

Roma, may 30, 2013

Neuromodulazione non invasiva delle facoltà cognitive

Brain Investigation & Neuromodulation Lab

Azienda Ospedaliera Universitaria Senese

Dipartimento di Neuroscienze

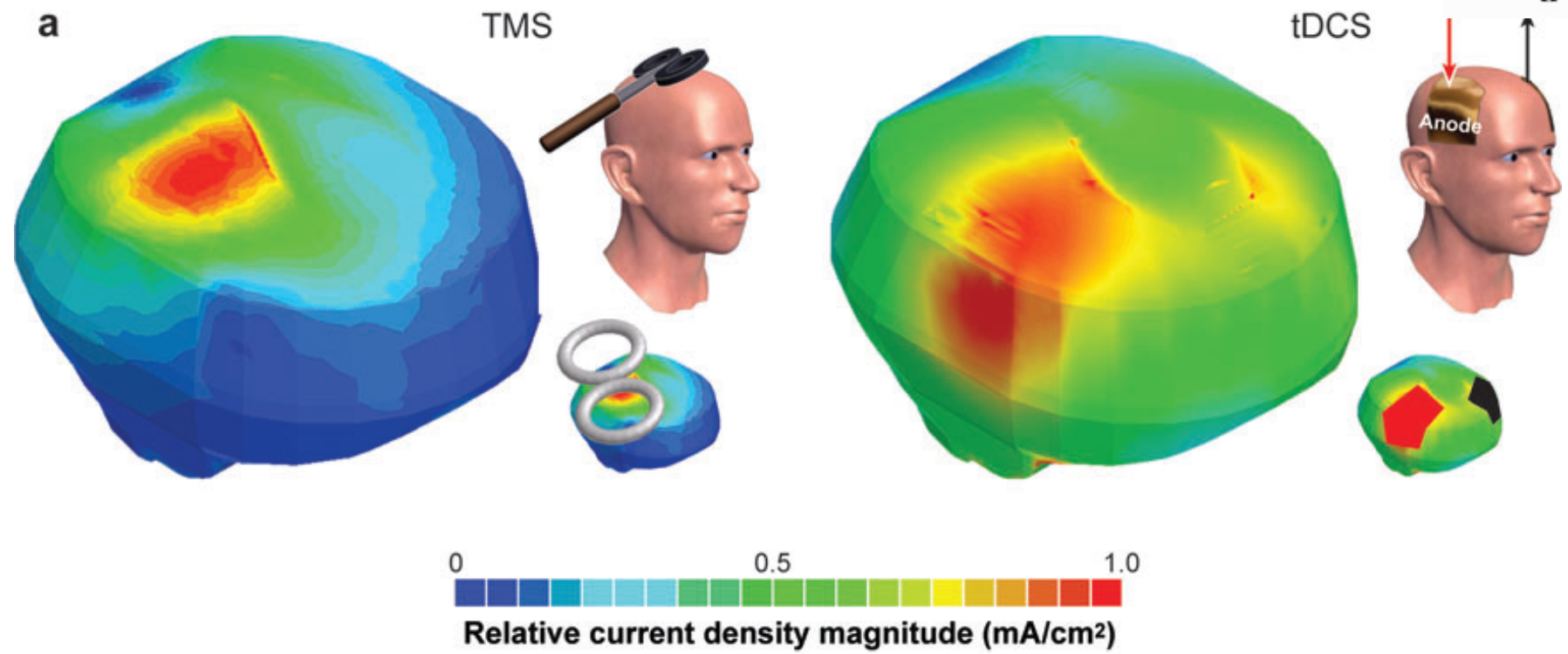
Sezione Neurologia e Neurofisiologia Clinica

Simone Rossi, contatti: rossisimo@unisi.it

Neuromodulation

- To deliver a small amount of electricity
- on a neural network (or structure/area/hub)
- which is part of, or connected with, a circuit which sustains a certain function (or is dysfunctional)
- with the objective to induce lasting functional changes
- thereby getting a behavioural effect (even therapeutic)

Induced fields by TMS and tDCS



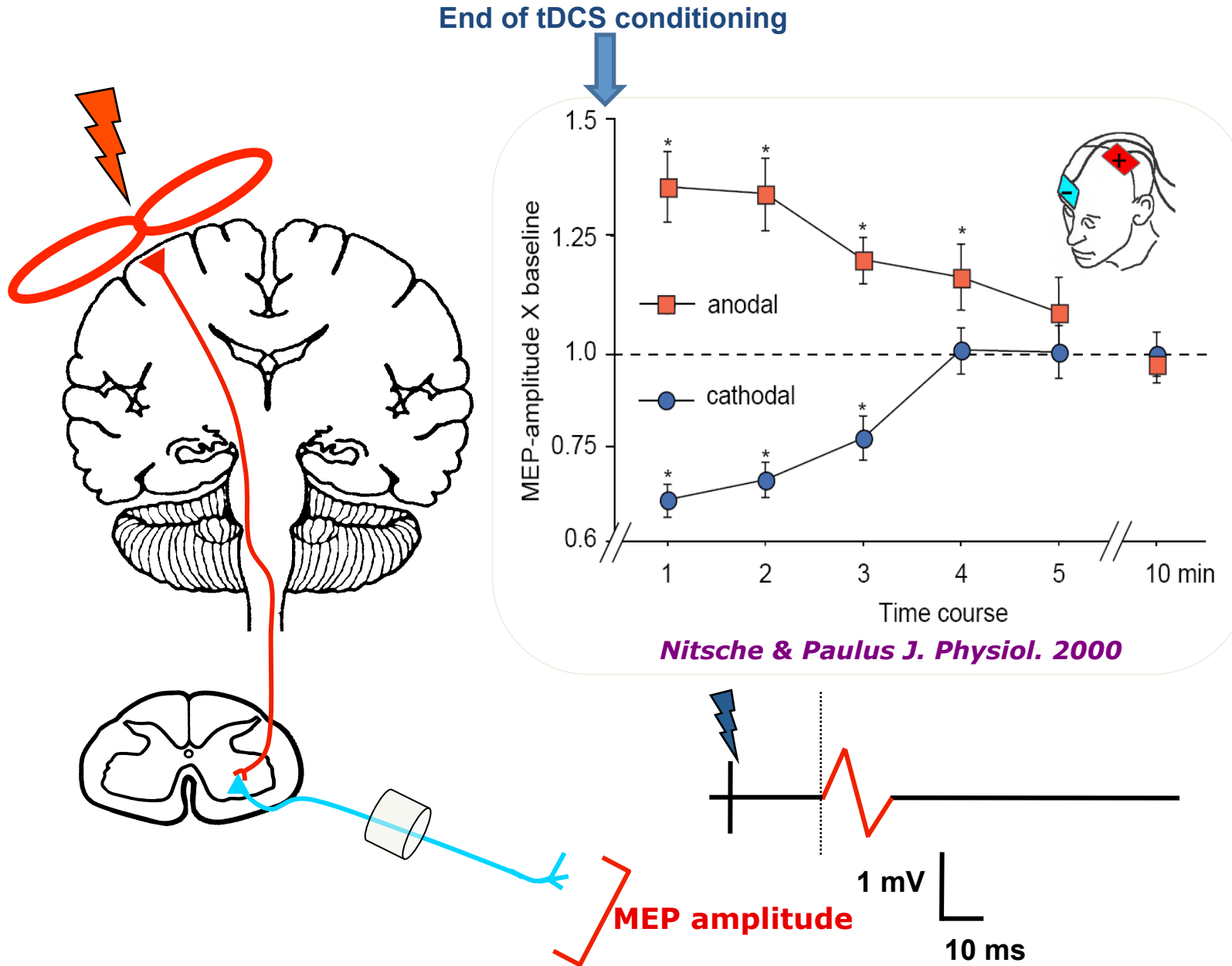
Wagner et al., 2007

TMS does induce action potentials
TMS induces muscle twitches

tDCS does not induce action potentials
tDCS does not induce muscle twitches

Polarization

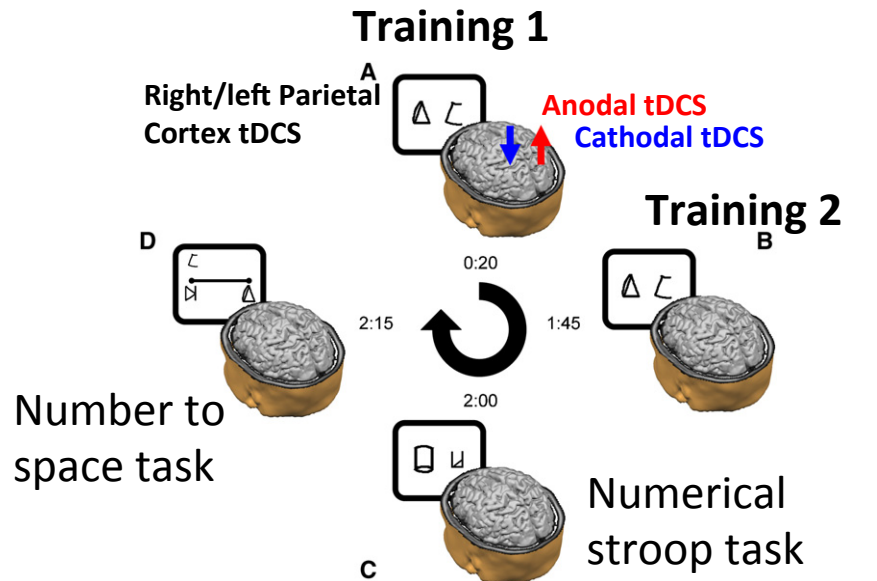
tDCS induces long-lasting polarity-specific after-effects



Modulating Neuronal Activity Produces Specific and Long-Lasting Changes in Numerical Competence

Roi Cohen Kadosh,^{1,*} Sonja Soskic,² Teresa Iuculano,^{1,3} Ryota Kanai,³ and Vincent Walsh³

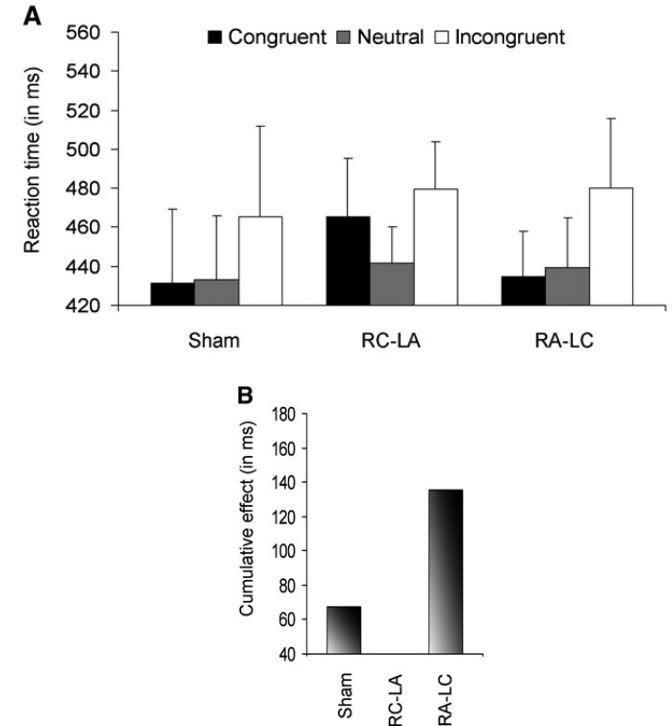
Current Biology 20, 2016–2020, November 23, 2010



a

1	2	3	4	5	6	7	8	9
▷	↵	⊥	⇒	□	€	⊗	∟	△

15 subjects – 6-day training

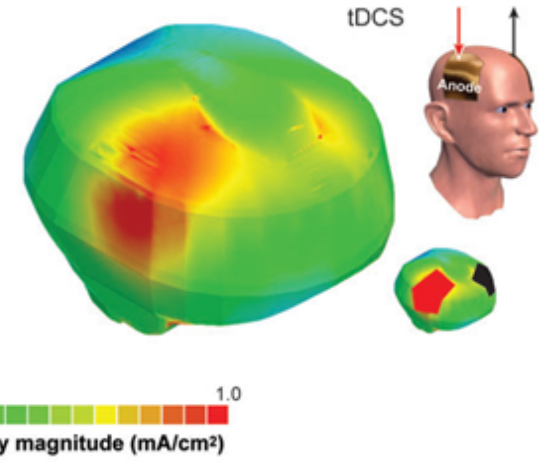
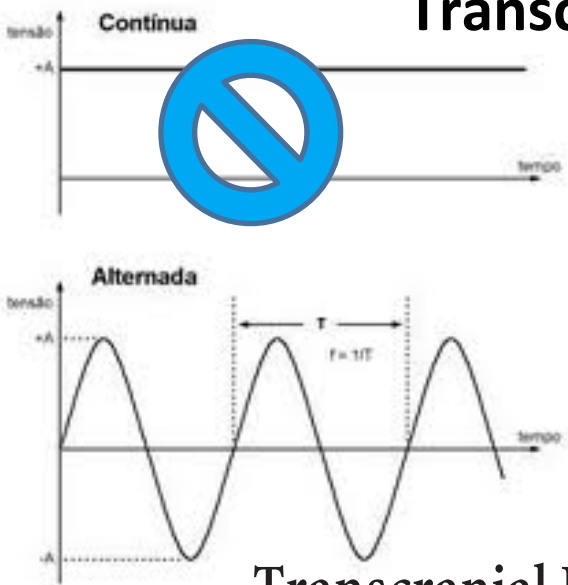


The polarity of the brain stimulation specifically enhanced or impaired the acquisition of automatic number processing and the mapping of number into space, both important indices of numerical proficiency.

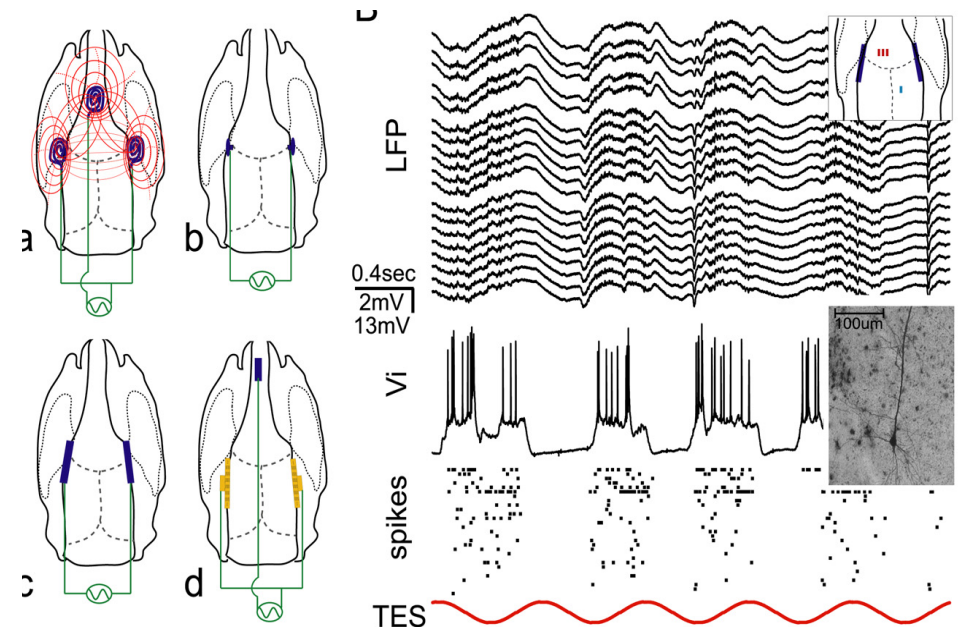
The improvement was still present 6 months after the training

Transcranial Alternating Current Stimulation

tACS



Transcranial Electric Stimulation Entraines Cortical Neuronal Populations in Rats *The Journal of Neuroscience*, August 25, 2010 • 30(34):11476–11485
Ozen et al.



THE ENTRAINMENT phenomenon

Neurons as ensembles of “oscillating elements”.

If they are exposed to a periodic external force, they start to oscillate with the same period
 period
 (phase alignment and amplitude increase).

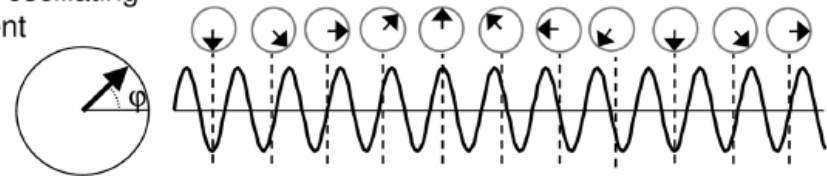


Entrainment of perceptually relevant brain oscillations by non-invasive rhythmic stimulation of the human brain

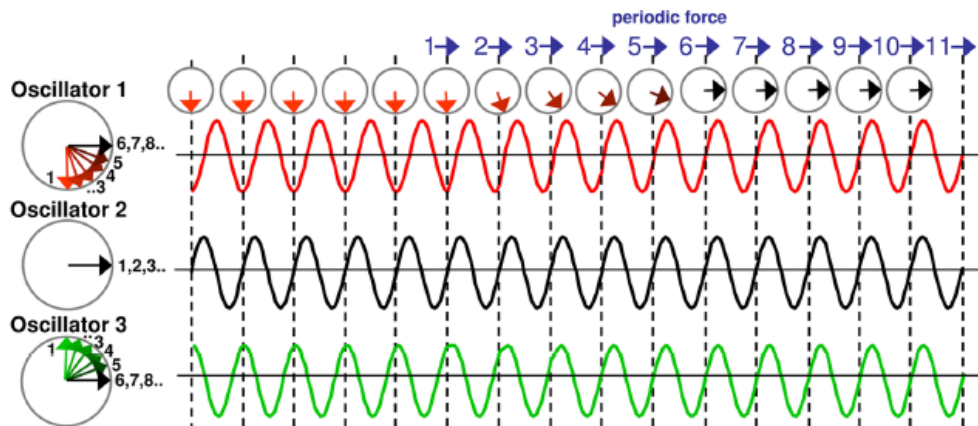
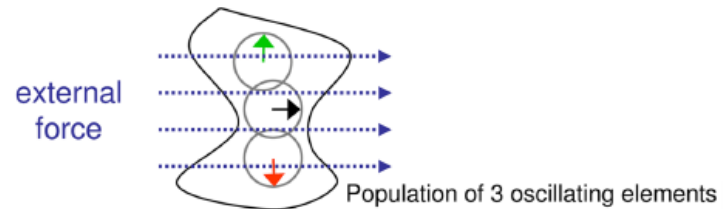
Gregor Thut*, Philippe G. Schyns and Joachim Gross

A Neural oscillation in a simple phase oscillator model

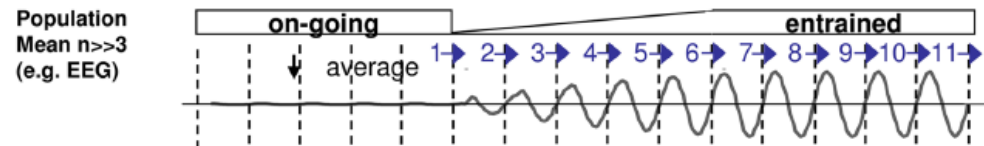
single oscillating element



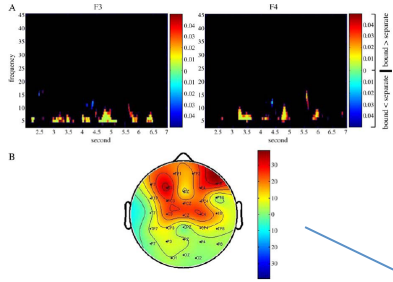
B Entrainment of neuronal oscillators by a periodic external force



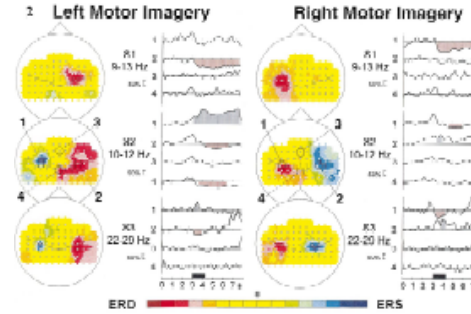
C Entrainment at the population level



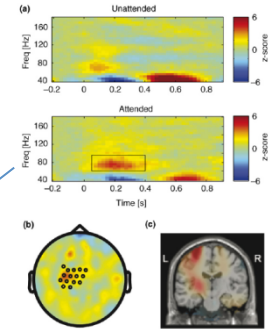
Θ : working /long-term memory



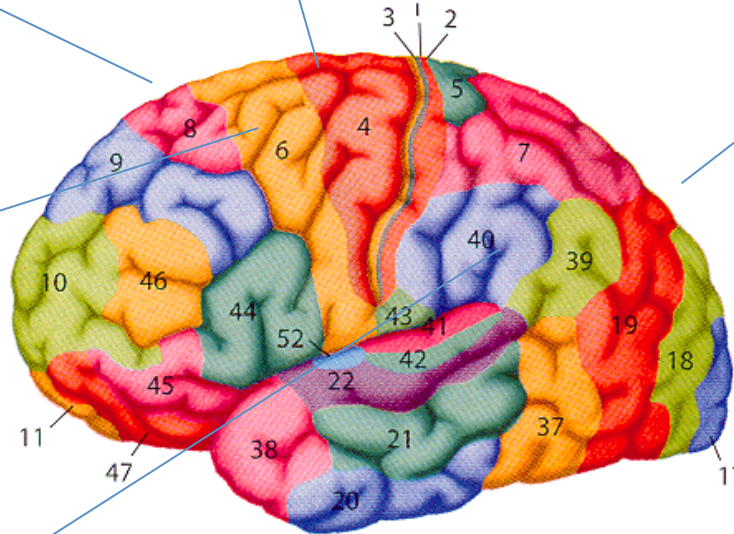
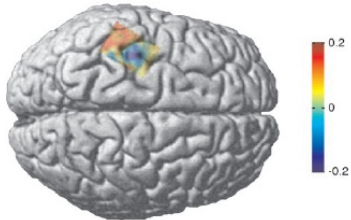
Beta: voluntary movement



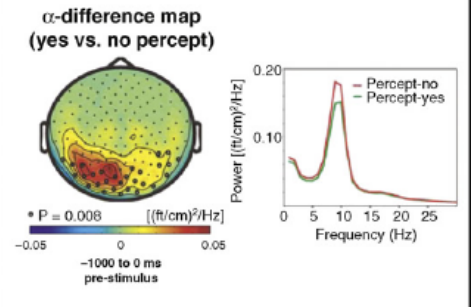
Gamma: selective attention



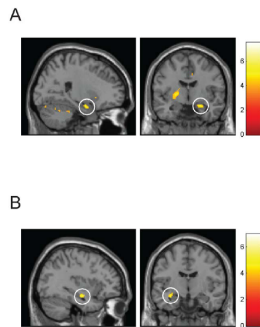
Alpha: automatic movements



Alpha: visual perception

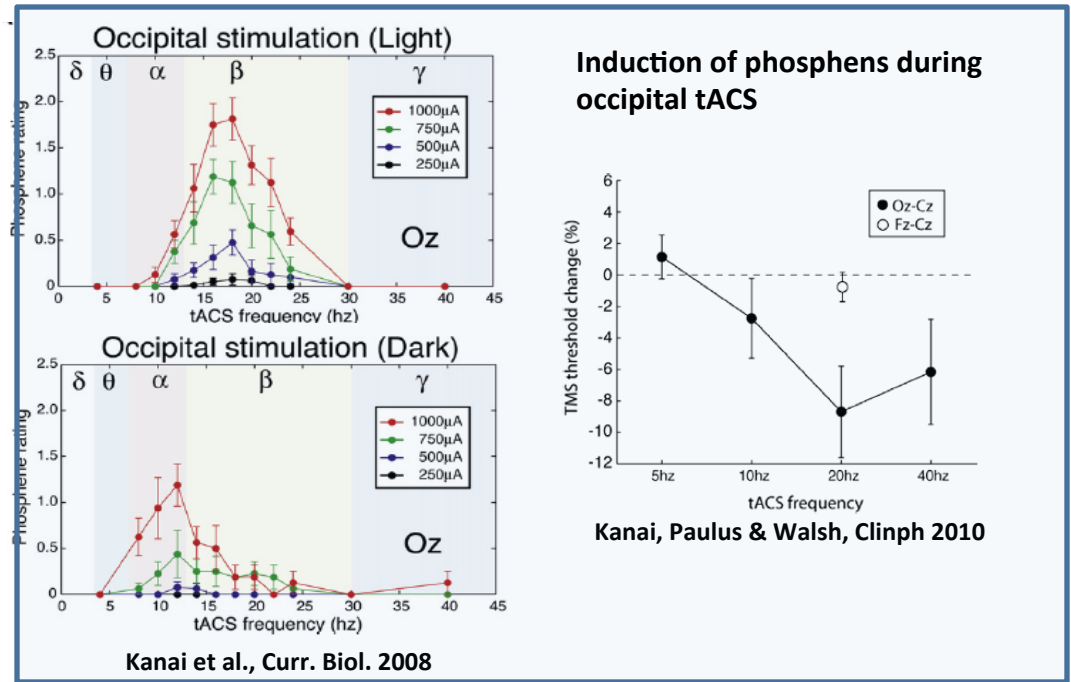
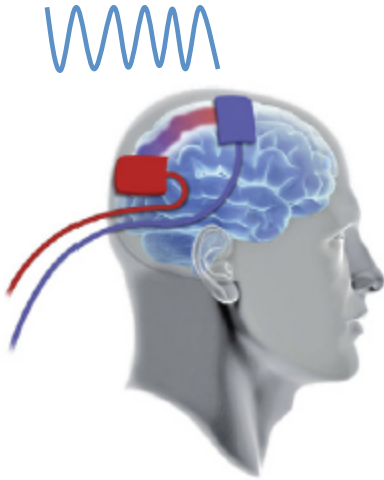


Is there a causal relation between frequency and specific functions?



Θ : spatial orienting

Transcranial Alternating Current Stimulation (tACS)



Low-intensity (1-1.5 mA),
frequency-specific

Theta = ≈5 Hz

Alpha = ≈10 Hz

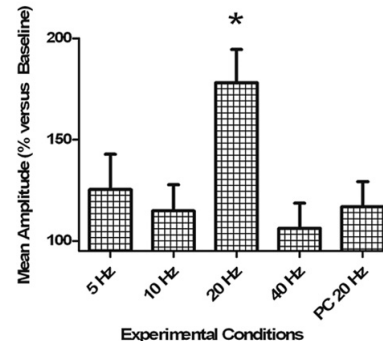
Beta = ≈20 Hz

Gamma = ≈30 Hz

Frequency-Dependent Tuning of the Human Motor System Induced by Transcranial Oscillatory Potentials

The Journal of Neuroscience, August 24, 2011 • 31(34):12165–12170 • 12165

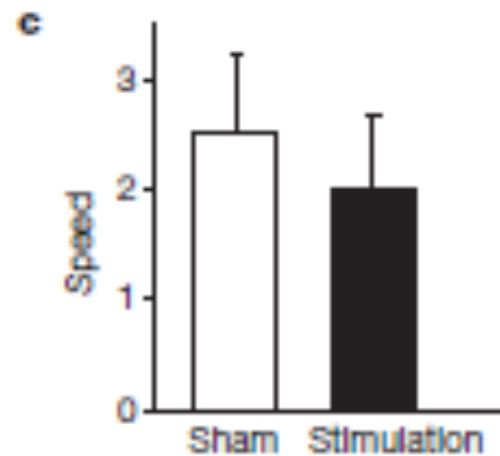
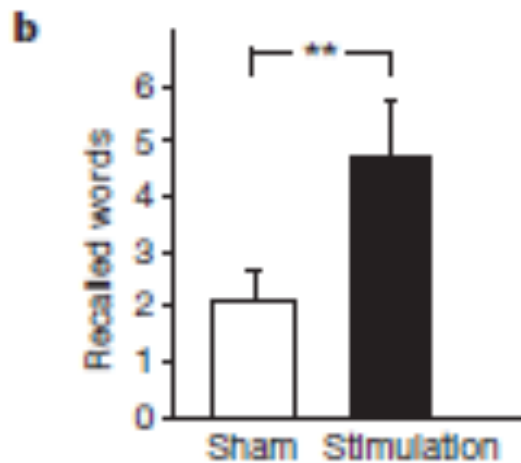
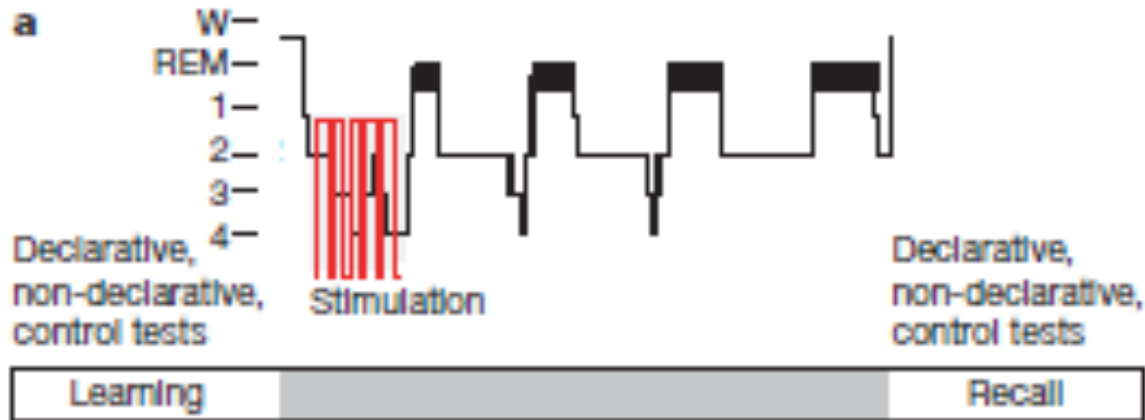
Matteo Feurra, Giovanni Bianco, Emiliano Santarnecchi, Massimiliano Del Testa, Alessandro Rossi, and Simone Rossi



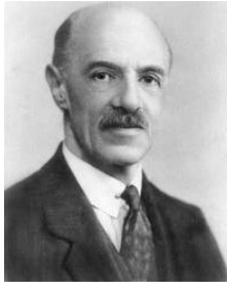


LETTERS

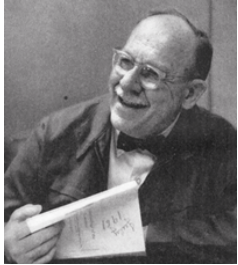
Boosting slow oscillations during sleep potentiates memory

Lisa Marshall¹, Halla Helgadóttir¹, Matthias Mölle¹ & Jan Born¹

What is intelligence?



Charles Edward Spearman. 1910: Individual cognitive abilities expressed with a psychometric factor “g” (= general intelligence factor)



Edwin Garrigues Boring. 1923: Intelligence is what the tests (IQ) test



David "Wex" Wechsler. 1949: the global capacity of a person to act purposefully, to think rationally, and to deal effectively with his/her environment.

He developed the WAIS test, based on VERBAL and NON-VERBAL capabilities



Robert Sternberg. 1988: the cognitive ability of an individual to learn from experience, to reason well, to remember important information, and to cope with the demands of daily living.

The Triarchic Mind (intelligence as analytical, creative and practical abilities)

What is intelligence?



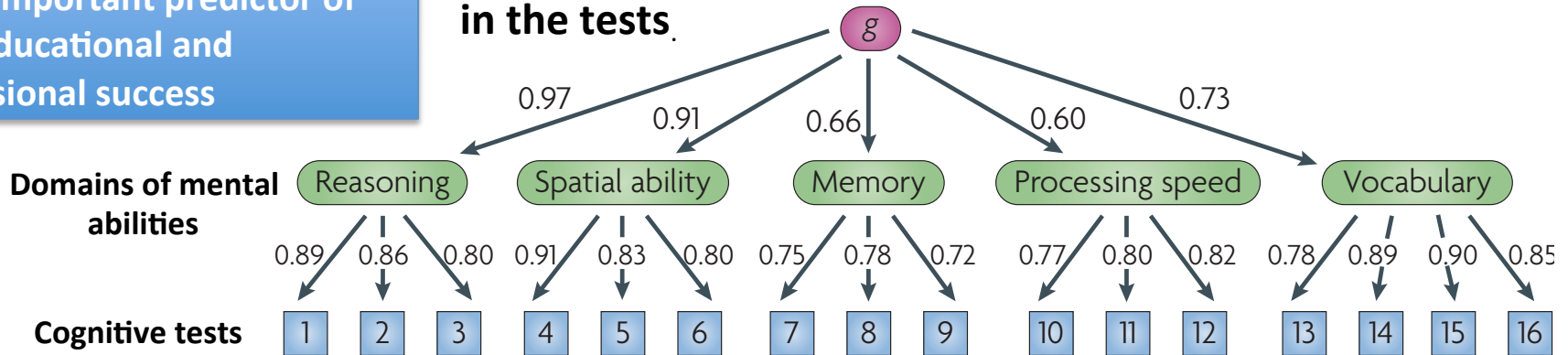
Louis Leon Thurstone. 1924: Primary Mental Abilities as independent group factors of intelligence that different individuals possess in varying degrees. He contrasted the “g” factor



Howard Earl Gardner. 1983: Theory of Multiple Intelligences (Verbal, Spatial, Mathematical, Musical.....) mainly independent each-other.

- “G” positively correlates with performance in a wide range of cognitive tasks;
- is an important predictor of both educational and professional success

g is not dependent on specific cognitive test batteries, as long as there is sufficient variety in the tests.



The Cattell (1941)-Horn (1965)-Carroll (1993) theory

Cristallized Intelligence (Gc): includes the breadth and depth of a person's acquired knowledge, the ability to communicate one's knowledge, and the ability to reason using previously learned experiences or procedures.



Intelligence-as-product



Measured with tests assessing stored knowledge, such as general facts or vocabulary

Fluid Intelligence (Gf): broad ability to reason, form concepts, and solve problems using unfamiliar information or novel procedures.
Experience-independent.



Intelligence-as-process



Measured with tests requiring on-the-spot processing

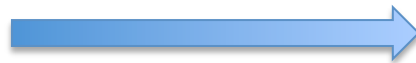
Che cosa è “il genio”? Fantasia, immaginazione, colpo d’occhio e velocità di esecuzione



Il Perozzi



**La “supercazzola”
del Mascetti**

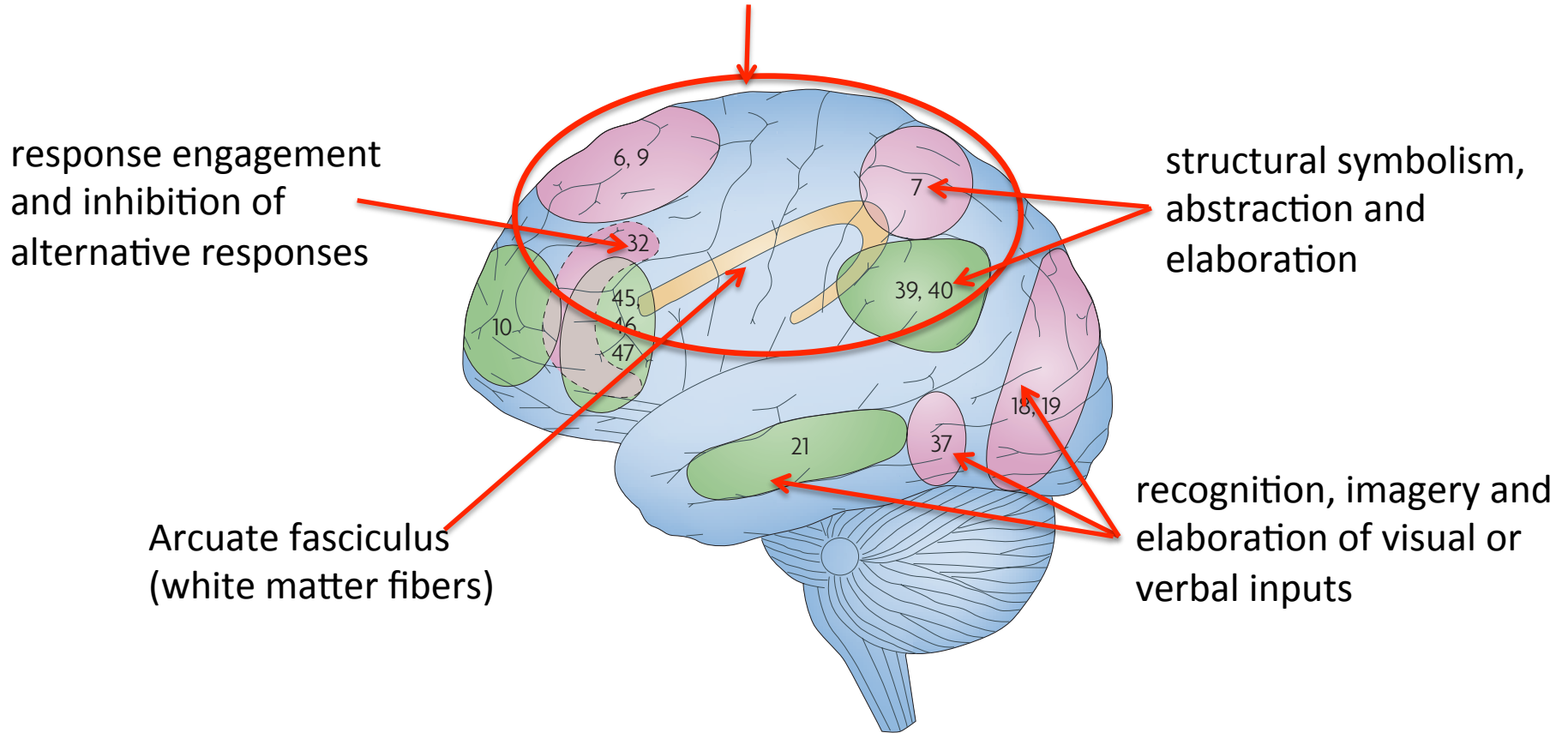


Parieto-frontal integration theory (PFIT) of intelligence

Meta-analysis of MRI-PET-fMR studies

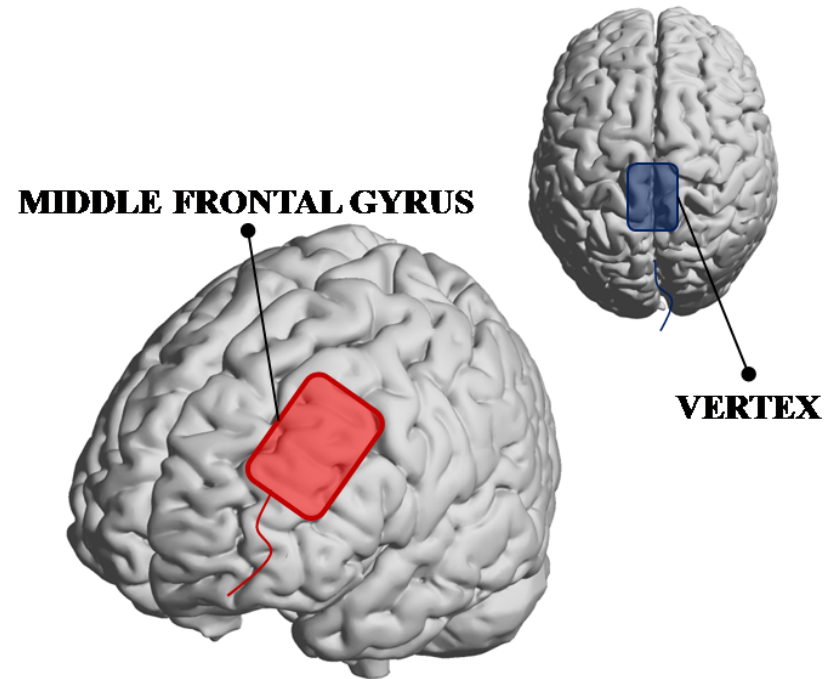
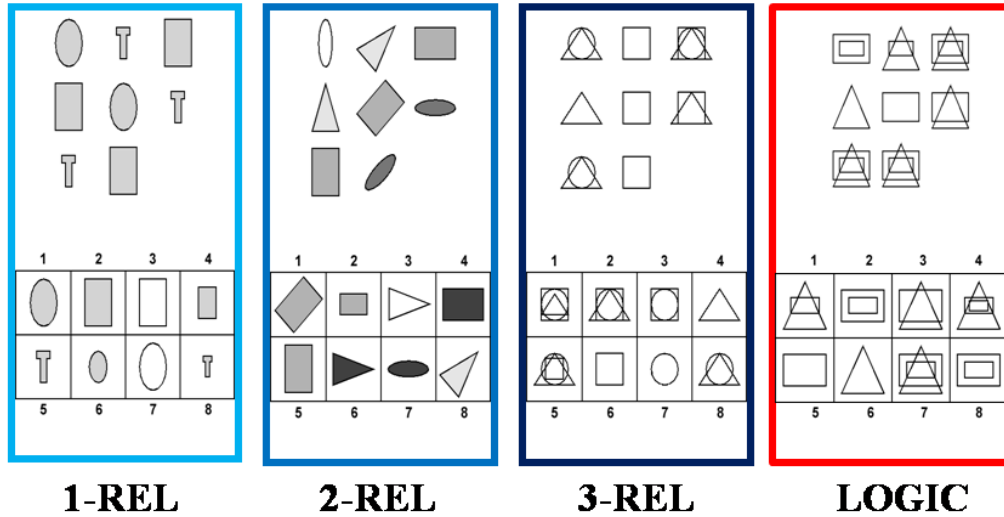
(from Jung et al. 2007 & Deary et al. 2010)

working memory network (maintenance, elaboration, selection of response)

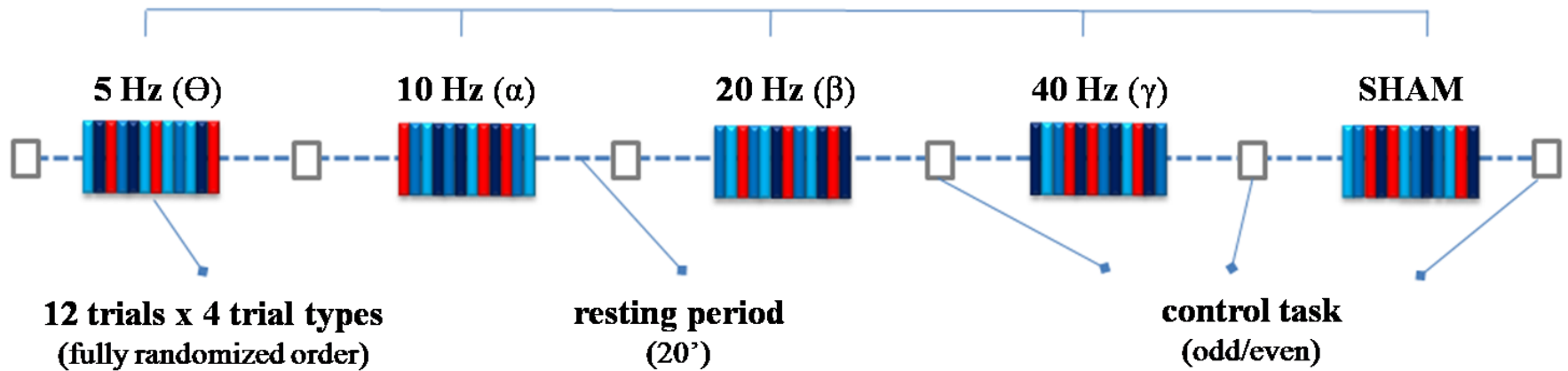


Gläscher et al. (Neuron, 2009): in 241 patients with brain lesion confirmed the role of PFC for verbal comprehension and PPC for perceptual organization

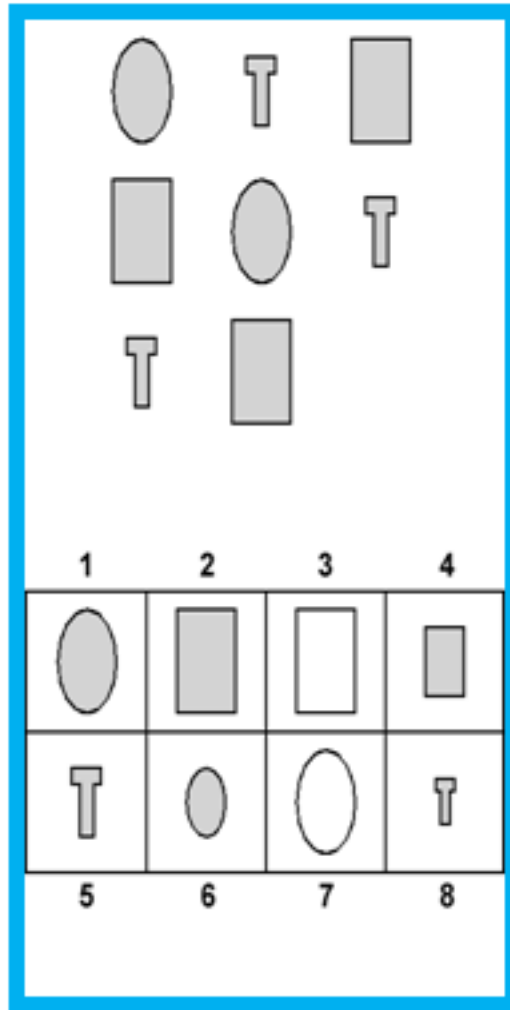
20 healthy subjects; 10 male; mean age 22



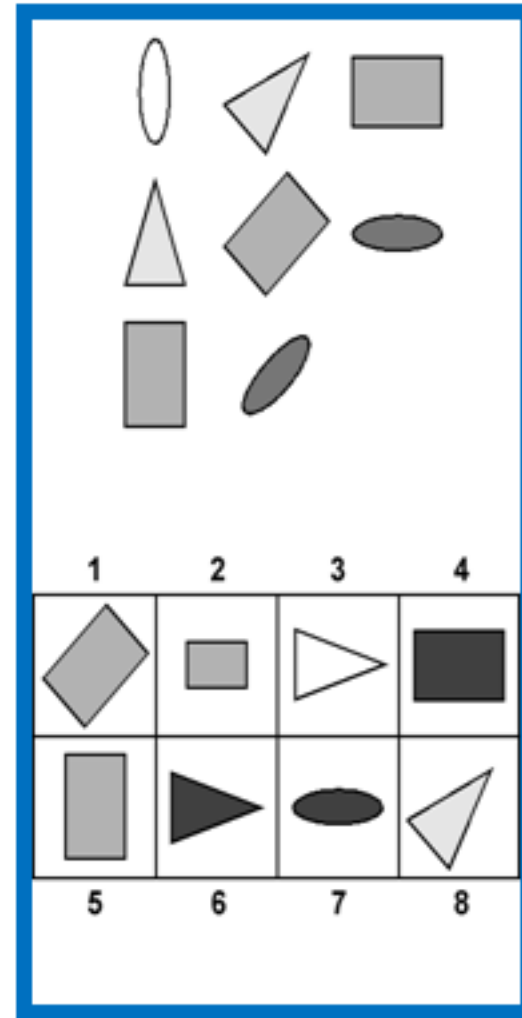
tACS condition
(randomized, balanced order)



Simple Raven's matrices account well for relational reasoning (Gf)



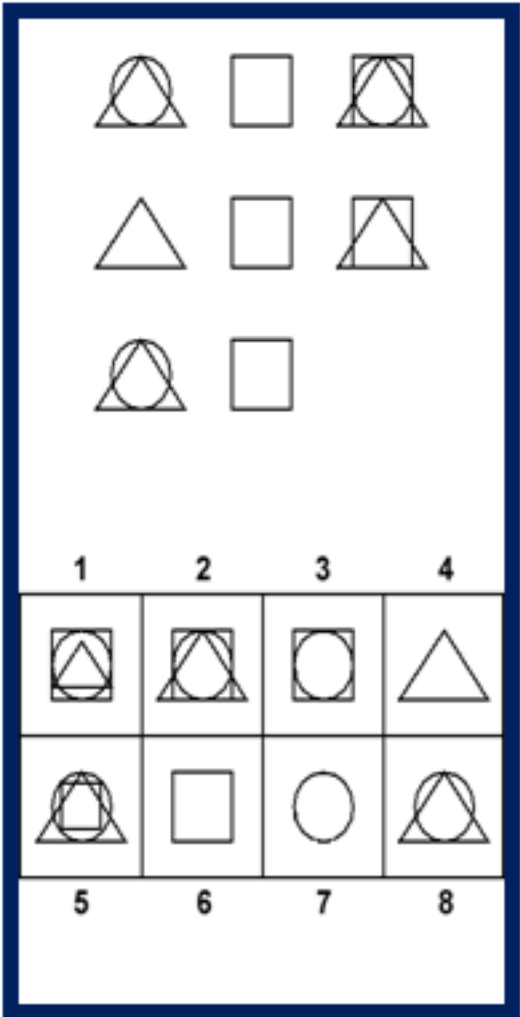
1-REL



2-REL

Relational, perceptual trials

Complex Raven's matrices account well for logic reasoning (Gf)

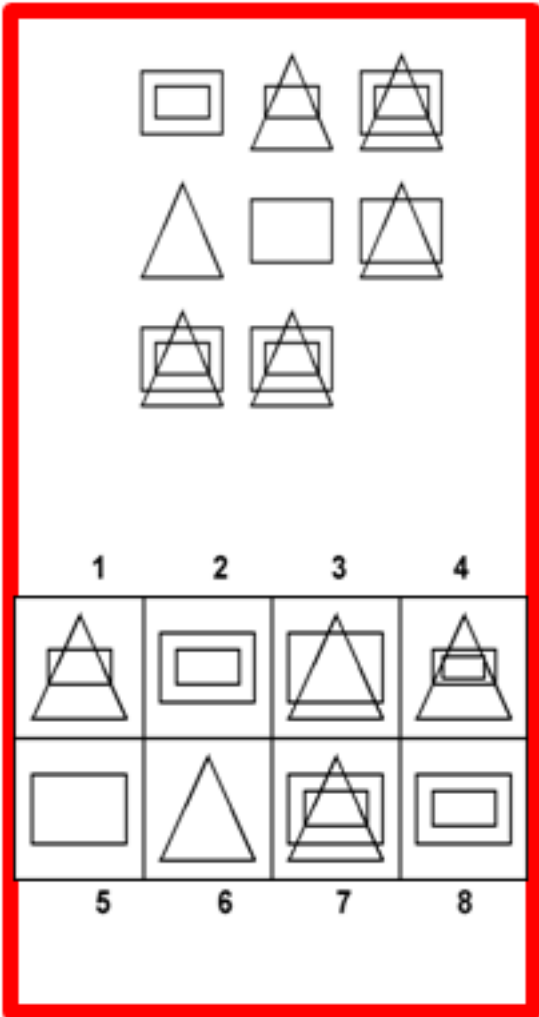


A 3x3 matrix puzzle labeled '3-REL' with a blue border. The matrix contains the following shapes:

Below the matrix is a 2x4 grid of options labeled 1 through 8:

1	2	3	4
5	6	7	8

3-REL



A 3x3 matrix puzzle labeled 'LOGIC' with a red border. The matrix contains the following shapes:

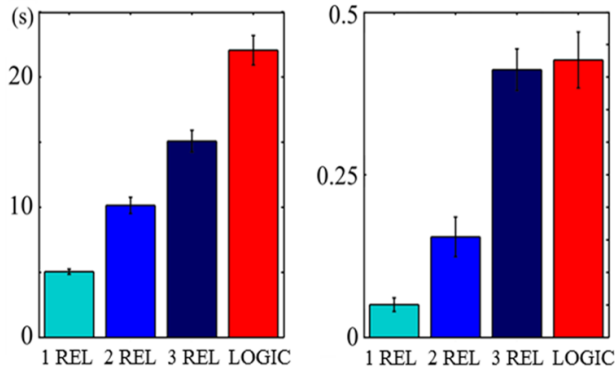
Below the matrix is a 2x4 grid of options labeled 1 through 8:

1	2	3	4
5	6	7	8

LOGIC

tACS and fluid intelligence, Results

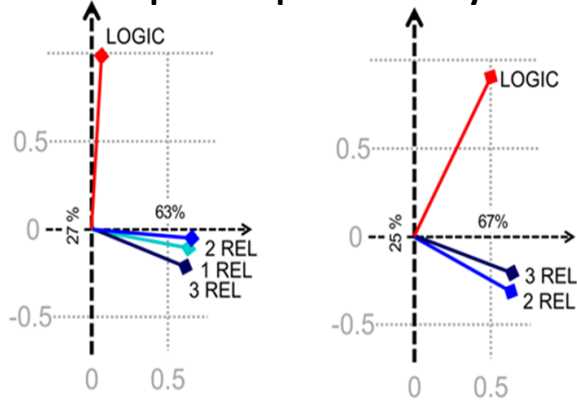
Basal Performance (Sham)



REACTION TIMES

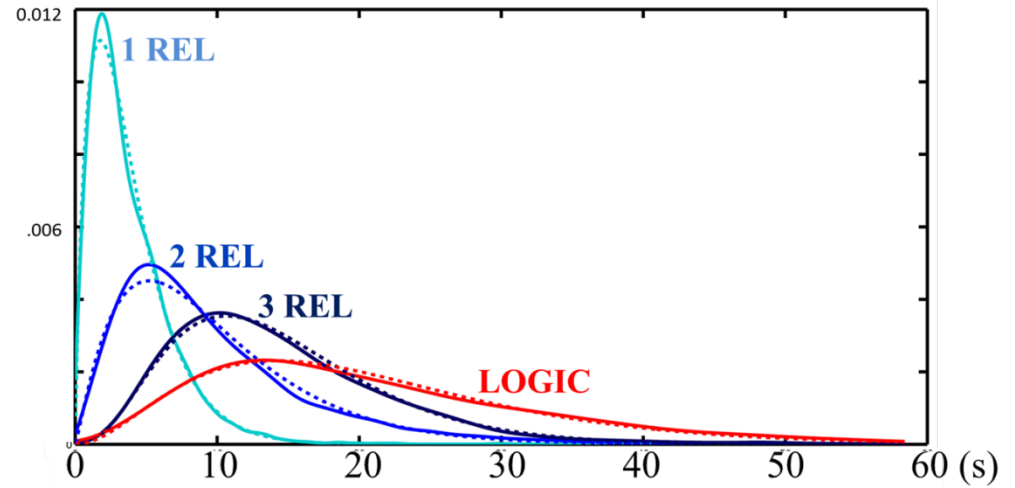
ERROR RATES

Principal Component Analysis



The solution of Logic matrices requires a different strategy

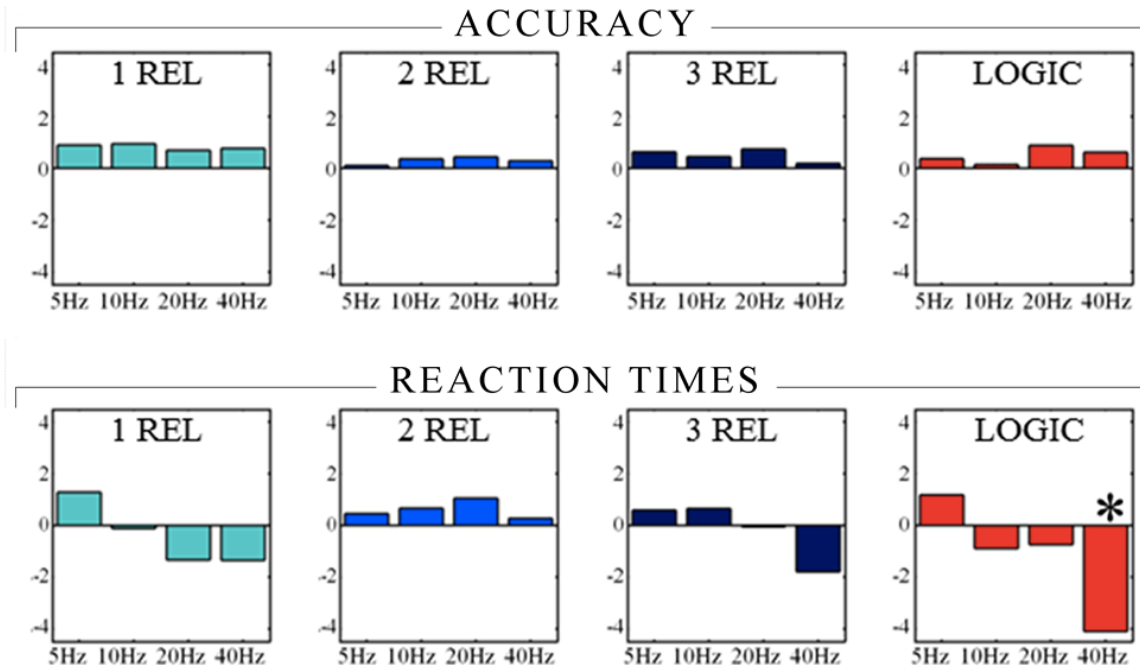
Distribution of RTs



Optimal fitting of RTs with gamma distribution

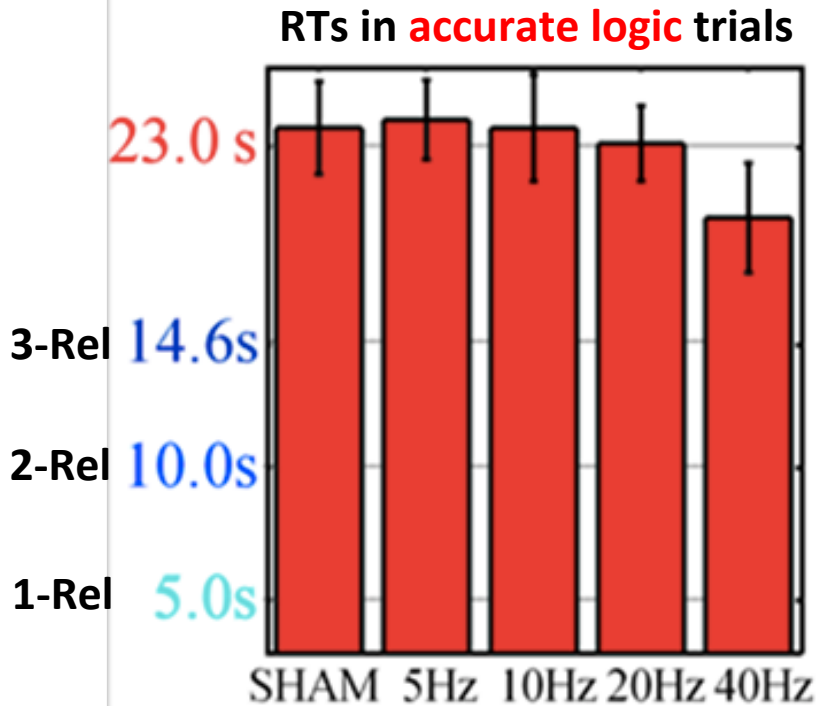
tACS and fluid intelligence, Results

**No effects on accuracy
(Generalized Estimating Equations)**



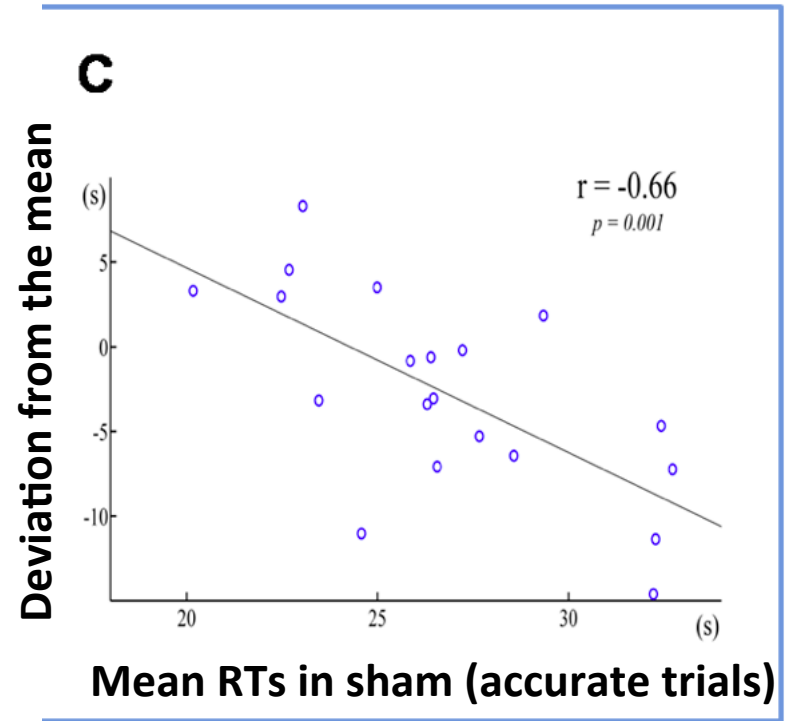
**Frequency-specific (gamma band) effects
on processing speed,
only for **logic** matrices
(**correct responses**)**

tACS and fluid intelligence, Results



Subjects became about 15% faster in correctly solving logic/conditional trials

Optimization of local information processing?



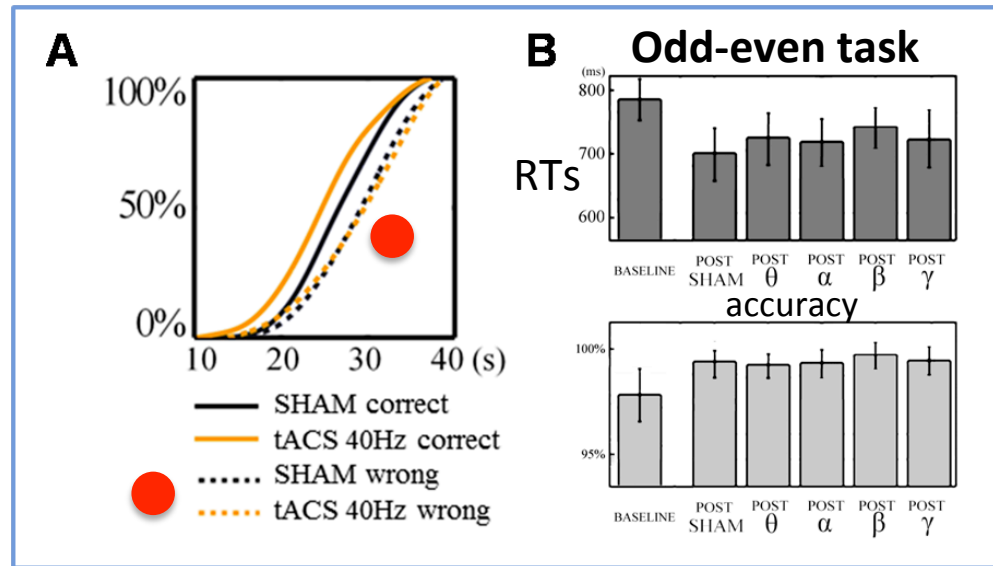
the effects of γ -tACS showed an inverse correlation with performance on the baseline (sham) condition ($r = -.66$, $p < .001$)

What observed tACS effects are not, 1:

- Speed-accuracy trade off

- Reduced attention/increased fatigue

Wrong responses are unaffected by tACS



- Task-switching cost

- Experimental demands (i.e., full randomization of Raven matrices) required continuous cognitive switching between relational and logic trials
- This is a costly process, mediated by prefrontal activity

performance did not benefit from repetition of logic or relational tasks (regression analysis: lack of main effect of preceding task, $\chi^2=0.39$, $p=0.55$, or preceding task*task interaction, $\chi^2=0.18$, $p=0.67$)

5 Hz (Θ)

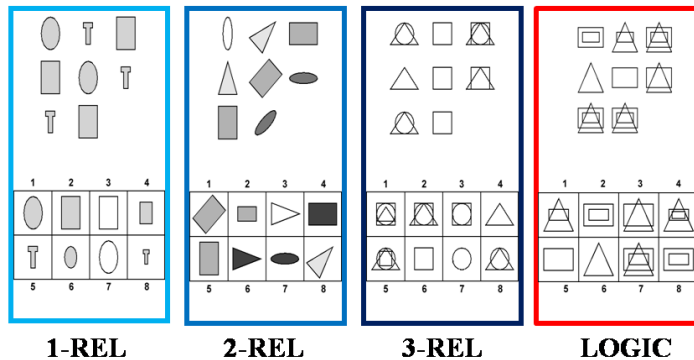


12 trials x 4 trial types

What observed tACS effects are not, 2:

- Improvement of working memory

- WM is actually part of fg (Jaeggi et al., 2008)
- WM can be transiently improved by phase-locked prefrontal theta-tACS (Polania et al., 2012)



WM load is low, if not absent

The Importance of Timing in Segregated Theta Phase-Coupling for Cognitive Performance

Rafael Polanía,^{1,2,3,*} Michael A. Nitsche,^{1,3} Carolin Korman,¹
Giorgi Batsikadze,¹ and Walter Paulus¹

Current Biology 22, 1314–1318, July 24, 2012

Gamma tACS was not effective in modifying
WM

Gamma band activity has been associated with:

- attention (Fries et al. 2001)
- optimizing stimulus processing (Womelsdorf et al. 2007)
- memory formation (Fries et al. 2003)
- neural binding (Womelsdorf et al. 2007)
- cognitive control of input processing (Canolty et al. 2006; Engel et al. 2001; Fries et al. 2001).

All these brain operations represent the building blocks of the complex cognitive processing underlying fluid intelligence efficiency.

Prefrontal gamma activity is causal for logic reasoning (i.e., for fluid intelligence abilities), rather than epiphenomenal to neuronal activity (Curr. Biol. 2013)

A new perspective for cognitive rehabilitation?

Need of technical advances (simultaneous EEG-tACS recording)