MSc in Artificial Intelligence and Robotics
MSc in Control Engineering
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Neuroengineering

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12- MULTI-SUBJECT SYSTEMS

Human-to-human interactions:

Are important in:

- Human cognition
- Development
- Well-being
- Society at large

- Are extremely complex:
  - Have unpredictable time trajectory
  - Require social settings
  - Include dynamic stimulation ("person stimuli") involving a large set of complex sensory features (face expressions, gestures, postures, actions, intonation)

Human-to-human interactions:

Are usually based on alignment:

- bodily synchrony
- turn-taking during conversation
- similar orientation of attention
- empathy

Can be non-verbal

Are dynamic and bilateral

Leader-follower or symmetrical

Hari et al, Neuron, 2015
Babiloni and Astolfi, Neurosc & Biobehav Rev 2012

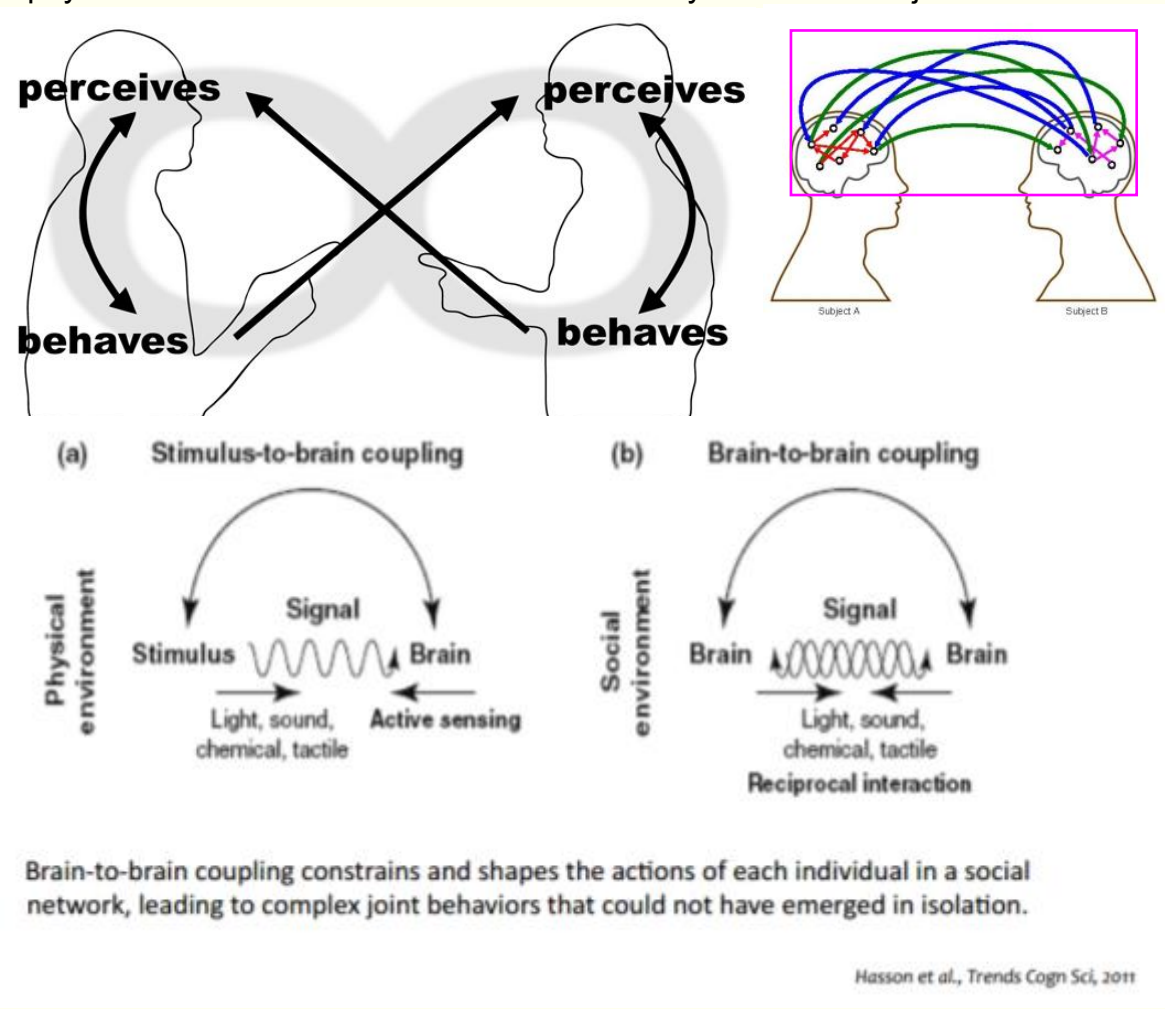
Studying the neurophysiology of social functions

- First studies on brain lesions or pathology (autism)
- Experimental studies on healthy volunteers: a single subject monitored during his/her interaction with an external agent (human or computer) in a social context re-created in laboratory.

Wood JN, Knutson KM, Grafman J., Cereb Cortex, 2005
Williams JH., Autism Res., 2008
Kourtis D, Knoblich G, Sebanz N, Neuropsychologia, 2013

Inter-brain coupling

when 2 people interact, each subject produces a personal stimulation in tho form of physical signals which are provided to the second subject as a physical stimulation as result of the bran activity of the first subject



- A complex system (group) cannot be fully understood by analyzing its single elements (single subjects): we need to study their interaction
- The content and timing of natural social interaction are unpredictable and differ from experiment to experiment
- Interdependencies between the two sets of brain signals can reveal brain processes that support the interaction

Simultaneous recordings of brain activity

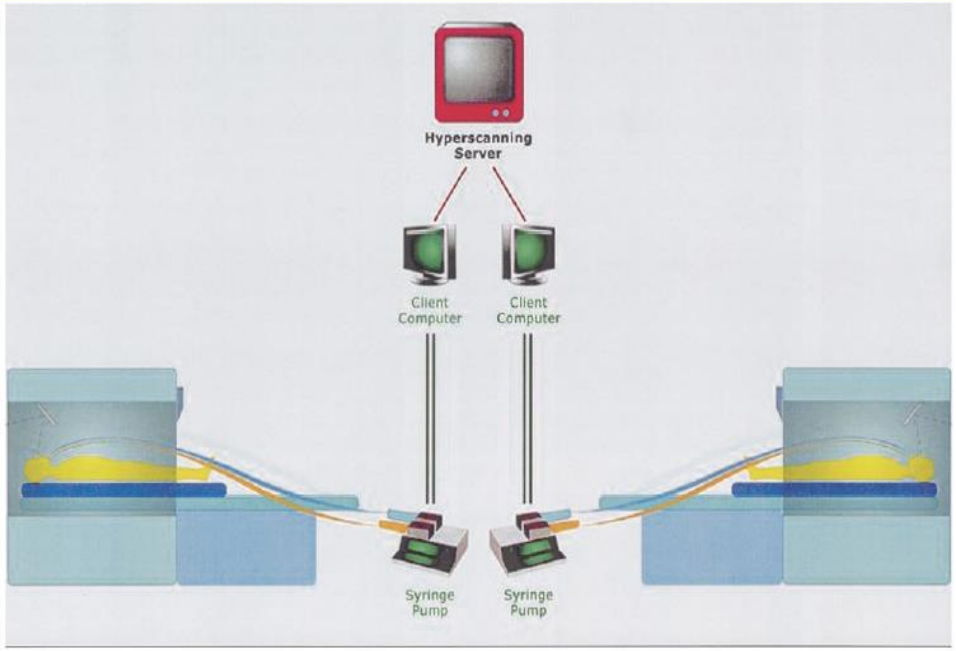
NeuroImage **16**, 1159–1164 (2002)
doi:10.1006/nimg.2002.1150

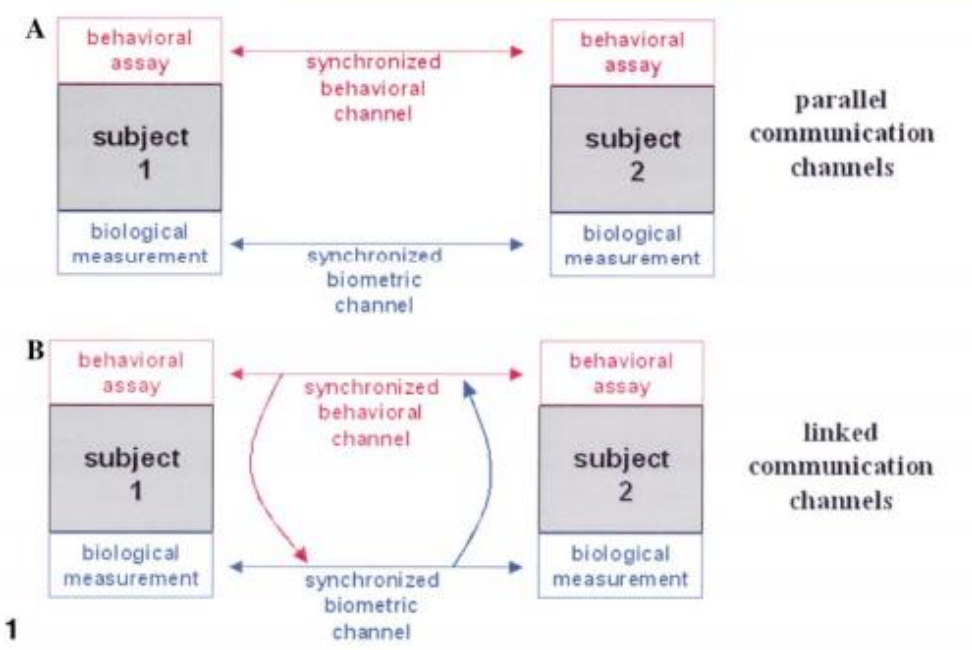
HYPER: we are moving from single subject dimension to the multiple subject dimension
SCAN: we are making a measure

COMMENTARY

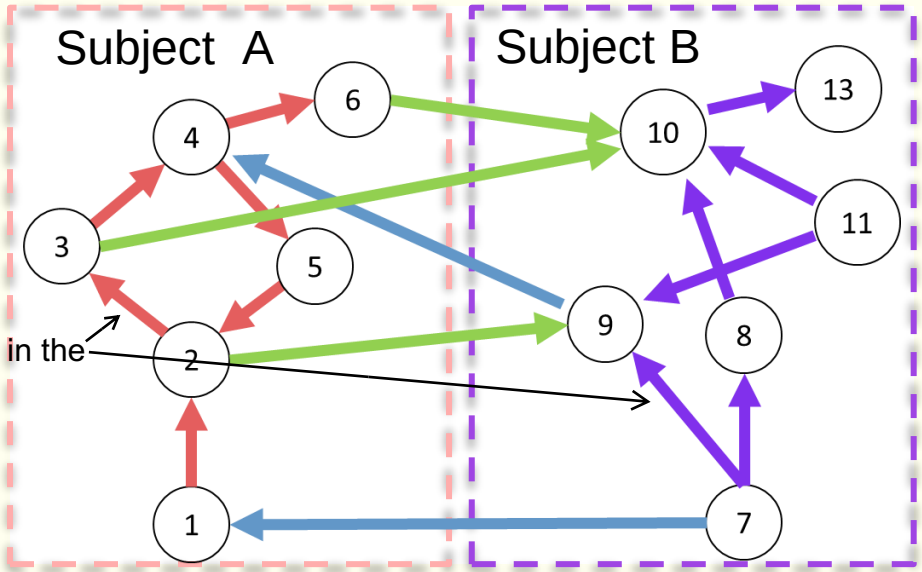
Hyperscanning: Simultaneous fMRI during Linked Social Interactions

P. Read Montague,* Gregory S. Berns,† Jonathan D. Cohen,‡ Samuel M. McClure,* Giuseppe Pagnoni,†
Mukesh Dhamala,† Michael C. Wiest,* Igor Karpov,* Richard D. King,*
Nathan Apple,* and Ronald E. Fisher*

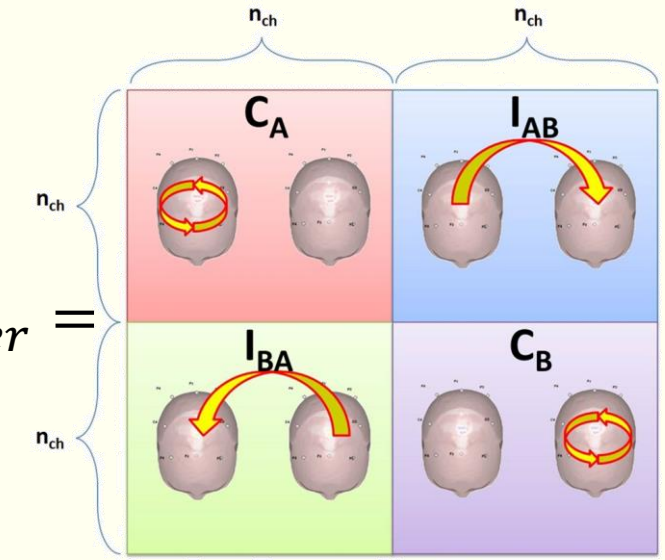




Multi-subject graph theory analysis



$$A_{iper} =$$



Modularity and Divisibility

$$Q = \frac{1}{W}\sum_{i,j}\left(w_{ij} - \frac{od_i id_j}{W}\right)\delta(C_i, C_j) \quad C_A\ C_B$$

$$D = \frac{W}{\sum_{ij} w_{ij}[1 - \delta(C_i, C_j)] + k} \quad I_{AB}\ I_{BA}$$

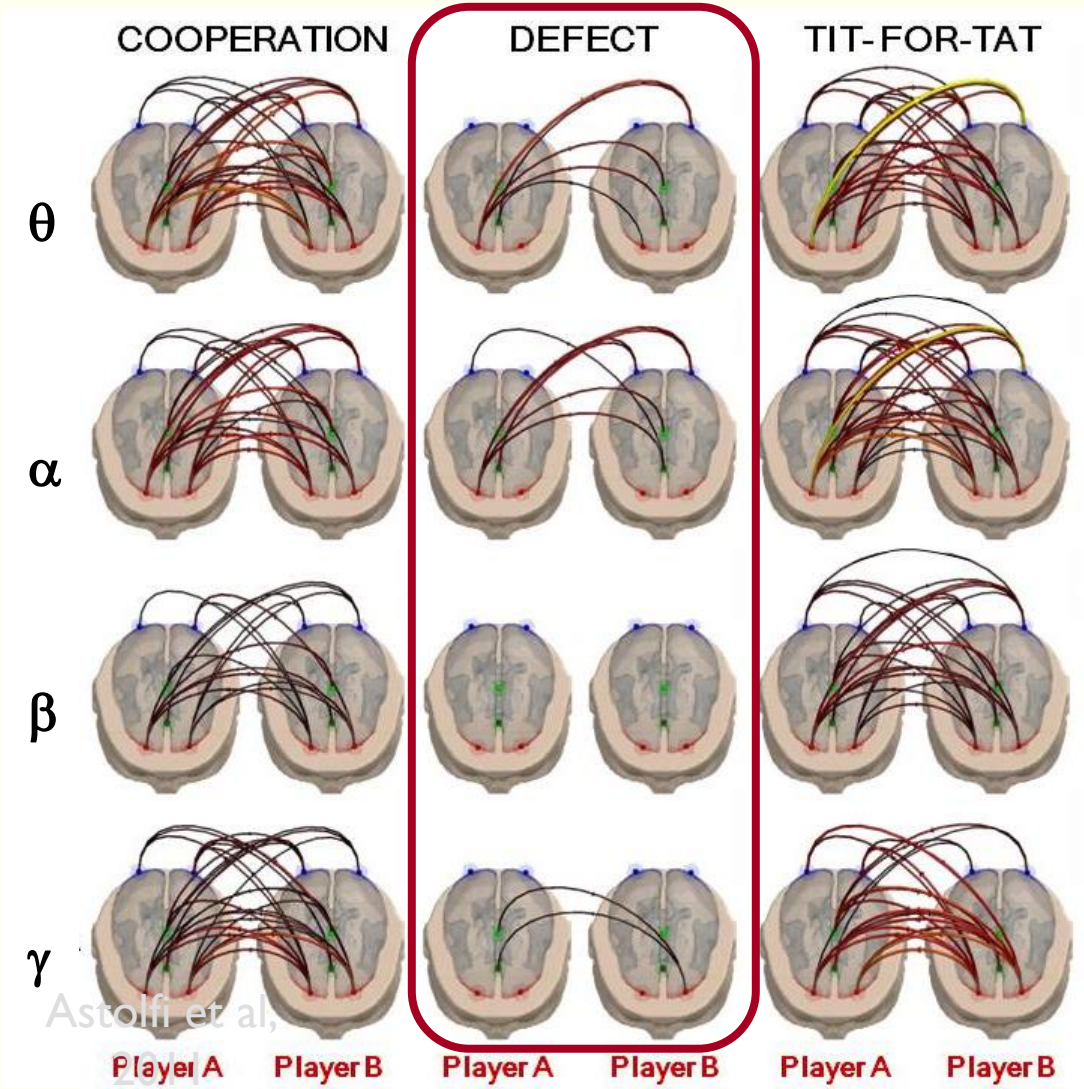
Inter/intra Ratio

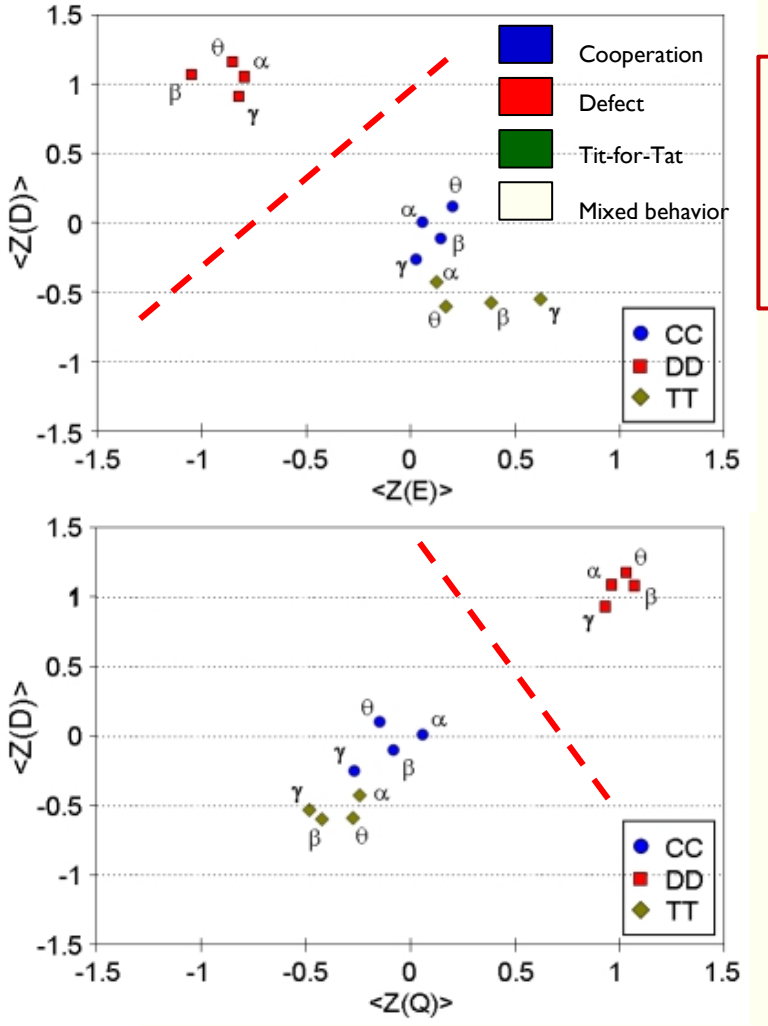
$$\frac{\#\text{ connections } I_{AB} + I_{BA}}{\#\text{ connections } C_A + C_B}$$

Inter-subjects density

of connections in I_{AB} + I_{BA} normalized

Cooperation and competition → opposite behaviors



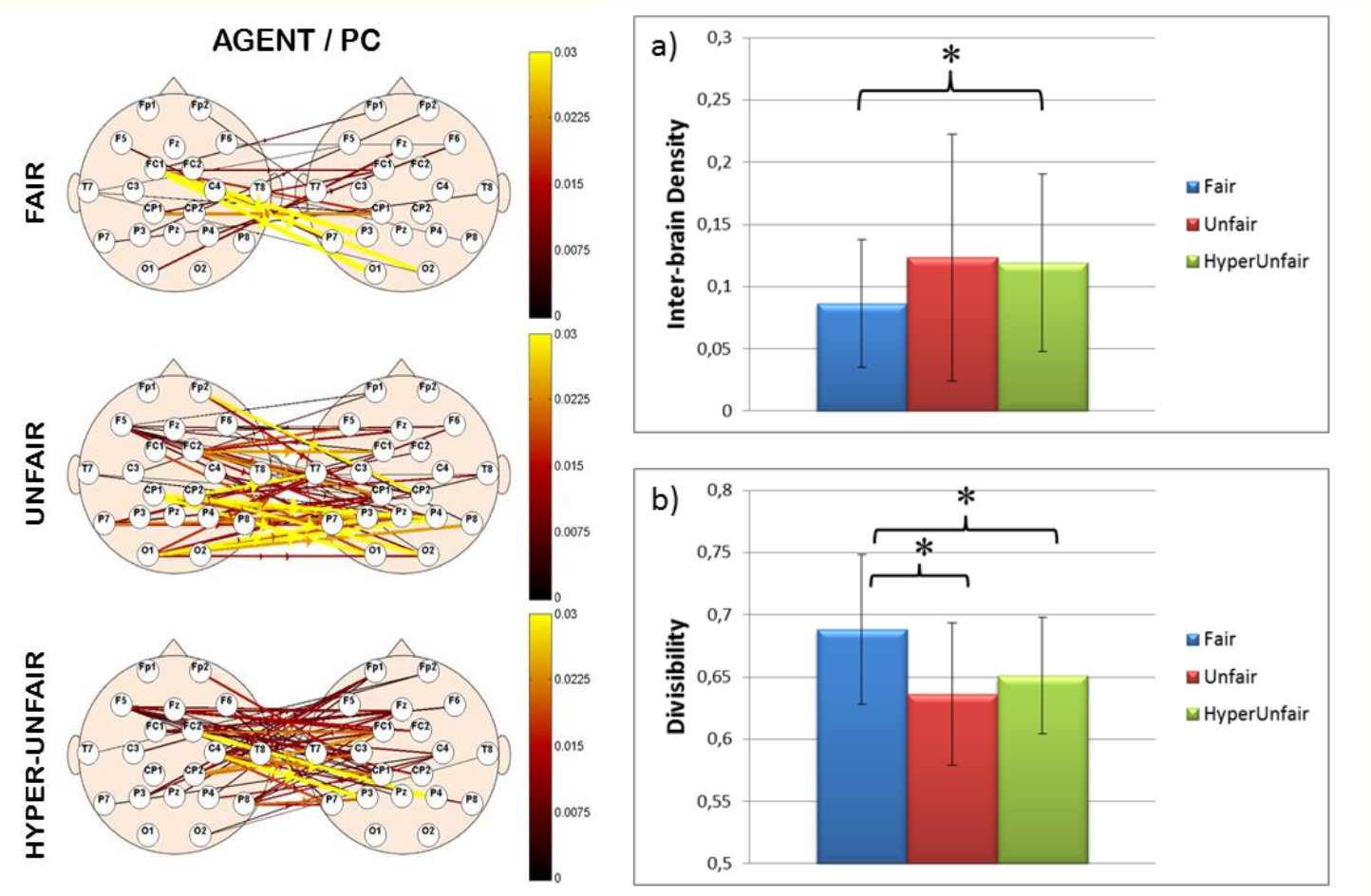


Classification accuracy = 91%

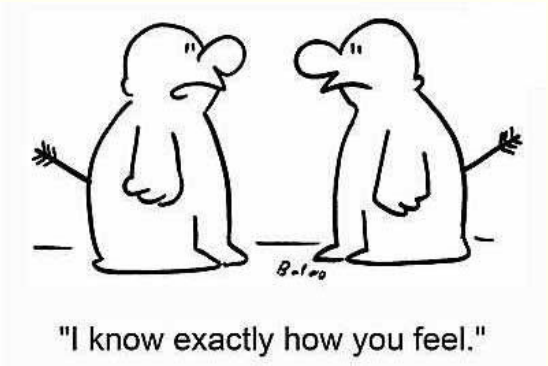
Astolfi et al, 2010

De Vico Fallani et al, PlosONE, 2010

Empathy modulation

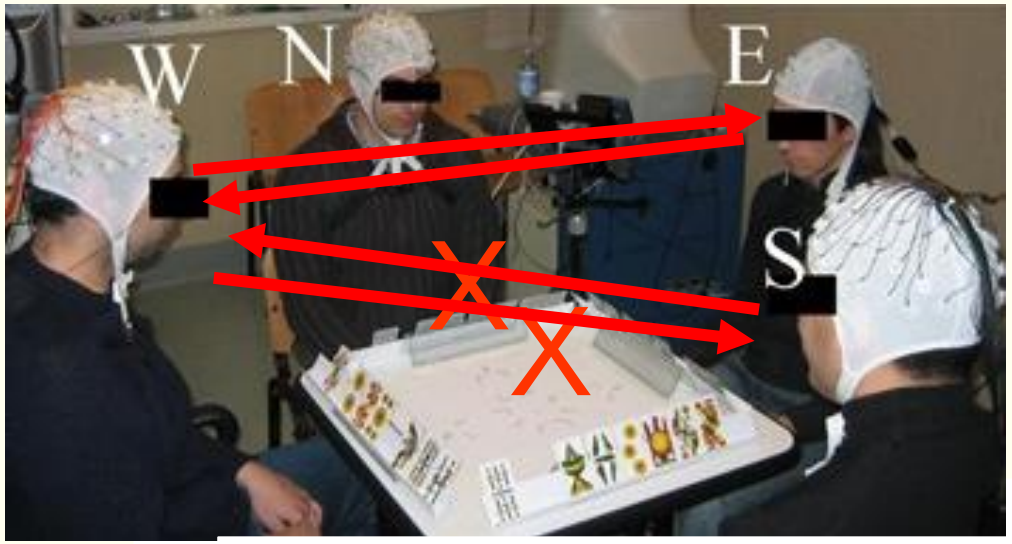


Ciaramidaro et al, Scientific Reports, 2018



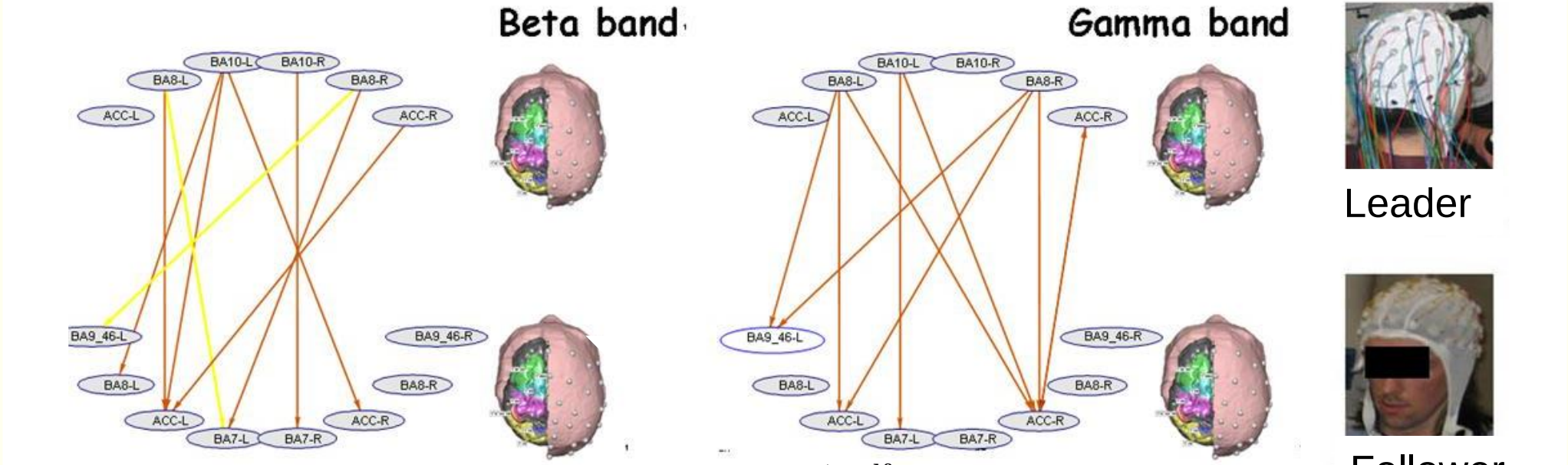
Graph indices are modulated by the level of empathy between the subjects (as measured by the level of fairness of the treatment experienced by one of them and by the consequent altruistic help provided by the other)

Real life setting: cooperation during a card game



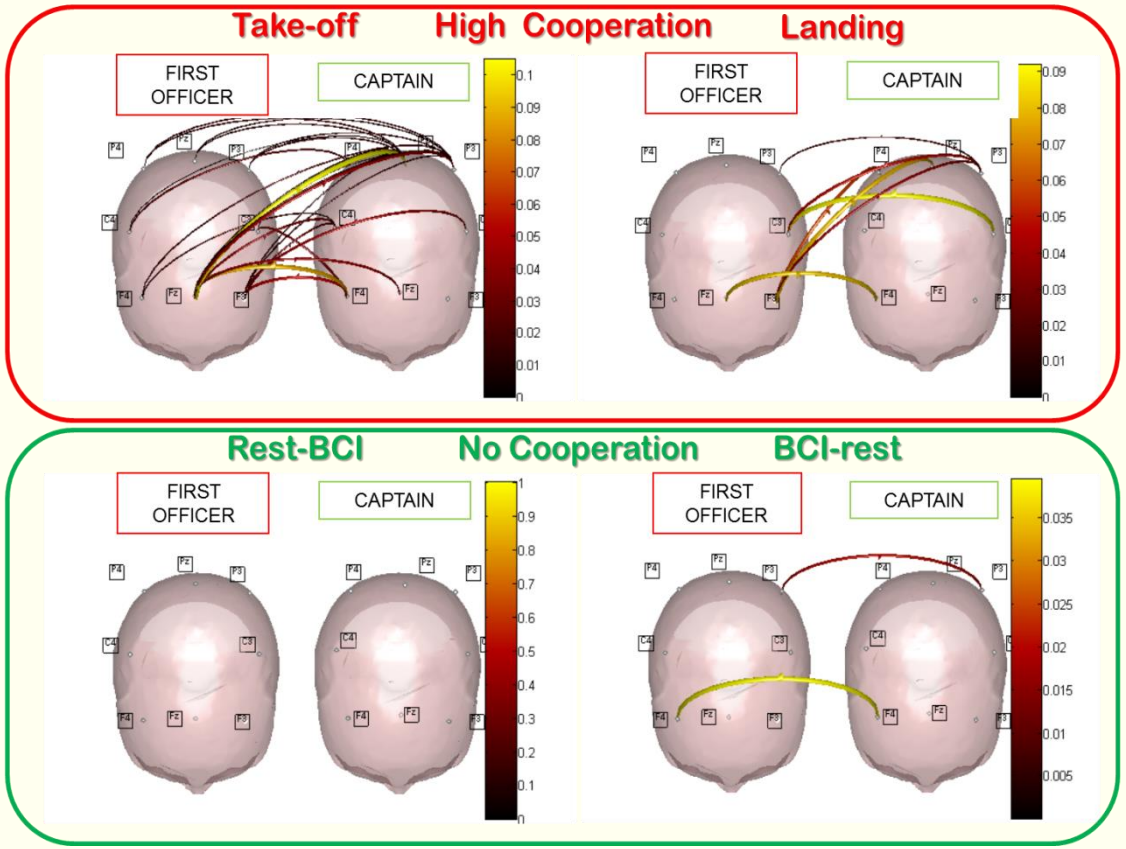
- 4 subjects recorded simultaneously
- Baseline condition: all possible pairs in the same game session
- Cooperation condition: players of the same team (asymmetrical task: first and second player)

(Astolfi et al, 2011)



Outside the lab - a study on professional pilots

- 12 professional Pilots (6 Captains and 6 First Officers)
- 15 EEG electrodes + ECG
- 90 min flight



Manipulation of the instrumentation and of the different situations during the simulated flight, to induce different levels and kind of interaction between the two pilots

Toppi et al, PlosONE 2016

Future directions

- Study of the development of cognitive functions in children and their modifications in psychiatric and behavioral disorders (Autism Spectrum Disorders)
- New approaches to:
  - Rehabilitation of cognitive functions in pathological conditions
  - Enhancement of social skills
- Definition of brain indices as outcome measures to quantify/describe the effect of a rehabilitative/enhancement intervention
- Social robotics: robots with human-like skills (able to mimic but also to interact with humans in a natural way)