# Neurophysiology of Natural Conversation : Previous Results and Future Work

Thierry Chaminade

# Research program: two sides of the same coin

## Social Cognitive Neurosciences


Cognitive and neurophysiological mechanisms involved in natural social interactions

**Normal and Pathological Social Cognition**

## Humanoid Sciences

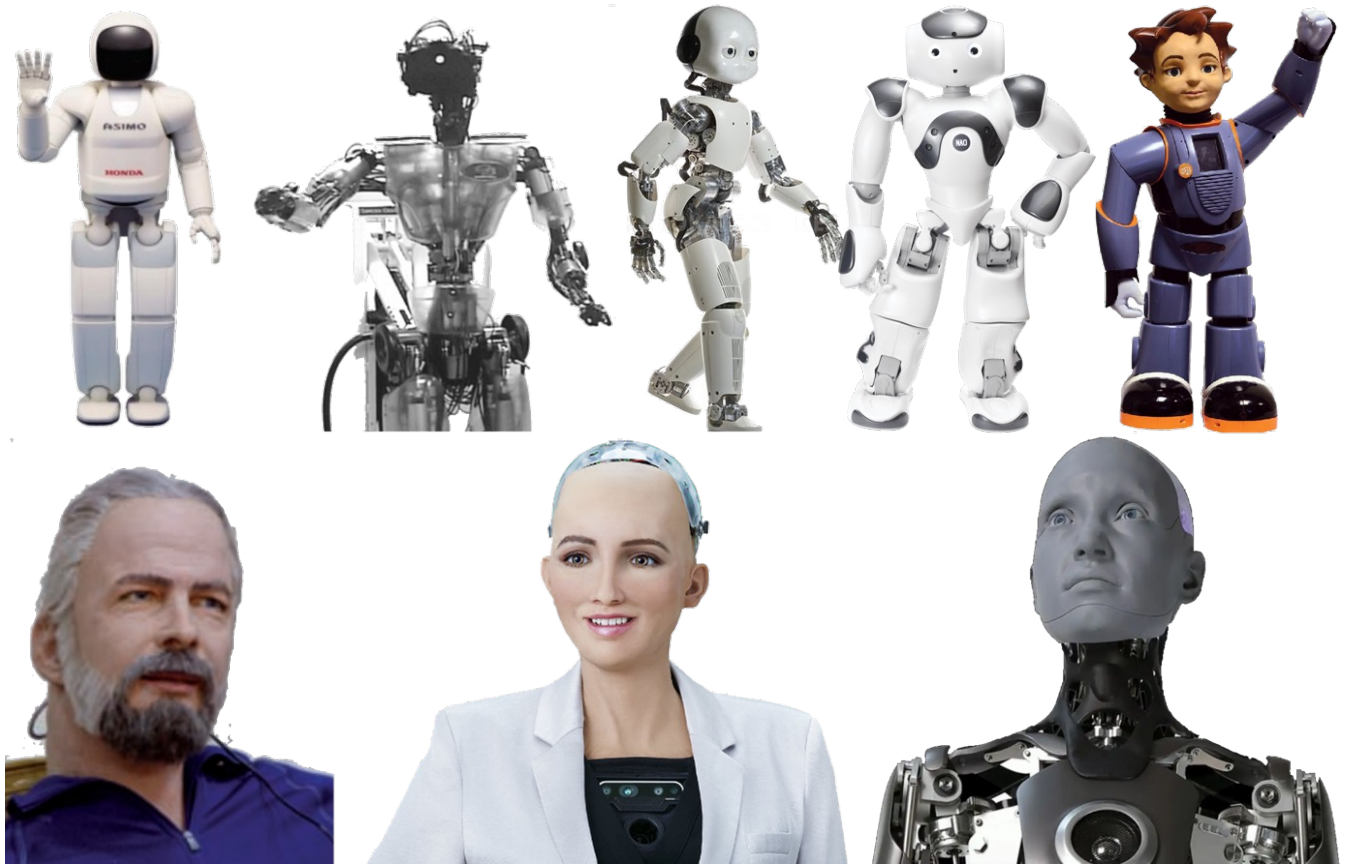

Cognitive and neurophysiological mechanisms involved in social interactions with artificla agents

**Social Competence of Artificial Agents**

Chaminade, T., & Kawato, M. (2012). *Mutual Benefits of Using Humanoid Robots in Social Neuroscience*. Oxford University Press.

# Humanoid Robotics : Experimental tools

- Humanoid robots have *human-like shape and behaviours*
- Humanoid robots are *fully controllable* and their behaviour *reproducible*
- Humanoid robots are clearly *artificial* agents




➢ Humanoid robots can be used as stimuli to disentangle perceptual from contextual processes related to human social cognition

Wykowska, A., Chaminade, T., & Cheng, G. (2016). Embodied artificial agents for understanding human social cognition. *Philosophical Transactions of the Royal Society B: Biological Sciences*


# Research Program


1. Dissecting mechanisms of social cognition with human-robot interactions

   2003-2015

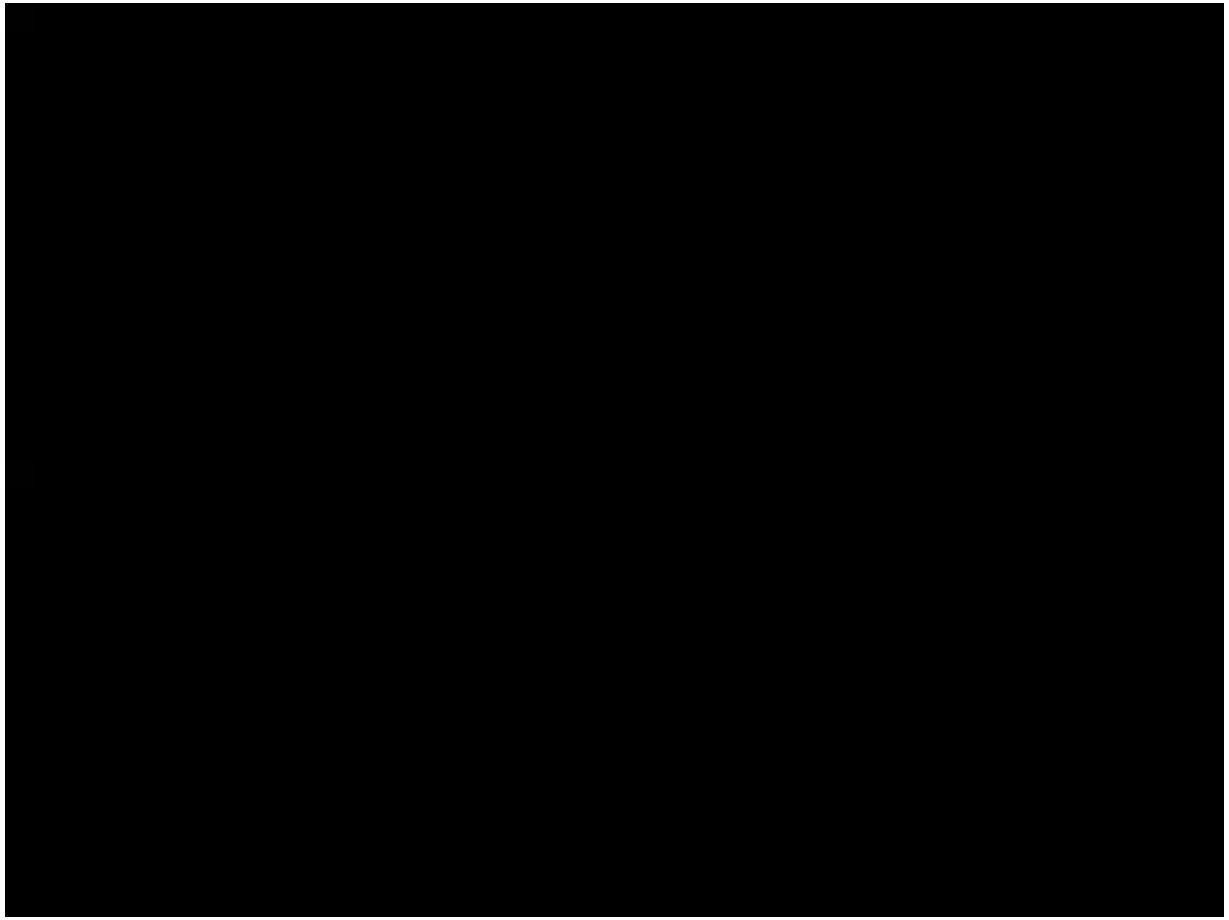
   - How do we think machines think?
   - Motor resonance with humanoid robots: behavioural and neurophysiological studies

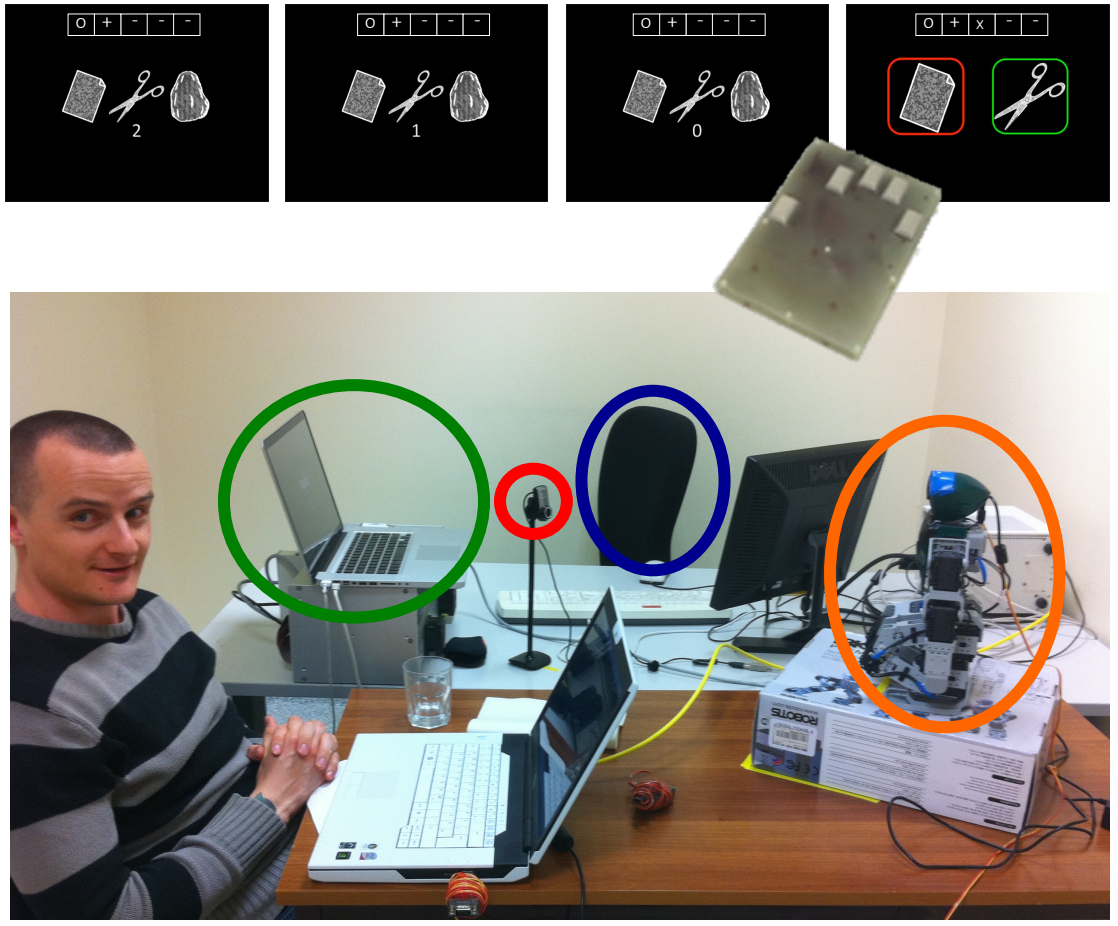
2. Brain bases of conversation investigated with human-robot interactions

   2015-2023

   - An fMRI corpus of natural social interactions
   - A neurophysiological Total Turing Test

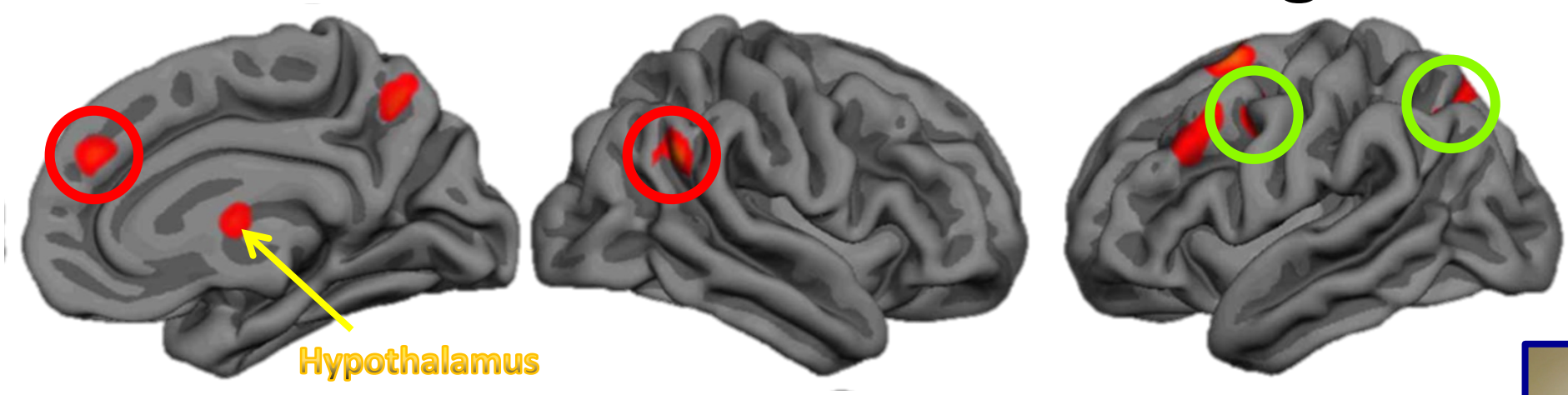
# How do we think robots think?



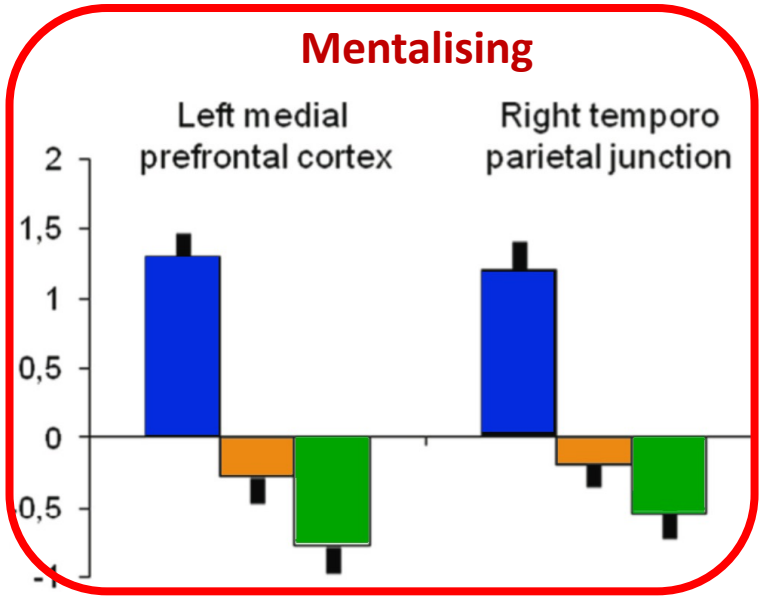


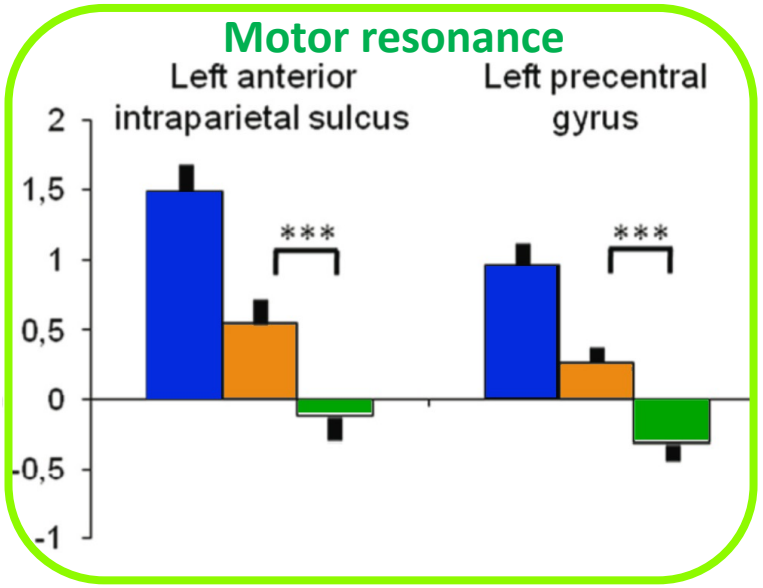

Chaminade, T., Rosset, D., Fonseca, D. D., Nazarian, B., Lutcher, E., Cheng, G., & Deruelle, C. (2012). How do we think machines think ? An fMRI study of alleged competition with an artificial intelligence. *Frontiers in Human Neuroscience*

# Motor resonance and Mentalizing networks




Human
*versus*
Computer



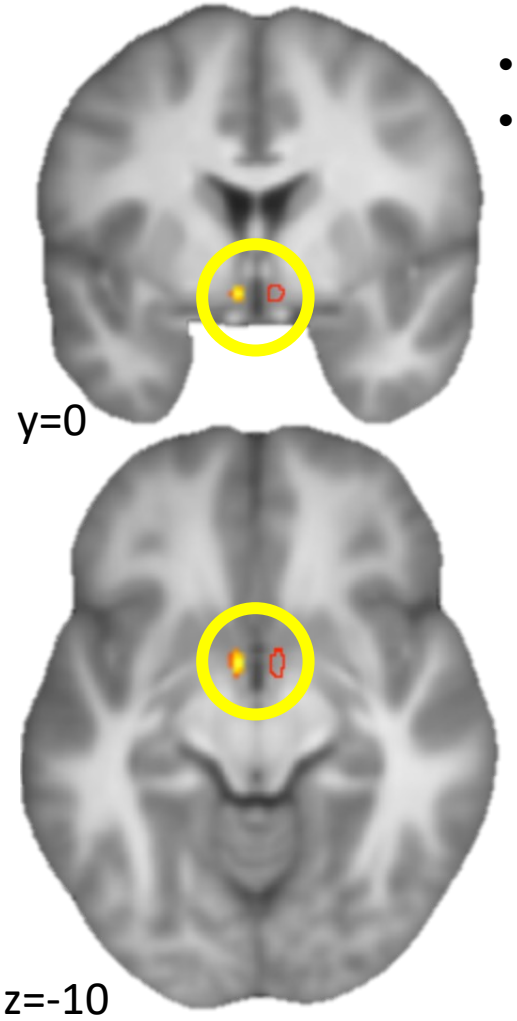





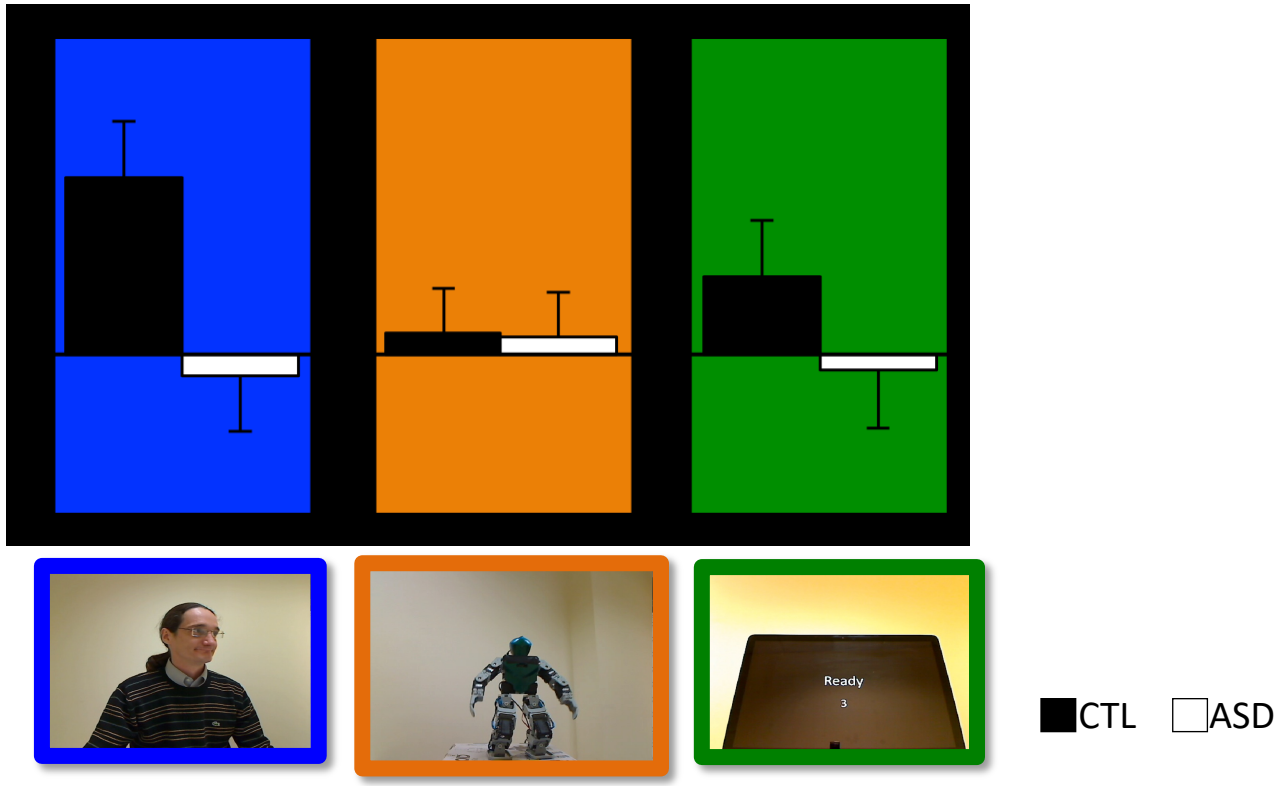
- **Intentional stance adopted for human-human interactions only**

Chaminade, T., Rosset, D., Fonseca, D. D., Nazarian, B., Lutcher, E., Cheng, G., & Deruelle, C. (2012). How do we think machines think ? An fMRI study of alleged competition with an artificial intelligence. *Frontiers in Human Neuroscience*

# Hypothalamus and Autism Spectrum Disorder



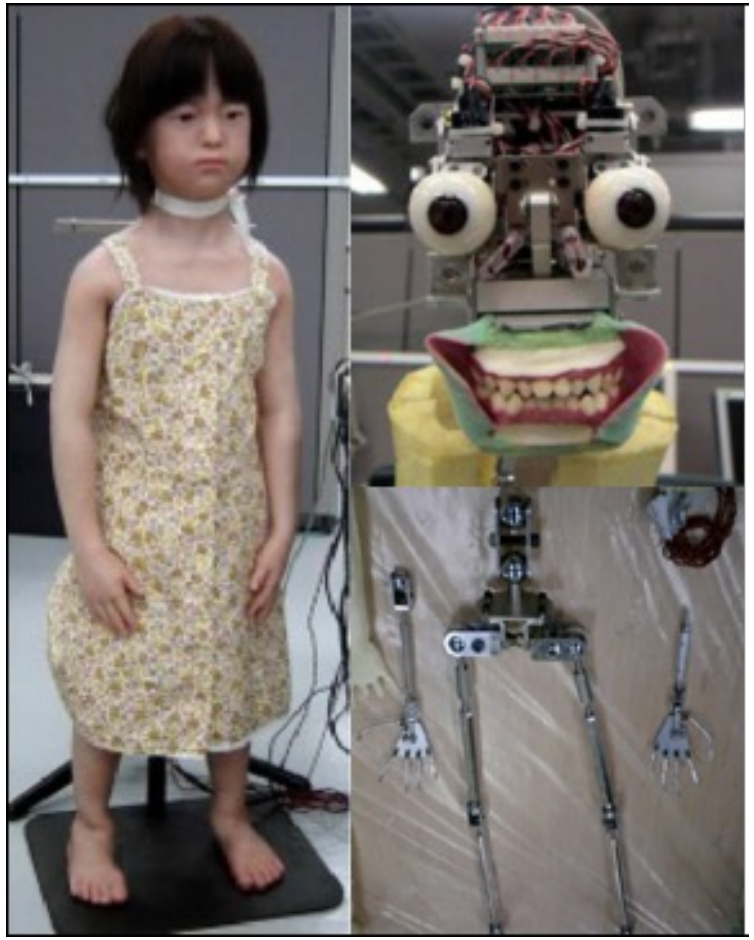

- The same paradigm is used in high-functioning Autism Spectrum Disorder individuals
- Analysis focused on Group x Agent interaction

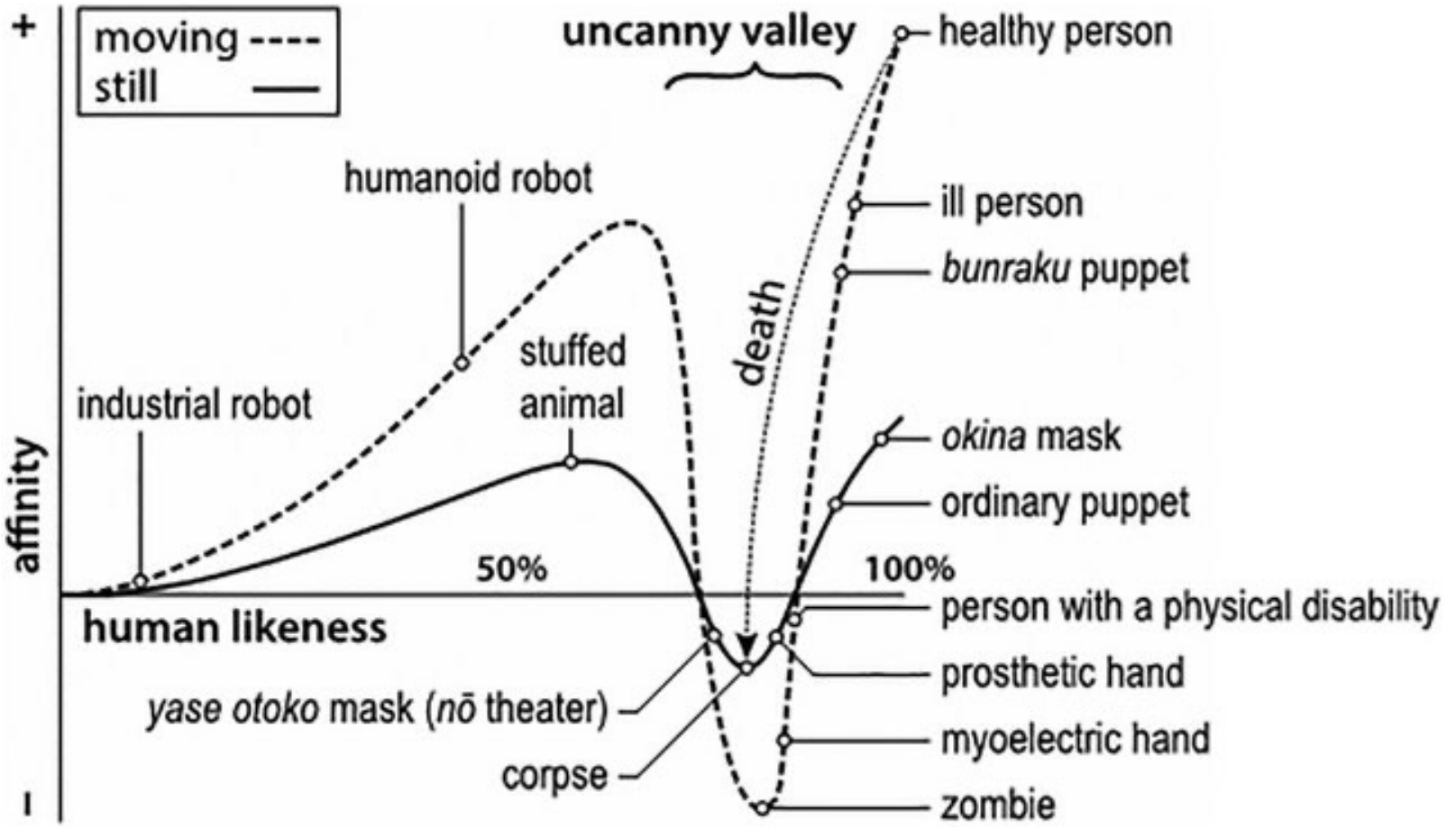



➢ **Hypothalamus activity when interacting with Humans absent in Autism**

Chaminade et al., JADD 2015

# Humanoid Robotics : Uncanny Valley





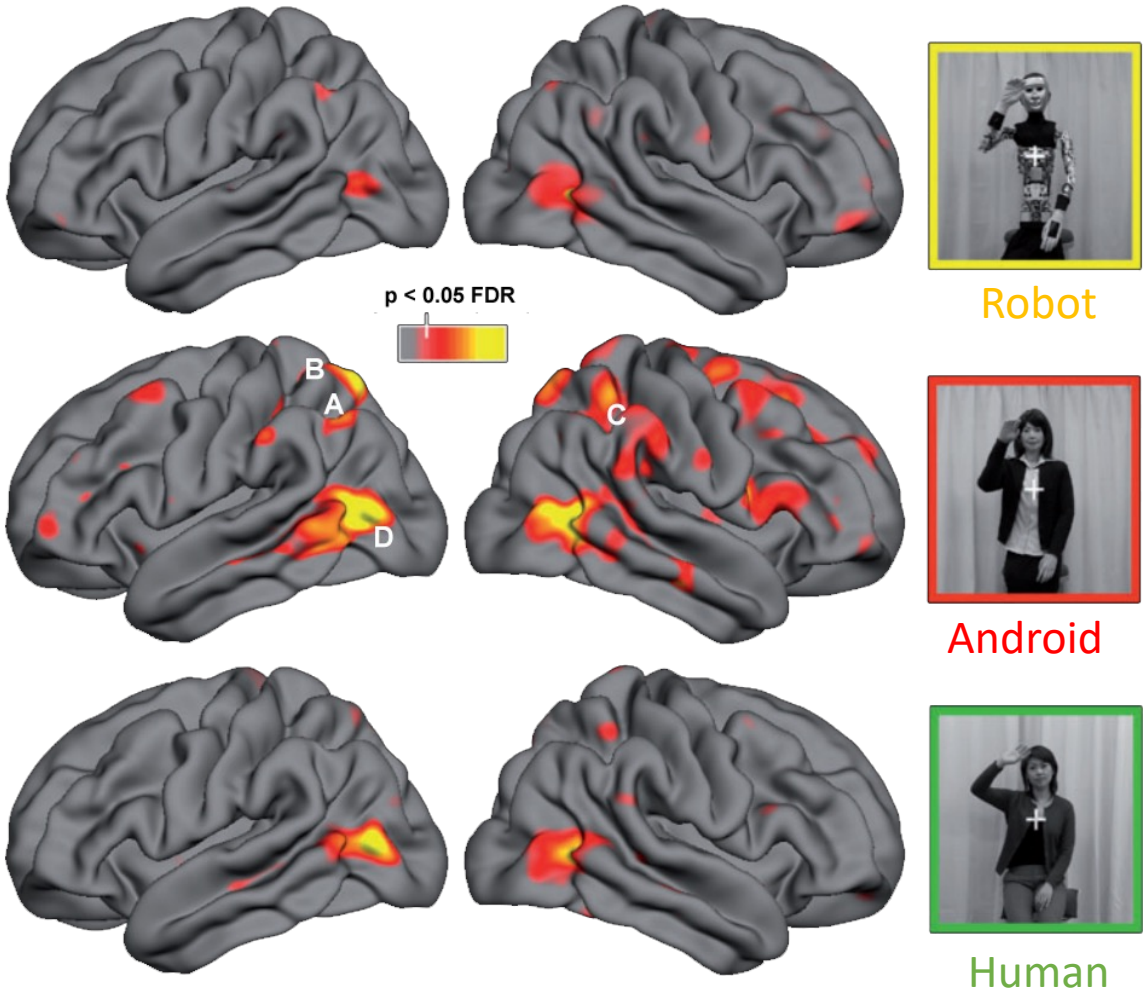

Mori et al. (2012)

# A journey in the Uncanny Valley


- Repetition priming experiment
  Brain areas responding to specific stimulus features have reduced activity when this feature is repeated in consecutive stimuli
- 3 features
  - Action
  - Appearance
  - Motion
- Focus on appearance:
  - Human
  - Android
  - Robot

Saygin, A. P.*, Chaminade, T.,* & Ishiguro, H. (2010). The perception of humans and robots : Uncanny hills in parietal cortex. *Proceedings of the Annual Meeting of the Cognitive Science Society*

# A journey in the Uncanny Valley





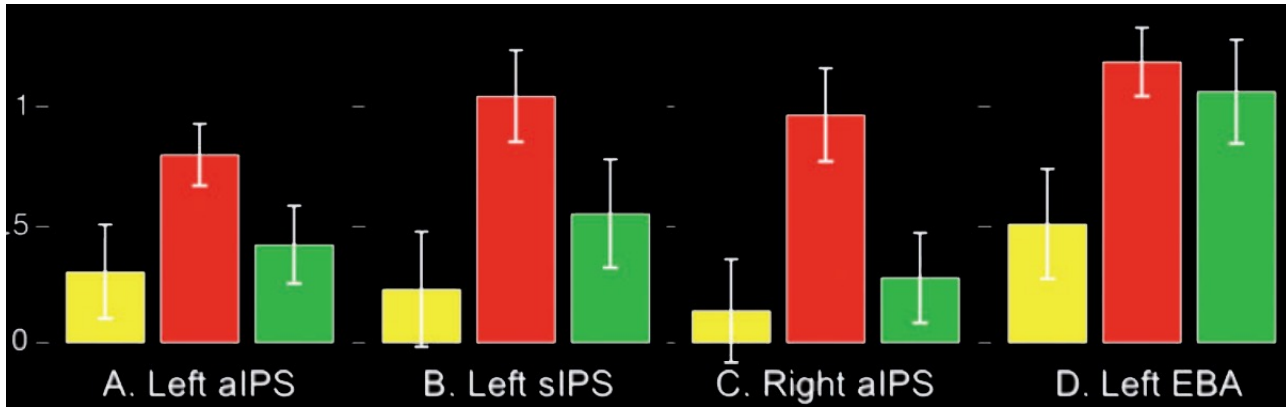

Robot



Android



Human

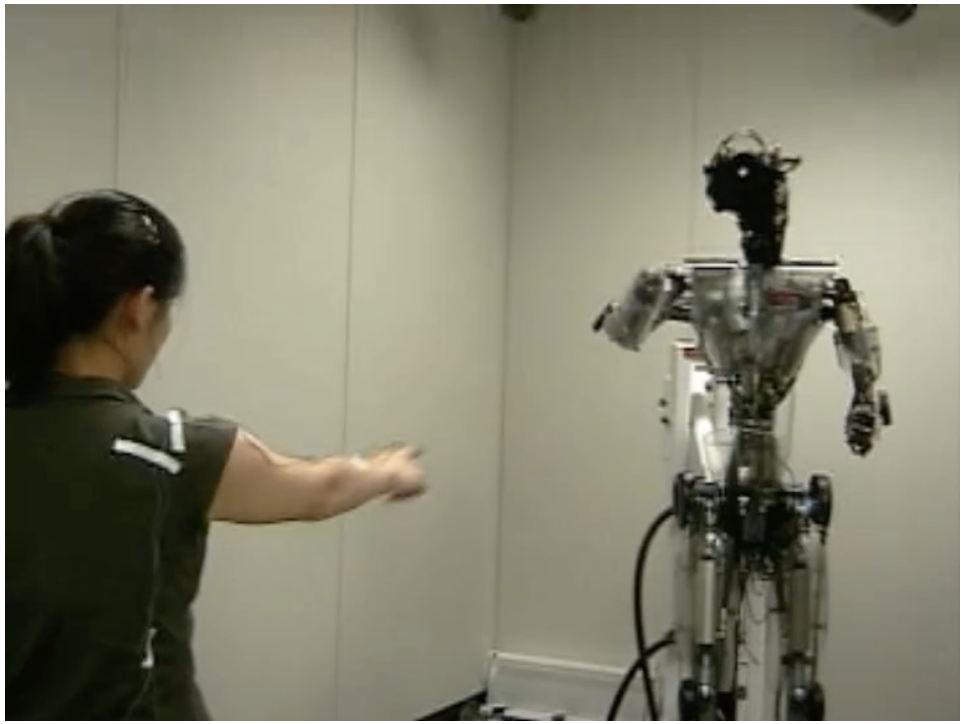



- Similar repetition priming for Human and Android in EBA
  - Visual area sensitive to overall human likeness
- Larger repetition priming for Android in IntraParietal Sulcus
  - Increased sensitivity to Motion/Shape incongruence
  - In areas involved in motor resonance

➢ **Motor Resonance is sensitive to human-like shape & motion congruency**

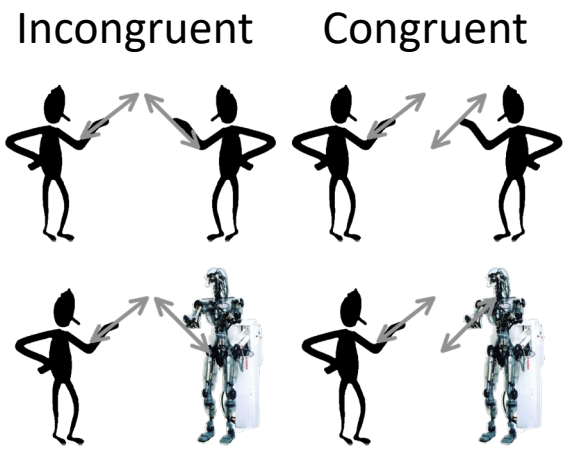
Saygin*, A. P., Chaminade*, T., Ishiguro, H., Driver, J., & Frith, C. (2012). The thing that should not be : Predictive coding and the uncanny valley in perceiving human and humanoid robot actions. *Social Cognitive and Affective Neuroscience*

# Motor Resonance towards a Humanoid Robot

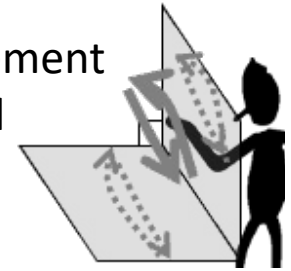


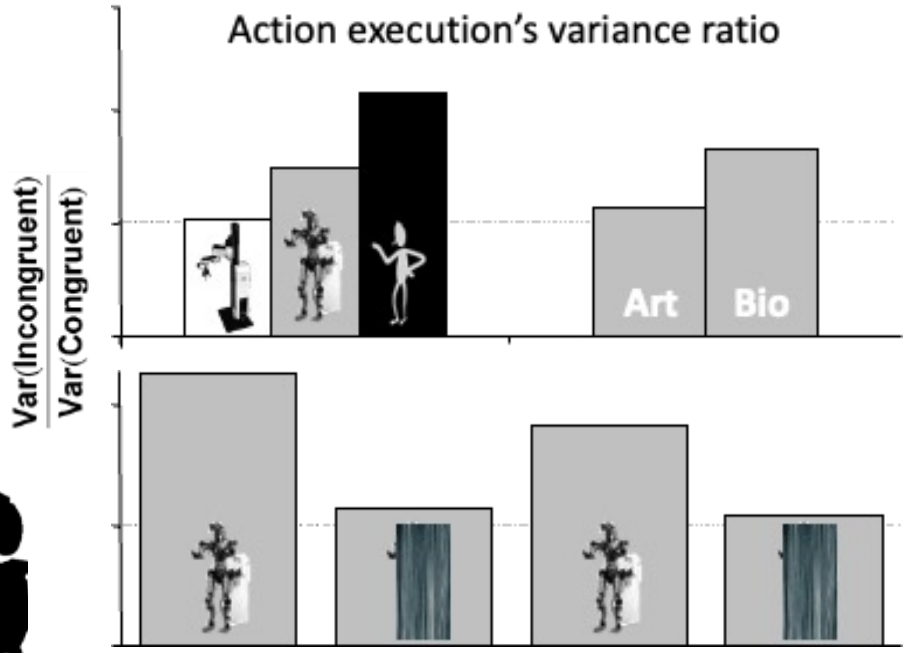
Humanoid DB

ATR




Variance of movement on horizontal and vertical planes

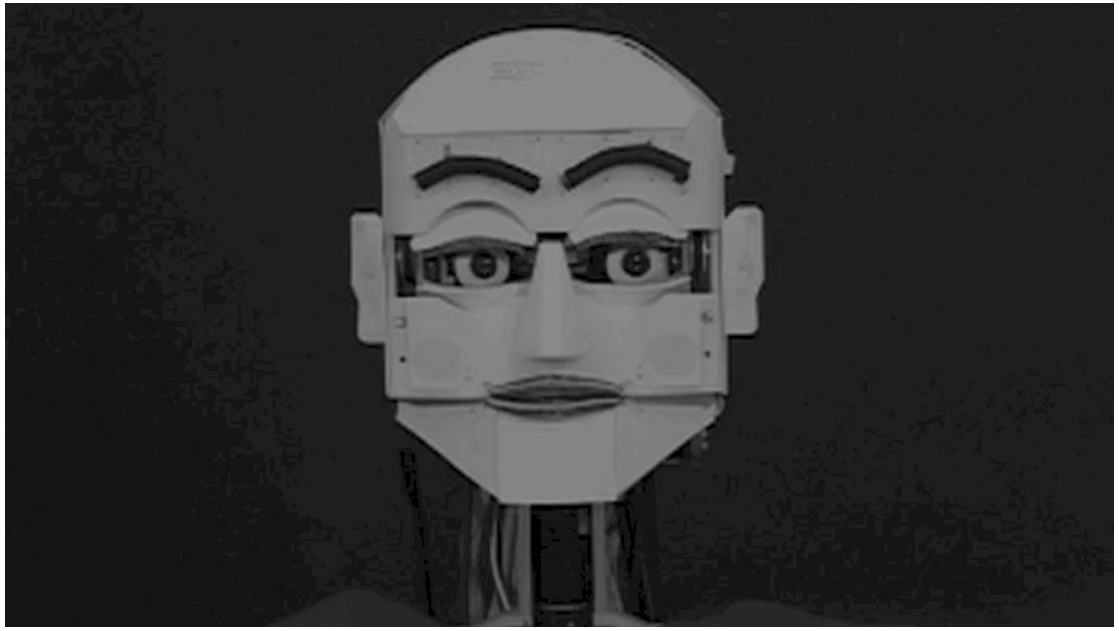


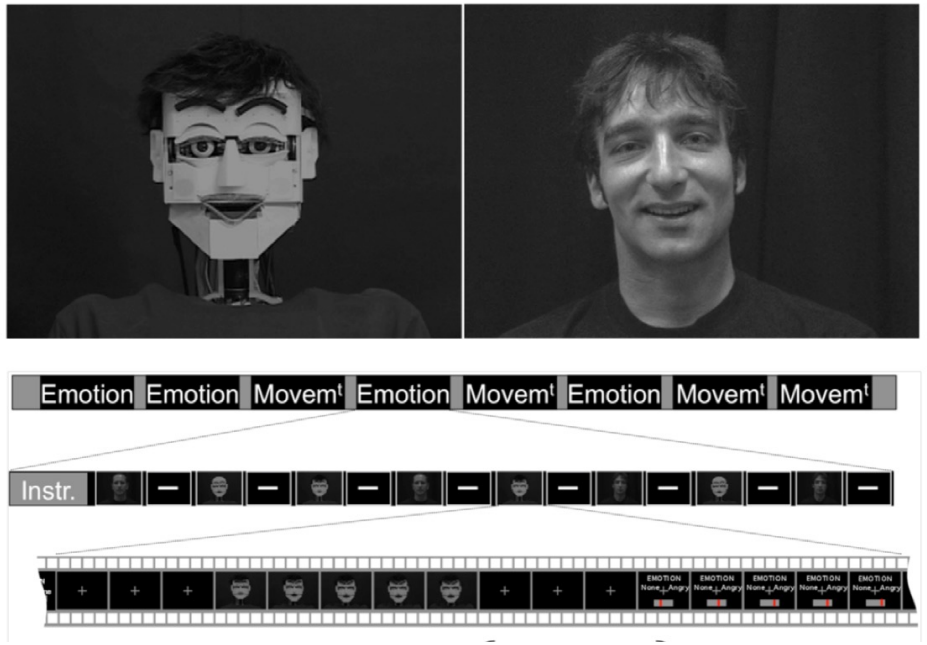



- **Motor resonance is automatic, influenced by body shape, visibility and motion**

Oztop, E., Franklin, D. W., Chaminade, T., & Cheng, G. (2005). Human–humanoid interaction : Is a humanoid robot perceived as a human? International Journal of Humanoid Robotics,
Chaminade and Cheng, J Physiology Paris, 2009

# Resonance with a Humanoid Robot





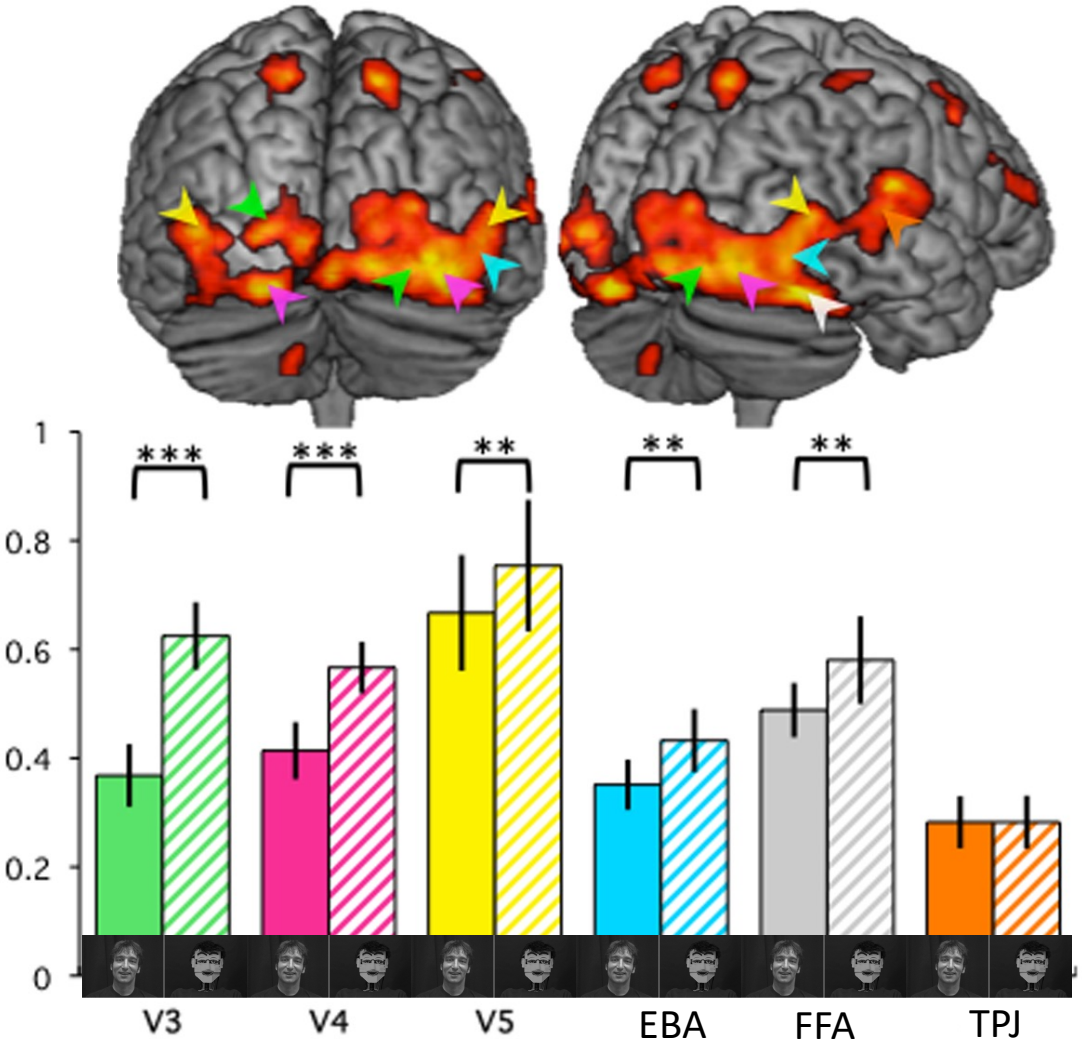

"Rate the emotion" or "rate the movements" in the videoclips showing a human *vs* humanoid robot WE-4RII facial expressions of emotions (Neutral [speech], Joy, Anger, Disgust)

Chaminade et al., PLOS One 2010

# Resonance with a Humanoid Robot

Increased response to robot in visual areas – Motion-sensitive Temporal area (MT), Extrastriate Body Area (EBA) and Fusiform Face Area (FFA) - but not in the Temporo-Parietal Junction (TPJ)

- **Visual areas activity increase with imperfect human-like appearance**

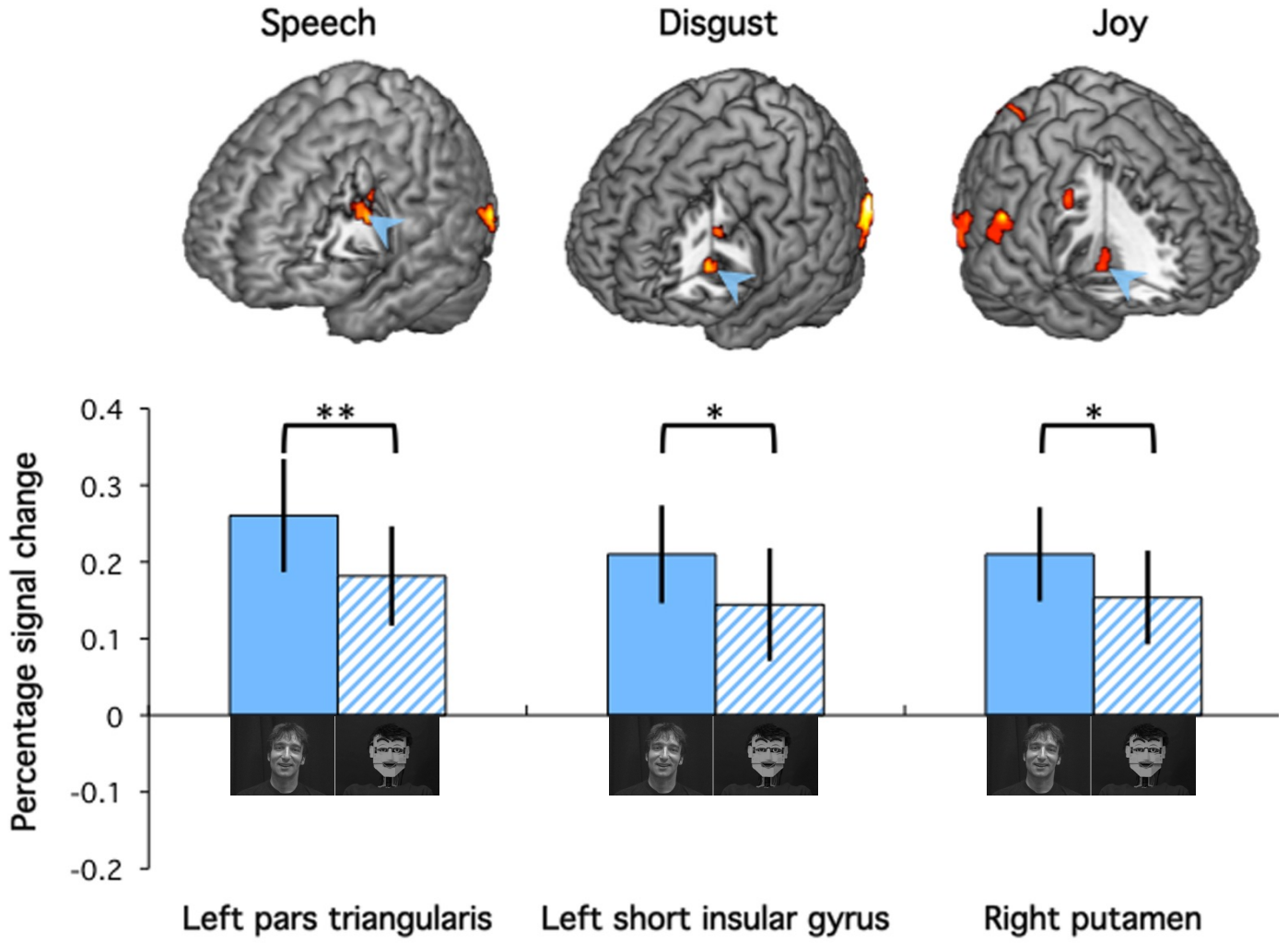



Chaminade et al., PLOS One 2010

# Resonance to Humanoid Robot

Response in regions specific to the content of stimuli is reduced when the agent is the robot compared to human

- **Reduced resonance to artificial agents**



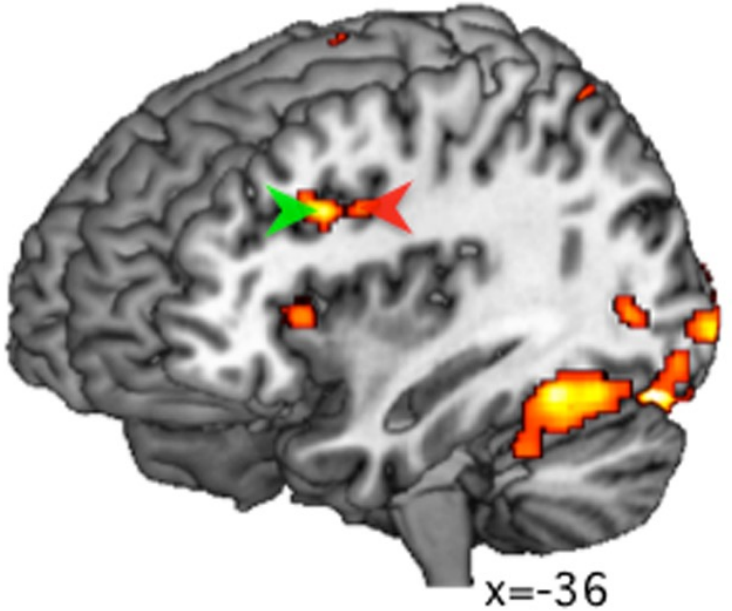

Chaminade et al., PLOS One 2010

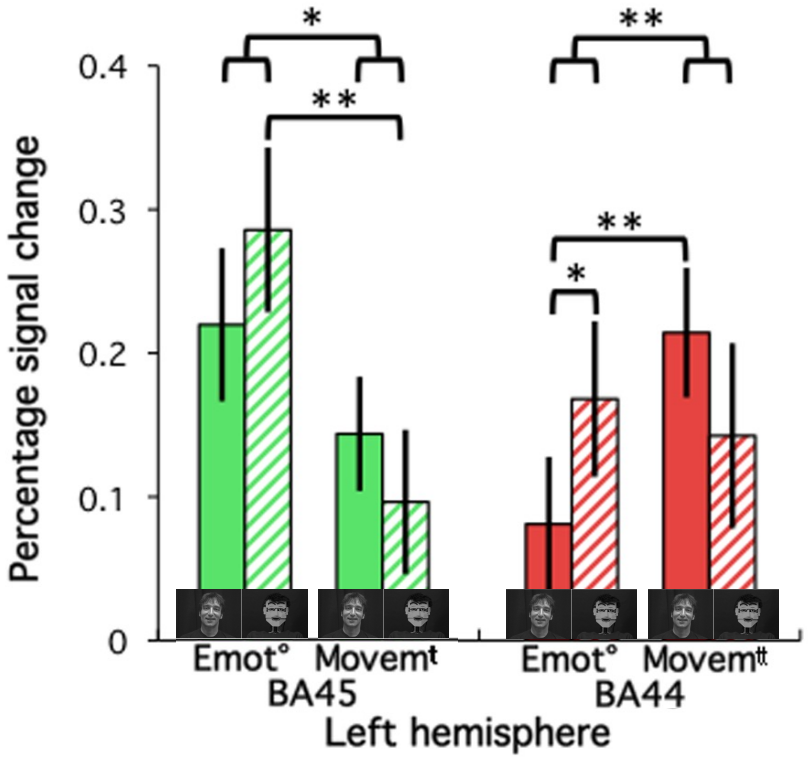
# Interplay between sensory and contextual information

- Significant interaction between Task and Agent in left anterior Inferior Frontal Gyrus Brodman Areas BA44 and BA45

- In most anterior Brodman Area (BA) 45 activity is increased when attention is oriented towards emotion (Emot°) compared to motion (Movem$^{t}$), but the difference is only statistically significant for the robot (hatched bars).

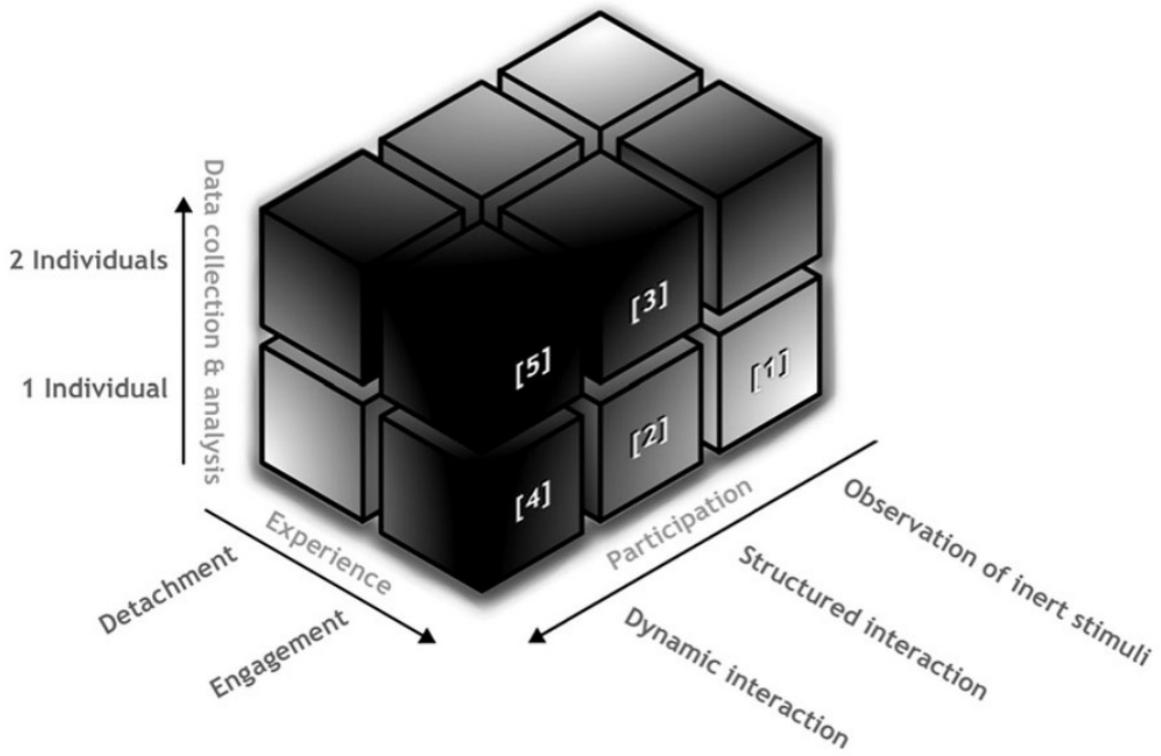
➢ Explicitly orienting attention to the intention of the observed action significantly increases response to robot stimuli




Chaminade et al., PLOS One 2010

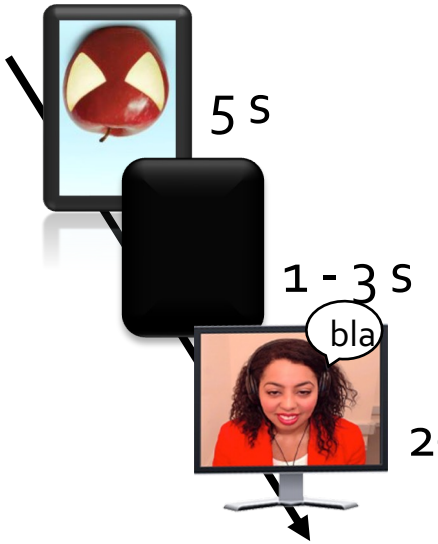
# A new paradigm to study natural social interactions

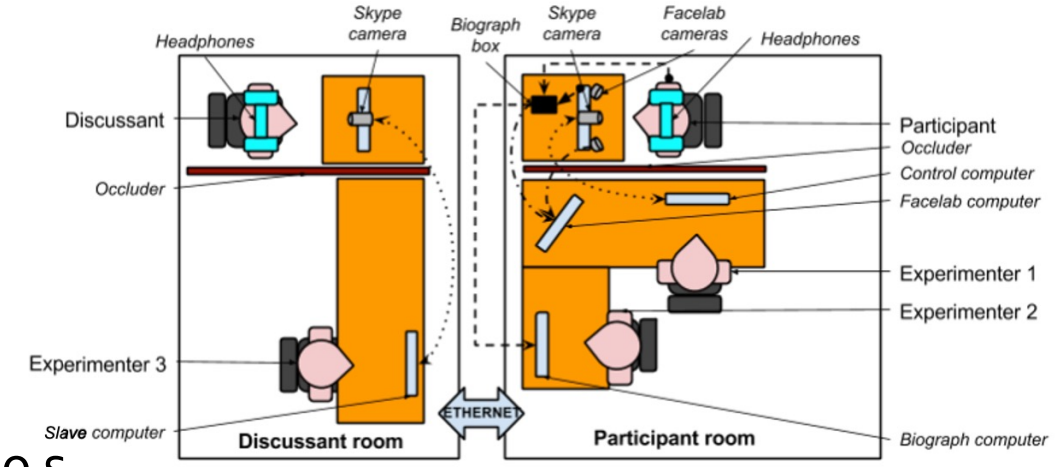


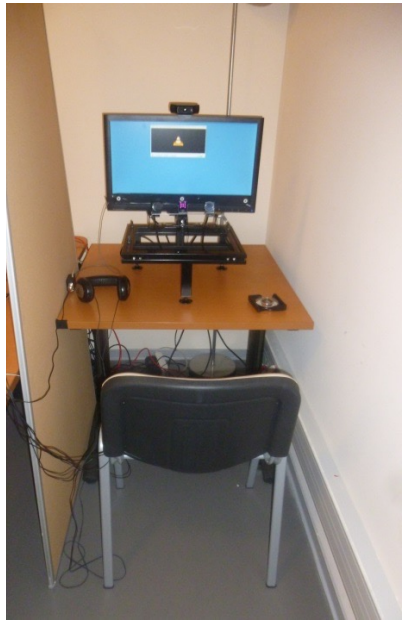

- *"Recent conceptual and empirical developments consistently indicate the need for investigations that allow* ***the study of real-time social encounters in a truly interactive manner****. This suggestion is based* ***on the premise that social cognition is fundamentally different when we are in interaction with others*** *rather than merely observing them."*
- Participants need to be unaware of the actual objective of the experiment: Cover story
- A 3-step framework
  - Record natural interactions, i.e. conversation
  - Extract relevant features from recorded behaviours
  - Use these features to analyze physiological measurements

Schilbach et al., BBS, 2013

# A new paradigm: Behavioural proof-of-concept

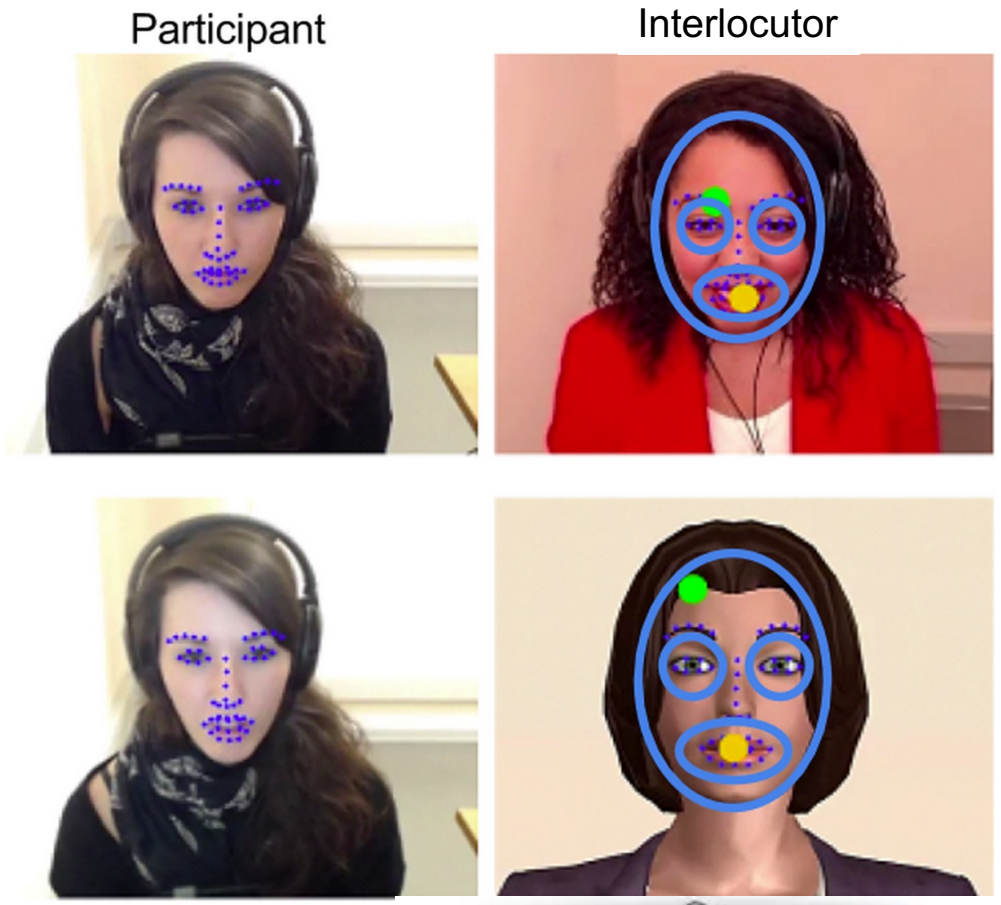


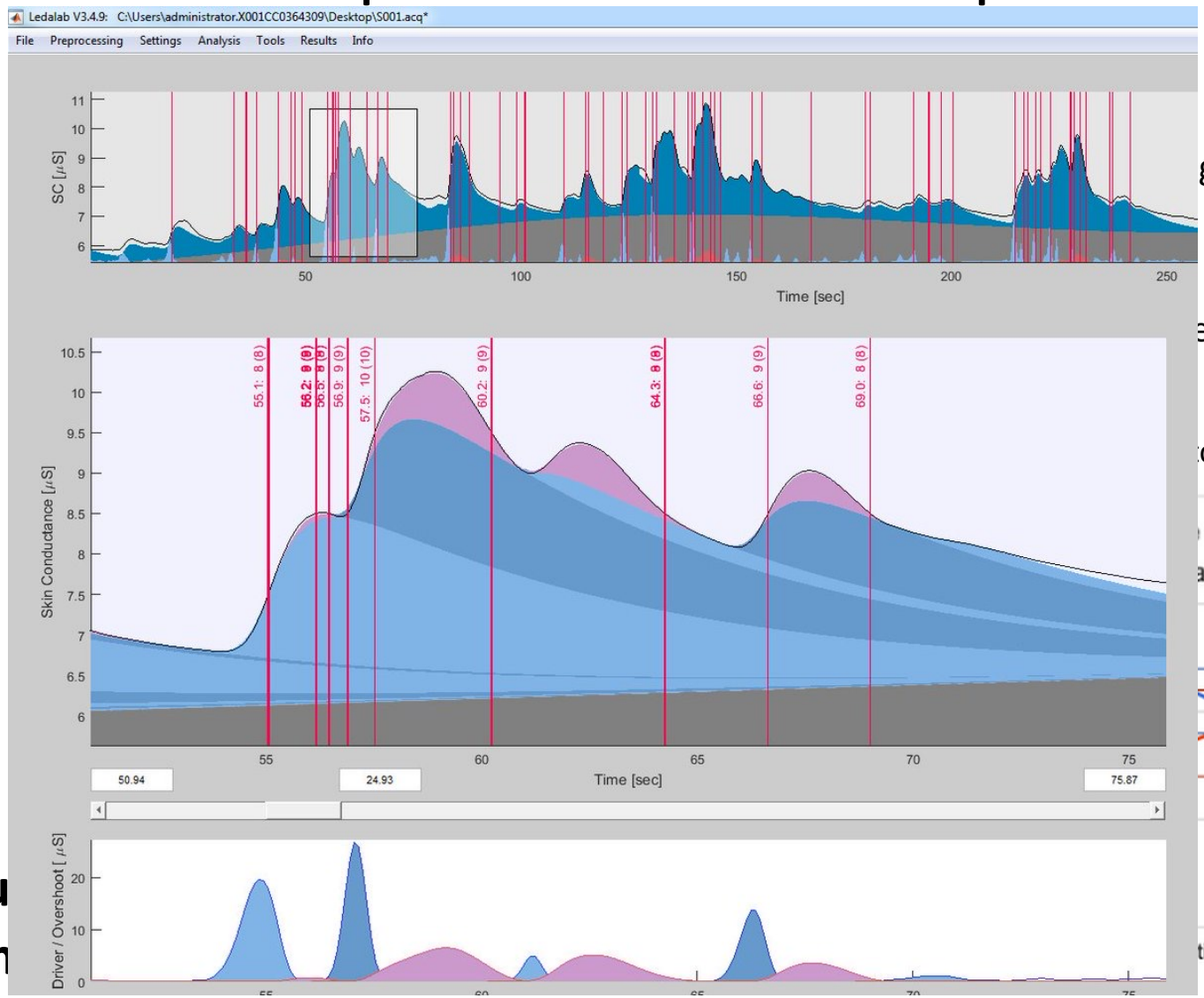



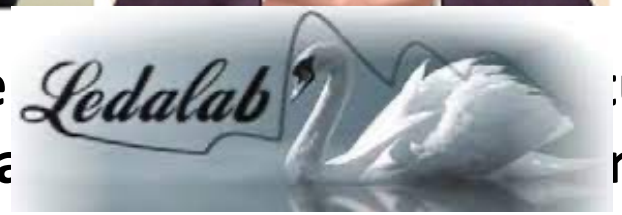
Magalie Ochs, Nathan Libermann, Axel Boidin, Thierry Chaminade, "Do You Speak to a Human or a Virtual Agent? Automatic Analysis of User's Social Cues during Mediated Communication", ICMI 2017.

# A new paradigm: Behavioural proof-of-concept



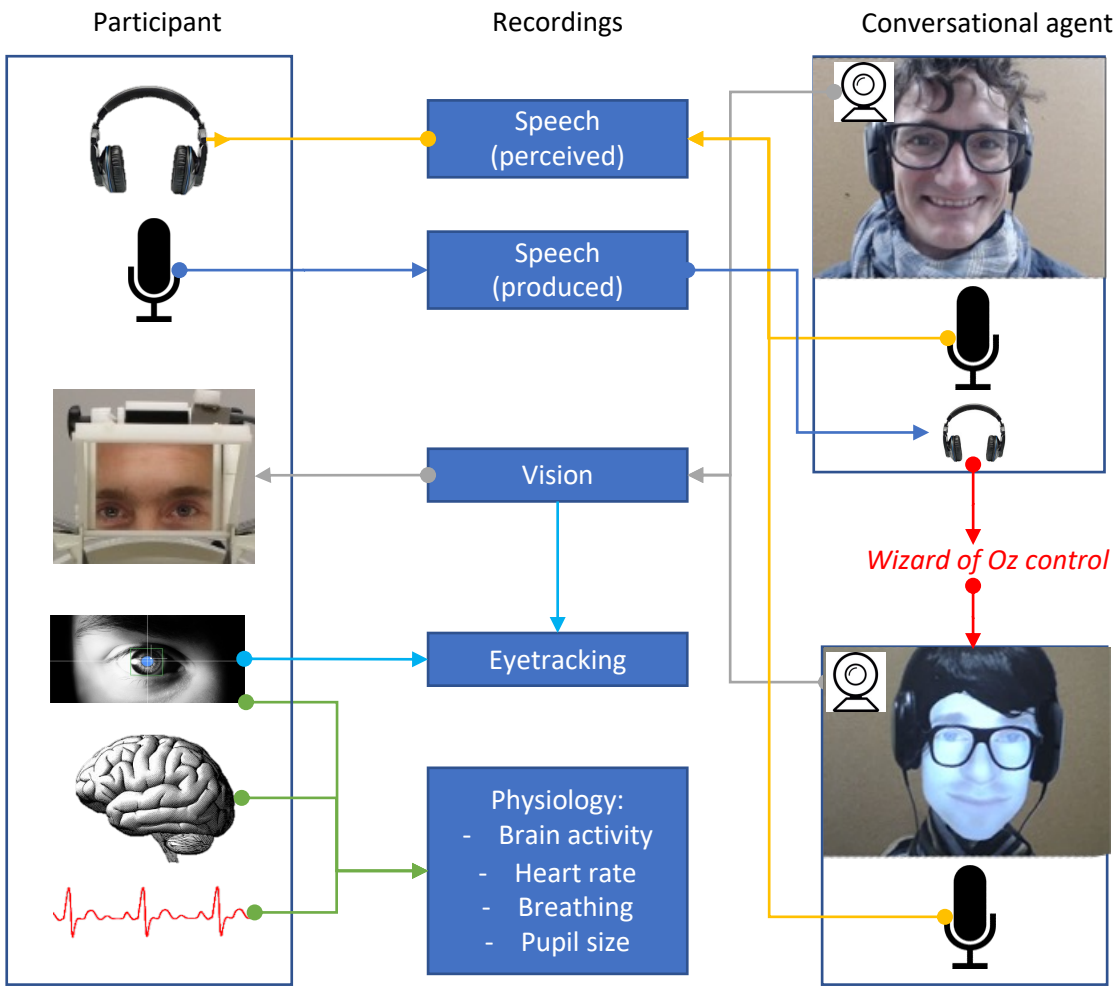




- **Importance** **(disambigua**

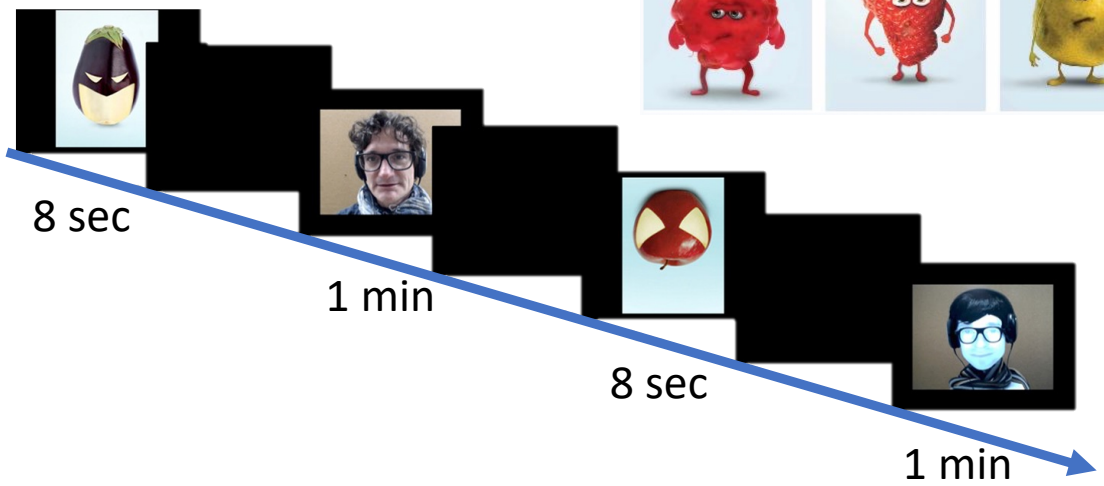



Chaminade, Interaction Studies, 2017

# Recording a neurophysiological corpus (fMRI)




Same cover story and images than the behavioural experiment




4 sessions:

- H → R → H → R → H → R

Rauchbauer, B., Nazarian, B., Bourhis, M., Ochs, M., Prévot, L., & Chaminade, T. (2019). Brain activity during reciprocal social interaction investigated using conversational robots as control condition. *Philosophical Transactions of the Royal Society B*

# Recording a neurophysiological corpus (fMRI)

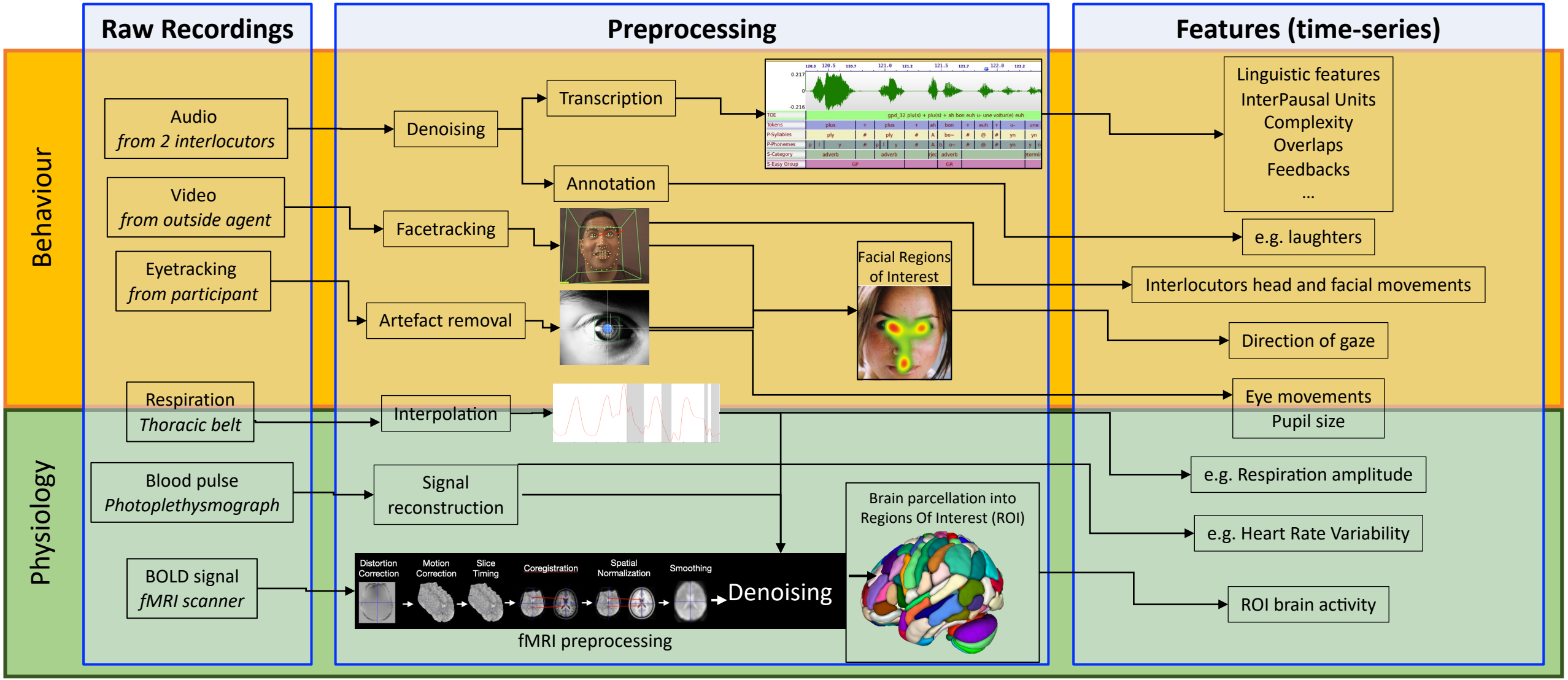
Human

Robot

- **25 participants**
- **24 minutes of conversation / participant**
- **10 hours corpus**

Rauchbauer, B., Nazarian, B., Bourhis, M., Ochs, M., Prévot, L., & Chaminade, T. (2019). Brain activity during reciprocal social interaction investigated using conversational robots as control condition. *Philosophical Transactions of the Royal Society B*

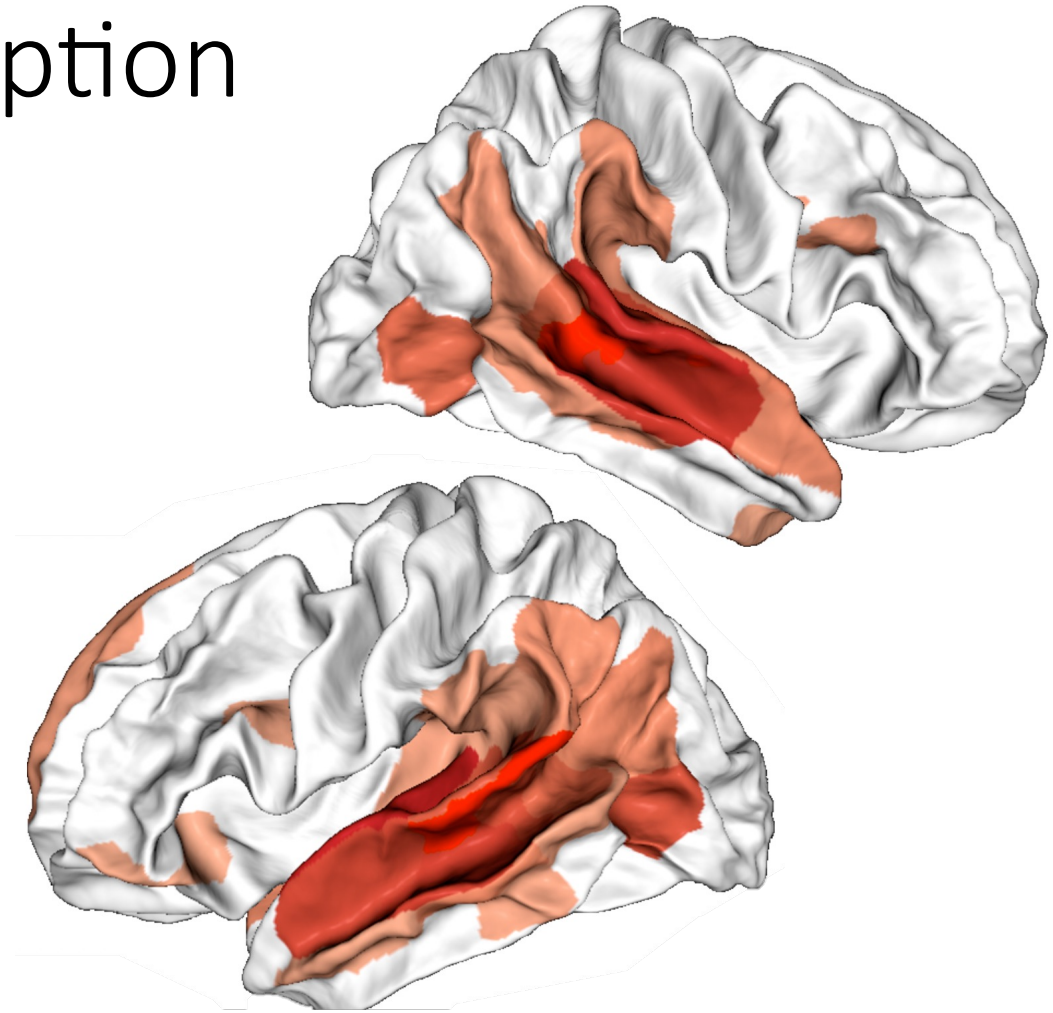
# Processing the corpus into features




Rauchbauer, B., Hmamouche, Y., Bigi, B., Prevot, L., Ochs, M., & Thierry, C. (2020). Multimodal corpus of bidirectional conversation of human-human and human-robot interaction during fMRI scanning. *12th Language Resources and Evaluation Conference*

# Correlates of speech perception

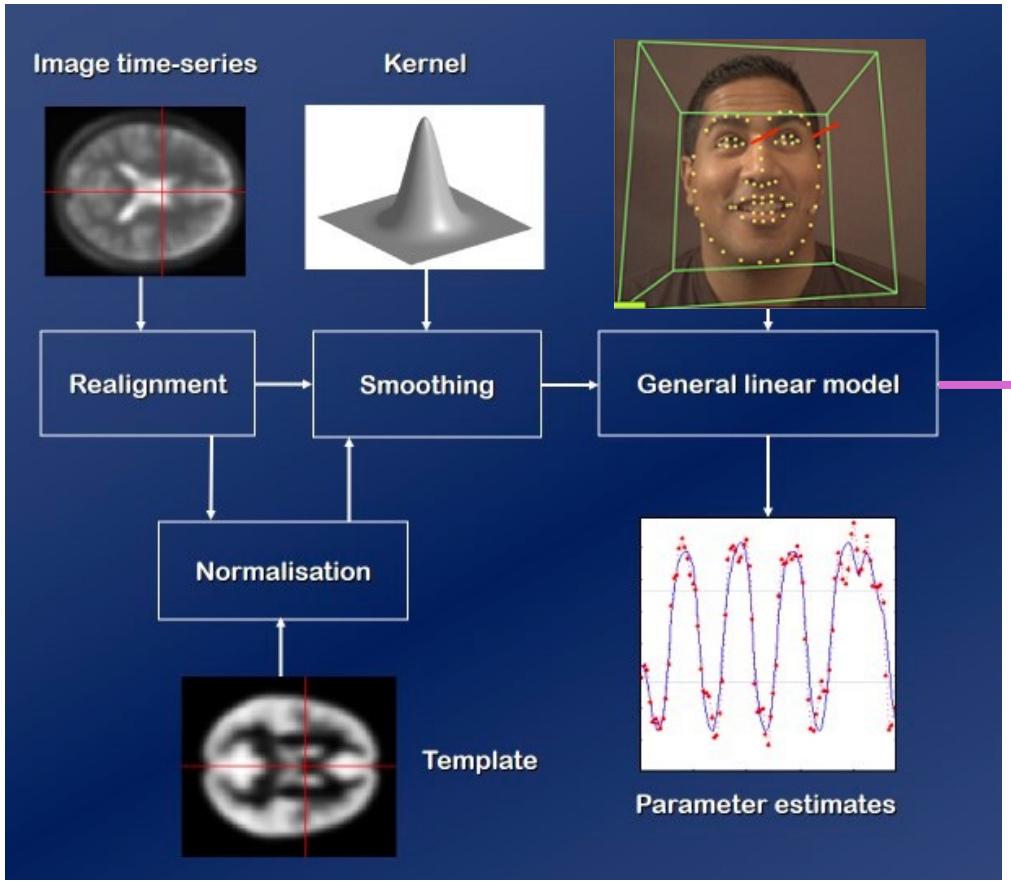
IPU 1: 1.15 - 3.95
bon franchement franchement t'as déjà cueilli des fruits quand t'étais petit
well frankly frankly did you already pick fruits when you were a kid
IPU 1: 4.28 - 5.61
j'en j'en ai dans mon jardin hein j'ai le cerisier on est train de faire la récolte de cerises en ce moment
I I have some in my garden, huh, I have the cherry tree we are doing the cherry harvest right now
IPU 2: 8.23 - 9.65
ah ouais en plus en plus c'est la saison
oh yep moreover moreover it is the season
IPU 2: 9.95 - 10.17
ouais
yep
IPU 3: 10.06 - 11.79
c'est la saison elles sont elles sont bonnes en ce moment
this is the season they are they are good right now
IPU 3: 11.92 - 14.83
elles sont elles sont petites elles sont brillantes comme la pomme
they are they are small they are bright like the apple
IPU 4: 15.28 - 18.07
ouais ah et toi donc toi t'as des très très beaux fruits
yep ah and you so you have very very beautiful fruits

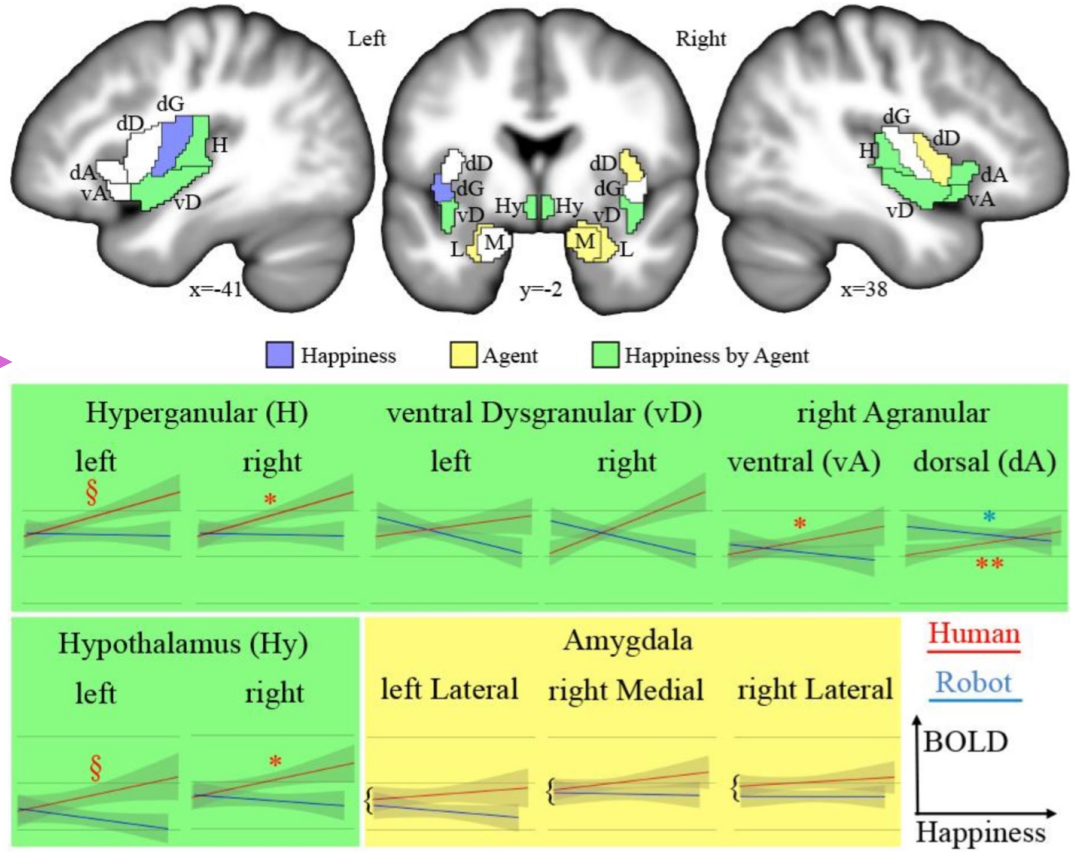


- **The quantity of speech perceived by the participant correlates with activity in the superior temporal sulcus but also with Inferior Frontal Gyrus Regions Of Interest belonging to Broca's area**

Hallart, C., Maes, E.., Spatola, N., Prévot, L., & Chaminade, T. (2021). Comparaison linguistique et neuro-physiologique de conversations humain humain et humain robot. *Traitement Automatique des Langues*

# The limbic system responds to human emotions



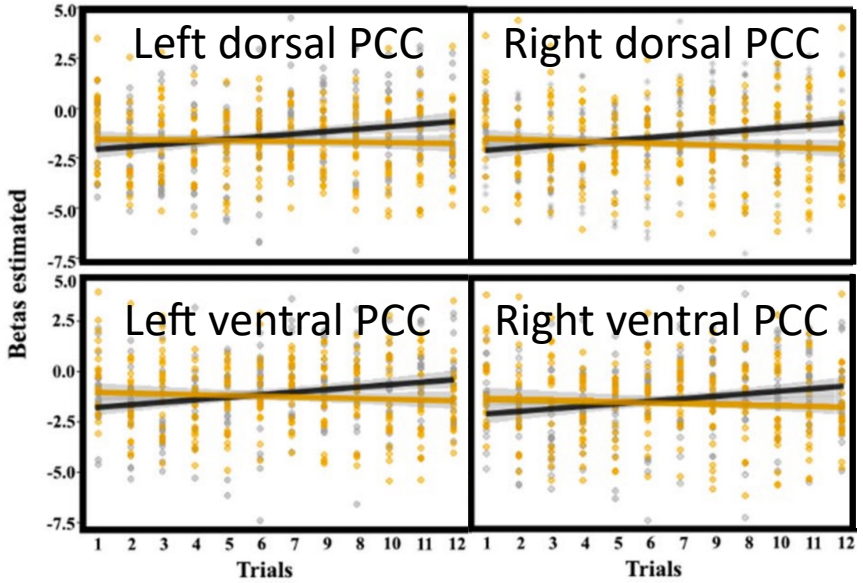




- **Analysis requires extracting behavioural features (e.g. Happiness expressed by the interlocutor) and using them for analysis of functional MRI measurement**

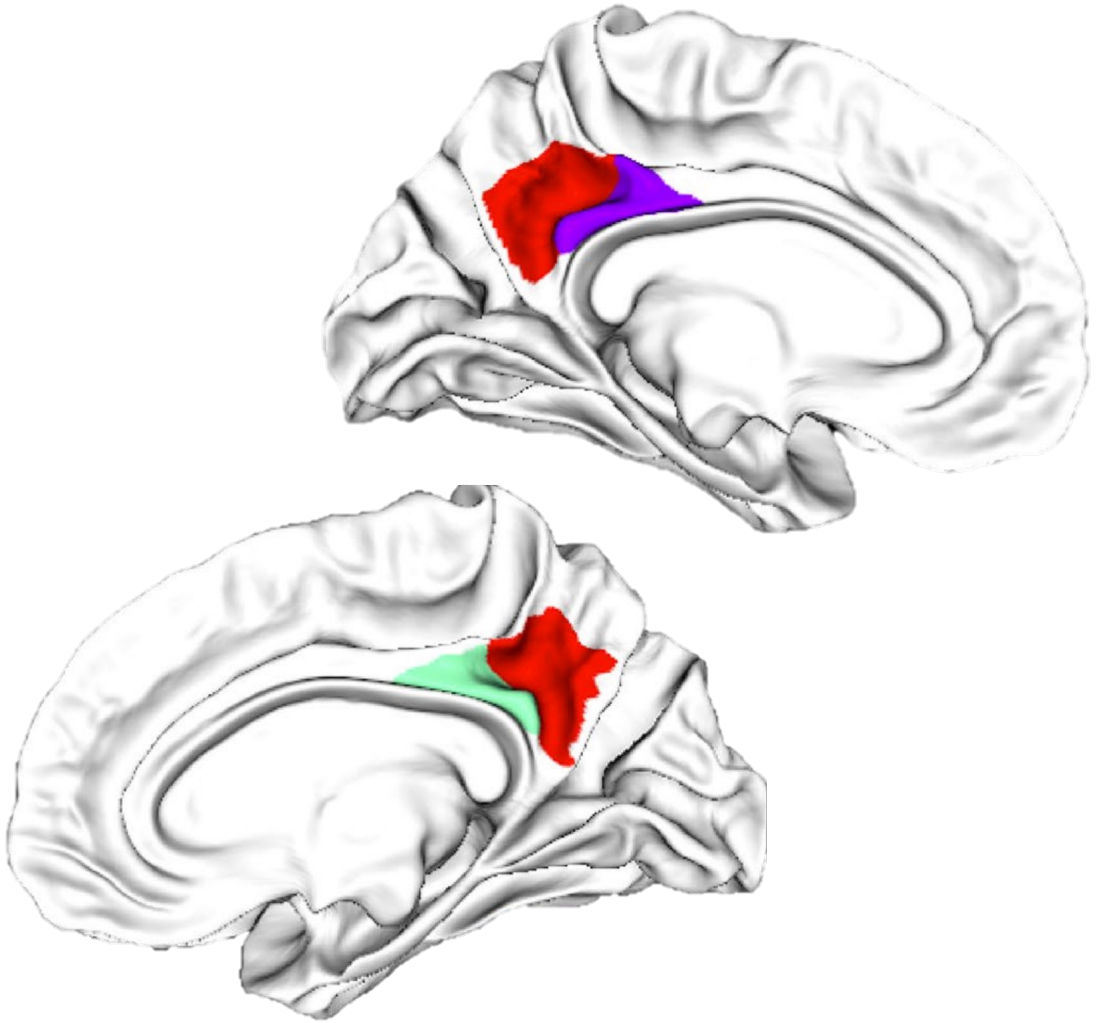
Chaminade, T., & Spatola, N. (2022). Perceived facial happiness during conversation correlates with insular and hypothalamus activity for humans, not robots. Frontiers in Psychology

# Changes in Posterior Cingulate Cortex activity

- Trial number is used as a proxy for time
- Statistical analysis identifies areas where interaction Agent x Time is significant
- Four regions around the posterior cingulate cortex bilaterally identified




Human
Robot

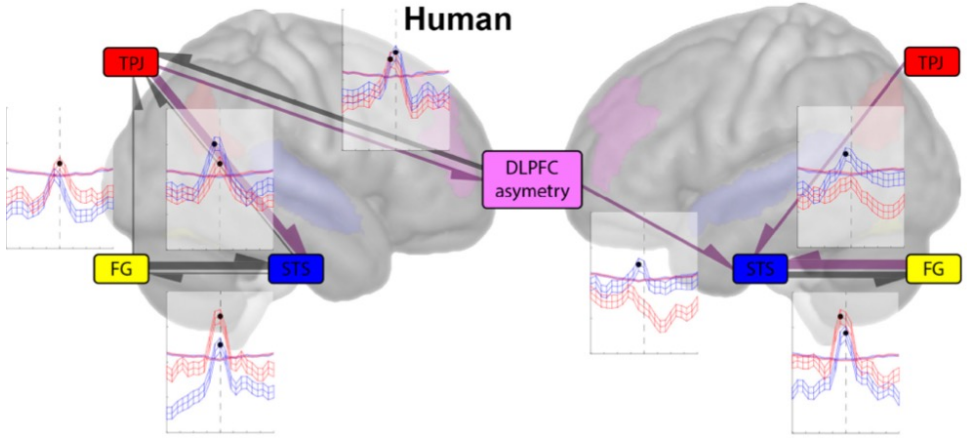


➢ **PCC involved in building social bonding when the interacting agent is a human, not a robot**

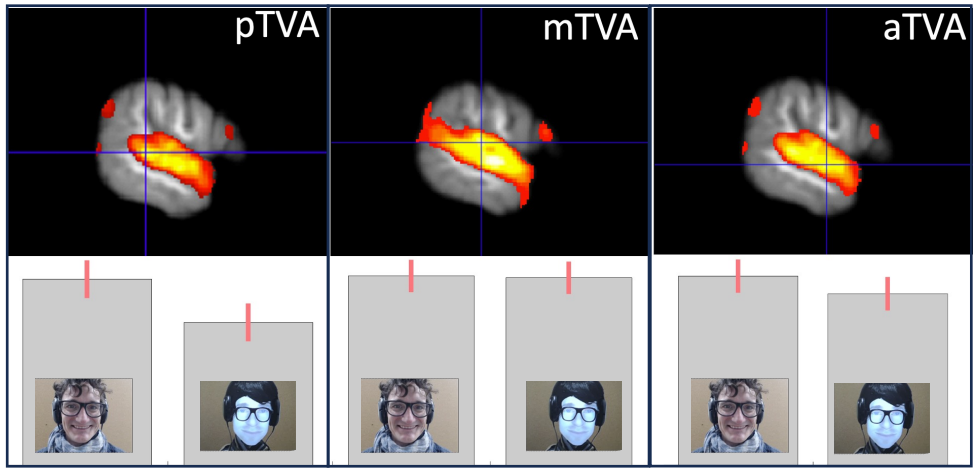
Spatola N, Chaminade T. (2022) Precuneus brain response changes differently during human-robot and human-human dyadic social interaction. Scientific Reports

# Ongoing analyses

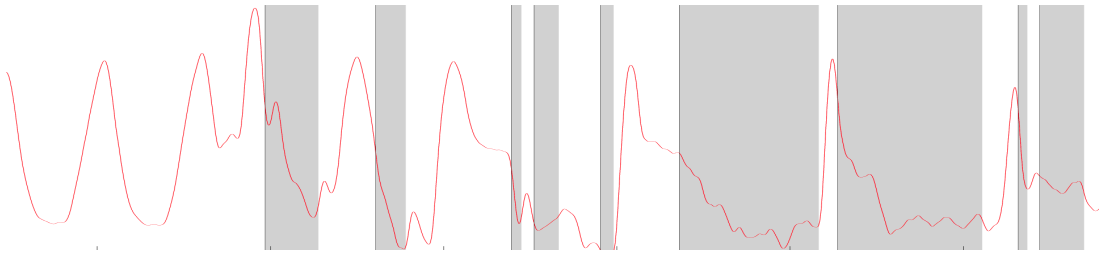
- **Brain correlates of laughter in Natural conversations**, with Chiara Mazzocconi, Benjamin O'Brien and Pascal Belin




- **Causal Analysis of Activity in Social Brain Areas During Human-Agent Conversation**, with Caio De Castro Martins and Marc Cavazza

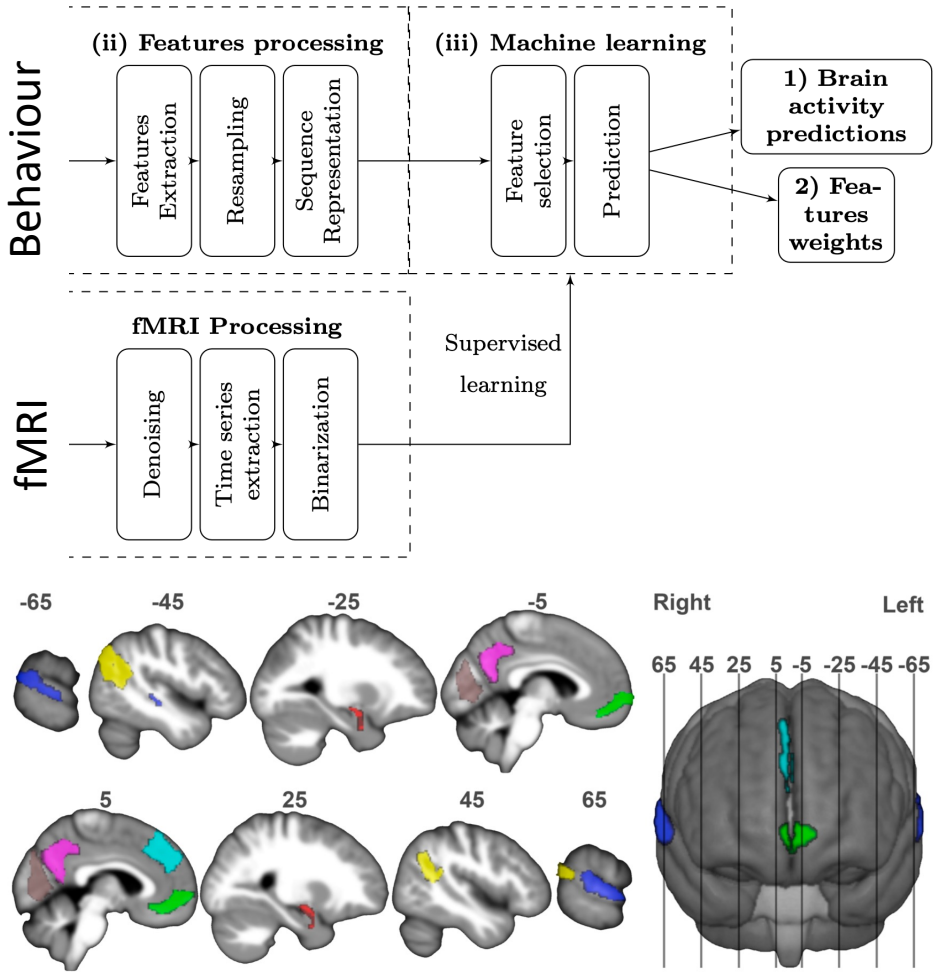



- **Response to synthetic voices in Temporal Voice Areas during natural conversation**, with Pascal Belin



- **Neurophysiology of respiration control during natural conversation**, with Antonin Marty, Lila de Pellegrin

# Predicting brain activity from multimodal features




| ROI | Recall score | Meta-features | Importance |
|---|---|---|---|
| rV1 | 0.63 | FaceDynamics-I<br>GazeDynamics-P<br>HeadDynamics-I | 0.45<br>0.38<br>0.16 |
| lSTS | 0.71 | SpeechDynamics-I<br>SpeechSocial-I | 0.85<br>0.12 |
| rSTS | 0.70 | SpeechDynamics-I<br>SpeechDynamics-P<br>GazeSocial | 0.52<br>0.21<br>0.15 |
| lTPJ | 0.62 | SpeechDynamics-P<br>SpeechDynamics-I<br>HeadDynamics-I<br>GazeSocial | 0.33<br>0.25<br>0.21<br>0.11 |
| rTPJ | 0.70 | SpeechDynamics-P<br>SpeechSocial-P | 0.67<br>0.33 |
| lPre | 0.63 | GazeDynamics-P<br>HeadDynamics-I<br>FaceDynamics-I<br>SpeechDynamics-P | 0.58<br>0.16<br>0.15<br>0.11 |
| rPre | 0.63 | HeadDynamics-I<br>SpeechDynamics-P<br>FaceDynamics-I<br>GazeSocial | 0.38<br>0.17<br>0.15<br>0.11 |
| rAmy | 0.63 | SpeechDynamics-P<br>SpeechDynamics-I<br>SpeechSocial-I<br>SpeechComplexity-I | 0.26<br>0.23<br>0.15<br>0.15 |
| rVMPFC | 0.61 | GazeDynamics-P<br>HeadDynamics-I | 0.45<br>0.34 |
| rDMPFC | 0.72 | SpeechDynamics-P | 1.00 |

- Measures the ability to predict brain activity (recall score) during interaction with Humans
- Provides the weigth of "meta-features" used to predict the activity for each area

➢ Using Machine Learning to assess involvement of multiple modalities to predict local brain activity in Human-Human and Human-Robot interactions

Hmamouche, Y., Ochs, M., Prevot, L., & Chaminade, T. (In press). Interpretable Prediction of Brain Activity during Natural Social Interactions using Multimodal Behavioral Signals. *PLOS ONE*.

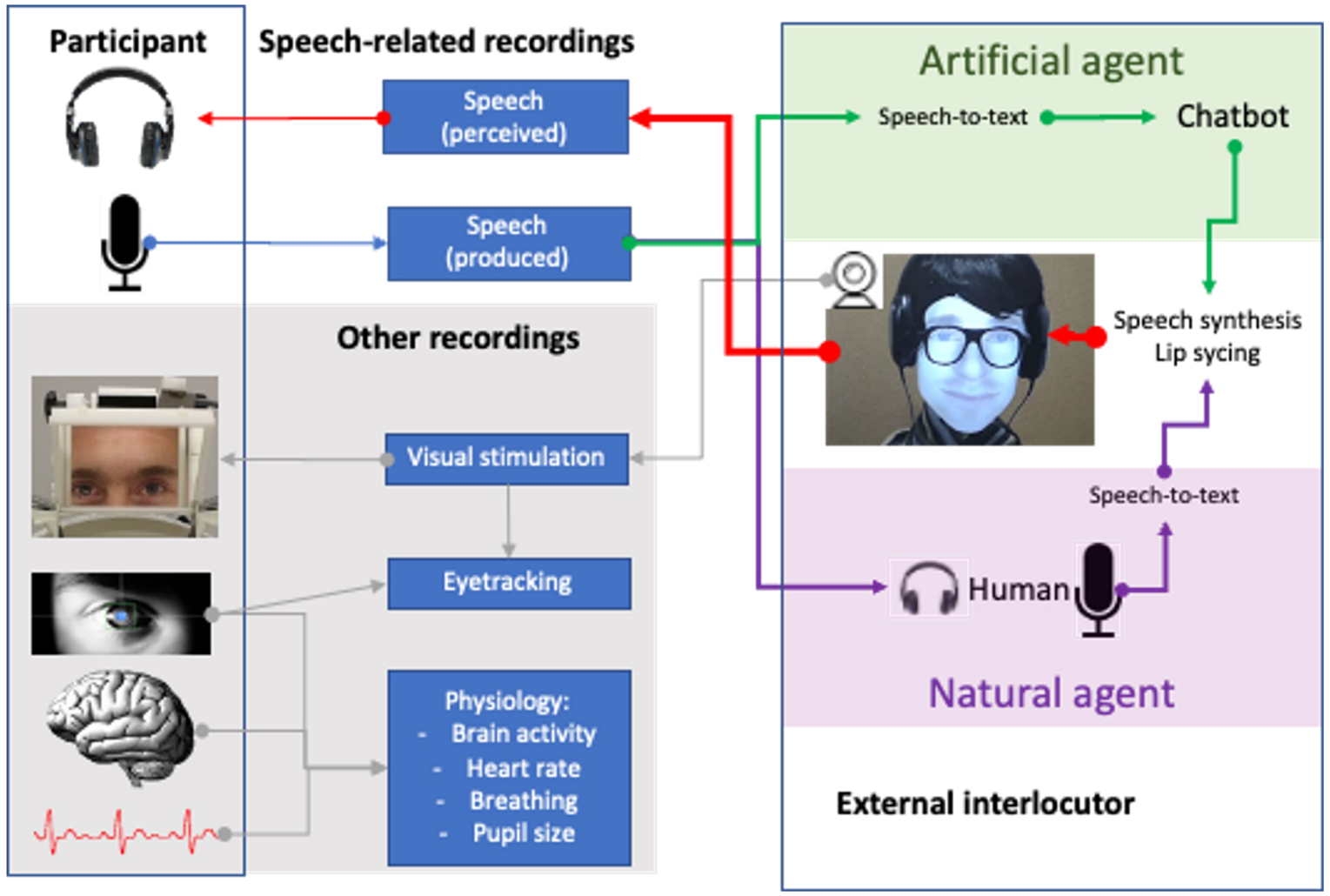
# Project: Total Turing Test

Camilla Di Pasquasio

- "Can Machine Think?": Turing Test TT (Turing, 1950)
  - Typewritten conversational exchanges with human or machine: Can a machine "imitate" humans social ability?
  - Large Language Models such as chatGPT enable realistic conversations
- Total Turing Test TTT (Harnad, 1991)
  - Adding embodiment and voice to the artificial agent to reproduce natural interactions
- Adapting “Neurophysiology of Conversation” to address the TTT
  - Original limitation of (T)TT - explicit priming the human agent about the nature of the interacting agent biases the naturalness of the interaction towards “testing” – can be addressed by assessing the response in brain aareas associated with mentalizing
  - Robotic devices provide the same sensory features for human and artificial agent.

Turing, A. M. (1950) Computing machinery and intelligence. Mind
Harnad, S. (1991) Other bodies, other minds: A machine incarnation of an old philosophical problem. Minds and Machines

# Project: Total Turing Test




- Participants' sensory information is fully independent of the nature of the agent
  - Same face and animation
  - Same voice and phonology
  - Different content (as in TT)

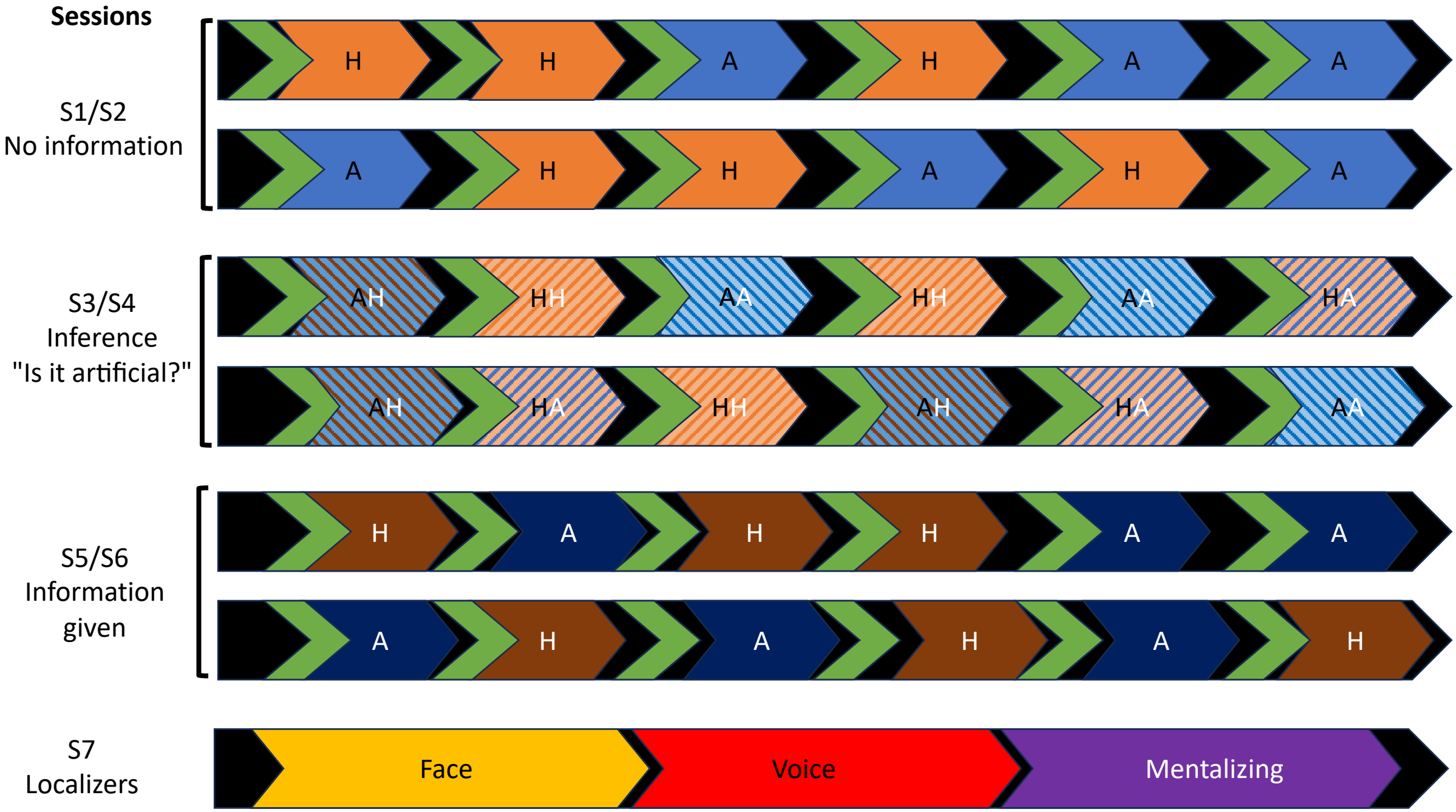

Turing, A. M. (1950) Computing machinery and intelligence. Mind

Harnad, S. (1991) Other bodies, other minds: A machine incarnation of an old philosophical problem. Minds and Machines

# Project: Total Turing Test

- Remaining questions on the experimental paradigm
  - Adding questionnaires on participants' "feelings" towards artificial agents (eg "Negative Attitude towards Robot Scale", Nomura 2007)
  - Need to develop and test the ability of artificial conversational agent
    - Collaboration with Laboratoire d'Informatique Avignon, Fabrice Lefèvre
    - Train chatGPT with existing conversations
    - Attempt to increase reference to mentalizing implicatures: "I think…, I believe…" requires a lot of programming while keeping the agent autonomous (not WoZ), under discussion with Marc Cavazza
- Remaining questions on the fMRI experimental paradigm
  - Need to increase number of recorded conversation per subject:
    - For Machine learning approaches
    - To have sufficient observations per new experimental conditions
  - Addition of localizers to have independence between localisation of regions of interest and
  - To dissociate bottom-up and top down influences, participants' information about the nature of the agent needs to be strictly controlled…

Nomura, T., Suzuki, T., Kanda, T., & Kato, K. (2006). Measurement of negative attitudes toward robots. *Interaction Studies. Social Behaviour and Communication in Biological and Artificial Systems*, *7*(3), 437-454.


Sessions
S1/S2
No information
H H A H A A
A H H A H A
S3/S4
Inference
"Is it artificial?"
AH HH AA HH AA HA
AH HA HH AH HA AA
S5/S6
Information
given
H A H H A A
A H A H A H
S7
Localizers
Face
Voice
Mentalizing

# Hypotheses

1. Mentalizing as a function of (unknown or inferred) nature of the agent:

   $(\text{Human-Artificial})_{\text{unknown}}$ *versus* $(\text{Human-Artificial})_{\text{known}}$

   ↘No differences in Mentalizat° *versus* ↘ Differences in Mentalization

   **➔Contextual, not sensory information, associated with Mentalization**

   $(\text{Inferred Human-Inferred Artificial})_{\text{inferred}}$ *versus* $(\text{Real Human-Real Artificial})_{\text{inferred}}$

   ↘Differences in Mentalizat° *versus* ↘ No differences in Mentalization

   **➔ Belief, more than actual nature, associated with Mentalization**

2. Association with speech transcript

   Investigation of relationships between mentalization implicatures and brain activity

3. Brain networks dynamics as a function of unknown, inferred and known nature of the agent
4. New multimodal corpus of conversational interactions