Shaping plasticity in cortical visual pathways: the applicability of cortico-cortical PAS for precise tuning of perceptual functions.

SIMPOSIO V
PAIRED ASSOCIATIVE STIMULATION (PAS) PROTOCOLS: ADVANCED TOOLS TO INVESTIGATE THE PLASTIC PROPERTIES OF THE HUMAN BRAIN

Paolo Di Luzio, PhD

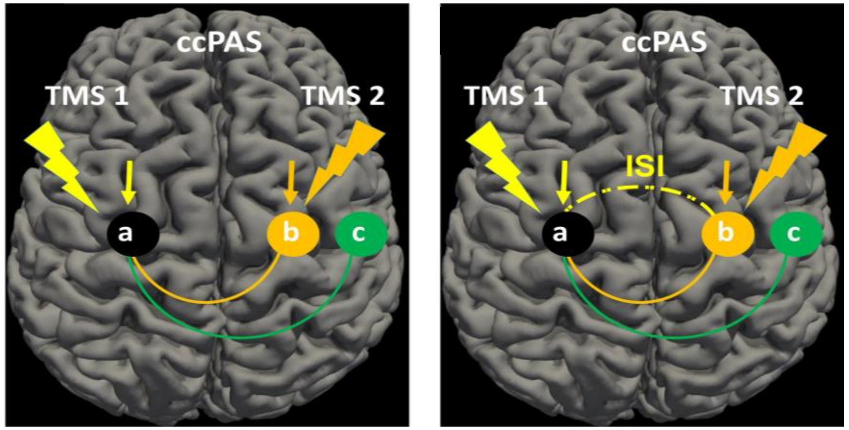
paolo.diluzio08@gmail.com;
paolo.diluzio@unich.it;
paolo.diluzio@unibo.it;

XXXI CONGRESSO NAZIONALE SIPF

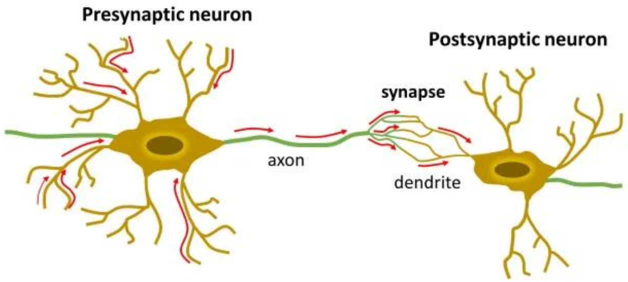
Siena, 9/11/2023

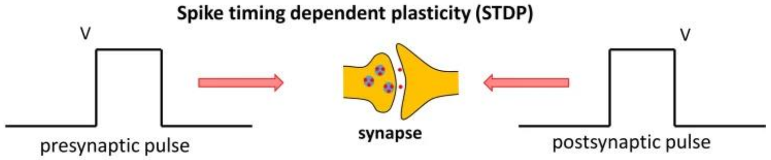
ccPAS: Principles and State of the art

- **Spatial specificity in ccPAS protocols**: makes it possible to modulate specific connections.
- **Temporal specificity in ccPAS protocols**: precise interstimulus interval (ISI) between two areas to increase vs. decrease connectivity.

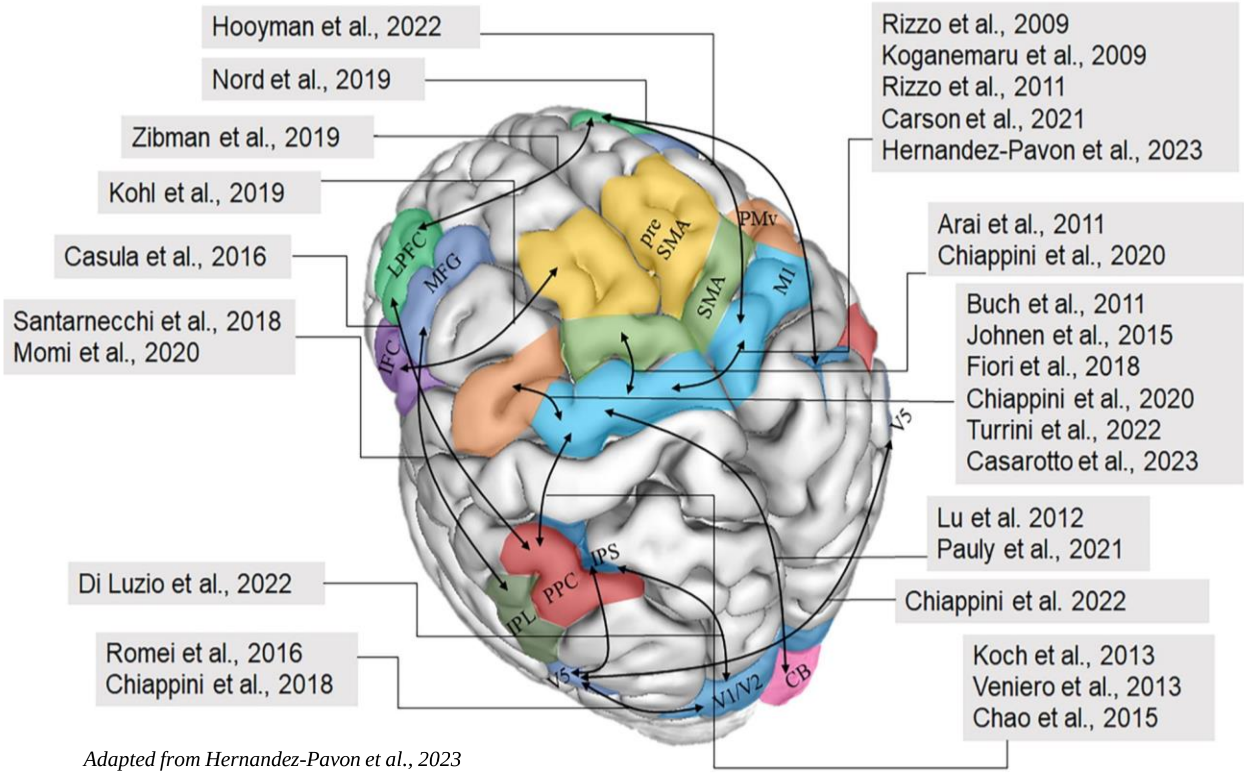


Adapted from Hernandez-Pavon et al., 2023





- Studies involving cortico-cortical paired associative stimulation (ccPAS) in healthy participants.



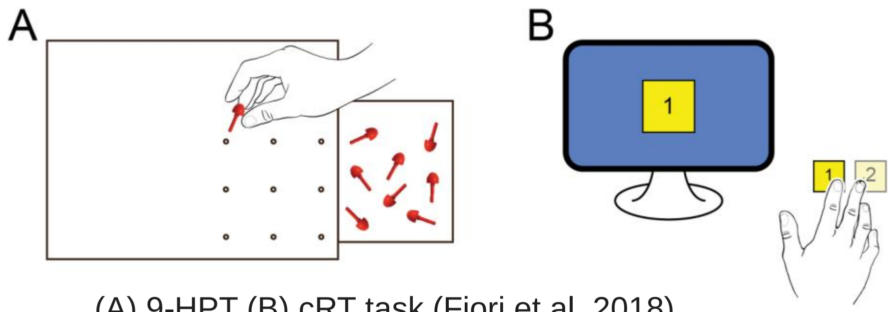
Adapted from Hernandez-Pavon et al., 2023

ccPAS: A practical tool of investigation

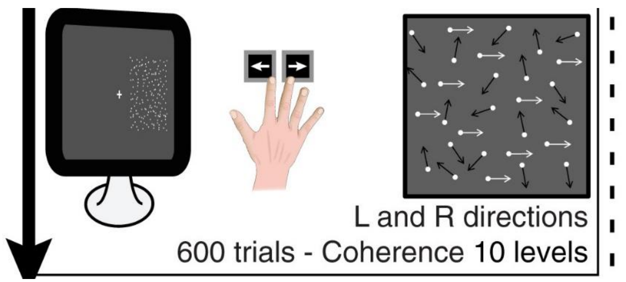
- targeting **motor pathway** connections and investigating outcomes related to hand dexterity and force (Chao et al., 2015, Fiori et al., 2018, Koganemaru et al., 2009, Rizzo et al., 2011)

- targeting the **visual pathway** and investigating outcomes related to motion discrimination (Chiappini et al., 2018, Chiappini et al., 2022, Romei et al., 2016).

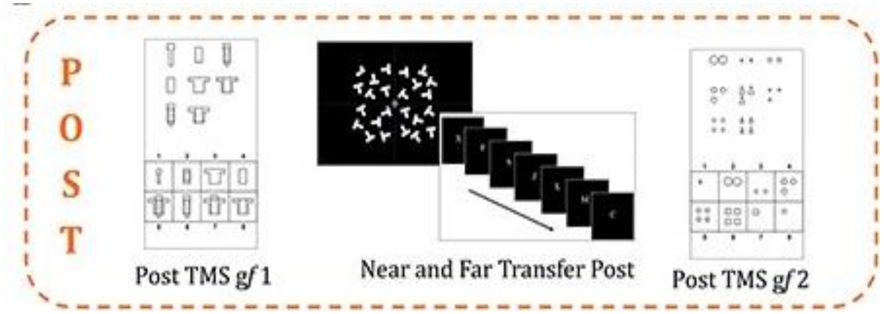
- targeting **frontal networks** and investigating measures of cognitive ability, as response inhibition (Kohl et al., 2019), decision-making control (Nord et al., 2019), fluid intelligence (Momi et al., 2020), and attentional bias (Zibman et al., 2019)



(A) 9-HPT (B) cRT task (Fiori et al.,2018)



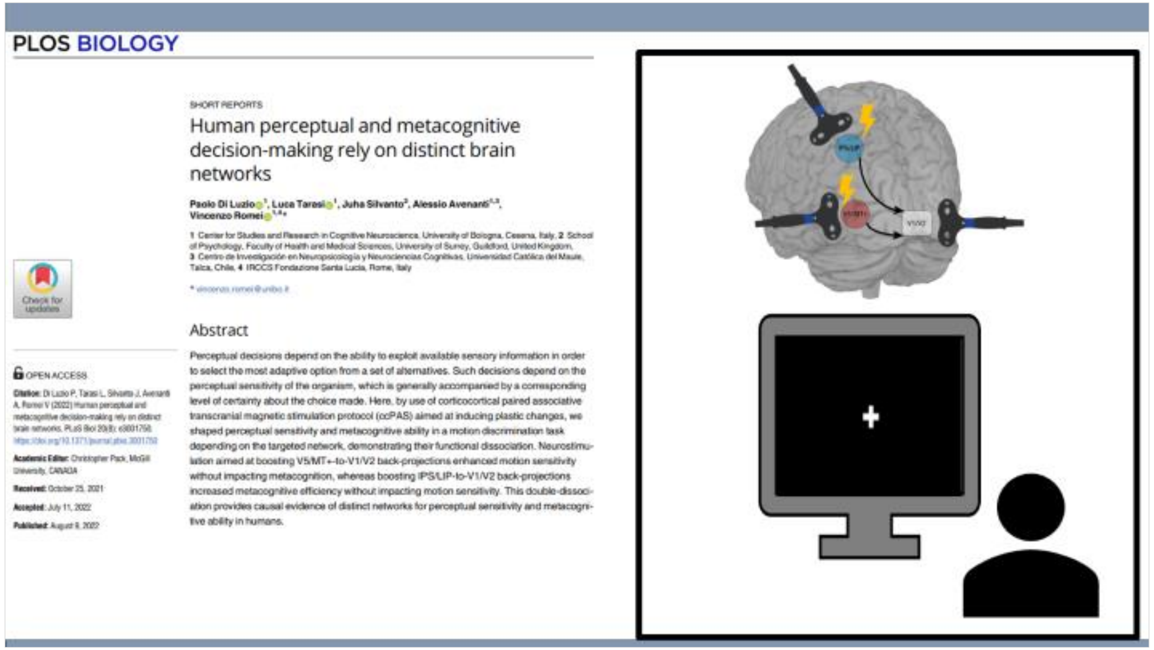
Motion discrimination task (Chiappini et al.,2018)

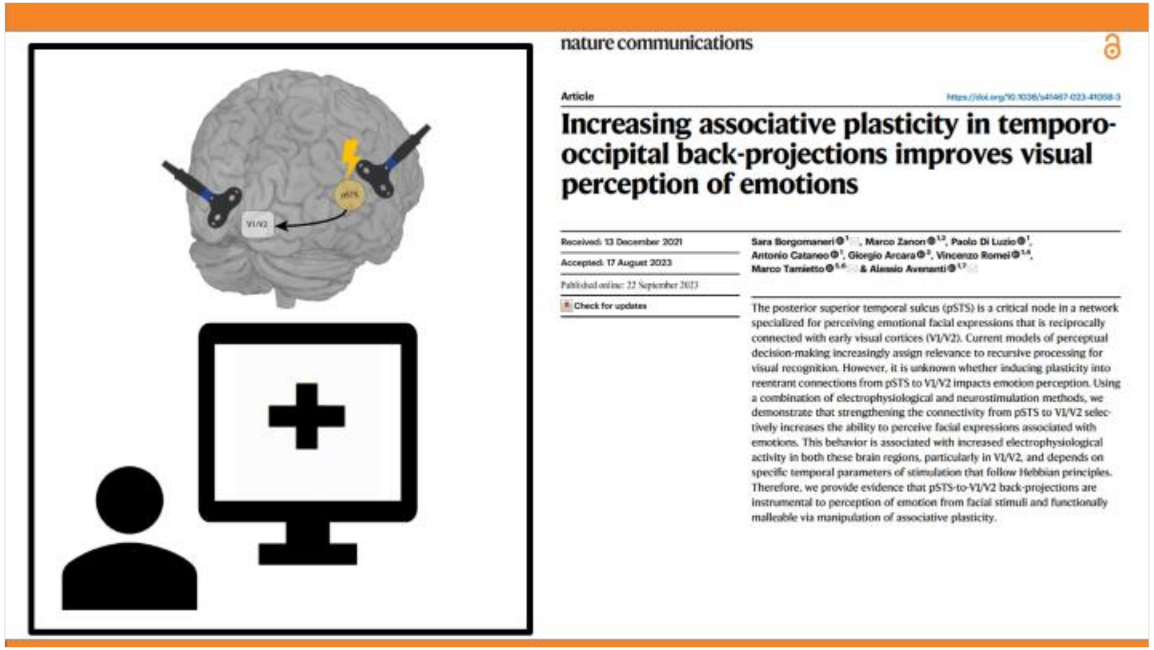


Gf, LNG (near transfer) and VS tasks (far transfer) (Momi et al.,2020)

<u>ccPAS to investigate perceptual visual networks:</u>

Recent lines of investigation





- Testing behavioral effects of connectivity modulation by means of ccPAS
- Taking advantage of ccPAS to prove models of visual elaboration

ccPAS to investigate perceptual visual networks:

Highlights

PLOS BIOLOGY

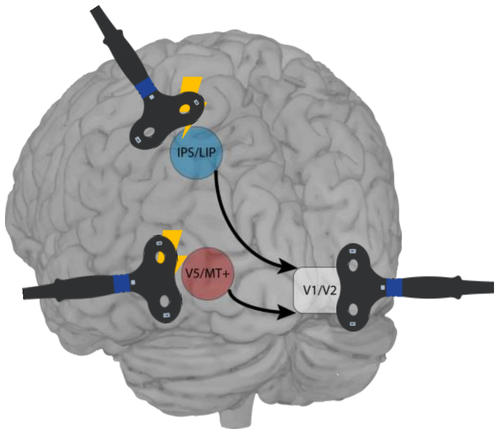
OPEN ACCESS PEER-REVIEWED

SHORT REPORTS

Human perceptual and metacognitive decision-making rely on distinct brain networks

Paolo Di Luzio, Luca Tarasi, Juha Silvanto, Alessio Avenanti, Vincenzo Romei

Published: August 9, 2022 • https://doi.org/10.1371/journal.pbio.3001750



- **ccPAS** is useful to empirically **prove theoretical models** of brain function.
- **ccPAS** allows to **causally** study **specific neural networks** in a controlled manner.
- **Effects** of ccPAS protocols can be evaluated on **psychophysiological and behavioral** levels.
- ccPAS is a flexible technique to prove the **function of cortico-cortical connections** of different **brain systems** (motor, visual, etc.)

nature communications

Article https://doi.org/10.1038/s41467-023-41058-3

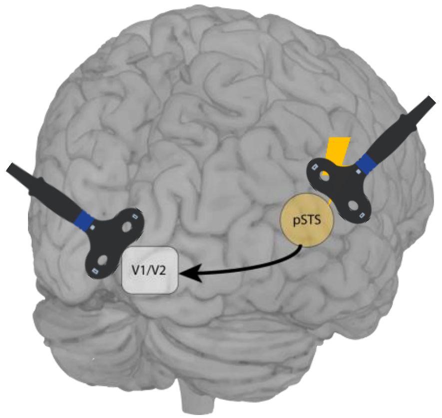
Increasing associative plasticity in temporo-occipital back-projections improves visual perception of emotions

Received: 13 December 2021

Accepted: 17 August 2023

Published online: 22 September 2023

Sara Borgomaneri[1], Marco Zanon[1,2], Paolo Di Luzio[1], Antonio Cataneo[1], Giorgio Arcara[3], Vincenzo Romei[1,4], Marco Tamietto[5,6] & Alessio Avenanti[1,7]



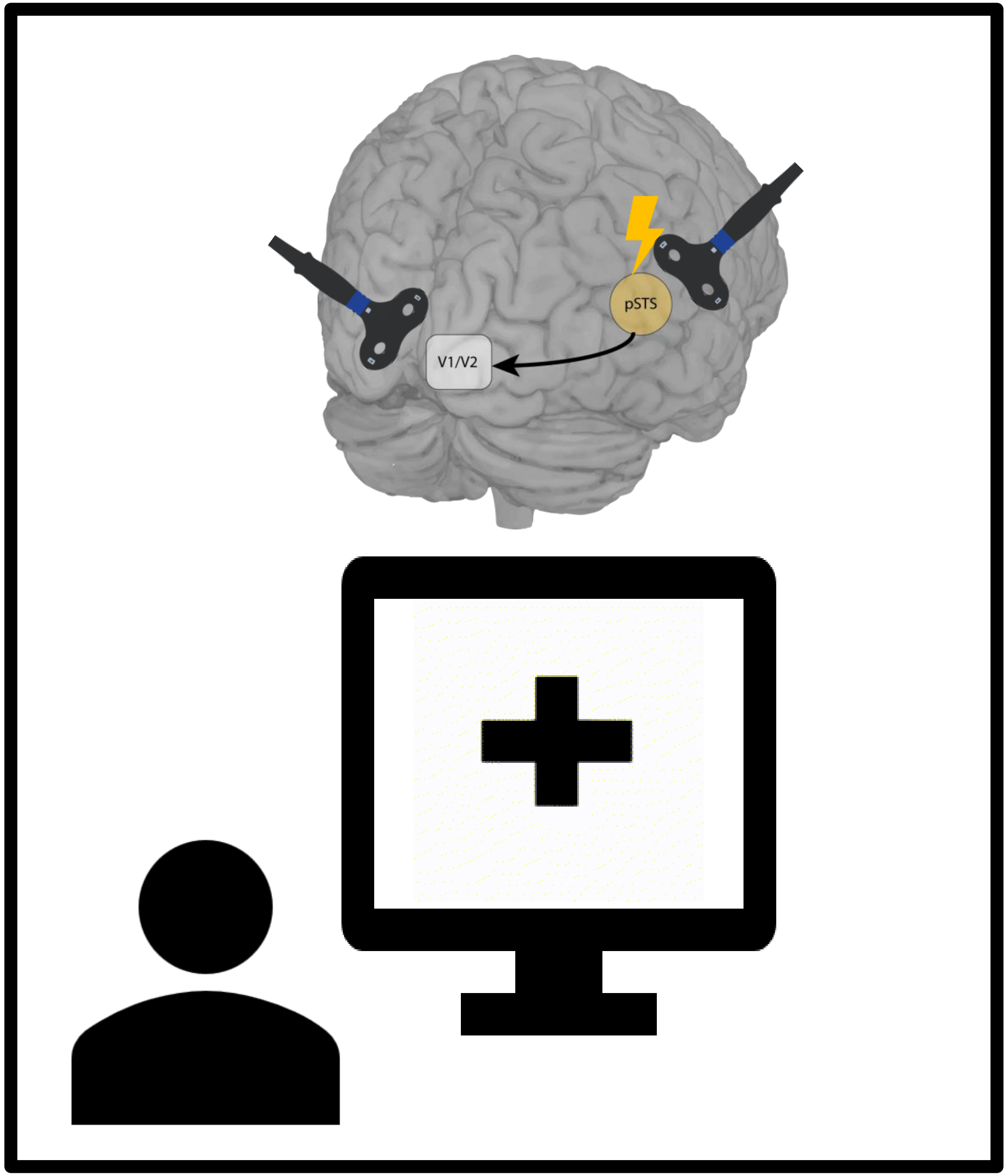
THANKS FOR YOUR ATTENTION!

Ackowledgment

ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA

Consciousness Group (resp. Vincenzo Romei)
https://psicologia.unibo.it/it/ricerca/gruppi-di-ricerca/gruppo-consciousness

Non-Invasive Brain Stimulation (NIBS) Group (resp. Alessio Avenanti)
https://psicologia.unibo.it/it/ricerca/gruppi-di-ricerca/non-invasive-brain-stimulation-nibs



nature communications

Article

https://doi.org/10.1038/s41467-023-41058-3

Increasing associative plasticity in temporo-occipital back-projections improves visual perception of emotions

Received: 13 December 2021

Accepted: 17 August 2023

Published online: 22 September 2023

Check for updates

Sara Borgomaneri[1], Marco Zanon[1,2], Paolo Di Luzio[1], Antonio Cataneo[1], Giorgio Arcara[3], Vincenzo Romei[1,4], Marco Tamietto[5,6] & Alessio Avenanti[1,7]

The posterior superior temporal sulcus (pSTS) is a critical node in a network specialized for perceiving emotional facial expressions that is reciprocally connected with early visual cortices (V1/V2). Current models of perceptual decision-making increasingly assign relevance to recursive processing for visual recognition. However, it is unknown whether inducing plasticity into reentrant connections from pSTS to V1/V2 impacts emotion perception. Using a combination of electrophysiological and neurostimulation methods, we demonstrate that strengthening the connectivity from pSTS to V1/V2 selectively increases the ability to perceive facial expressions associated with emotions. This behavior is associated with increased electrophysiological activity in both these brain regions, particularly in V1/V2, and depends on specific temporal parameters of stimulation that follow Hebbian principles. Therefore, we provide evidence that pSTS-to-V1/V2 back-projections are instrumental to perception of emotion from facial stimuli and functionally malleable via manipulation of associative plasticity.

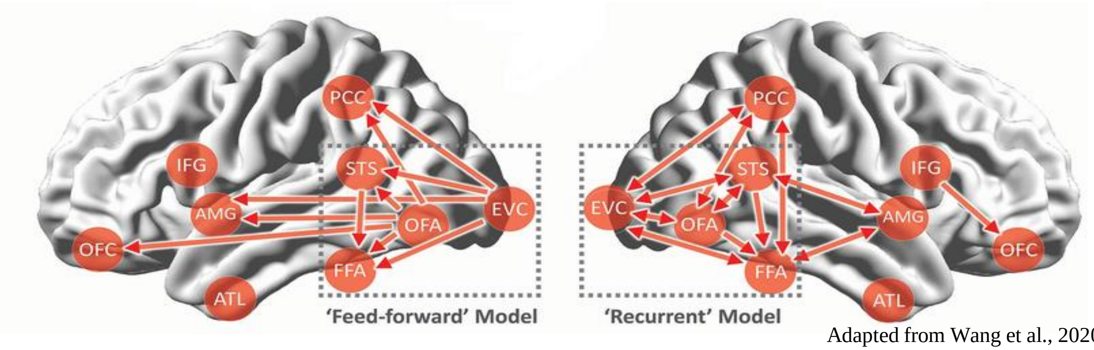
Theoretical background: Face Elaboration Network

nature communications

Increasing associative plasticity in temporo-occipital back-projections improves visual perception of emotions

Sara Borgomaneri, Marco Zanon, Paolo Di Luzio, Antonio Cataneo, Giorgio Arcara, Vincenzo Romei, Marco Tamietto & Alessio Avenanti

Nature Communications **14**, Article number: 5720 (2023) | Cite this article

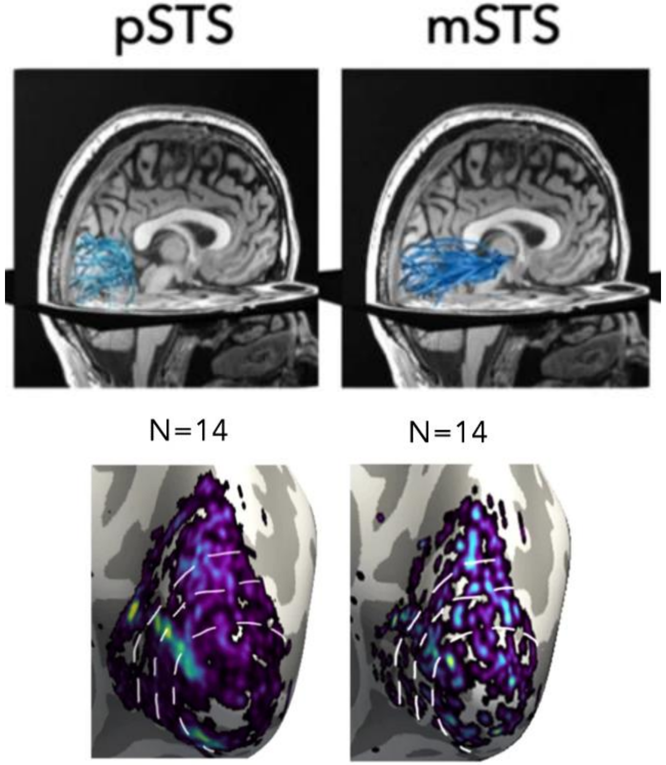


Adapted from Wang et al., 2020

- Current white matter evidence contradicts conventional hierarchy and claims that **face analysis operates in a simultaneous and interactive manner** rather than in a strict order (Wang et al., 2020)

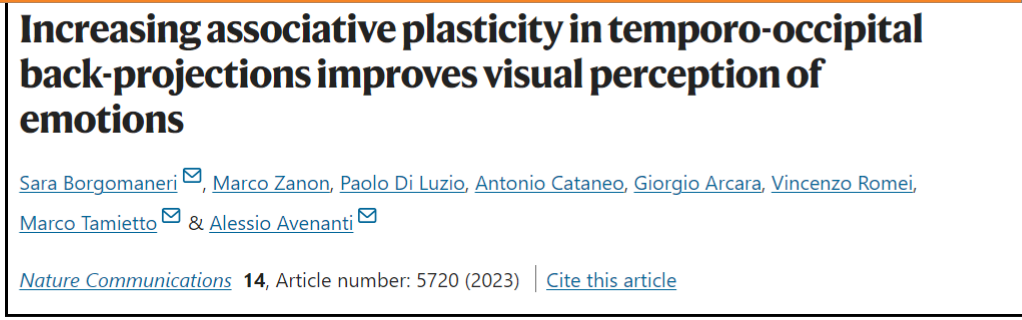
- **White matter** tracts connecting EVC and STS **face-selective regions** (Finzi et al., 2021)

- Endpoint density of fiber **tracts connecting STS with EVC** (Finzi et al., 2021)



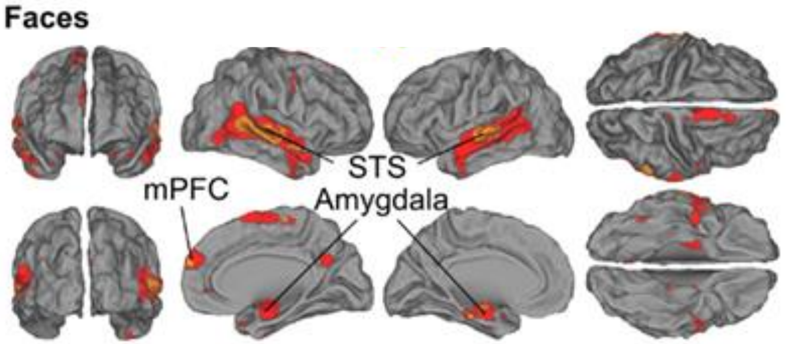
Adapted from Finzi et al., 2021

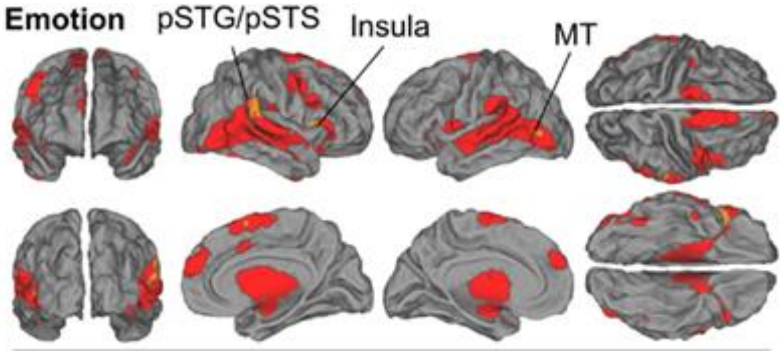
Theoretical background: Perceiving Emotional Expressions


Increasing associative plasticity in temporo-occipital back-projections improves visual perception of emotions

Sara Borgomaneri, Marco Zanon, Paolo Di Luzio, Antonio Cataneo, Giorgio Arcara, Vincenzo Romei, Marco Tamietto & Alessio Avenanti

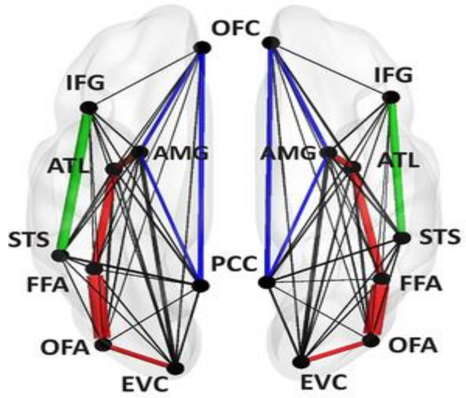
Nature Communications **14**, Article number: 5720 (2023) | Cite this article





Adapted from Lahnakoski et al., 2013

- **pSTS** is engaged in the **computation of changing attributes of faces** like those of **expression**
- Major hub for **emotion perception** from faces (Lahnakoski et al., 2013; Pitcher, 2011)
- Face-processing network via specific **long-distance channels**



Adapted from Wang et al., 2020

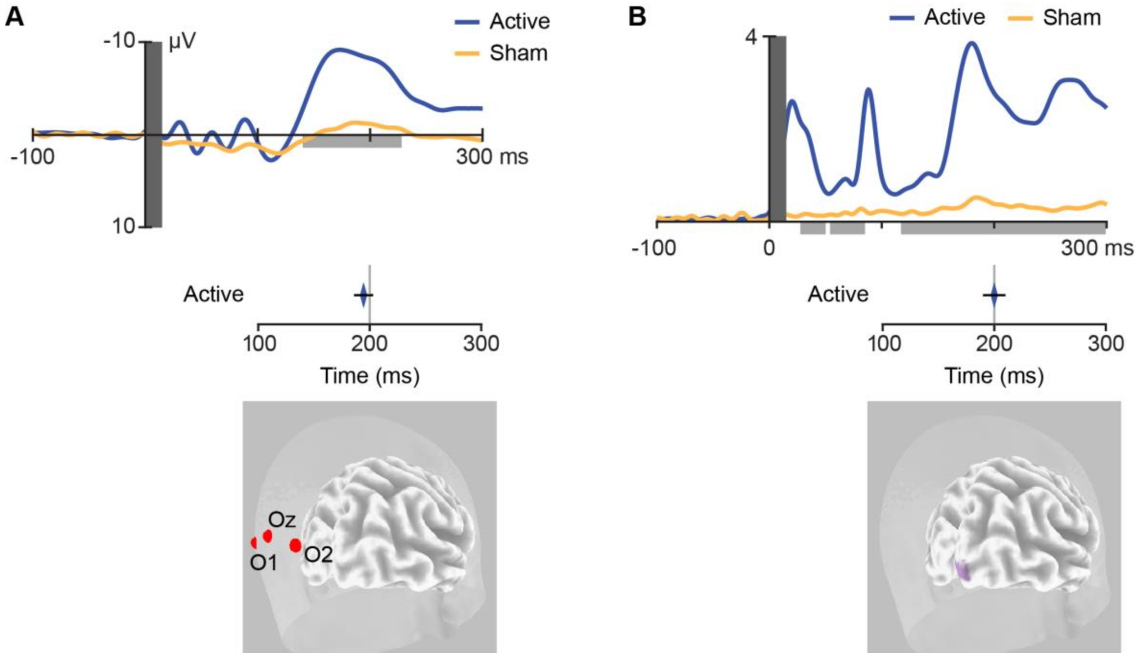
nature communications

Increasing associative plasticity in temporo-occipital back-projections improves visual perception of emotions

Sara Borgomaneri, Marco Zanon, Paolo Di Luzio, Antonio Cataneo, Giorgio Arcara, Vincenzo Romei, Marco Tamietto & Alessio Avenanti

Nature Communications **14**, Article number: 5720 (2023) | Cite this article

Tracking signal propagation from pSTS to V1/V2: TMS-EEG co-registration

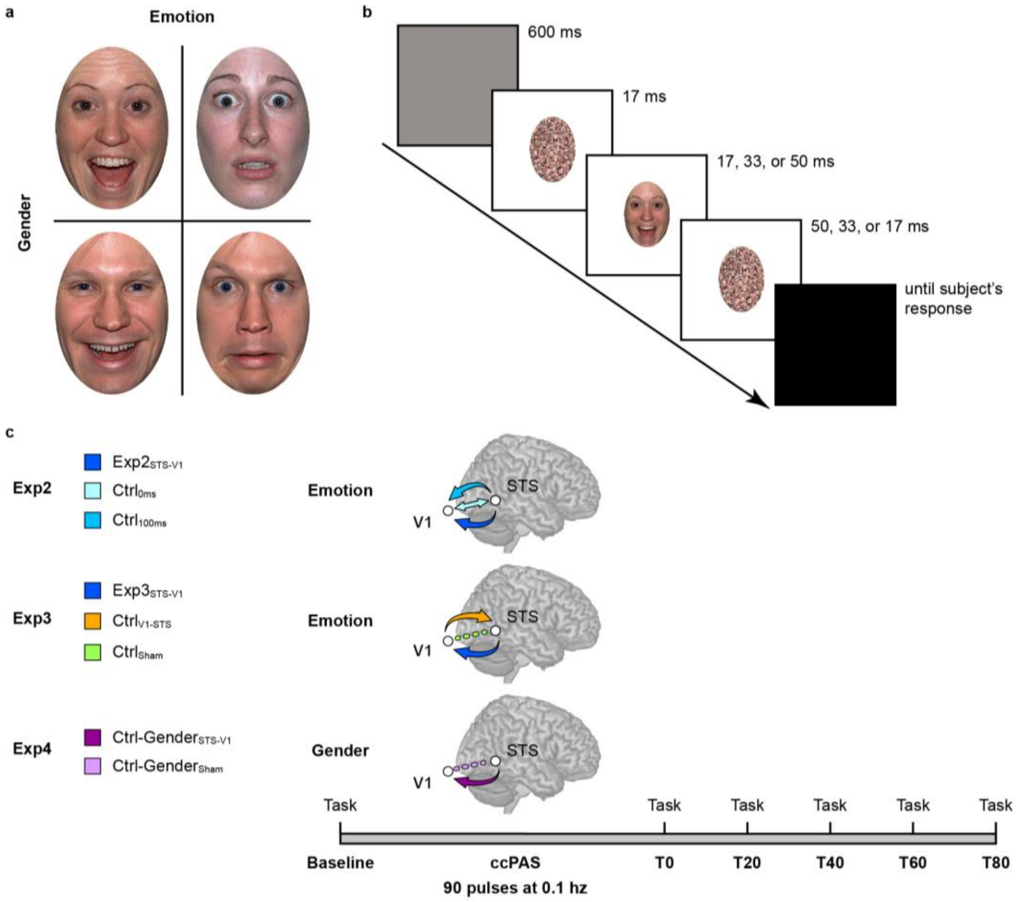


- 60 active vs sham TMS pulses at rest, over the right pSTS
- Time-course of activity and mean Latency of the main TEPs peaking at ~200ms following pSTS stimulation at the sensor (A) and source (B) levels.
- Target sensors (O1,Oz, O2) and Cortical regions included in the V1/V2 ROI (Talairach coordinates: x = 19, y = –98, z = 1).

nature communications

Testing functional relevance of pSTS-V1 connectivity:

Information-based ccPAS experiments



Increasing associative plasticity in temporo-occipital back-projections improves visual perception of emotions

Sara Borgomaneri, Marco Zanon, Paolo Di Luzio, Antonio Cataneo, Giorgio Arcara, Vincenzo Romei, Marco Tamietto & Alessio Avenanti

Nature Communications **14**, Article number: 5720 (2023) | Cite this article

3 EXPERIMENTS

Experiment 2. *control for stimulation time:*

- 3 groups (STS-V1; Ctrl_0ms; Ctrl_100ms)
- Emotion recognition task
- 42 participants

Experiment 3. *control for stimulation directions:*

- 3 groups (STS-V1; CtrlV1-STS; CtrlSham)
- Emotion recognition task
- 39 participants

Experiment 4. *control for task:*

- 2 groups (STS-V1; CtrlSham)
- Gender recognition task
- 28 participants

nature communications

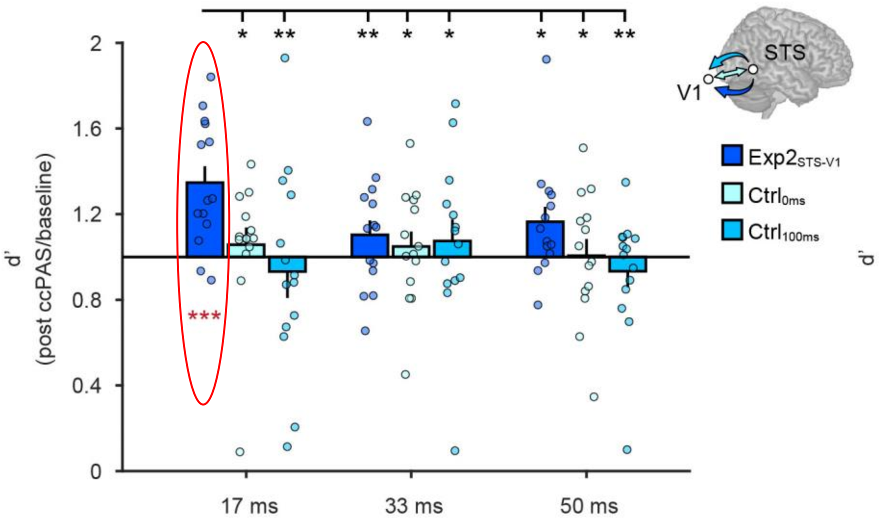
Increasing associative plasticity in temporo-occipital back-projections improves visual perception of emotions

Sara Borgomaneri, Marco Zanon, Paolo Di Luzio, Antonio Cataneo, Giorgio Arcara, Vincenzo Romei, Marco Tamietto & Alessio Avenanti

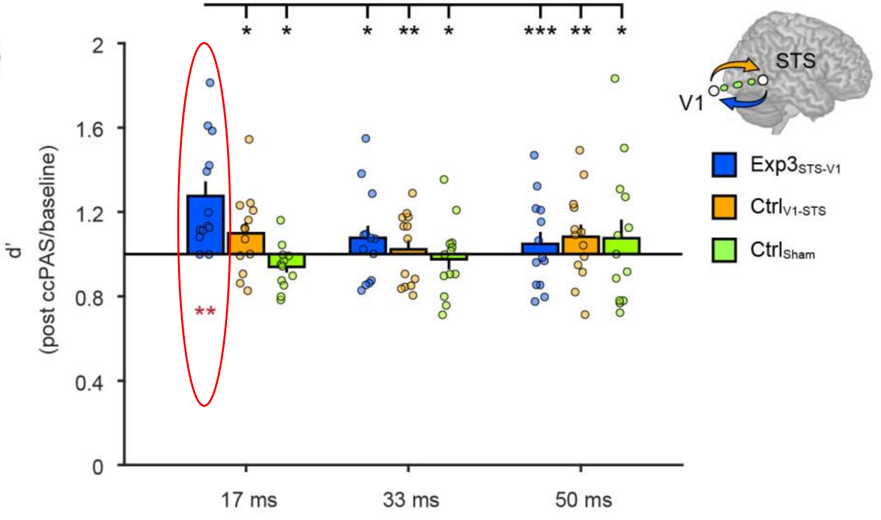
Nature Communications 14, Article number: 5720 (2023) | Cite this article

Testing functional relevance of pSTS-V1 connectivity:

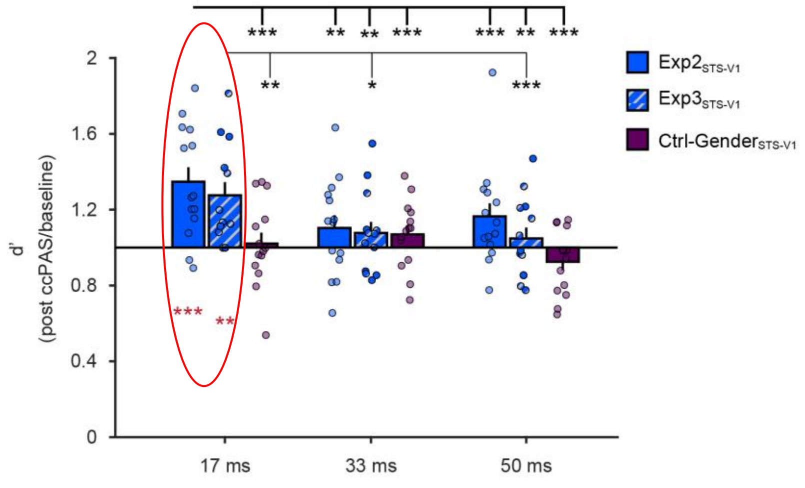
Information-based ccPAS experiments



Exp 2: Time specificity of pSTS-to-V1 back-projections for emotion perception



Exp 3: Direction specificity of pSTS-to-V1 back-projections



Exp 4: Task specificity of pSTS-to-V1 back-projections

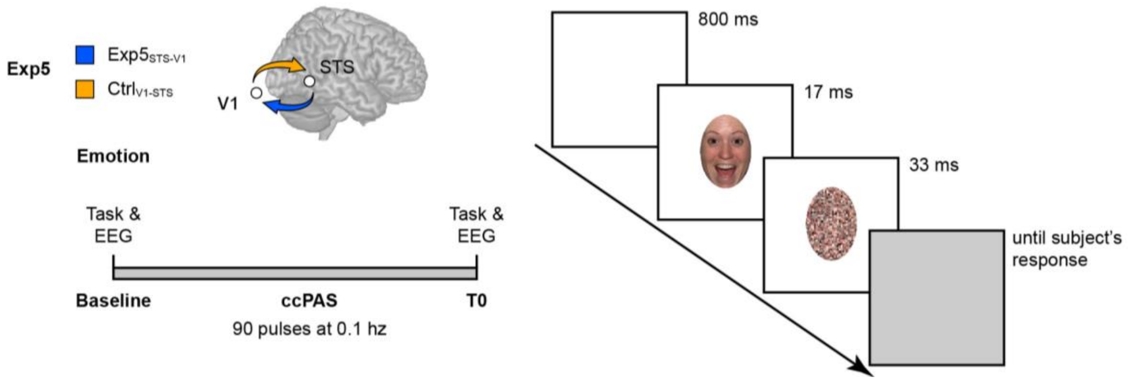
nature communications

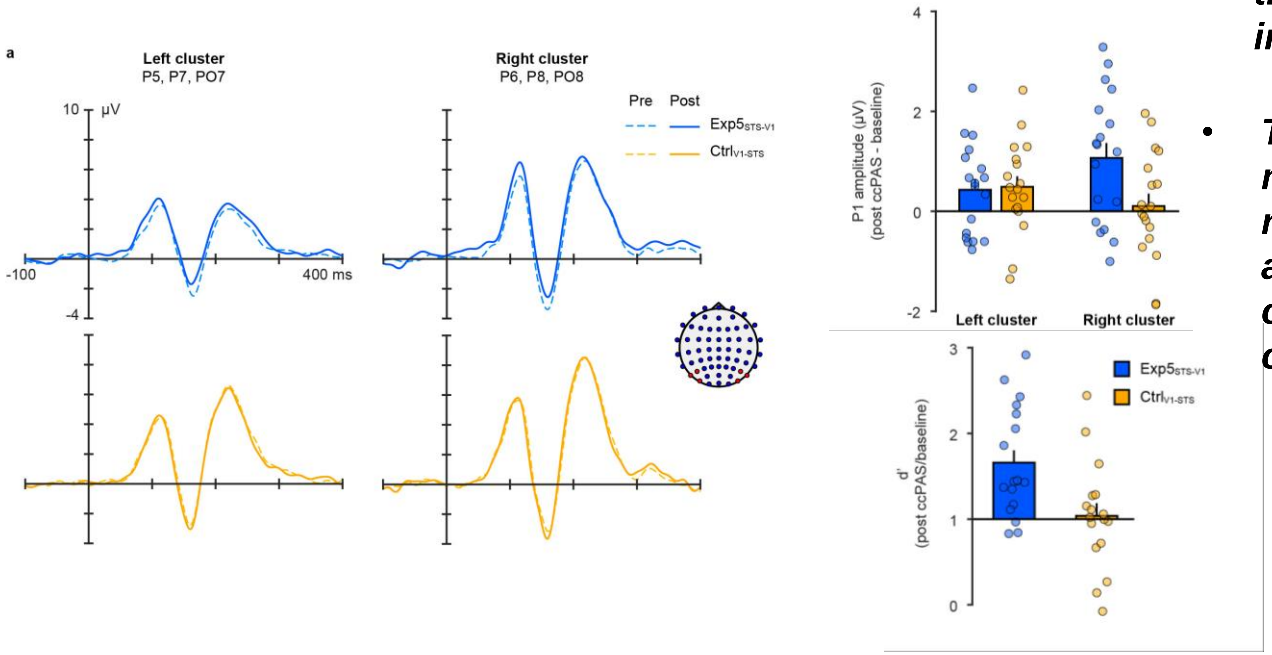
Electrophysiological correlates of pSTS-to-V1/V2 ccPAS: TMS-EEG follow-up

Increasing associative plasticity in temporo-occipital back-projections improves visual perception of emotions

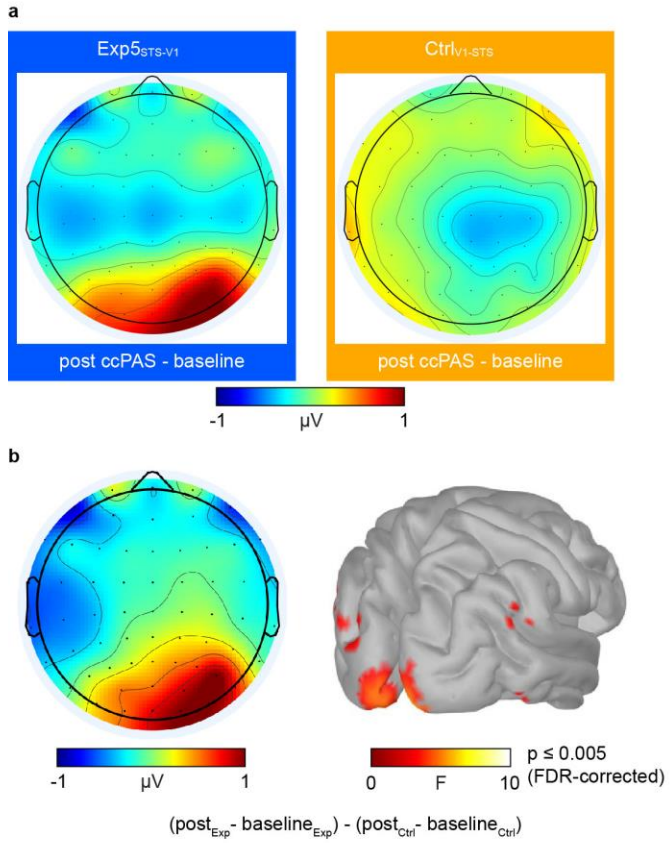
Sara Borgomaneri, Marco Zanon, Paolo Di Luzio, Antonio Cataneo, Giorgio Arcara, Vincenzo Romei, Marco Tamietto & Alessio Avenanti

Nature Communications 14, Article number: 5720 (2023) | Cite this article





- *significant ERP (P1) increase relative to baseline following the critical ccPAS condition in the stimulated emisphere*
- *The increase in activity was maximal over early occipital regions, with the peak of activation in the ROI coincident with early visual cortices.*

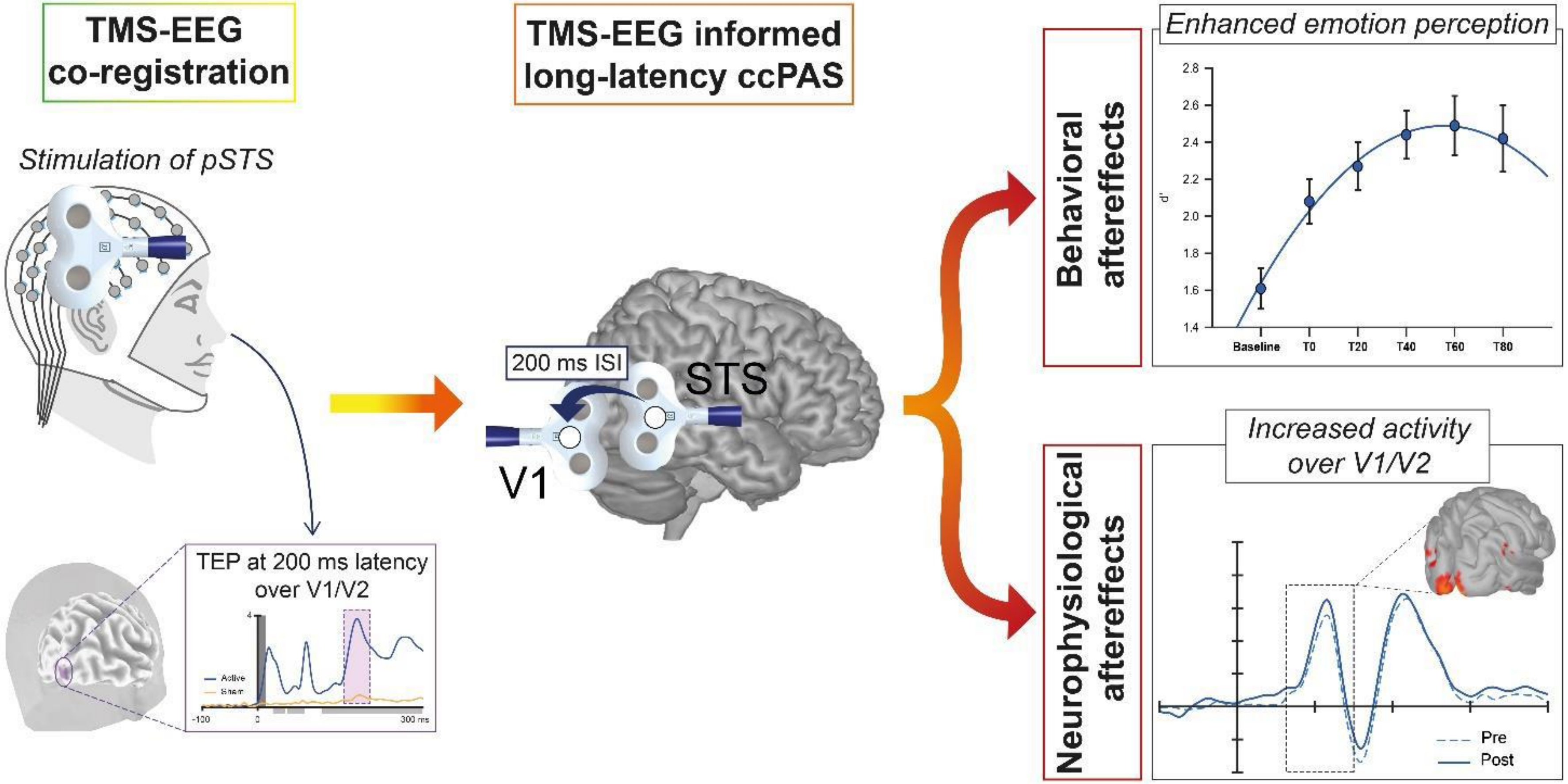


ccPAS to study perceptual function and correlates: Summary of findings

Increasing associative plasticity in temporo-occipital back-projections improves visual perception of emotions

Sara Borgomaneri, Marco Zanon, Paolo Di Luzio, Antonio Cataneo, Giorgio Arcara, Vincenzo Romei, Marco Tamietto & Alessio Avenanti

Nature Communications 14, Article number: 5720 (2023) | Cite this article



PLOS BIOLOGY

SHORT REPORTS

Human perceptual and metacognitive decision-making rely on distinct brain networks

Paolo Di Luzio[1], **Luca Tarasi**[1], **Juha Silvanto**[2], **Alessio Avenanti**[1,3], **Vincenzo Romei**[1,4]*

1 Center for Studies and Research in Cognitive Neuroscience, University of Bologna, Cesena, Italy, **2** School of Psychology, Faculty of Health and Medical Sciences, University of Surrey, Guildford, United Kingdom, **3** Centro de Investigación en Neuropsicología y Neurociencias Cognitivas, Universidad Católica del Maule, Talca, Chile, **4** IRCCS Fondazione Santa Lucia, Rome, Italy

* vincenzo.romei@unibo.it

Citation: Di Luzio P, Tarasi L, Silvanto J, Avenanti A, Romei V (2022) Human perceptual and metacognitive decision-making rely on distinct brain networks. PLoS Biol 20(8): e3001750. https://doi.org/10.1371/journal.pbio.3001750

Academic Editor: Christopher Pack, McGill University, CANADA

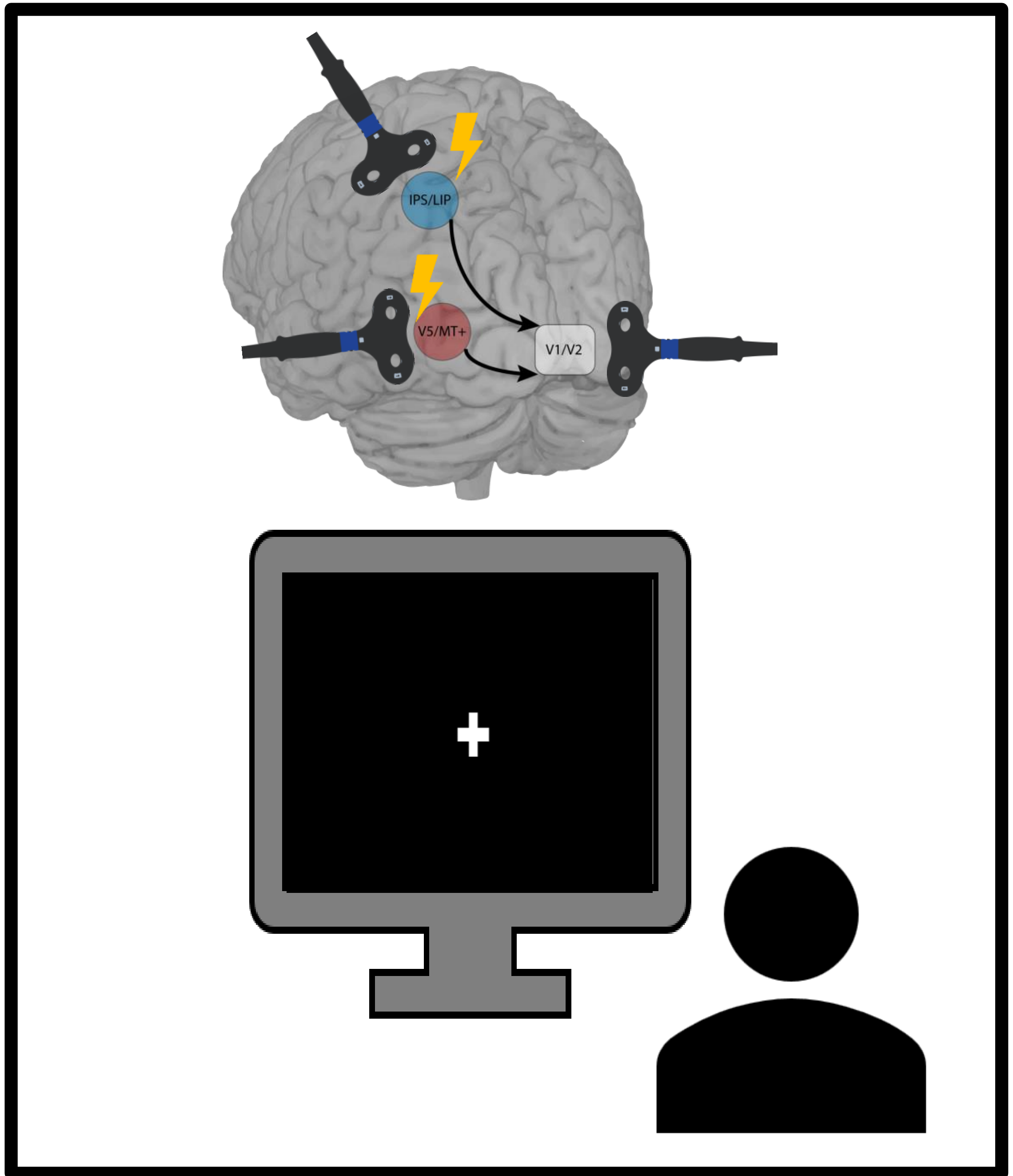
Received: October 25, 2021

Accepted: July 11, 2022

Published: August 9, 2022

Abstract

Perceptual decisions depend on the ability to exploit available sensory information in order to select the most adaptive option from a set of alternatives. Such decisions depend on the perceptual sensitivity of the organism, which is generally accompanied by a corresponding level of certainty about the choice made. Here, by use of corticocortical paired associative transcranial magnetic stimulation protocol (ccPAS) aimed at inducing plastic changes, we shaped perceptual sensitivity and metacognitive ability in a motion discrimination task depending on the targeted network, demonstrating their functional dissociation. Neurostimulation aimed at boosting V5/MT+-to-V1/V2 back-projections enhanced motion sensitivity without impacting metacognition, whereas boosting IPS/LIP-to-V1/V2 back-projections increased metacognitive efficiency without impacting motion sensitivity. This double-dissociation provides causal evidence of distinct networks for perceptual sensitivity and metacognitive ability in humans.



PLOS BIOLOGY

OPEN ACCESS PEER-REVIEWED

SHORT REPORTS

Human perceptual and metacognitive decision-making rely on distinct brain networks

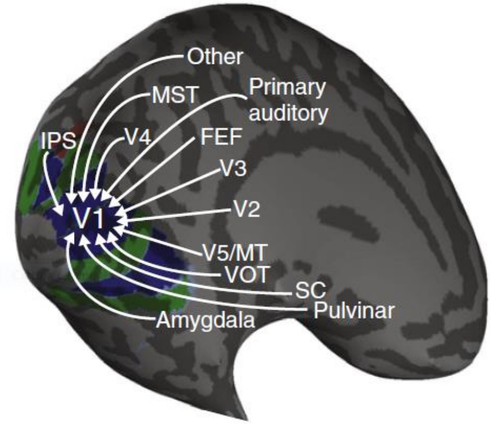
Paolo Di Luzio, Luca Tarasi, Juha Silvanto, Alessio Avenanti, Vincenzo Romei

Published: August 9, 2022 • https://doi.org/10.1371/journal.pbio.3001750

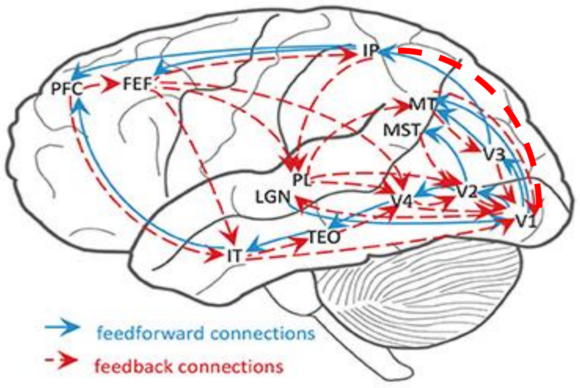
Theoretical background:

Perceptual-decision making networks

- Many cortical regions connected directly, or indirectly, to V1 (Muckli et al,. 2013)



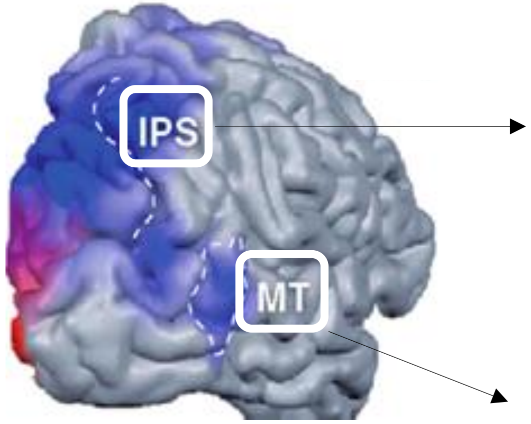
Adapted from Muckli et al., 2013



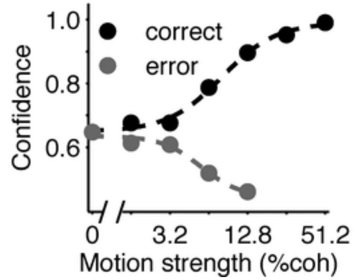
Adapted from Briggs et al., 2020

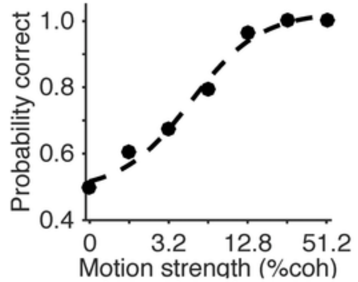
- **Neurons in parietal cortex (LIP/IPS) represent** decision and the **degree of certainty** underlying the decision (Kiani & Shadlen,2009).

- **Neurons in the middle temporal area (V5/MT+)**, which tune to the **direction of motion stimuli**, are essential for providing sensory acuity (Britten et al., 2003; Hanks et al., 2005)



Adapted from Wei et al., 2015





PLOS BIOLOGY

OPEN ACCESS PEER-REVIEWED

SHORT REPORTS

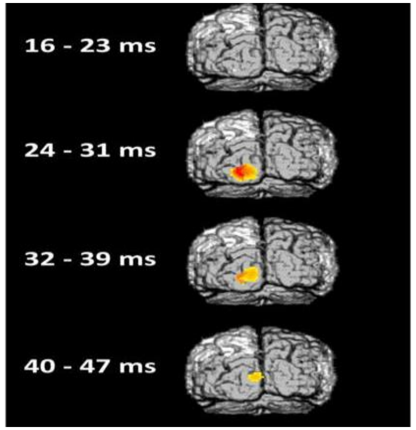
Human perceptual and metacognitive decision-making rely on distinct brain networks

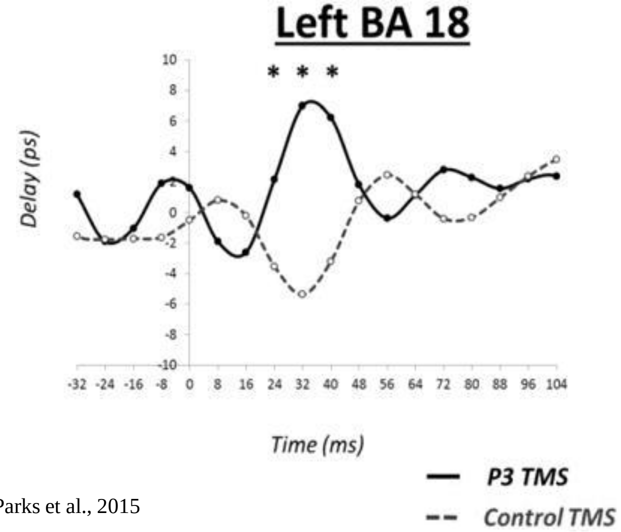
Paolo Di Luzio, Luca Tarasi, Juha Silvanto, Alessio Avenanti, Vincenzo Romei

Published: August 9, 2022 • https://doi.org/10.1371/journal.pbio.3001750

Theoretical background:
Timing of interareal connectivity

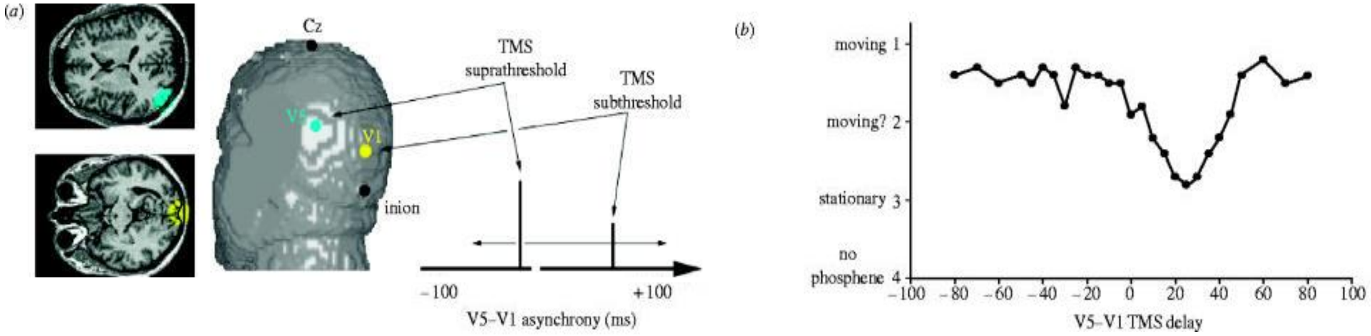
- **Parieto-occipital feedback modulation** of early visual cortex (Silvanto et al., 2009; Parks et al., 2015; Koivisto, 2011).





Adapted from Parks et al., 2015

- **Backward connectivity between V5-V1** is crucial for awareness of motion (Pascual-Leone et al., 2001; Silvanto et al., 2005; Romei et al., 2016)



Adapted from Cowey et al., 2005

PLOS BIOLOGY

OPEN ACCESS PEER-REVIEWED

SHORT REPORTS

Human perceptual and metacognitive decision-making rely on distinct brain networks

Paolo Di Luzio, Luca Tarasi, Juha Silvanto, Alessio Avenanti, Vincenzo Romei

Published: August 9, 2022 • https://doi.org/10.1371/journal.pbio.3001750

Investigation of decision-making behavior:

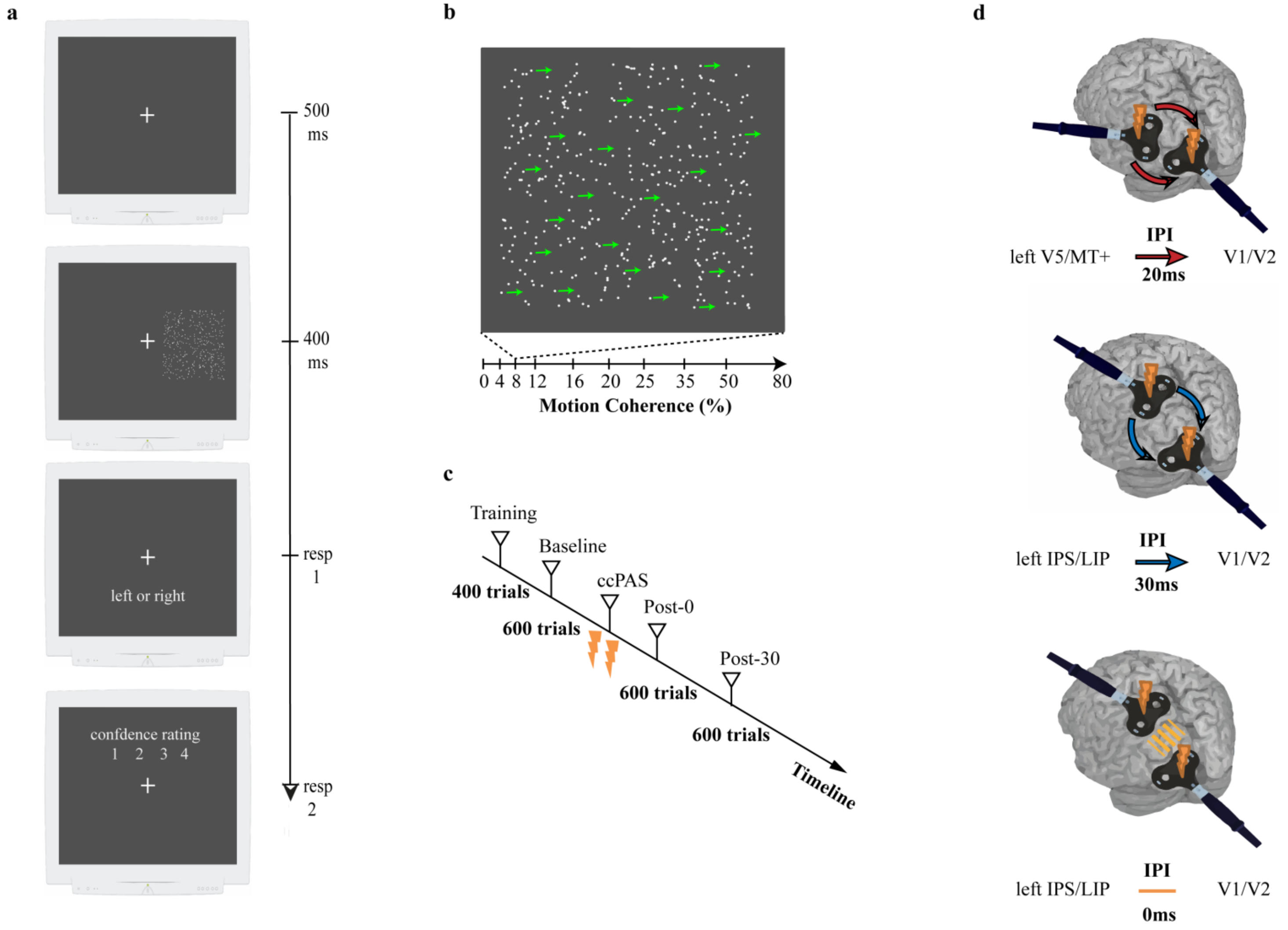
Targeting perceptual networks using ccPAS

- 51 healthy participants

- RDM task (600 trials)
- motion discrimination (left/right)
- Confidence rating (1 to 4)

- 3 Session
  (BSL, T00, T30)

- Stimulation protocols:
- V5-to-V1 (20ms)
- IPS-to-V1 (30ms)
- IPS—V1 (0ms)



OPEN ACCESS PEER-REVIEWED

SHORT REPORTS

Human perceptual and metacognitive decision-making rely on distinct brain networks

Paolo Di Luzio, Luca Tarasi, Juha Silvanto, Alessio Avenanti, Vincenzo Romei

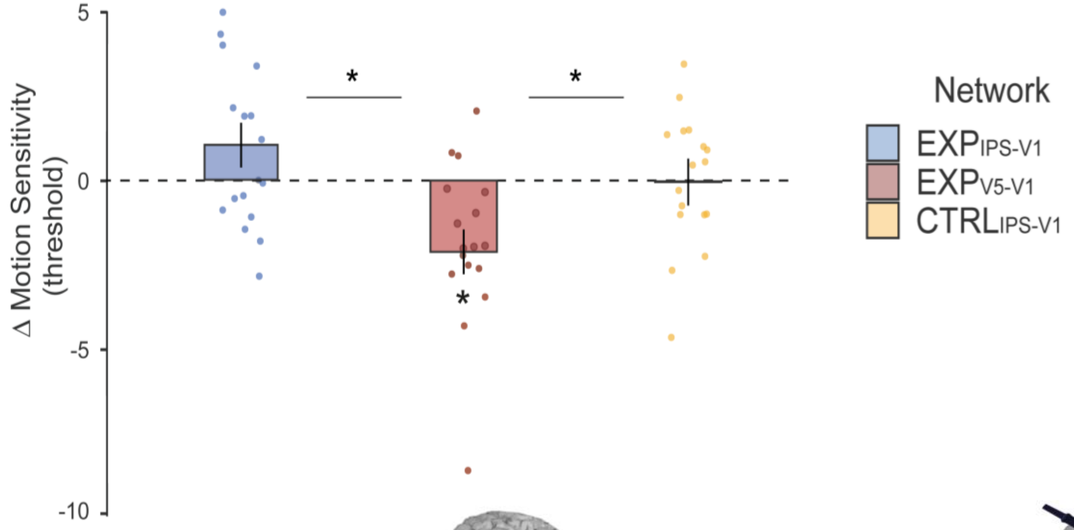
Published: August 9, 2022 • https://doi.org/10.1371/journal.pbio.3001750

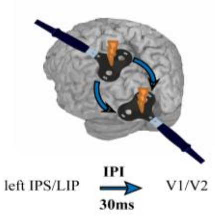
Investigation of decision-making behavior:

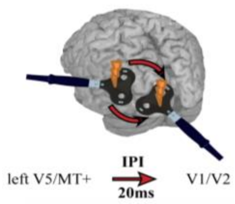
Assessing perceptual motion discrimination

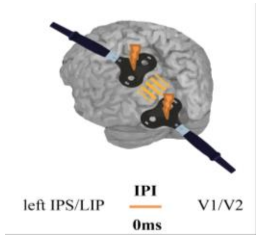
- Motion threshold significant reduction (better perceptual sensitivity) following **V5-to-V1** ccPAS

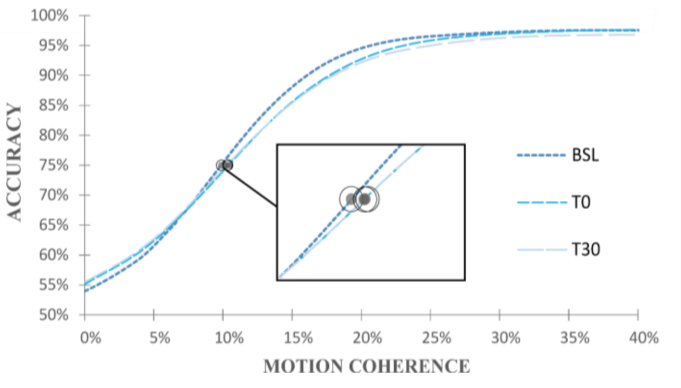
- Absence of behavioral changes in sensory discrimination in parieto-occipital stimulations

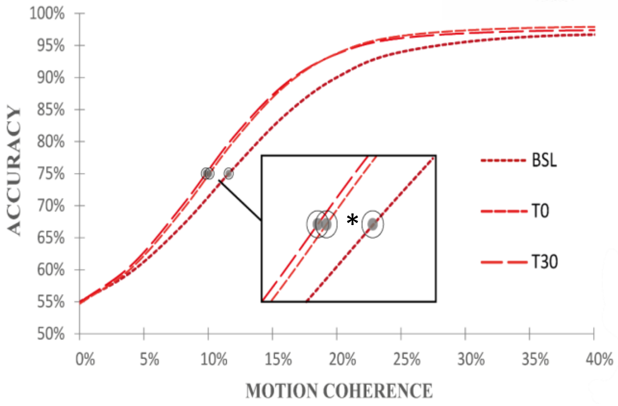


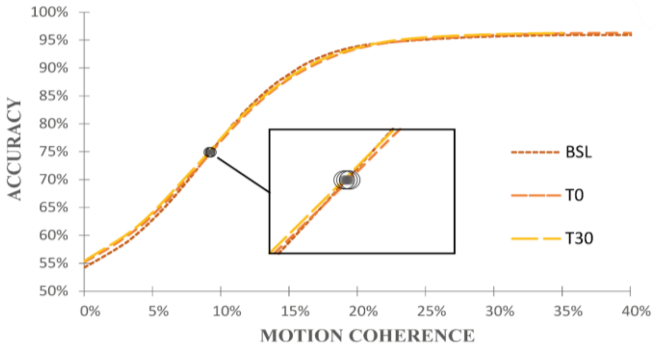












OPEN ACCESS PEER-REVIEWED

SHORT REPORTS

Human perceptual and metacognitive decision-making rely on distinct brain networks

Paolo Di Luzio, Luca Tarasi, Juha Silvanto, Alessio Avenanti, Vincenzo Romei

Published: August 9, 2022 • https://doi.org/10.1371/journal.pbio.3001750

Investigation of decision-making behavior:

Assessing metacognitive ability

- Unspecific confidence increase following V5-to-V1 ccPAS
- Specific increase of correct trial confidence following IPS-V1 ccPAS

- Metacognitive efficiency improvement (stronger accuracy x confidence mapping) only following **IPS-to-V1** ccPAS
- Effect present specifically at participant’s threshold level