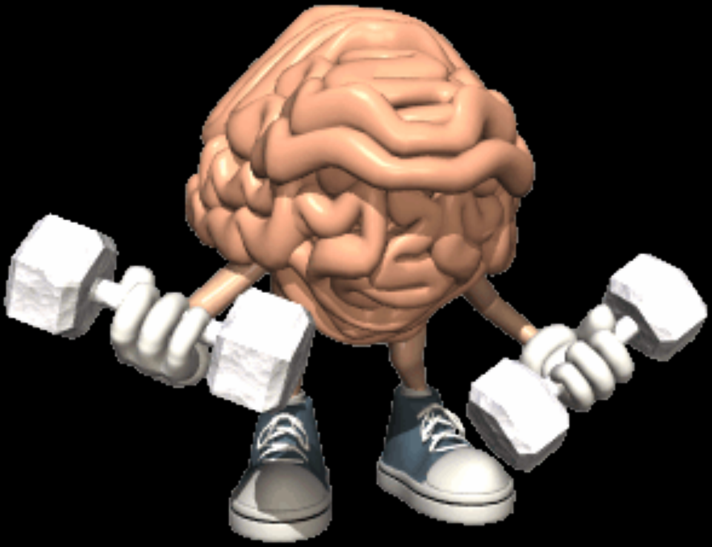
Cognition and Neuroscience



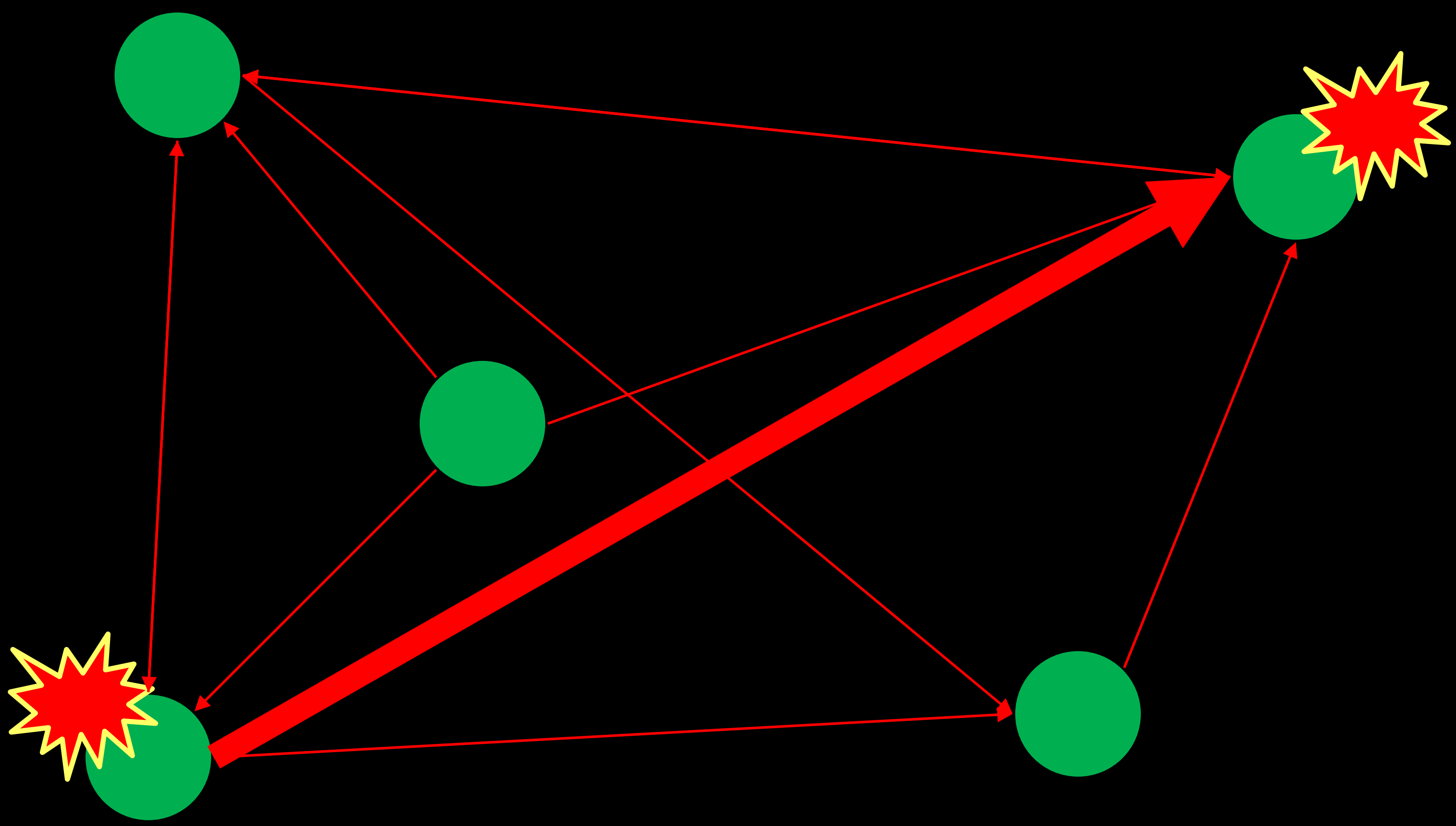
Vincenzo Romei

Lecture 7

The plastic human brain

Hebbian plasticity

Repetitive activation of neuronal circuits can induce long-term changes in subsequent responses generated by synapses in many regions of the brain and such plasticity of synaptic connections is regarded as a cellular basis for developmental and learning-related changes in the central nervous system. ***(Hebb, 1949; Bliss, 1993)***



Background

- Evidence in macaques (*Lamme et al., 1998*) and humans (*Pascual-Leone & Walsh, 2001; Silvanto et al., 2005*) has provided important insights on the role of feedback projections from extrastriate areas to primary visual area (V1) in visual awareness.

- Moreover the state of V1 at the time of visual input (*Silvanto et al., 2005; Romei et al., 2008*) has shown to be a critical factor for visual awareness to arise.

However how the state of the connectivity between extrastriate areas and V1 impacts visual awareness has still to be determined

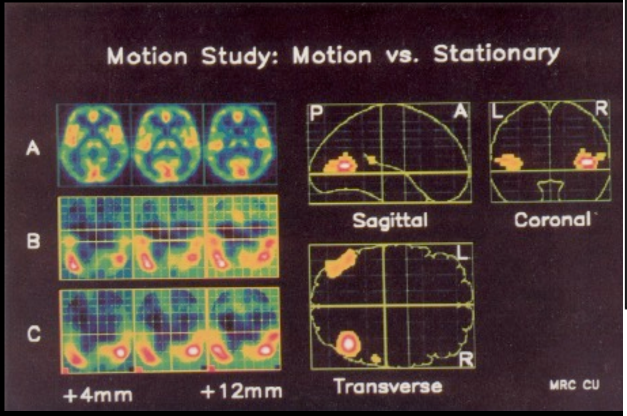
Background

Visual Motion perception

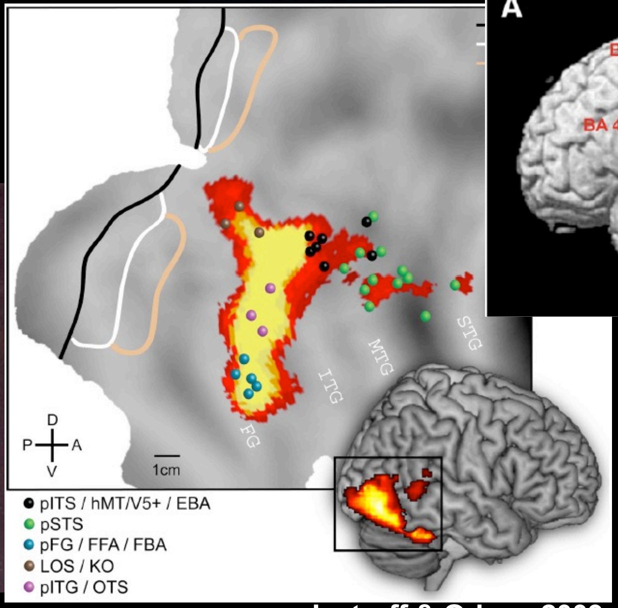
Low level moving percepts

Biological dot-pattern motion

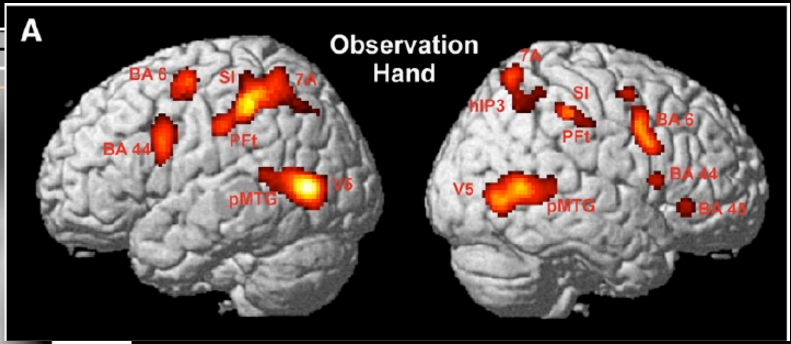
High level human movements



Zeki et al., 1991 JNeurosci



Jastorff & Orban, 2009 JNeurosci

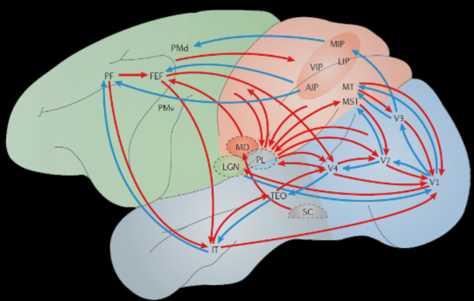


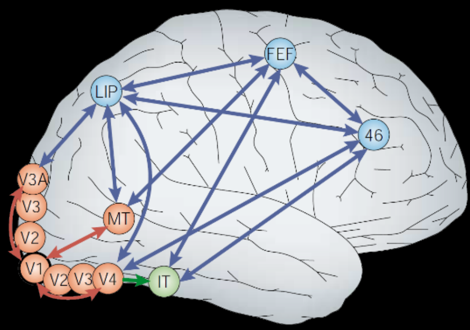
Caspers et al., 2010 NeuroImage

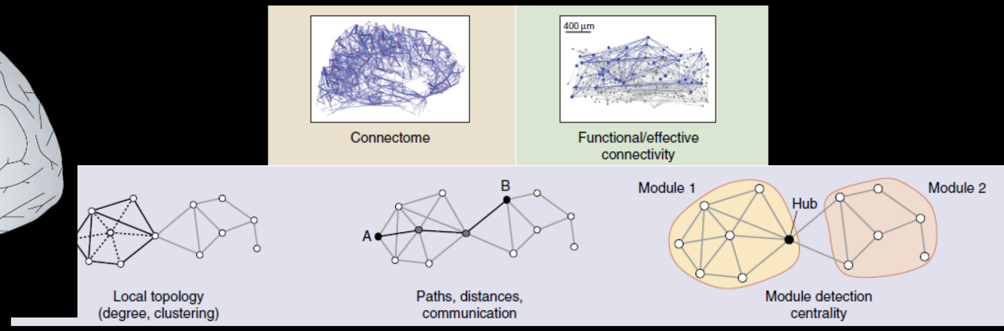
Key concepts

1 Connectivity

How visual motion areas are connected?







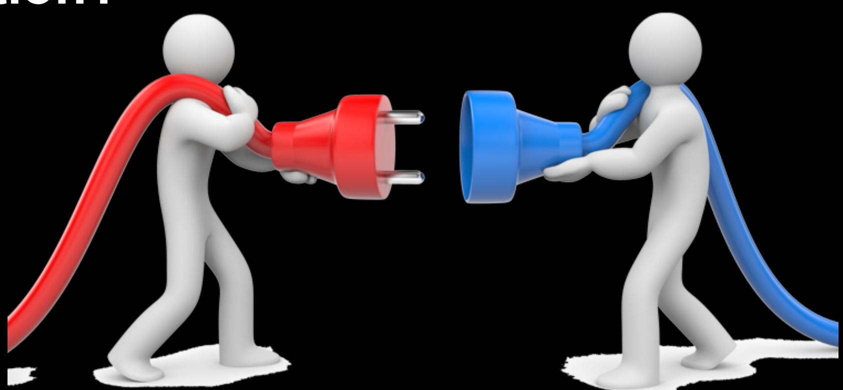
Gilbert & Li, 2013 NatRevNeurosci

Tong, 2003 NatRevNeurosci

Bassett & Sporns, 2017 NatNeurosci

2 Brain Plasticity

How changing the weight of a connection modulates the perception of motion?



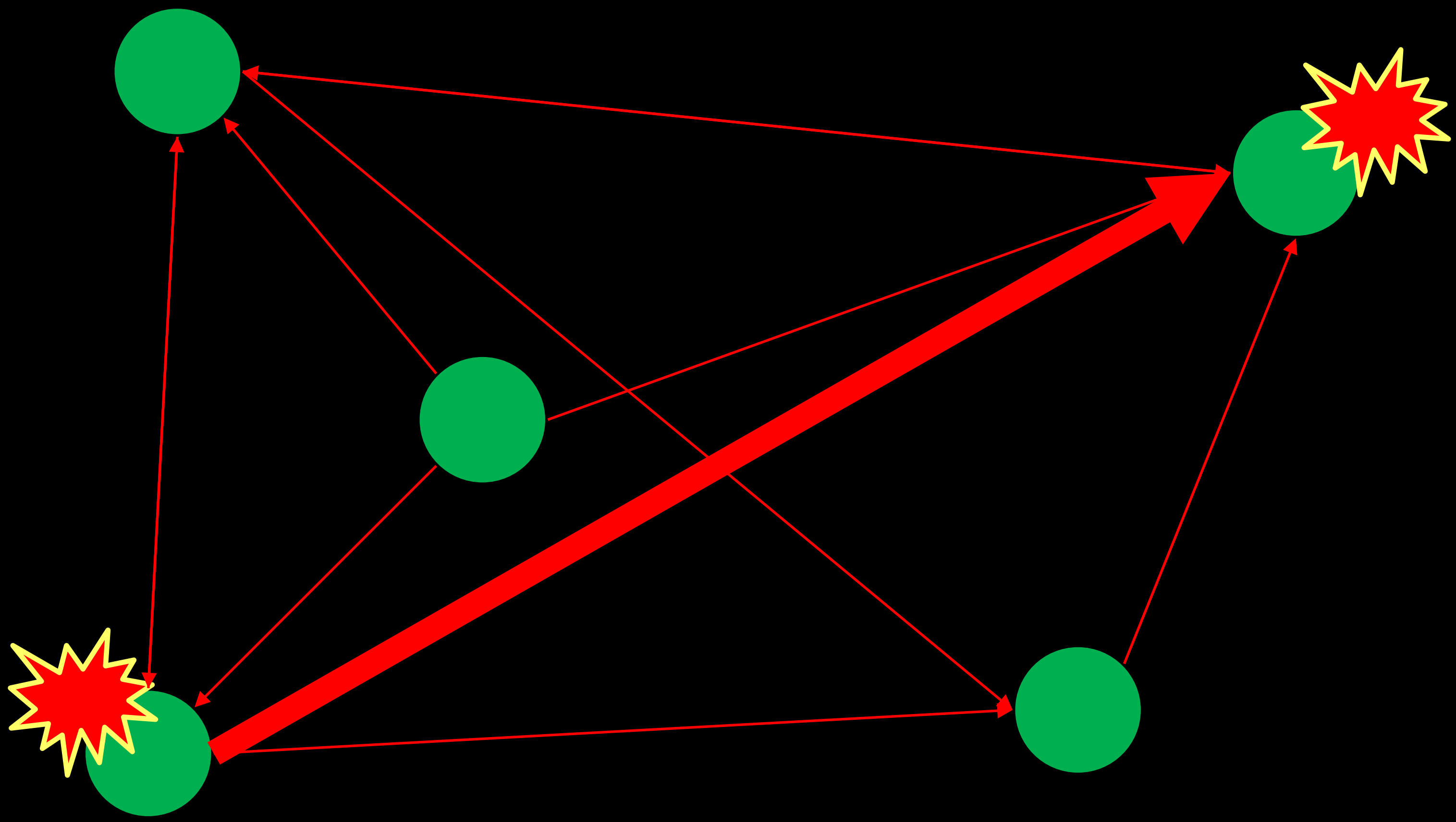
Aims

- To causally test how the feedback connectivity from motion visual area (V5) to V1 affects sensitivity to motion.
- To do this by directly modulating connectivity using a novel cortico-cortical paired associative stimulation paradigm (ccPAS)

Romei, Chiappini, Hibbard, Avenanti, 2016 Curr Biol

Hebbian plasticity

Repetitive activation of neuronal circuits can induce long-term changes in subsequent responses generated by synapses in many regions of the brain and such plasticity of synaptic connections is regarded as a cellular basis for developmental and learning-related changes in the central nervous system. *(Hebb, 1949; Bliss, 1993)*



Romei, Chiappini, Hibbard, Avenanti, 2016 Curr Biol

Hebbian-like plasticity

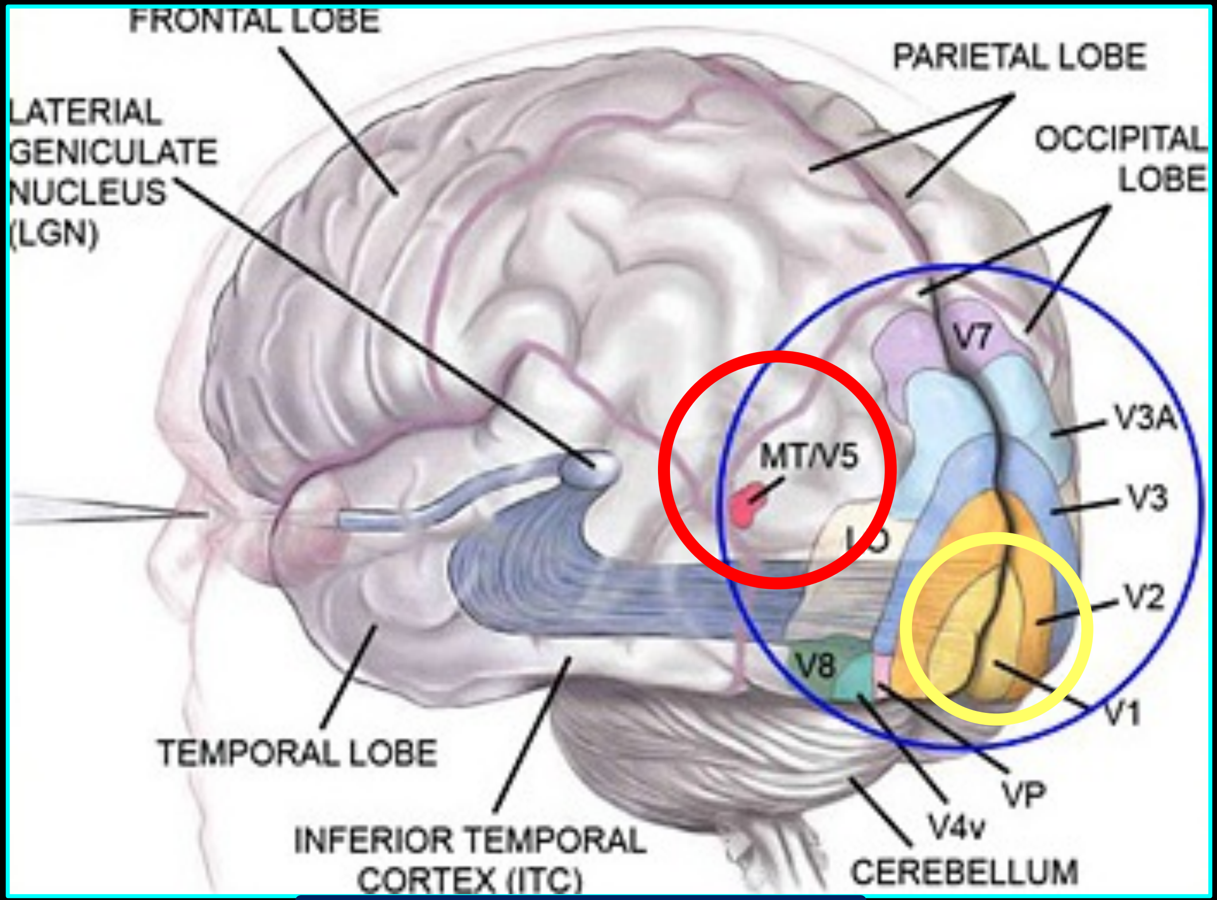
Evidence for Hebbian-like plasticity which has been found at various scales of neural organization, from single synapses in slice preparations, to in vivo expression in mammals (Bliss et al., 1973; Jackson et al., 2006)

Neuronal population 1

Neuronal population 2

Romei, Chiappini, Hibbard, Avenanti, 2016 Curr Biol

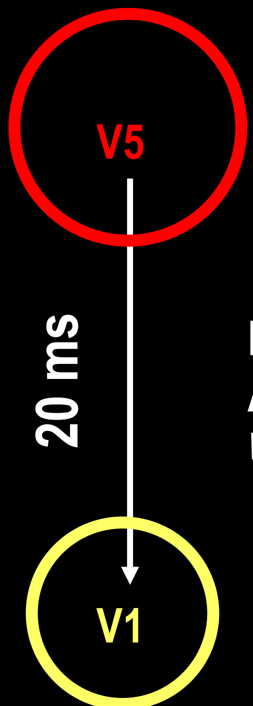
Human Visual System



TARGET AREAS

Romei, Chiappini, Hibbard, Avenanti, 2016 Curr Biol

Human Visual System



MOTION DETECTION AREA ***(Beckers 1995)***

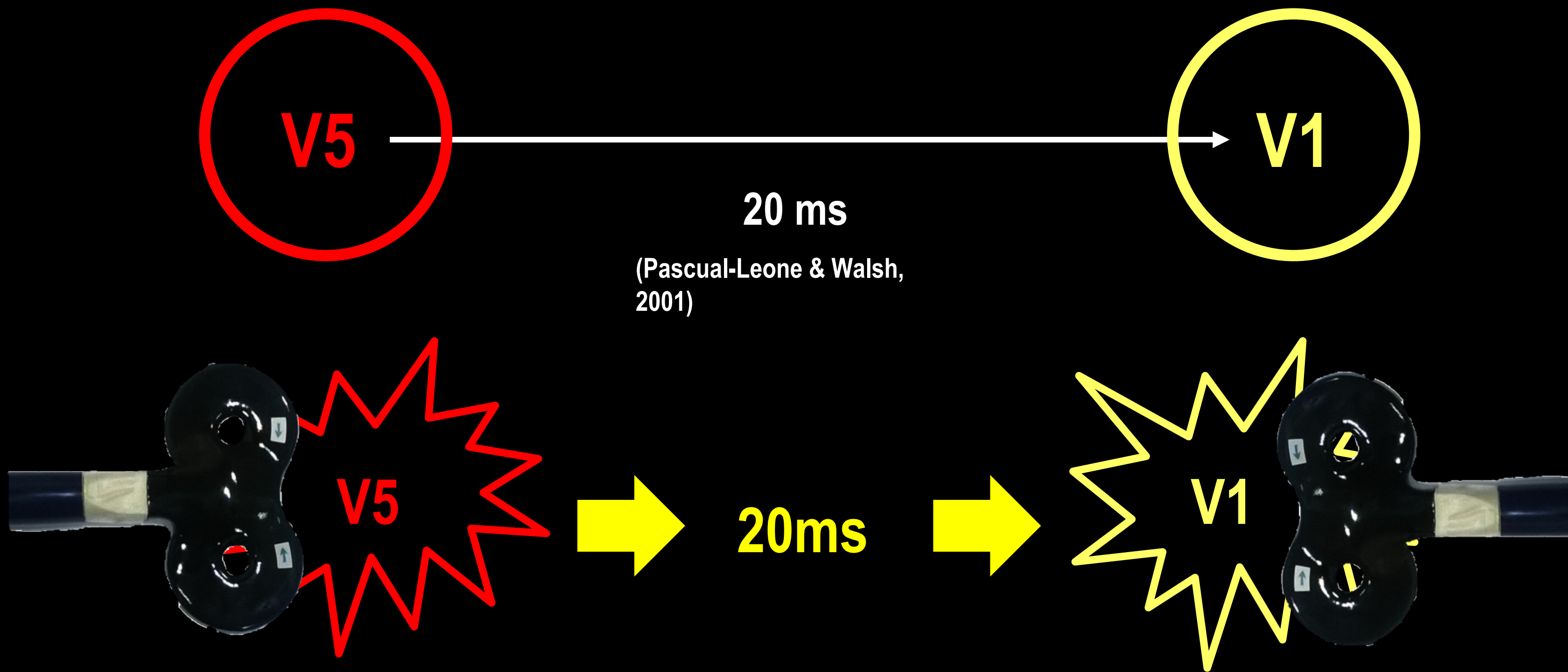
BACKPROJECTIONS FROM V5 TO V1
AWARENESS OF MOTION ***(Pascual-Leone & Walsh, 2001; Silvanto et al., 2005)***

VISUAL AWARENESS ***(e.g. Cowey & Walsh, 2000; Rees & Heeger 2003)***

Can we strengthen V5-V1 connection to improve visual motion sensitivity?

Romei, Chiappini, Hibbard, Avenanti, 2016 Curr Biol

Experimental condition

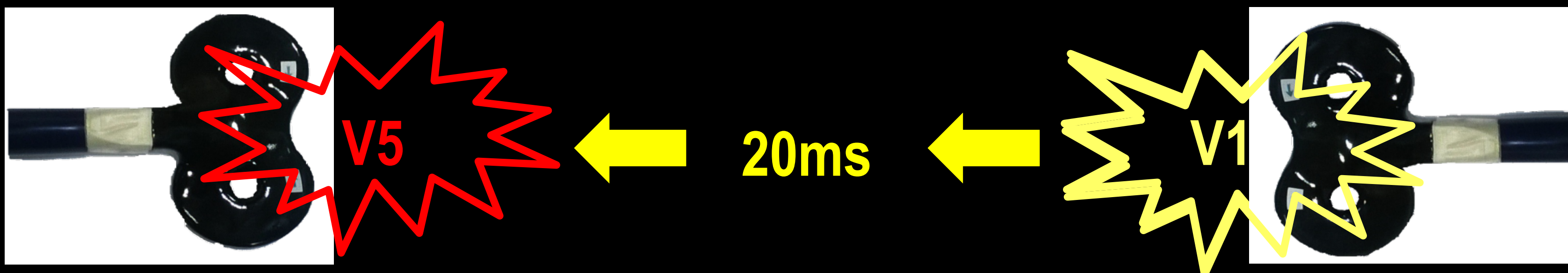


cc-PAS
- Intensity: 70% m.o.s.
- Frequency: 0.01 Hz
- Number of pulses: 90 x 2
- Sites of stimulation:
  - V5: 3 cm dorsal and 5 cm lateral (left) from the inion
  - V1: 2 cm dorsal from the inion

Romei, Chiappini, Hibbard, Avenanti, 2016 Curr Biol

Control conditions

- CONTROL GROUP DIRECTION: CTRL_V1-V5

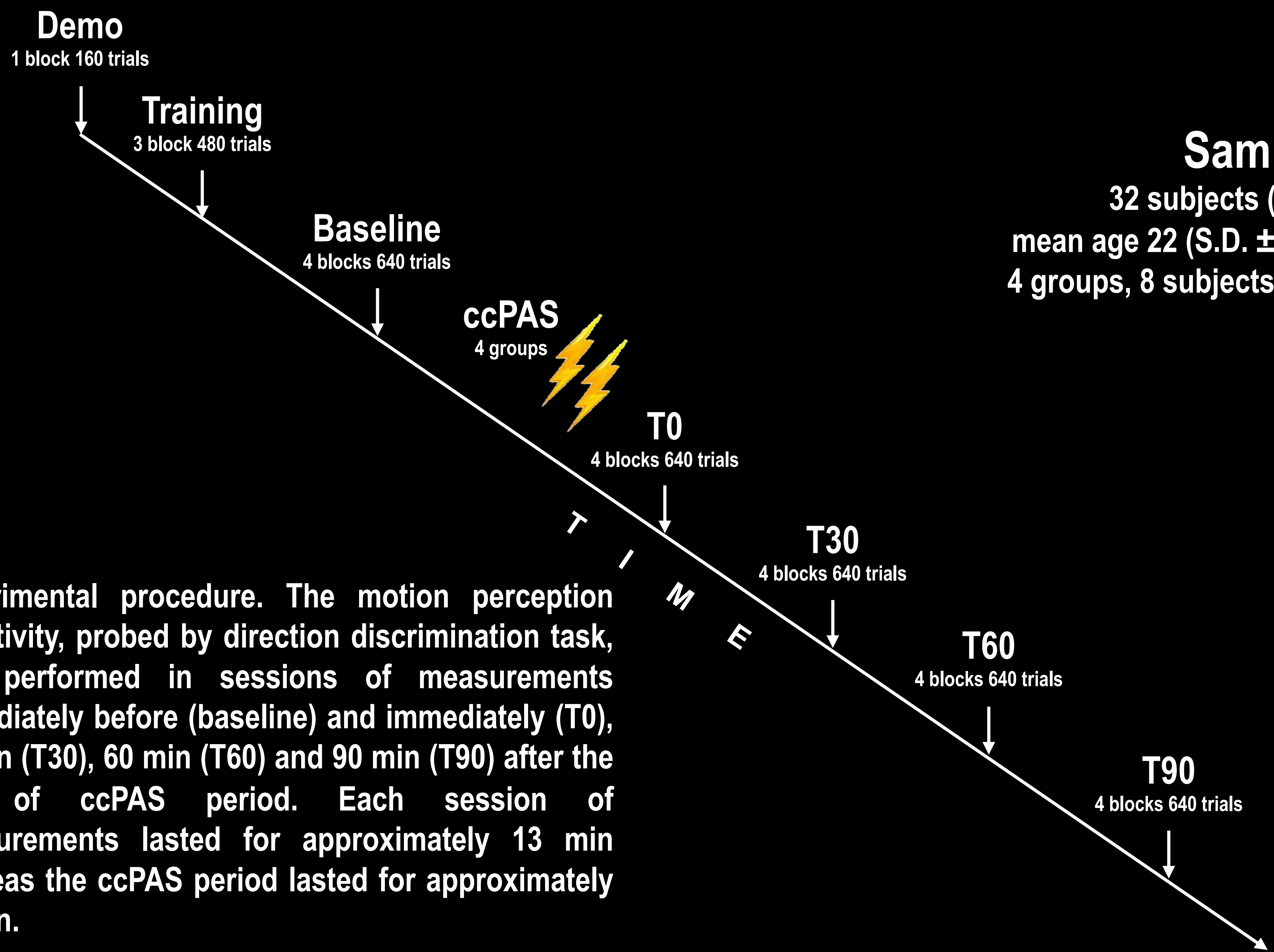


- CONTROL GROUP TIMING: **CTRL_0ms**

- CONTROL GROUP PLACEBO: SHAM

Romei, Chiappini, Hibbard, Avenanti, 2016 Curr Biol

Experimental procedure



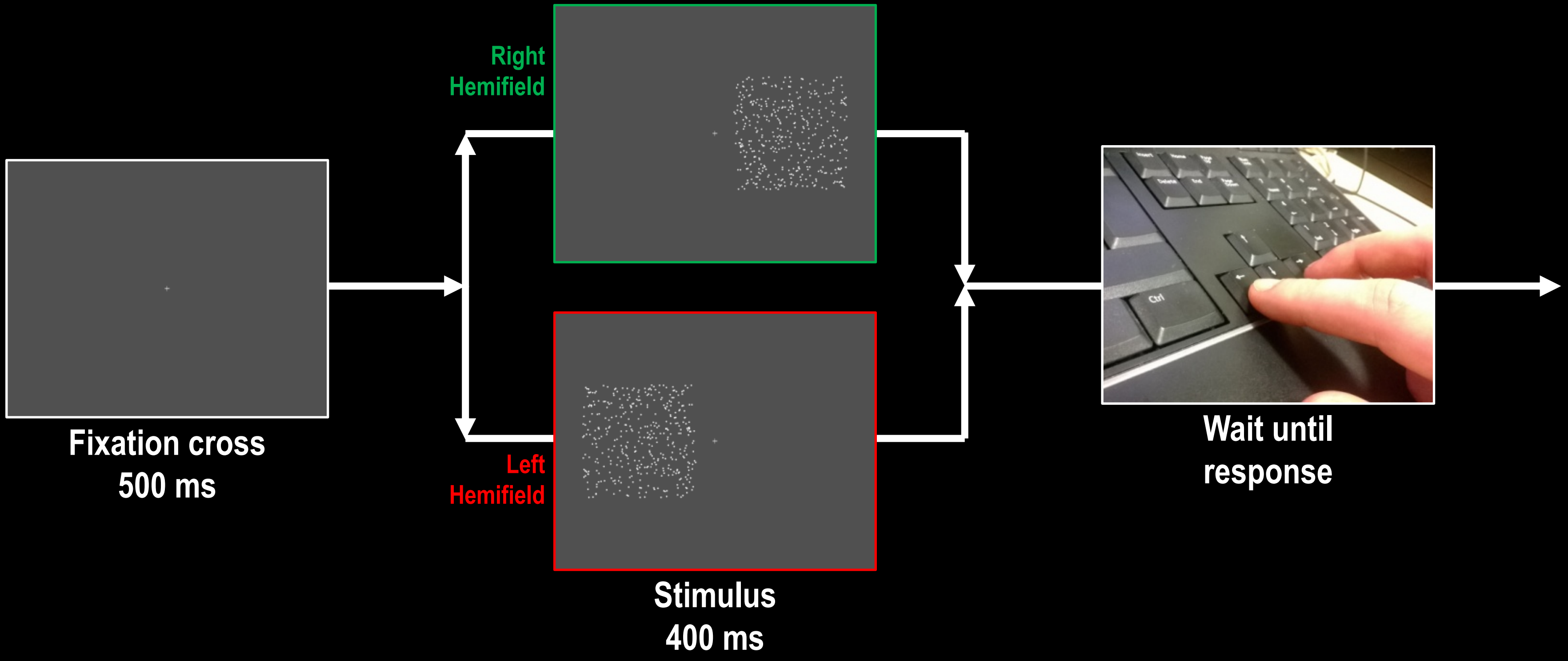
Sample:
32 subjects (11 M)
mean age 22 (S.D. ± 4,14)
4 groups, 8 subjects each

Experimental procedure. The motion perception sensitivity, probed by direction discrimination task, was performed in sessions of measurements immediately before (baseline) and immediately (T0), 30 min (T30), 60 min (T60) and 90 min (T90) after the end of ccPAS period. Each session of measurements lasted for approximately 13 min whereas the ccPAS period lasted for approximately 15 min.

Romei, Chiappini, Hibbard, Avenanti, 2016 Curr Biol

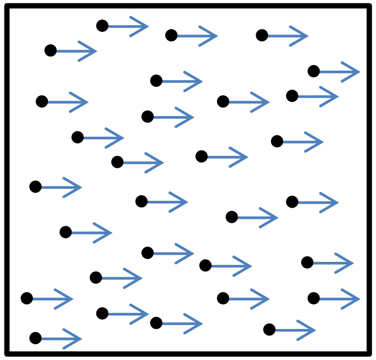
Task – Trial sequence

Two-alternative forced choice computerised task
Towards which direction dots are coherently moving?
Right or Left?
Answer accurately, if not sure, guess!

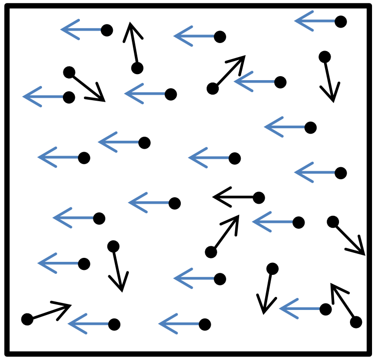


Romei, Chiappini, Hibbard, Avenanti, 2016 Curr Biol

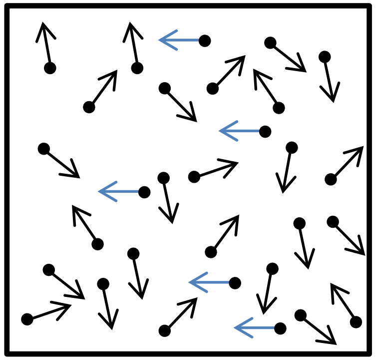
Task – Coherent motion



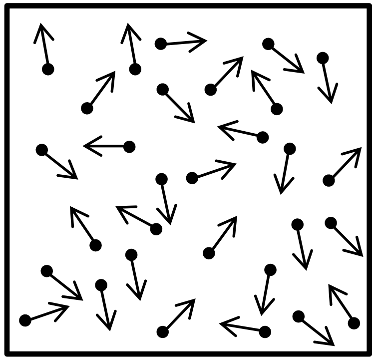
100% coherent motion towards right



75% coherent motion towards left



16% coherent motion towards left



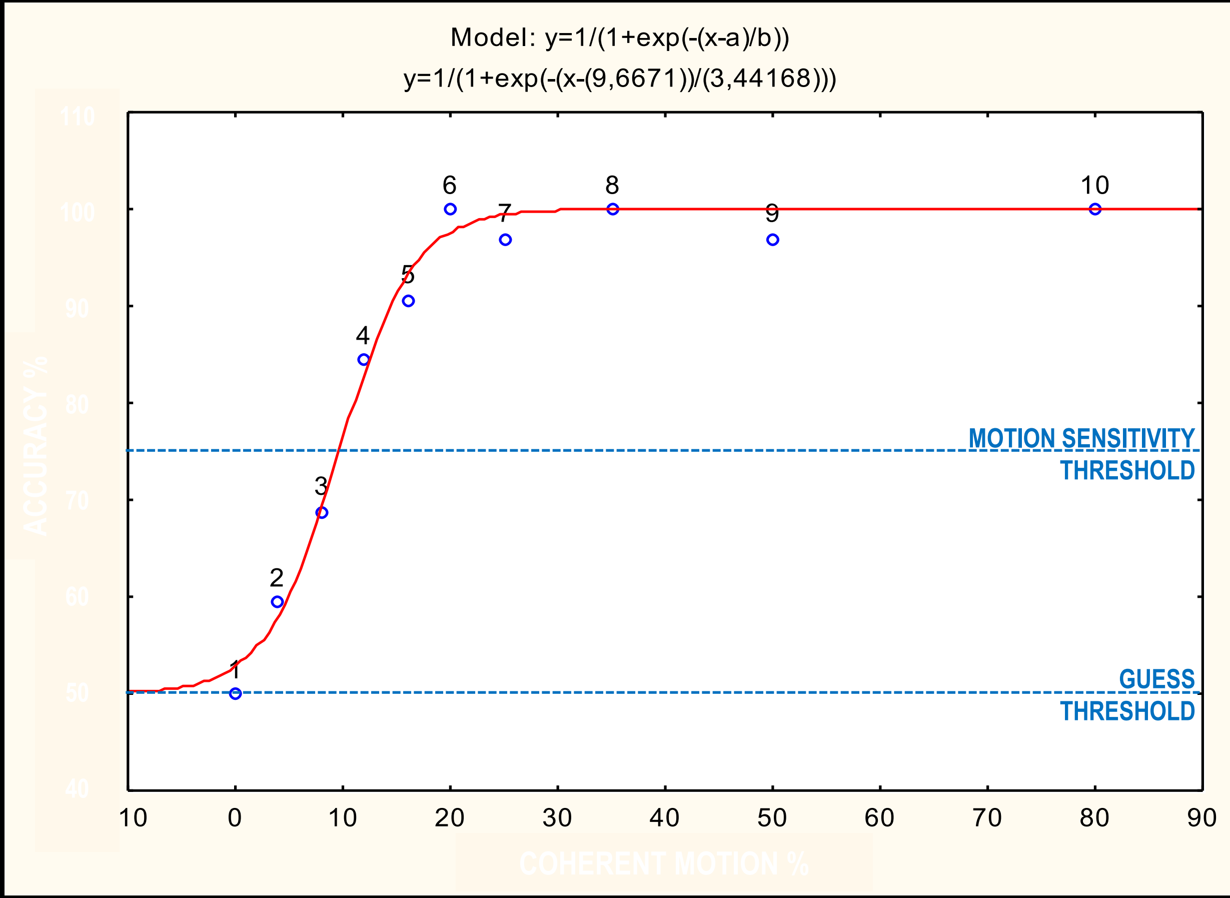
0% coherent motion random motion

Level of motion coherence: 0 – 4 – 8 – 12 – 16 – 20 – 25 – 35 – 50 – 80 %

Romei, Chiappini, Hibbard, Avenanti, 2016 Curr Biol

Personal motion sensitivity threshold

Motion sensitivity threshold (MST) is meant to be the minimum motionpercentage of coherent necessary to discriminate the coherent direction of the moving dots with an accuracy of 75%.



Can we manipulate participants' threshold?

Romei, Chiappini, Hibbard, Avenanti, 2016 Curr Biol

Analysis MST

Experimental design:

5 Time (BSL, T0, T30, T60, T90)
x 2 HemiField (LEFT, RIGHT)
x 4 Group (EXP_V5-V1, CTRL_V1-V5; CTRL_0ms; CTRL_SHAM)

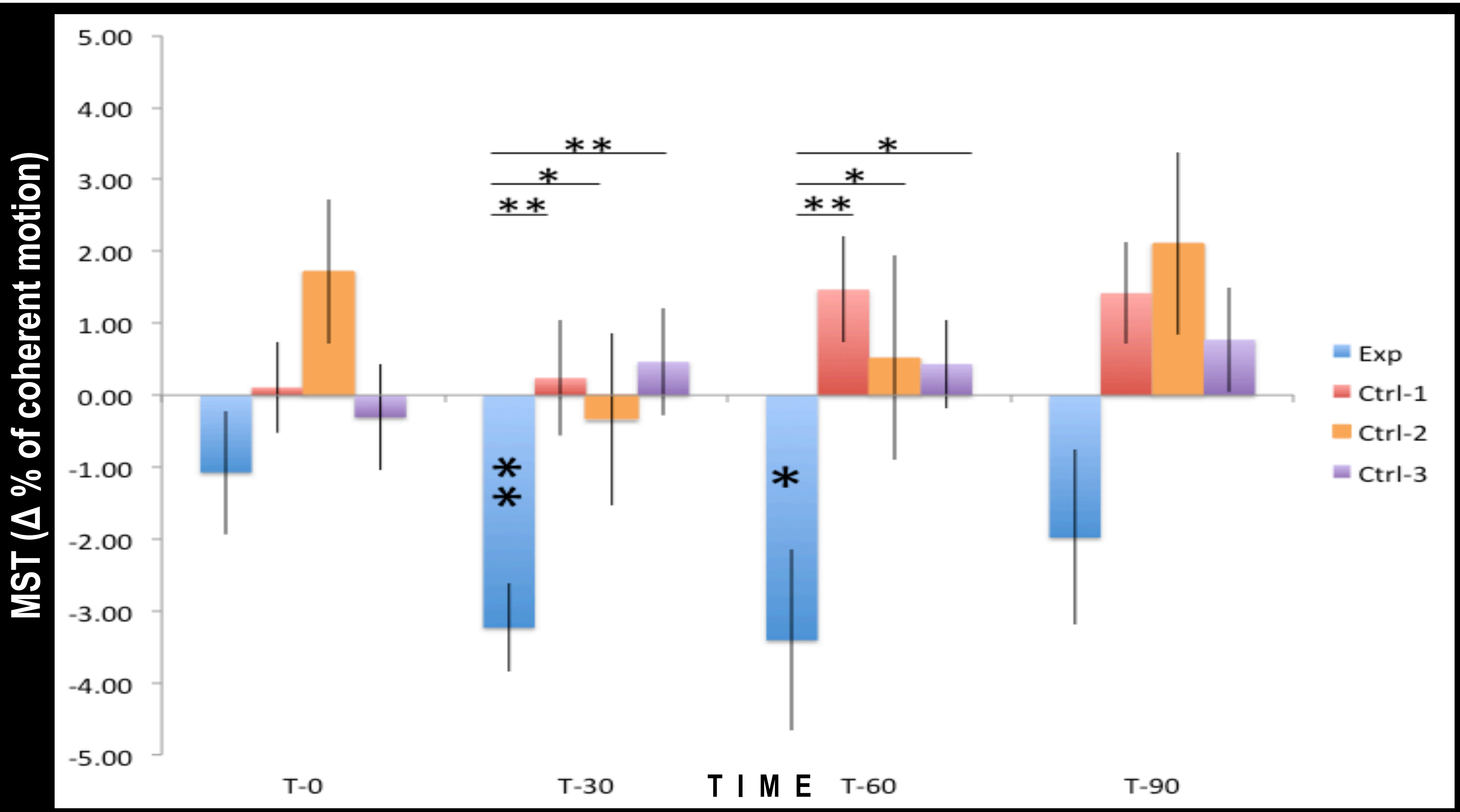
Main effect of Time: $F_{4,112} = 2.51$, $p = 0.046$

Interaction Time x Group: $F_{12,112} = 2.51$, $p = 0.006$

No other statistically significant effects (all ps >0.1)

Romei, Chiappini, Hibbard, Avenanti, 2016 Curr Biol

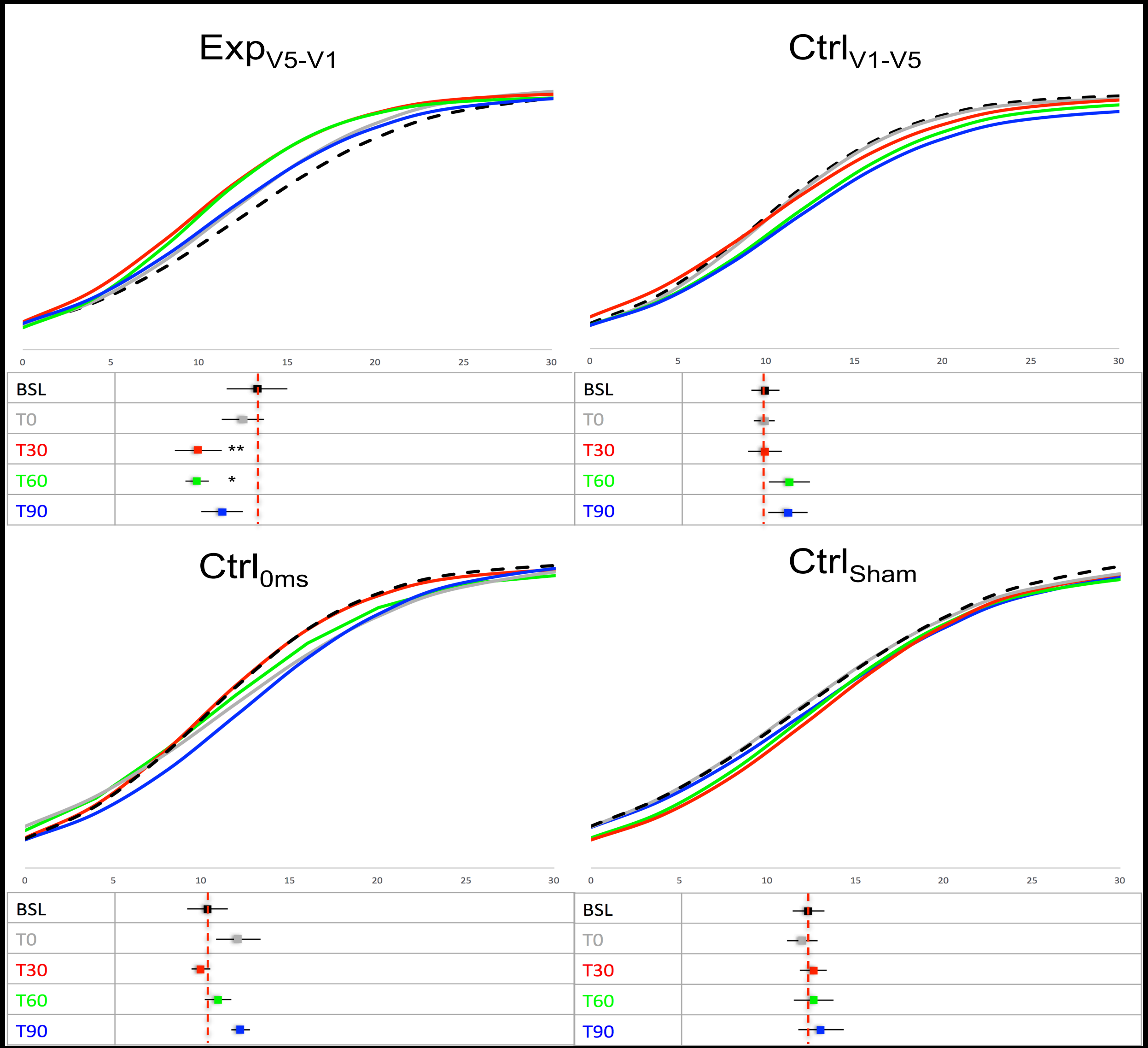
Results – Baseline corrected



There is a significant improvement of motion perception 30 and 60 minutes after ccPAS, and it is notable only in the experimental condition

Romei, Chiappini, Hibbard, Avenanti, 2016 Curr Biol

Results - within group



Romei, Chiappini, Hibbard, Avenanti, 2016 Curr Biol

Take home message

- ccPAS over two functionally connected visual regions improves visual processing depending on the parameters of stimulation (e.g. directionality, timing, etc.).

- Empowering reentrant connections from V5 to V1, implicated in the conscious perception of visual motion, boosts visual motion sensitivity.

Results provide first causal evidence that selective empowering of reentrant projections from V5 to V1 can enhance visual processing of motion

Romei, Chiappini, Hibbard, Avenanti, 2016 Curr Biol

Strengthening functionally specific neural pathways with transcranial brain stimulation

Emilio Chiappini
University of Bologna

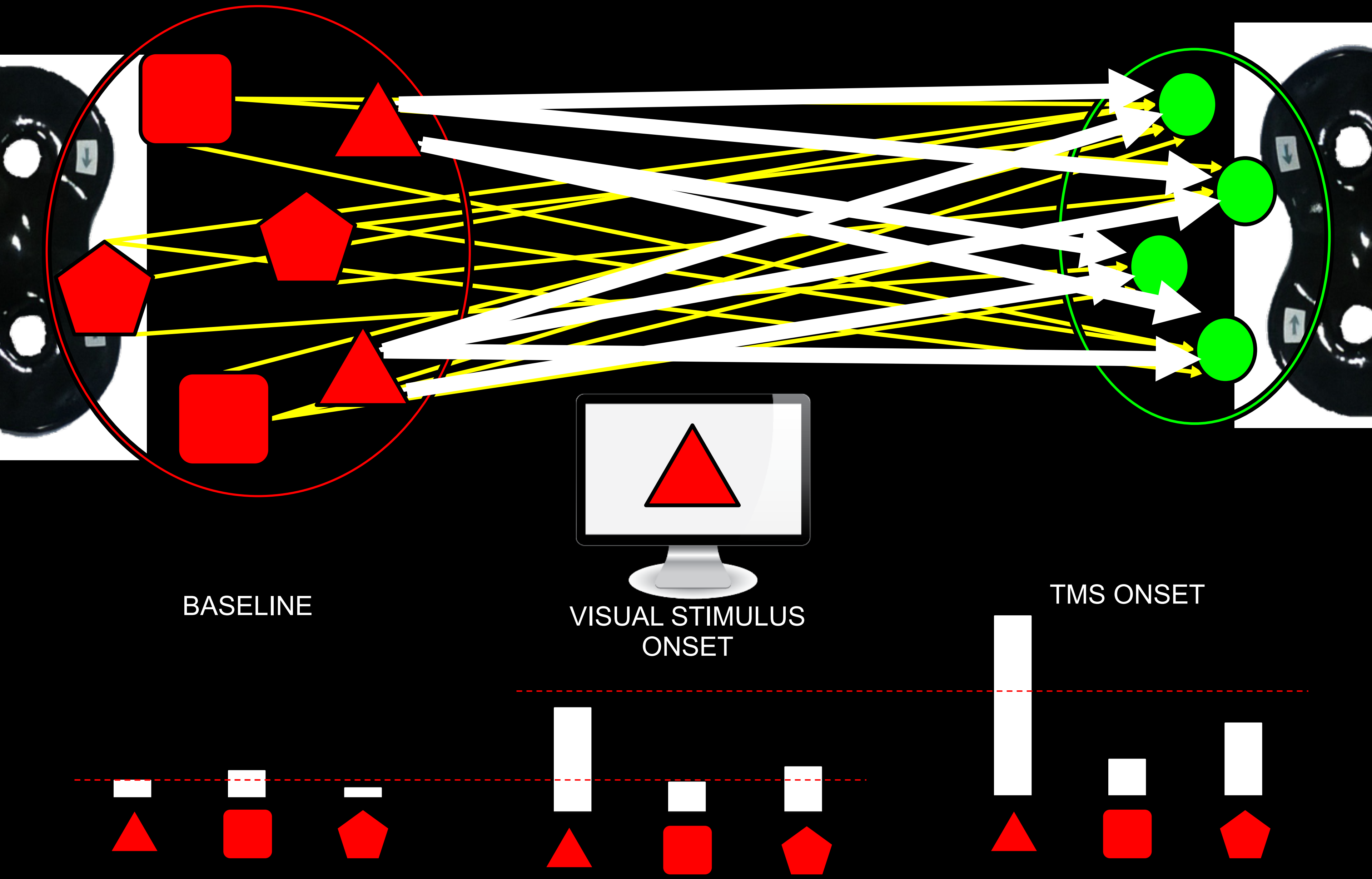
Alessio Avenanti
University of Bologna

Paul Hibbard
University of Essex

Juha Silvanto
University of Westminster

Chiappini, Silvanto, Hibbard, Avenanti, Romei. CurrBiol 2018

ccPAS: functional state-dependency – Study 2



Connectivity manipulation: cc-PAS

Hebbian-like plasticity TMS-induced in functional-independent connections:

State dependent cc-PAS

Intensity:
- V5: 80 or 100% of PT
- **V1: 100% of PT**

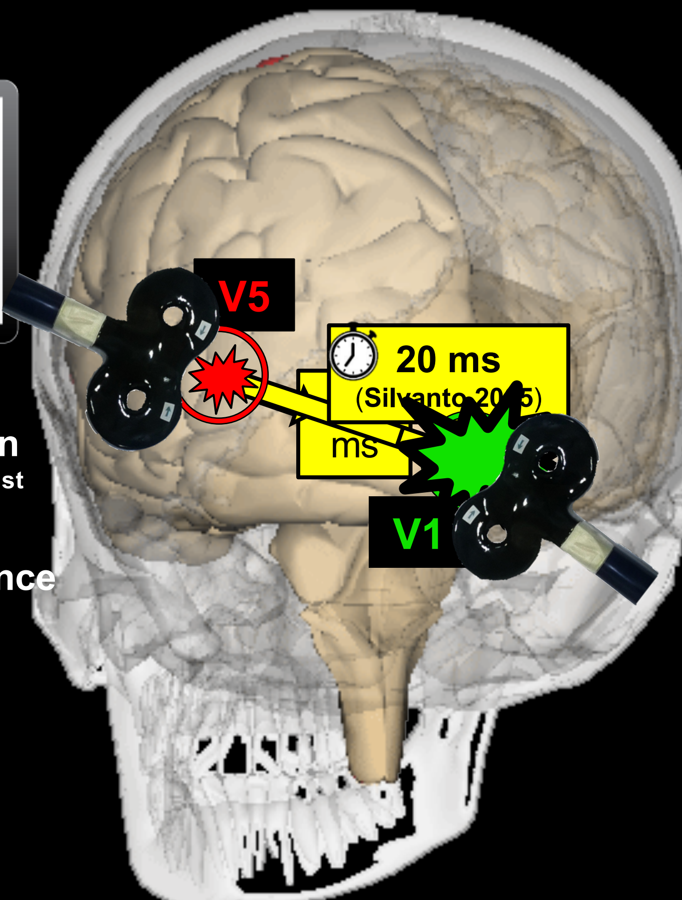
Frequency: 0.1 Hz

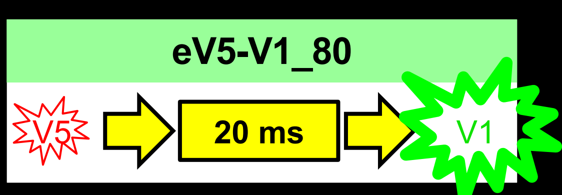
Number of pulses: 90 x 2

Sites of Stimulation:
- **V5: 3 cm dorsal, 5 cm lateral (left) from inion**
- **V1: 2 cm dorsal from inion**

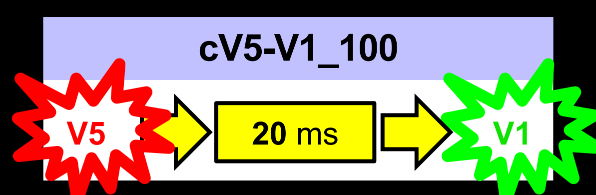
ISI: 20 **ms**

Online visual exposition
- **SOA 150 ms before 1st pulse**
- **100% motion coherence**

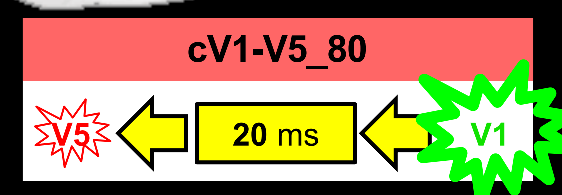




Experimental ccPAS



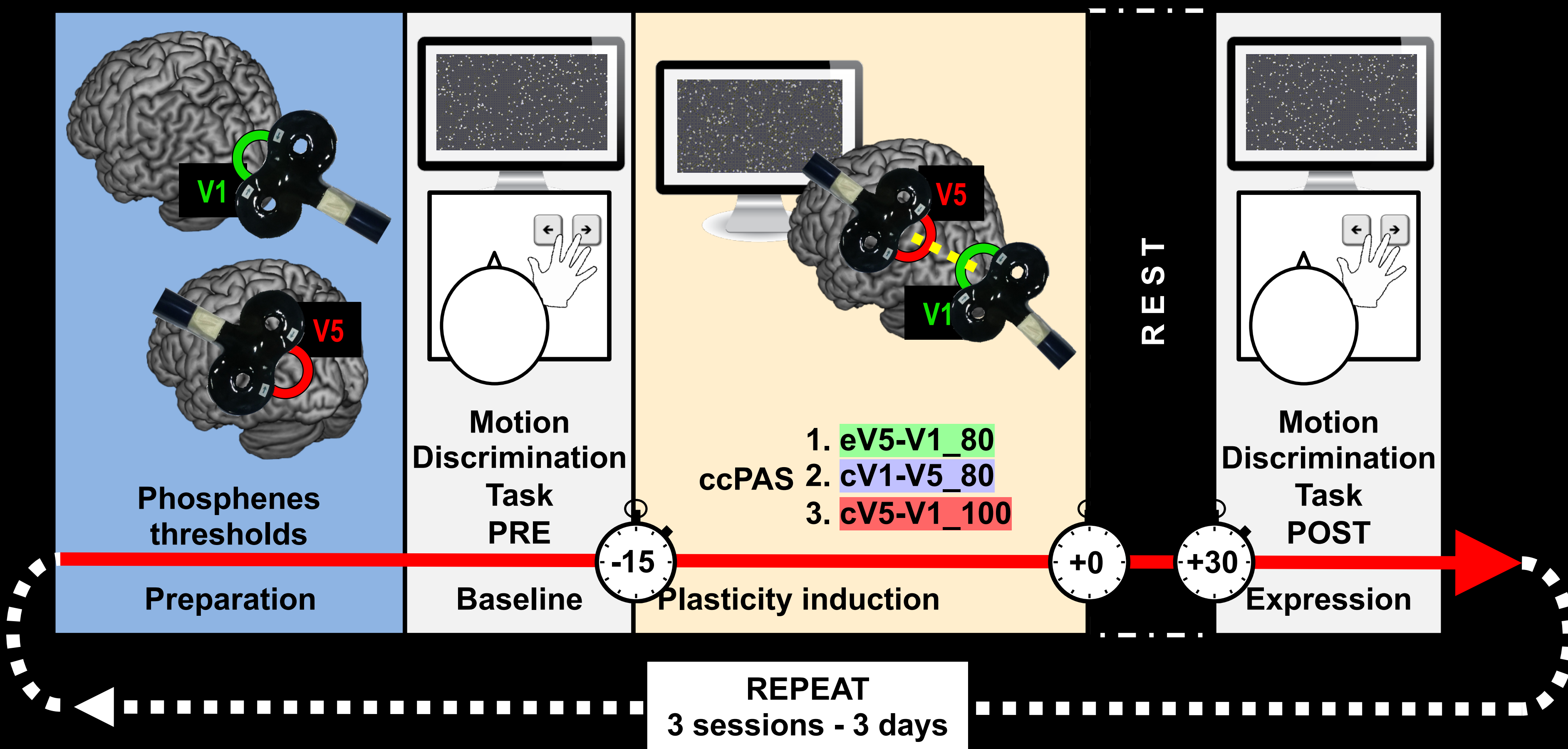
Intensity control



Direction control

Chiappini, Silvanto, Hibbard, Avenanti, Romei. CurrBiol 2018

Experiment timeline

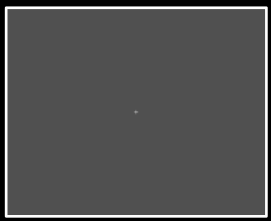


Experimental procedure. The motion perception sensitivity, probed by direction discrimination task, was performed before (PRE) and 30 min after (POST) the end of the ccPAS. Each session of measurements lasted for approximately 12 min whereas the ccPAS period lasted for 15 min.

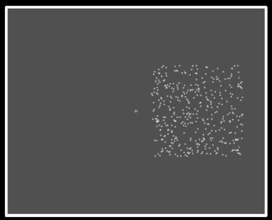
Chiappini, Silvanto, Hibbard, Avenanti, Romei. CurrBiol 2018

Motion discrimination task – Study 2

Two-alternative forced choice computerised task
Towards which direction dots are coherently moving? Right or Left?
Answer accurately, if not sure, guess!

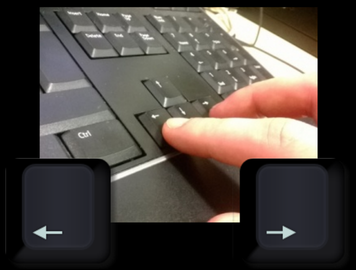


Fixation cross
500 ms

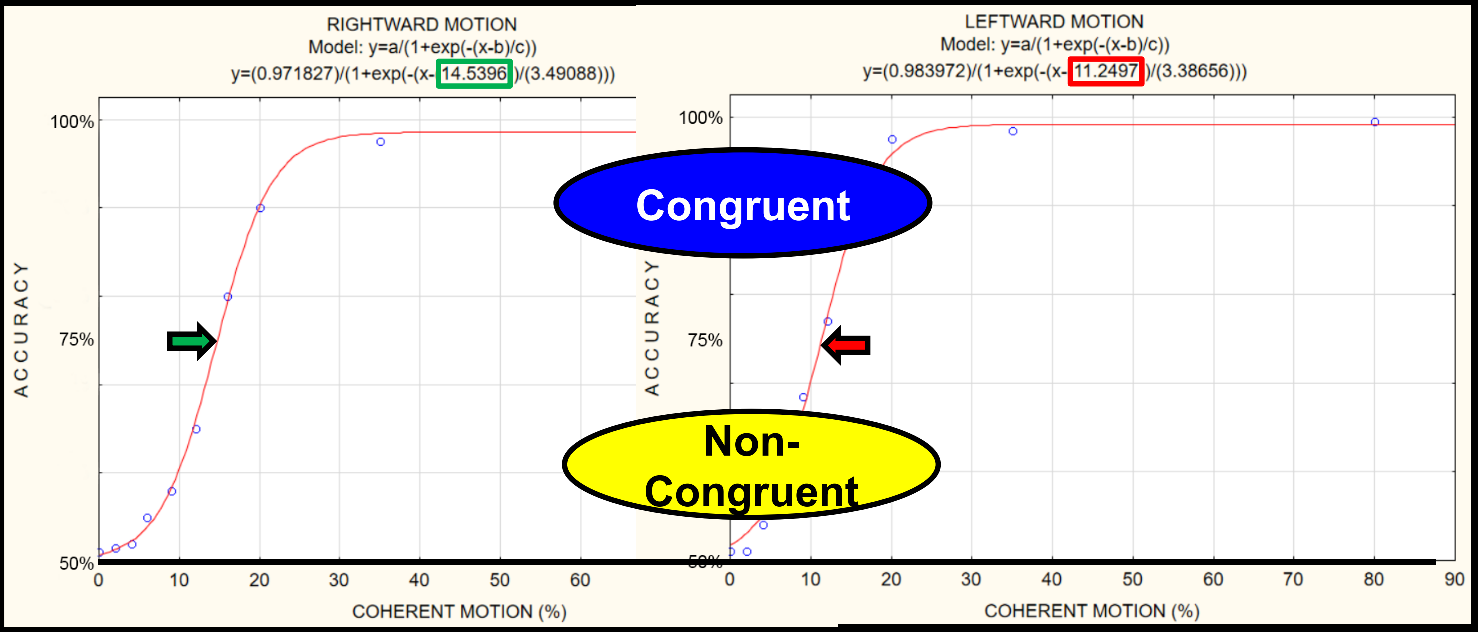


Stimulus
400 ms

Fixation cross
until response



$$y = \frac{a}{1 + e^{-\frac{x-b}{c}}}$$



Motion **co**herence levels (%)

Chiappini, Silvanto, Hibbard, Avenanti, Romei. CurrBiol 2018

Results – ccPAS modulations

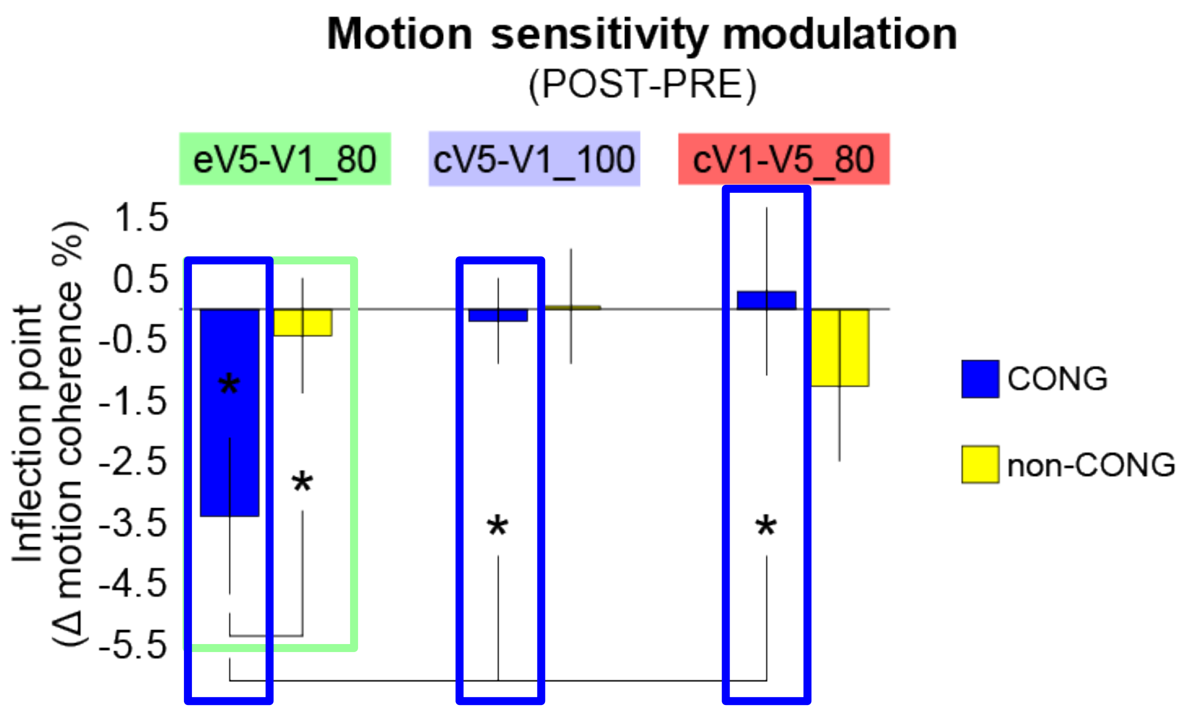
Sample:
age: 25 ±8
n = 16
♂ = 5
♀ = 11

Planned comparisons (BF corr)
Cong vs. non-Cong direction eV5-V1_80: p = 0.035

→ Function-specific modulation

Within group comparisons:
Cong direction, eV5-V1_80 vs. cV5-V1_100: p = 0.018
cV1-V5_80: p = 0.019

→ Experimental ccPAS modulates more than others



Chiappini, Silvanto, Hibbard, Avenanti, Romei. CurrBiol (in press)

Conclusions – Study 1&2

- **ccPAS can temporarily induce Hebbian-like plasticity in the visual system**
- **ccPAS can target and enhance the efficiency of specific pathways functionally selected**
- **Re-entrant connectivity from higher order to early visual areas is functionally relevant to motion perception**
- **Re-entrant V5-V1 pathways carry function-specific information for the processing of motion direction**

Conclusions

- **Functional connections are highly plastic in the brain and follow Hebbian rules**
- **Feedback connectivity allows for efficient processing of information**
- **Cognitive Neuroscience developments have allowed for causal testing of such principles in the human brain**
- **Informing models of artificial intelligence developments: Machine Learning, deep learning, artificial neural networks, etc.**