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Complexity inside and outside the brain: how to manage internal (interoceptive) and external (domotics) environment during adaptive inter-actions

Laura Angioletti & Michela Balconi

International research center for Cognitive Applied Neuroscience (IrcCAN), Catholic University of the Sacred Heart, Milan, Italy

Research Unit in Affective and Social Neuroscience, Department of Psychology, Catholic University of the Sacred Heart, Milan, Italy

Background

- Brain activity is slightly sub-critical in normal waking consciousness [1], and in this way it can exert better control over the rest of the world, most of which is critical
- This control may take the form of **managing endogenous processes** within the brain or **interacting with the environment in order to functionally shape it** [2]
- The relationship between complex systems, i.e., human-to-environment relation, from an adaptive perspective is mediated by the sensory system with the main goal of maintaining a balance, aiming for harmony and avoiding ruptures

Q1: How the outside influences the inside?

- **1st study:** Brain activity "reacts" differently to different tech-interaction points in a Smart Home System (SHS) [for the full experiment see **3,4,5**]

Q2: How the inside influences the outside?

- **2nd study:** Brain activity and homeostasis can be modified through interoceptive manipulations, and this can impact on empathic behavior [for the full experiment see **6,7,8**]

Advantages

- New look and perspective in Cognitive Applied Neuroscience
  - Reliable methods
  - **High replicability**
- Comprehension of human interaction to a complex system at 360° (CNS, ANS, self-report)
- Information on **implicit correlates of human experience** → absence of explicit cognitive bias

What about the methodology to explore **complex human systems?**

Multi-method and multi-level neuroscientific approach [9]

Methodology

1st study – Interaction with Smart Environments

BIO-EEG-EYETRACKING application

EEG indices [15-channel EEG system (LiveAMP, Brain Products, München, 136 Germany)]:

- **frequency bands power: delta** (0.5–4 Hz), **theta** (4–8 Hz), **alpha** (8–12 Hz), and **beta** (14–20 Hz)

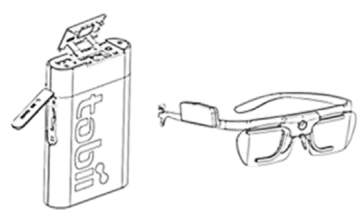
Autonomic indices [biofeedback 2000x-pert system with radio module MULTI (Schuhfried GmbH, Mödling, Austria)]:

- Heart Rate **(HR),** Skin Conductance Level **(SCL),** Skin Conductance Response **(SCR),** Pulse Volume Amplitude **(PVA)** and Blood Volume Pulse **(BVP)**

Eye-tracking indices:

- heatmaps, fixation points, gaze plots, time to first fixation

Self-report measures



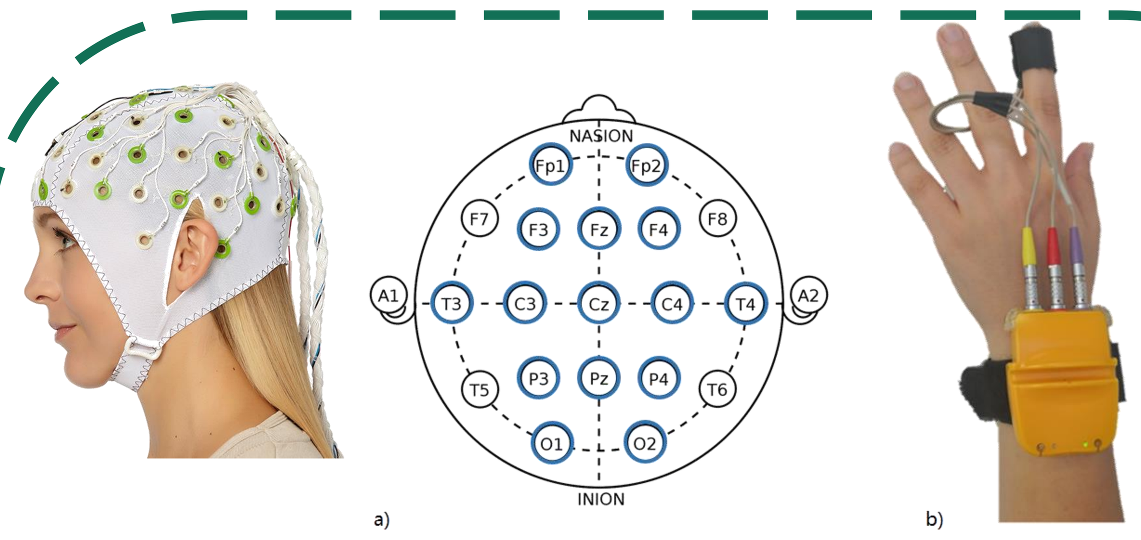


Fig.1. EEG montage and biofeedback tool display. a) 15-channel EEG montage adopted in the two studies, according to the 10/20 system of electrode placement (Jasper, 1958). b) Biofeedback 2000x-pert system with radio module MULTI (Schuhfried GmbH, Mödling, Austria).

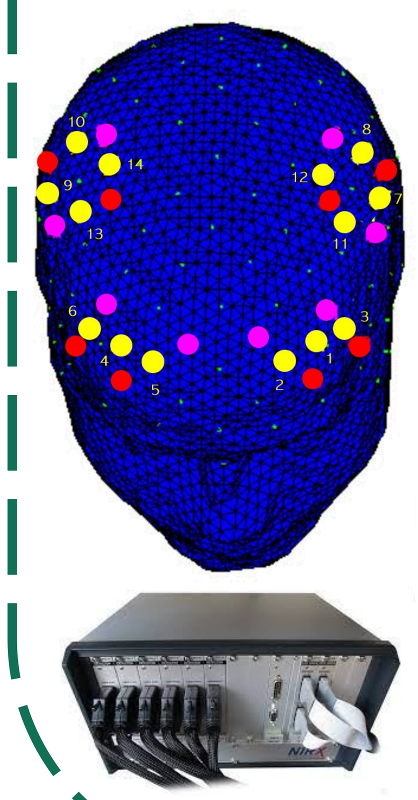


Fig.2. fNIRS montage. Location of the sources (red) and detectors (violet) of fNIRS montage. Thank to a fNIRS Cap, 8 light sources/emitters and 8 detectors were positioned over the scalp according to the international 10/5 system. Emitter-detector distance was kept at 30mm for contiguous optodes and near-infrared light of two wavelengths (760 and 850 nm) was used.

The following 14 channels (yellow) were acquired: Ch1 (AF3-F3), Ch2 (AF3-AFF1h), Ch3 (F5-F3), Ch4 (AF4-F4), Ch5 (AF4-AFF2h), Ch6 (F6-F4), Ch7 (CCP5h-FCC5h), Ch8 (CCP5h-CCP3h), Ch9 (CCP6h-FCC6h), Ch10 (CCP6h-CCP4h), Ch11 (FCC3h-FCC5h), Ch12 (FCC3h-CCP3h), Ch13 (FCC4h-FCC6h), Ch14 (FCC4h-CCP4h).

Signals obtained from the 14 NIRS channels were acquired with a sampling rate of 6.25 Hz (NIRStar Acquisition Software) and analyzed and transformed with nirsLAB software (v2014.05; NIRx Medical Technologies LLC, 15Cherry Lane, Glen Head, NY, USA), according to their wavelength and location, resulting in values for the changes in the concentration of oxy and deoxygenated hemoglobin for each channel, scaled in mmol*mm. The raw O2Hb and HHb data from each channel were digitally band-pass filtered at 0.01–0.09 Hz (Pinti et al., 2019). For D values calculation see Balconi, Grippa, Vanutelli (2015).

For the statistical analysys, the Frontal Regions of Interest (ROI) the values obtained from Ch1-Ch2-Ch3 and Ch4-Ch5-Ch6 were averaged as representative of the activity of the left/right DLPFC areas (BA9). For the Central ROI, the values obtained from Ch7-Ch8-Ch11-Ch12 and Ch9-Ch10-Ch13-Ch14 were averaged as representative of the activity of left/ right somatosensory areas (BA 1, BA2, BA3).

2nd study – Interoceptive manipulation

BIO-EEG-fNIRS application

NIRScout System (NIRx Medical Technologies, LLC. Los Angeles, California)

- 14-channel optodes matrix was adopted to record hemodynamic responses (variations of O2Hb and HHb concentrations)

Self-report measures

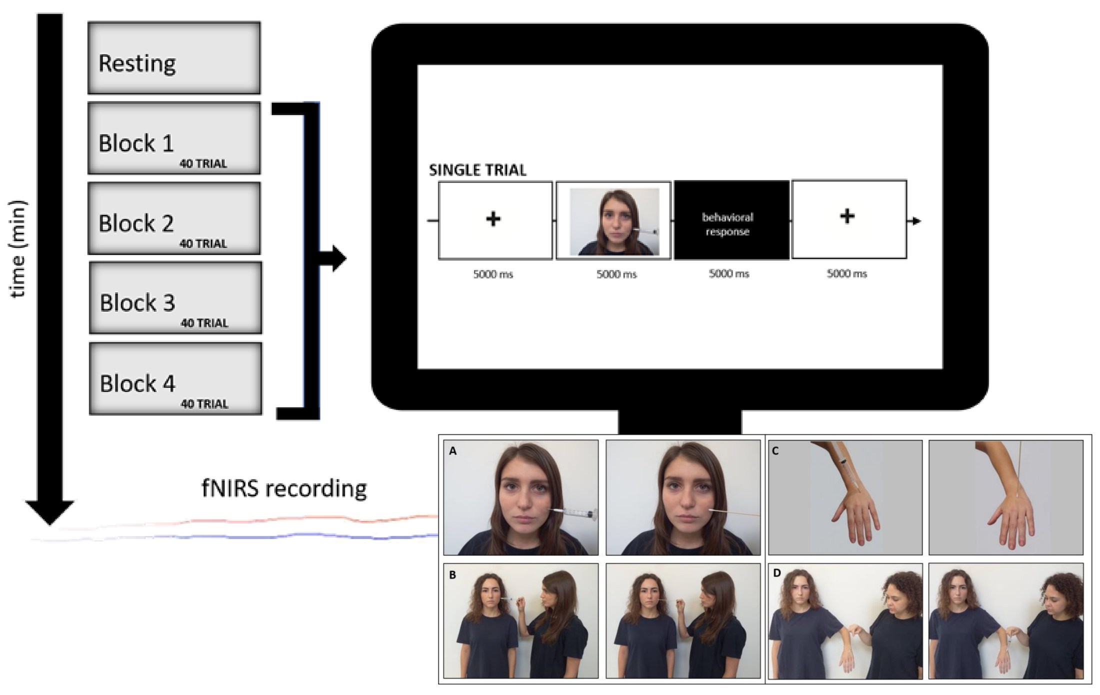


Fig.3. Experimental setting with BIO-EEG-fNIRS recording during observation of pain in others' task performance

Highlights of EEG results

R1: How the outside influences the inside?

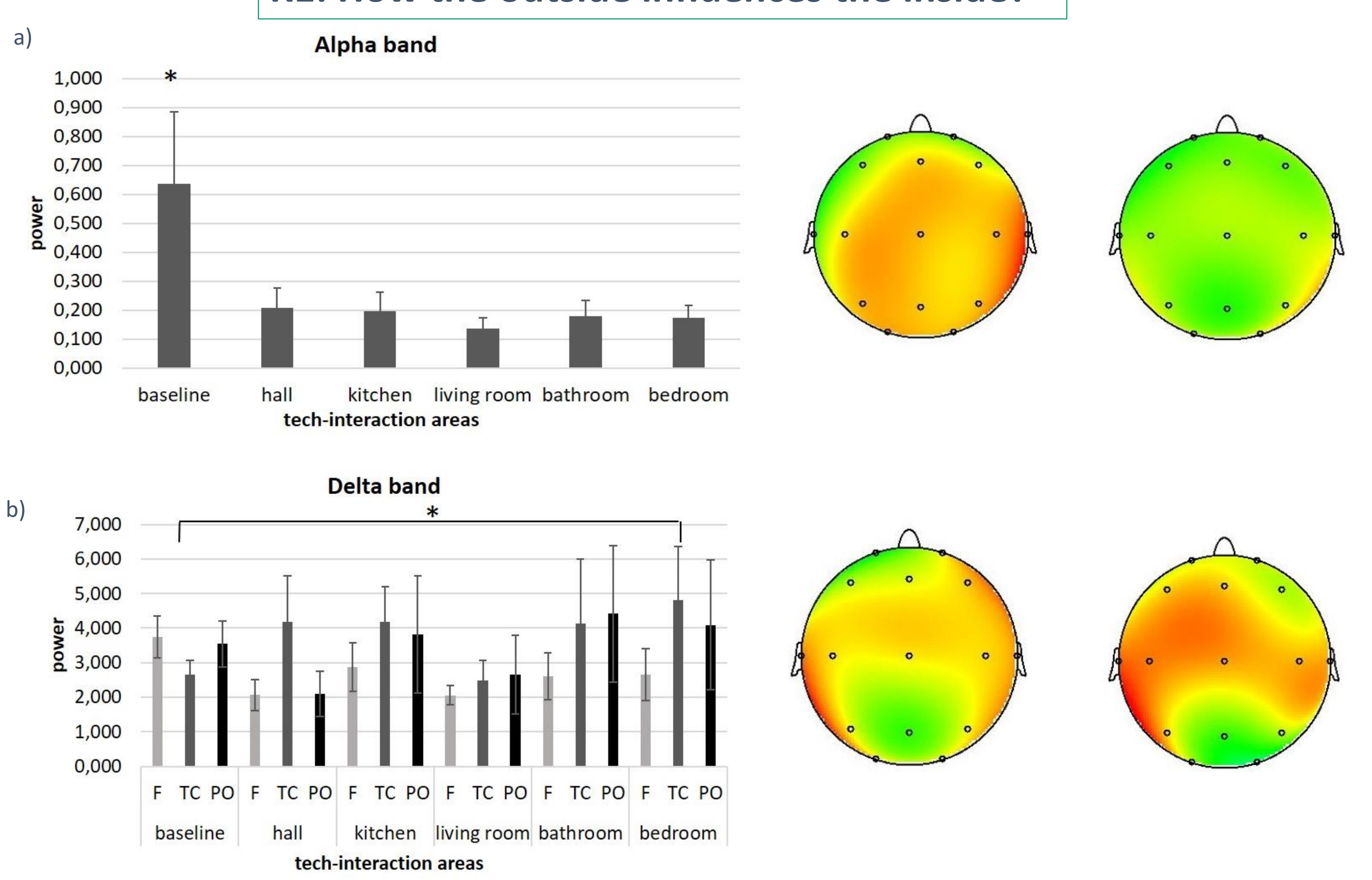


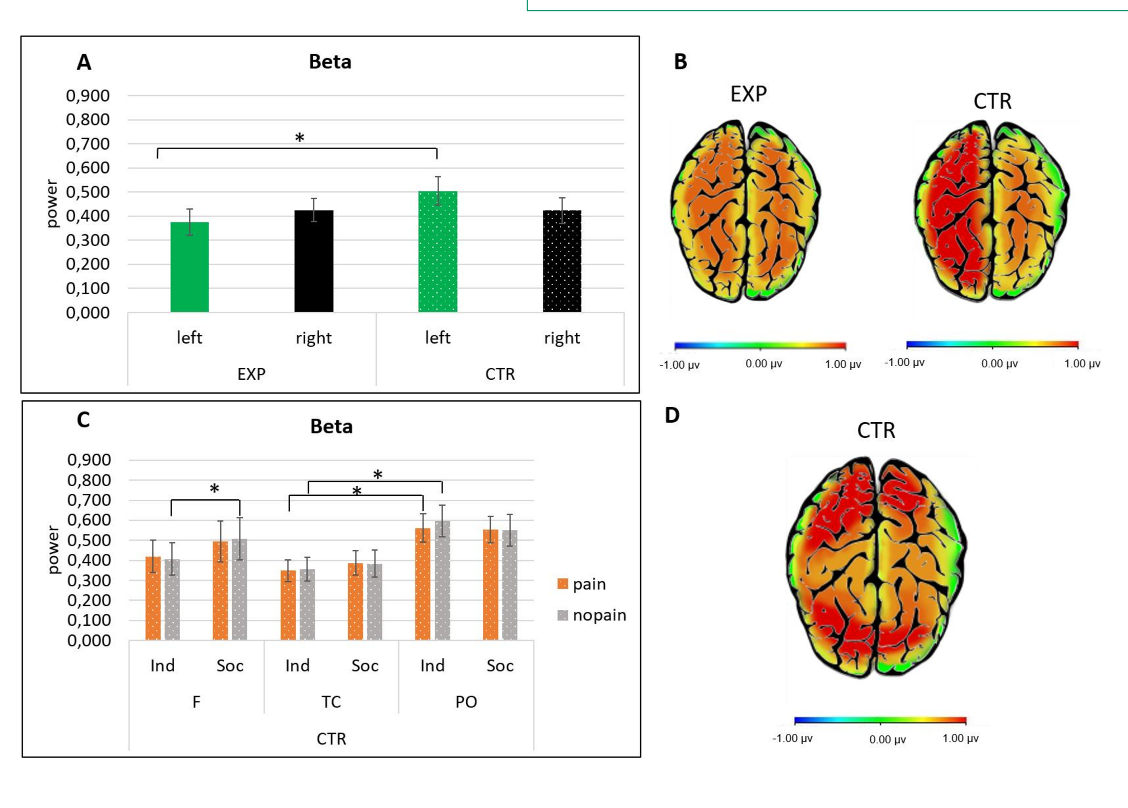
Fig.4a-b. EEG neurophysiological results of User Experience in Smart Home Systems (SHS)

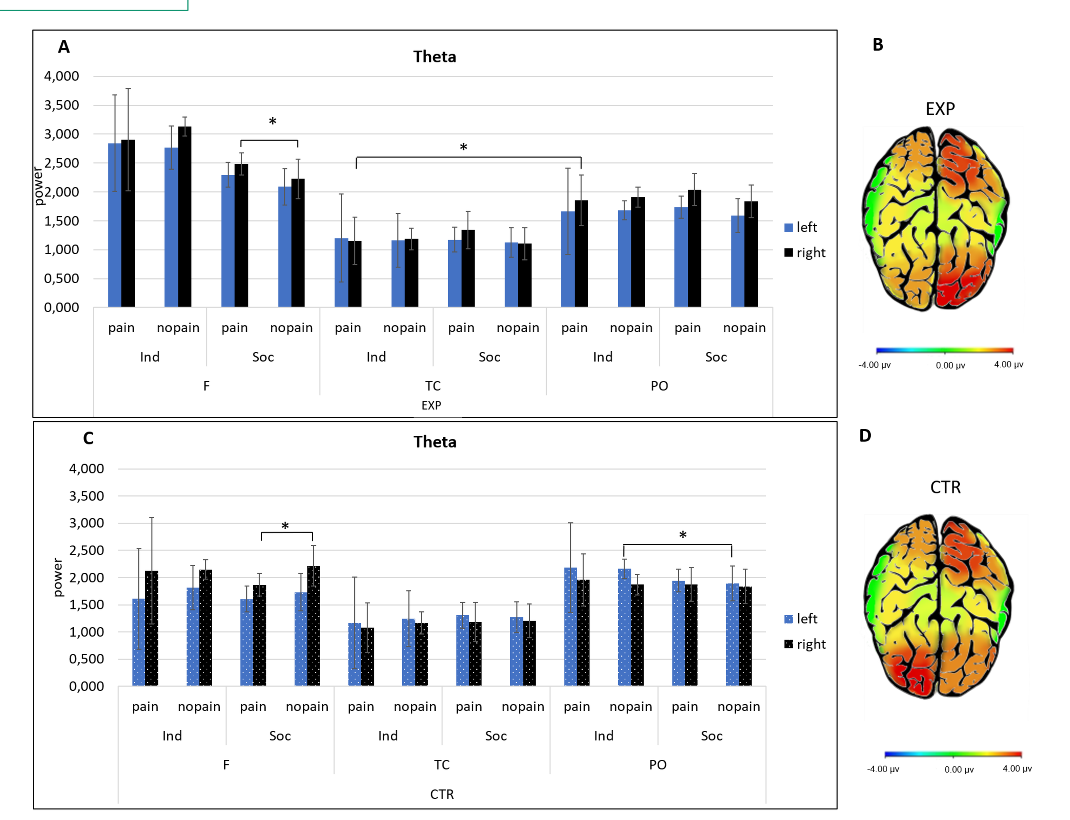
a) Bar graph shows significant differences for alpha band activity between baseline and other tech-interaction areas. Bars represent±1SE. Stars mark statistically significant pairwise comparisons. Alpha power representation of average baseline activity (left head) compared to the average activity of the other tech-interaction areas (right head).

b) Bar graph shows significant differences for delta band activity in temporo-central ROI between baseline and bedroom area. Bars represent±1SE. Stars mark statistically significant pairwise comparisons. Delta power representation of average baseline activity in TC (left head) compared to the average bedroom activity in TC (right head)

For the full set of results, please see **[4].**

R2: How the inside influences the outside?





EEG neurophysiological results of the study on the effect of the interoceptive manipulation on empathic behavior

Fig. 5a-d. EEG Theta band. a) Bar charts show theta power mean values in the EXP group. b) Theta power representation for the EXP group. The red area represents the increase of theta power in the right hemisphere for painful stimuli, with a frontal activation for the social condition (left head), and a parieto-occipital increase for the individual condition (right head). c) Bar charts show theta power mean values in the CTR group. d) Theta power representation for the CTR group. The red area represents the increase of theta power for non-painful stimuli, with a right frontal activation for the social condition (left head), and a left parieto-occipital activation for the individual condition (right head).
For all charts, bars represent ± 1 SE; all asterisks mark statistically significant differences, with p ≤ .05.
For the full set of results, please see **[7].**

Fig. 6a-d. EEG Beta band. a) Bar charts show beta power lateralization in the two groups. b) Beta power representation for the EXP and the CTR group. The red area represents the increase of beta power mean values in the left hemisphere for CTR compared to EXP. c) Bar charts show beta power mean values in the CTR group. d) Beta power representation for the CTR group. The red area represents the increase of beta power in frontal areas for non-painful stimuli in the social condition (left head), and in parieto-occipital areas for non-painful stimuli in the individual condition (right head).
For all charts, bars represent ± 1 SE; all asterisks mark statistically significant differences, with p ≤ .05.
Abbreviations. EXP: experimental group; CTR: control group; F: frontal; TC: temporo-central; PO: parieto-occipital; Ind: individual condition; Soc: Social condition; pain: painful stimuli; nopain: non-painful stimuli.

Conclusions

- This multimodal neuroscientific approach allowed distinguishing effects of domotics (SHS) on users' cognitive and emotional behavior in terms of distinct EEG neural activity (alpha and delta band) according to the different environments. The increasing level of environmental complexity was detected in the present sample by EEG and autonomic modulation activity
- The interoceptive manipulation enhances emotional representation of painful stimuli, by highlighting the negative and unpleasant features of observation of pain in others (in the empathic processing). The lateralization of EEG theta and beta bands mark the interoceptive process of observing pain in others. Also, social interactions stimuli elicited higher frontal areas responsiveness

References

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Contact

E-mail address: laura.angioletti1@unicatt.it