and 3 figures

Subjects: **General Physics (physics.gen-ph)**

Report number: Starlab TN00177 (June 2009)

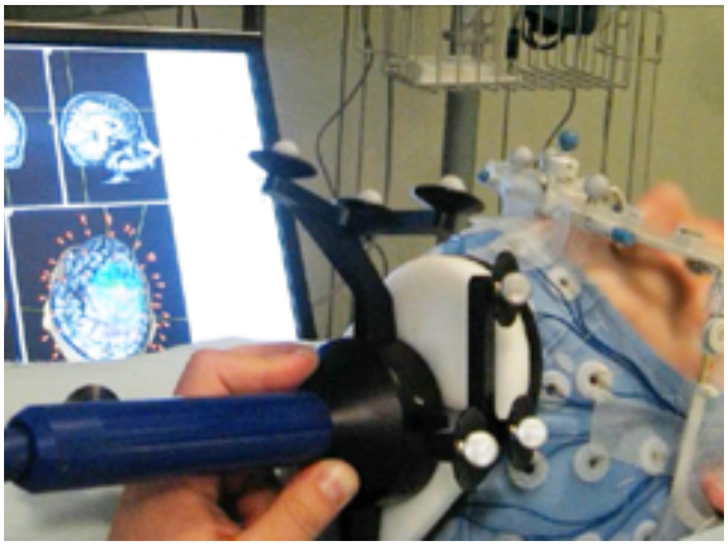
Cite as: arXiv:0903.1193 **[physics.gen-ph]**
(or **arXiv:0903.1193v3 [physics.gen-ph]** for this version)

Technology

Studying consciousness
in the electrical brain

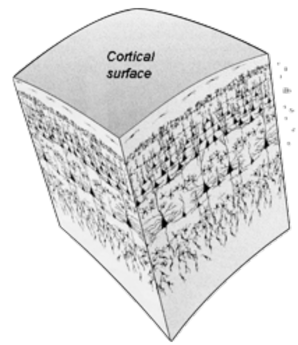
luminous

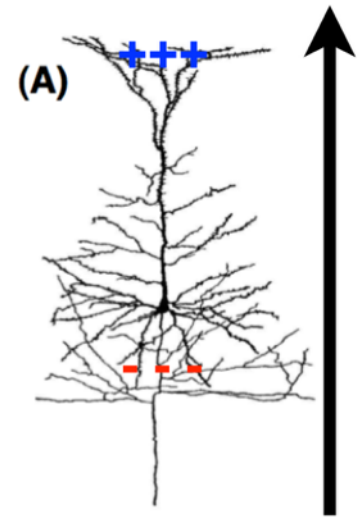
Technology / Technique: tCS and TMS



Transcranial current stimulation

NE®



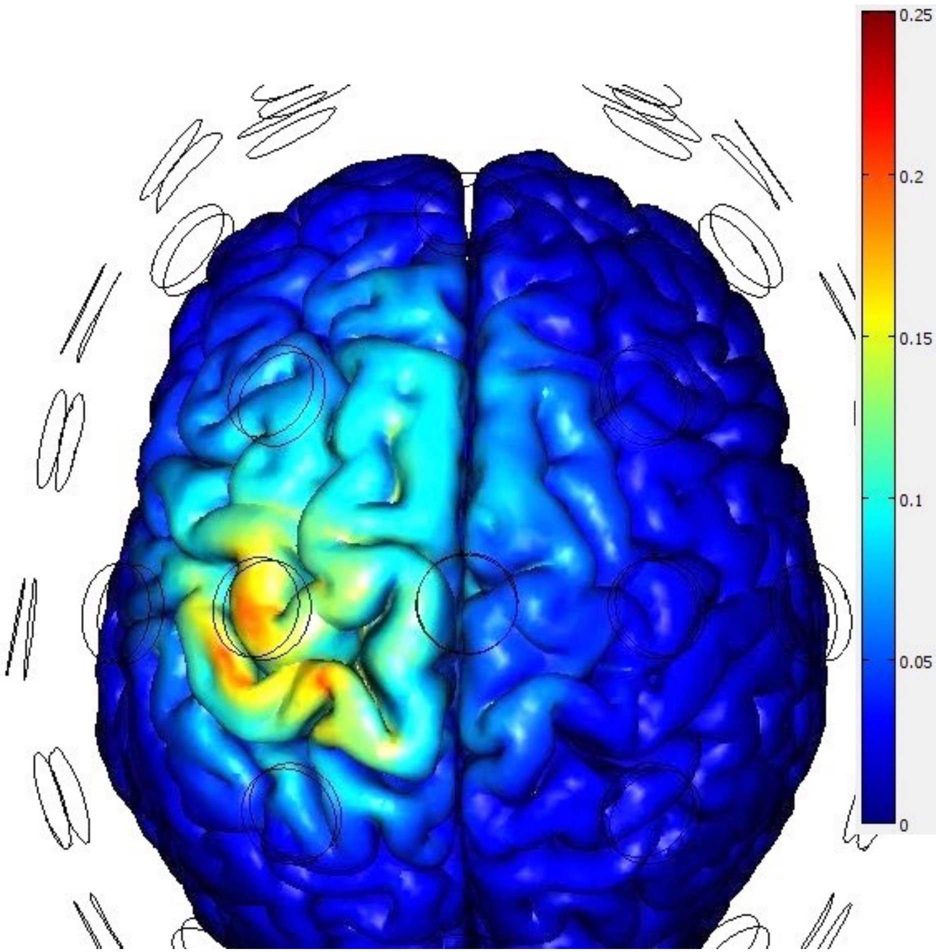


Transcranial Magnetic Stimulation (TMS)

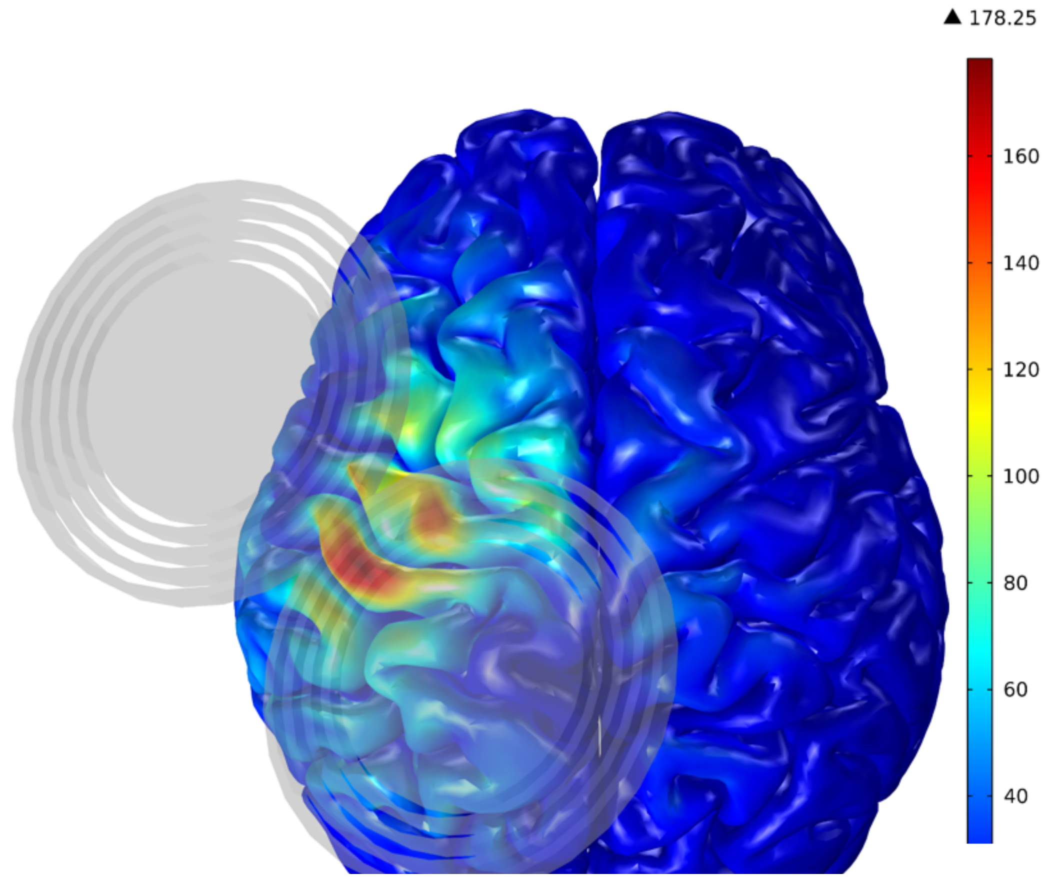
Technology / Technique: tCS and TMS

E-field's
mag (V/m)

E-field distribution - MtDCS



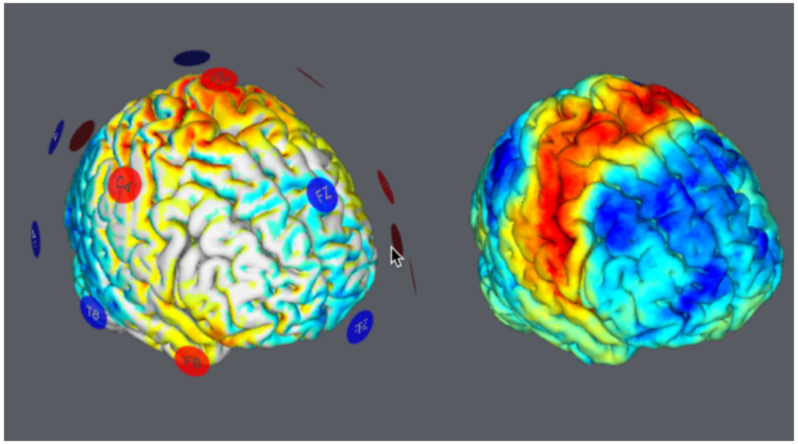
E-field distribution - TMS



R. Salvador & P. Miranda, G. Ruffini 2015, in prep

Luminous project

Targeting networks



the wonders of multichannel tCS

New technologies such as Starstim (multichannel tCS) can be used to target the cortex in old and new ways: going after cortical networks

Optimization of multifocal transcranial current stimulation for weighted cortical pattern targeting from realistic modeling of electric fields

CrossMark

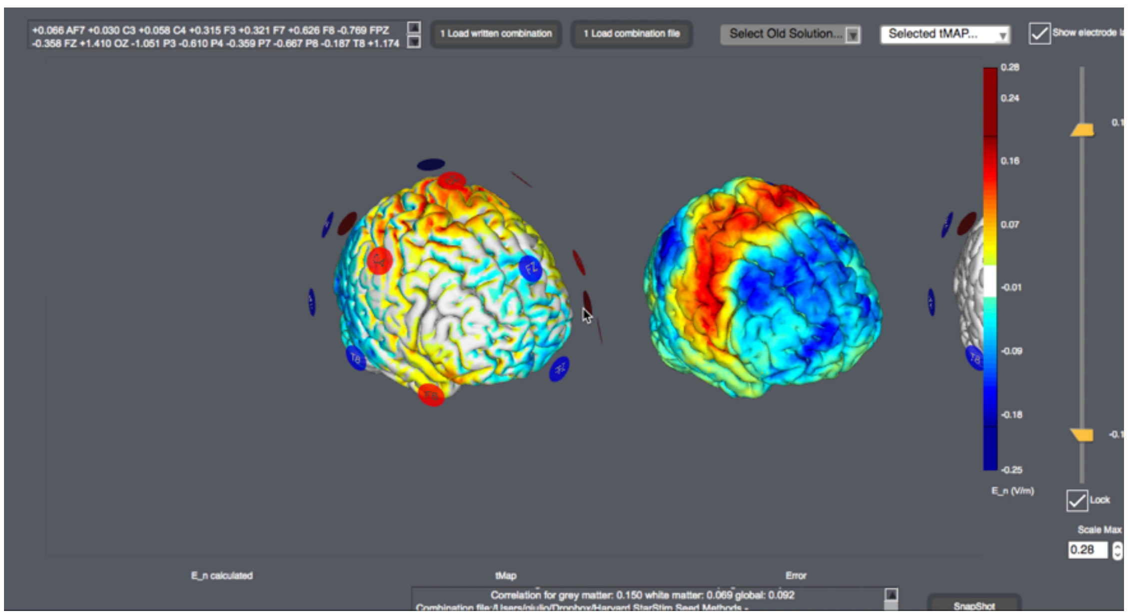
Giulio Ruffini [a,b,*], Michael D. Fox [c,d], Oscar Ripolles [b], Pedro Cavaleiro Miranda [b,e], Alvaro Pascual-Leone [d,f]

Fox et al 2014

Resting-state networks link invasive and noninvasive brain stimulation across diverse psychiatric and neurological diseases

Michael D. Fox[a,b,c,1], Randy L. Buckner[c,d,e], Hesheng Liu[c], M. Mallar Chakravarty[f,g], Andres M. Lozano[h,i], and Alvaro Pascual-Leone[a]

Optimized solution: Stimweaver



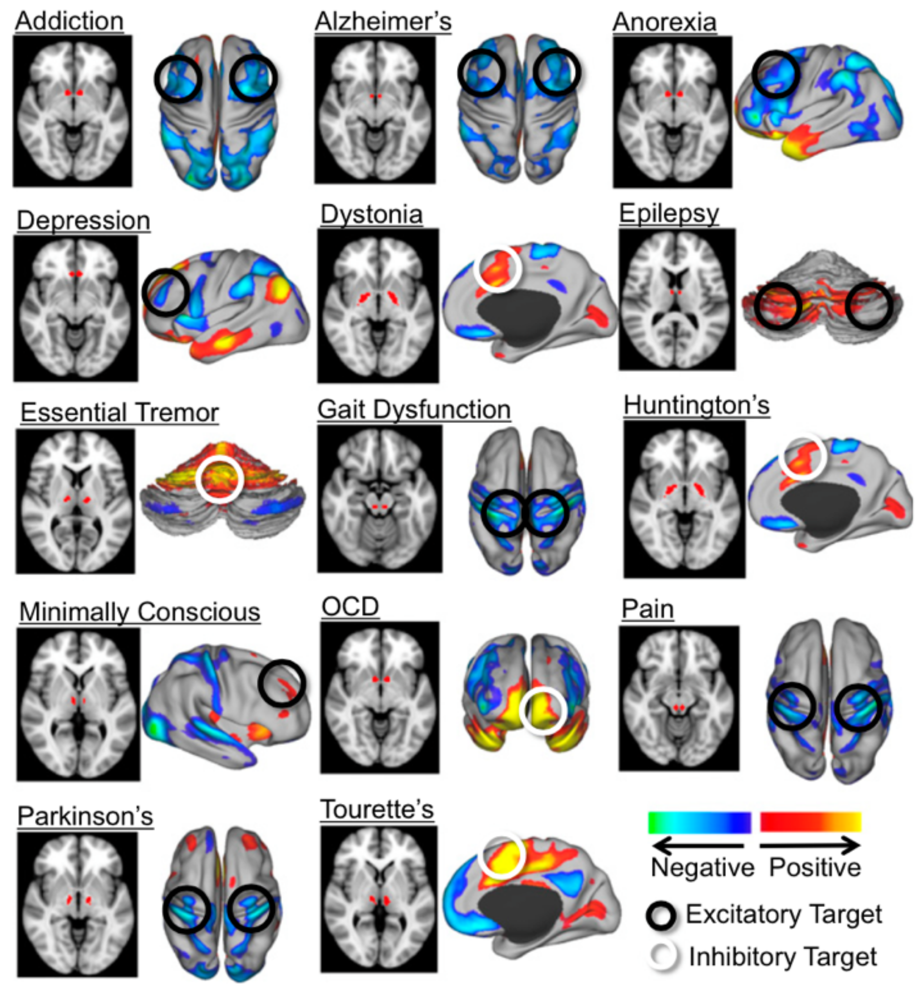
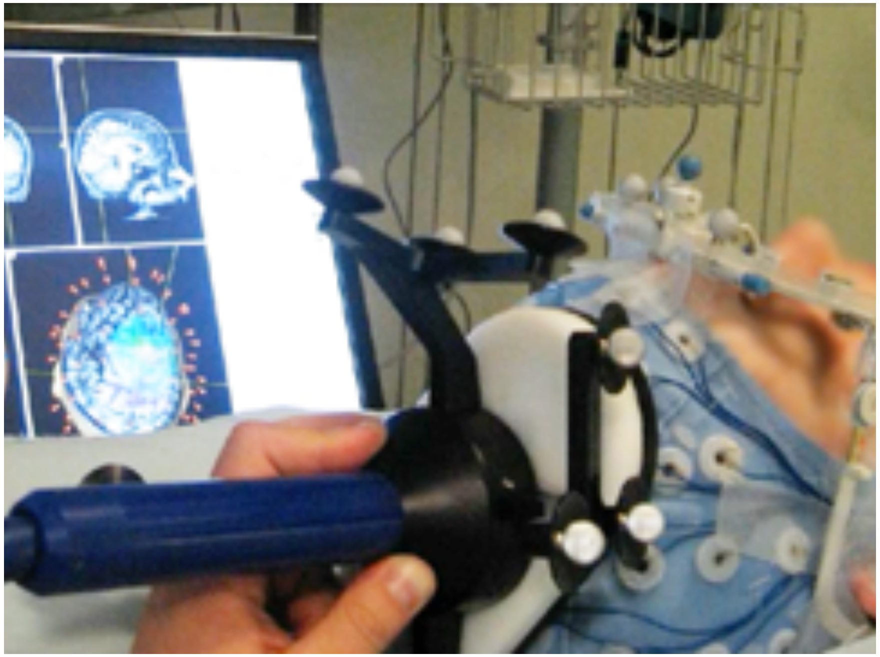


Fig. 2. Sites for invasive and noninvasive brain stimulation with the best evidence of therapeutic efficacy in each disease are functionally connected. For each disease, the site at which DBS is most effective is shown in red. Resting-state functional connectivity with this site is shown along with the correspondence to the site at which noninvasive stimulation is most effective in each disease (circles). Black circles indicate sites at which noninvasive excitatory stimulation (>5 Hz TMS or anodal tDCS) has been reported to be efficacious. White circles indicate sites where inhibitory stimulation (<1 Hz TMS or cathodal tDCS) has been reported to be efficacious.

Probing the brain with NIBS



Consciousness will someday be electromagnetically measured.

NIBS: tCS and TMS

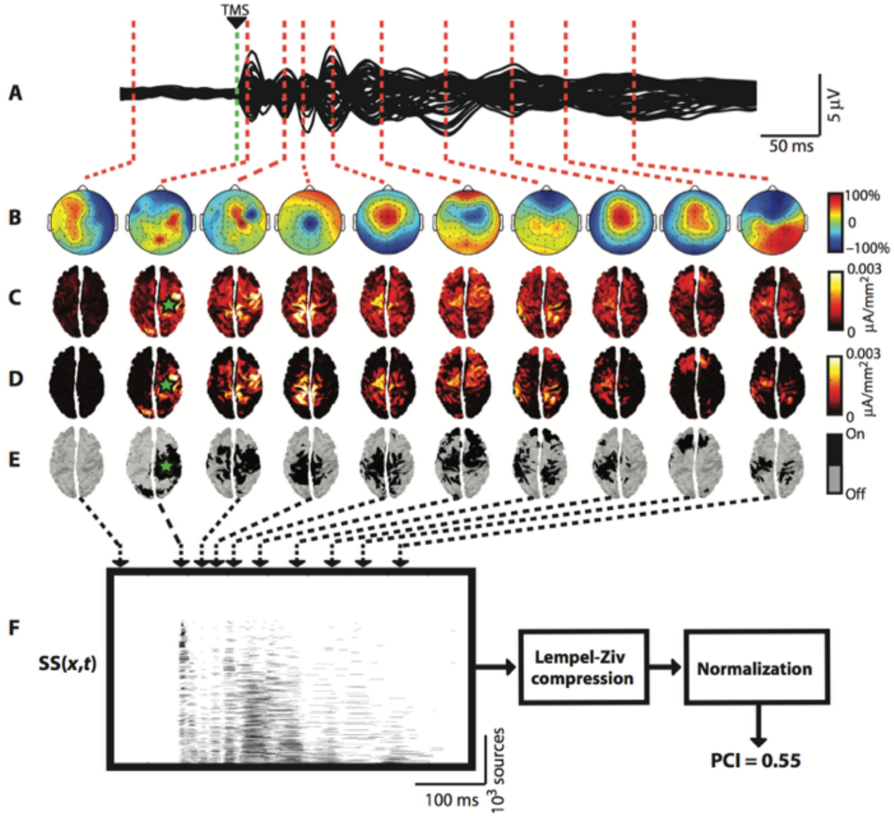
TMS has already been used to probe brain connectivity by Massimini, Casali et al.

In fact, complexity measures have been used to quantify the response.

A similar approach can be explored with tCS: stimulate the brain and record responses (short term) or long term changes in electrical activity

A Theoretically Based Index of Consciousness Independent of Sensory Processing and Behavior

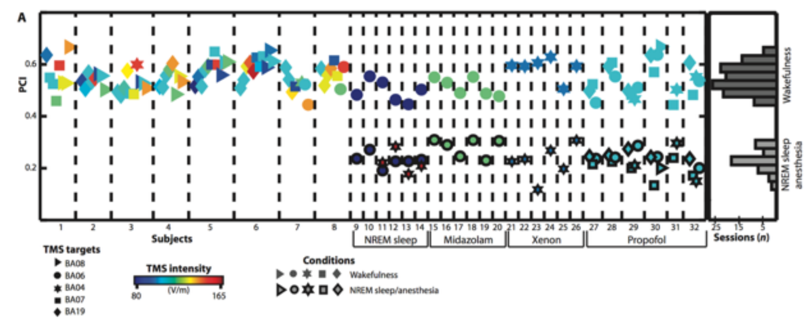
Adenauer G. Casali,[1*†] Olivia Gosseries,[2*] Mario Rosanova,[1] Mélanie Boly,[2‡] Simone Sarasso,[1] Karina R. Casali,[1,3] Silvia Casarotto,[1] Marie-Aurélie Bruno,[2] Steven Laureys,[2] Giulio Tononi,[4] Marcello Massimini[1,5§]



Can Machines Be Conscious?

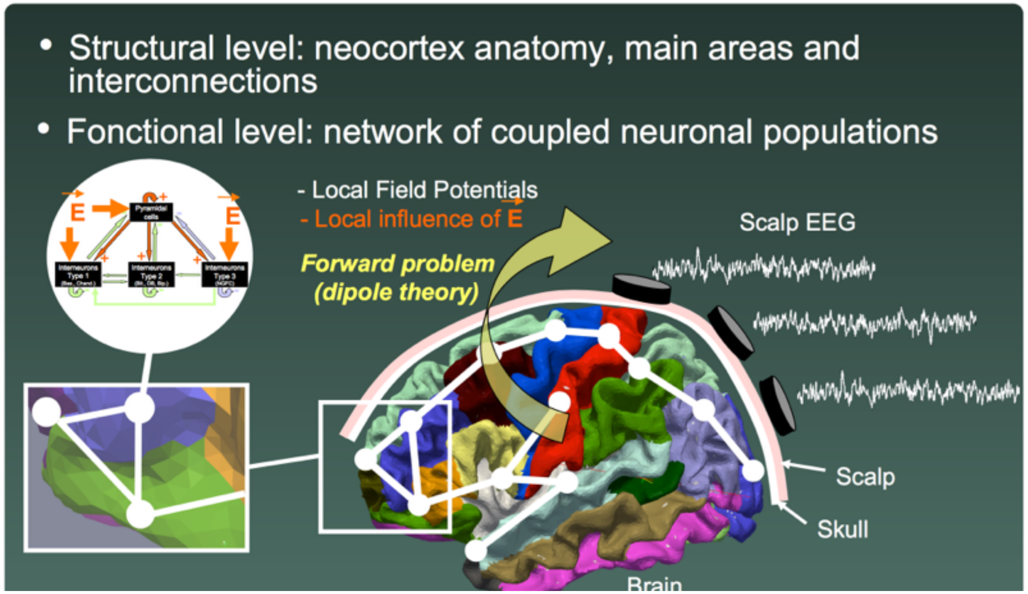
YES—AND A NEW TURING TEST MIGHT PROVE IT

BY CHRISTOF KOCH AND GIULIO TONONI



Luminous project

Modeling



Modeling EEG under NIBS

Based on existing models connecting population models.

Extend to include connectome, plasticity, thalamocortical loop, represent SRP and complex stimulation

A bit about scenarios

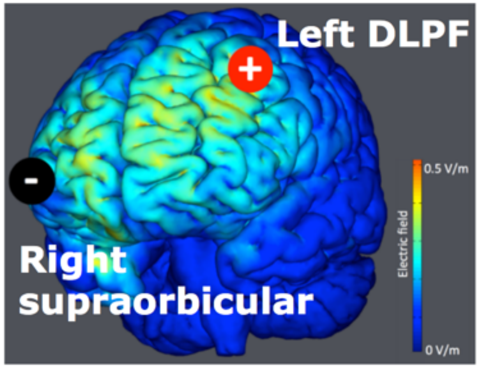
Studying consciousness
in the electrical brain

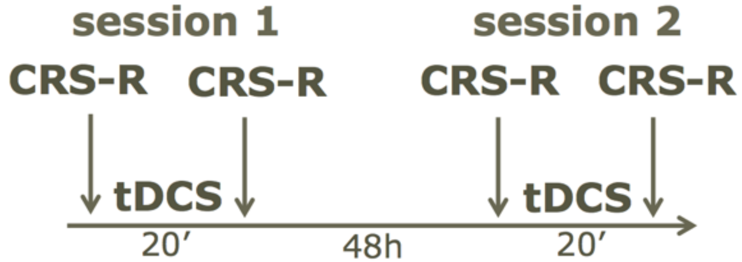
LUMINOUS®

Diseases of Consciousness

tDCS single session

- Randomized, double blind, sham controlled, cross-over study
- Direct current; 2 mA; 20 min
- 55 patients included
  (25 VS/UWS; 30 MCS;
  35 chronic; 25 TBI; 43±18y)

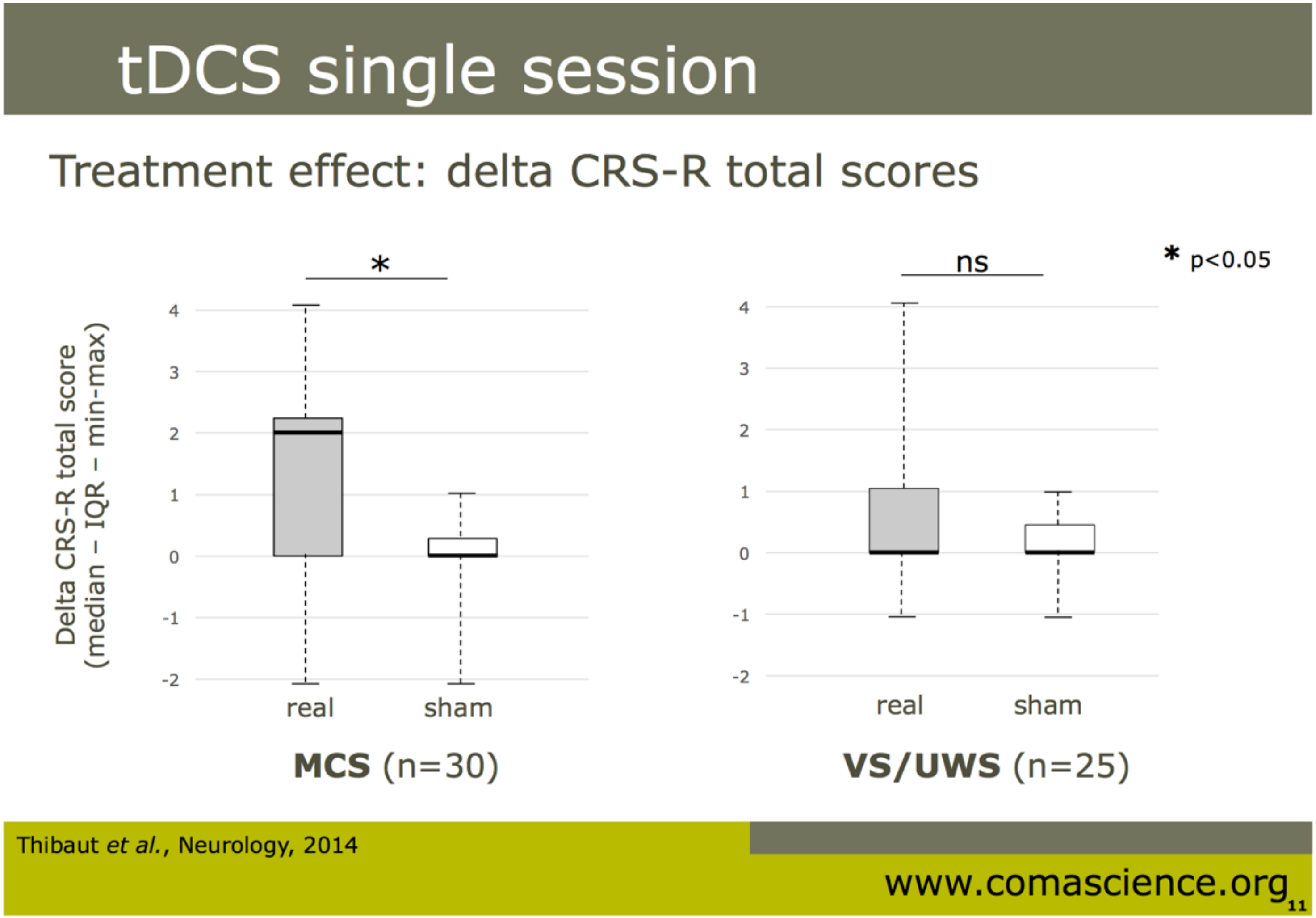




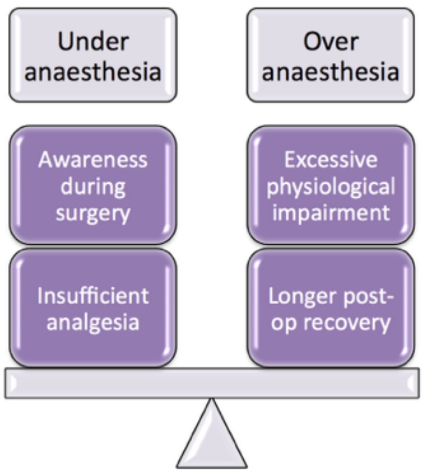
Thibaut *et al.*, Neurology, 2014

www.comascience.org 10

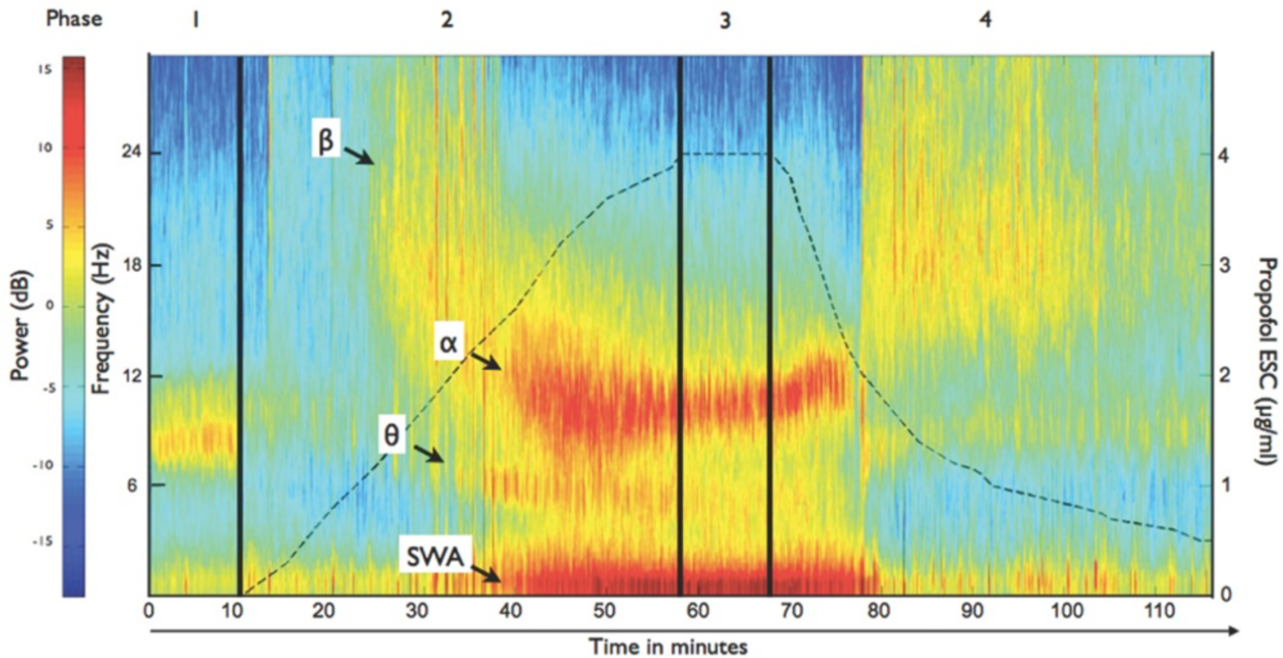
Diseases of Consciousness



Anesthesia



EEG time-frequency analysis: bench data for all channels and volunteers



Power in Slow Wave Activity (0.5-1.5Hz) and alpha (8-14Hz) frequency bands increase with increasing propofol dose

AAAS

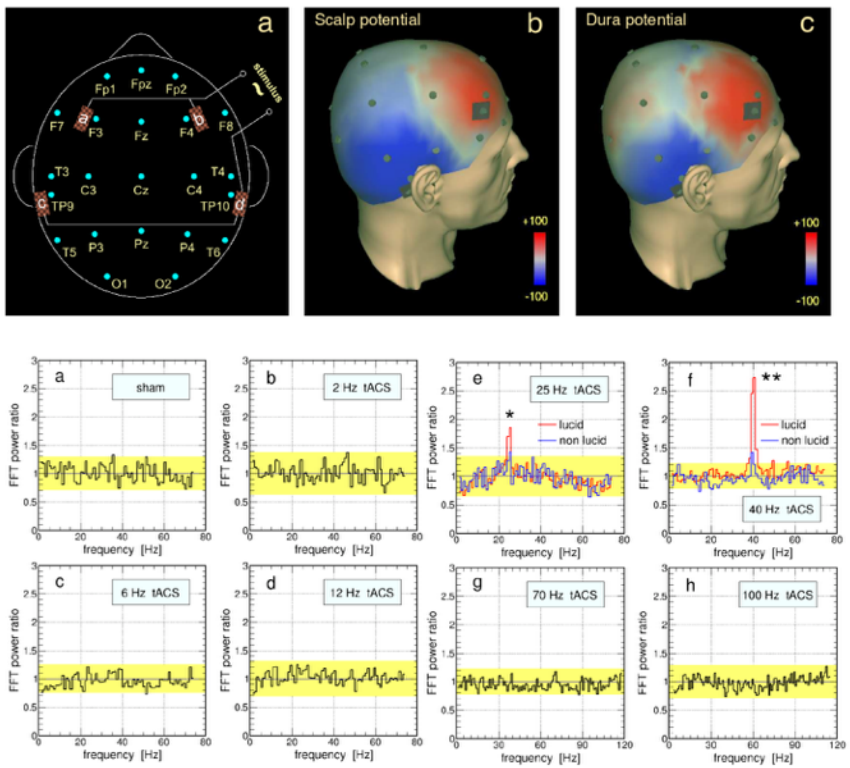
CONSCIOUSNESS

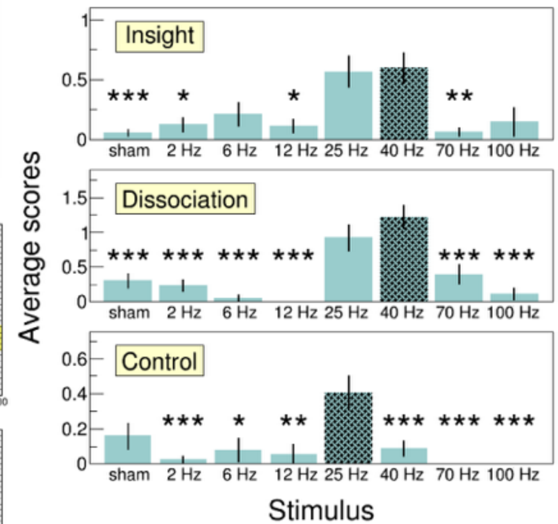
Slow-Wave Activity Saturation and Thalamocortical Isolation During Propofol Anesthesia in Humans

Róisín Ní Mhuircheartaigh,* Catherine Warnaby,*† Richard Rogers, Saad Jbabdi, Irene Tracey

Lucid dreaming

Pilot studies: Oscillatory activity in dreams



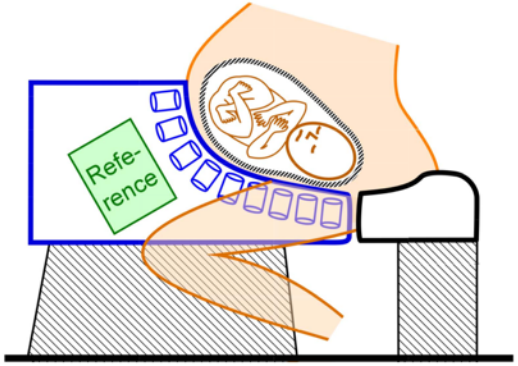


Voss et al. 2014

Fetal consciousness

Neuronal processes established in fetus

- auditory evoked fields can be recorded after 20th week of gestation and the latency decreases over gestation
  Schleussner et al. 2001, Lengle et al. 2001, Holst et al. 2005
- fetuses show mismatch-like responses to auditory stimulation in the last trimester of gestation
  Huotilainen et al. 2005, Draganova et al. 2005, 2007
- visual evoked responses can be recorded in the last trimester of gestation and the response latency decreases over gestation
  Eswaran et al. 2002, McCubbin et al. 2007
- fetuses show habituation and dishabituation to auditory and visual stimuli
  Matuz et al. 2012, Muenssinger et al. 2013 a,b
- fetuses show numerosity related mismatch responses
  Schleger et al. 2014
- the fetal behavioral state influences the evoked response latency
  Kiefer-Schmidt et al. 2013



UNIVERSITÄTS KLINIKUM TÜBINGEN

EBERHARD KARLS UNIVERSITÄT TÜBINGEN

SEVENTH FRAMEWORK PROGRAMME

Nudge-it.

DZD Deutsches Zentrum für Diabetesforschung aim for the stars ….

Closing

- Our project has just started
- Very intersting team and technologies
- Will not solve the hard problem, but should provide new metrics and insights into consciousness useful for the field
- Open to collaborate!

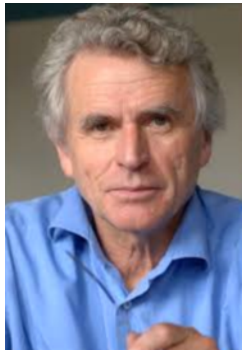
Some of the faces in the project ….















Advisory board: G. Tononi (theory of consciousness, ITh, neurophilosophy), A. Pascual-Leone (neuroscience, brain stimulation), D. Wolpert (AI, mathematics), I. Aleksander (MC, robotics)

Thank you!

giulio.ruffini@starlab.es

http://luminous-project.eu

Studying consciousness
in the electrical brain

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