Social interaction and inter-individual neural synchronization in the human prefrontal cortex.

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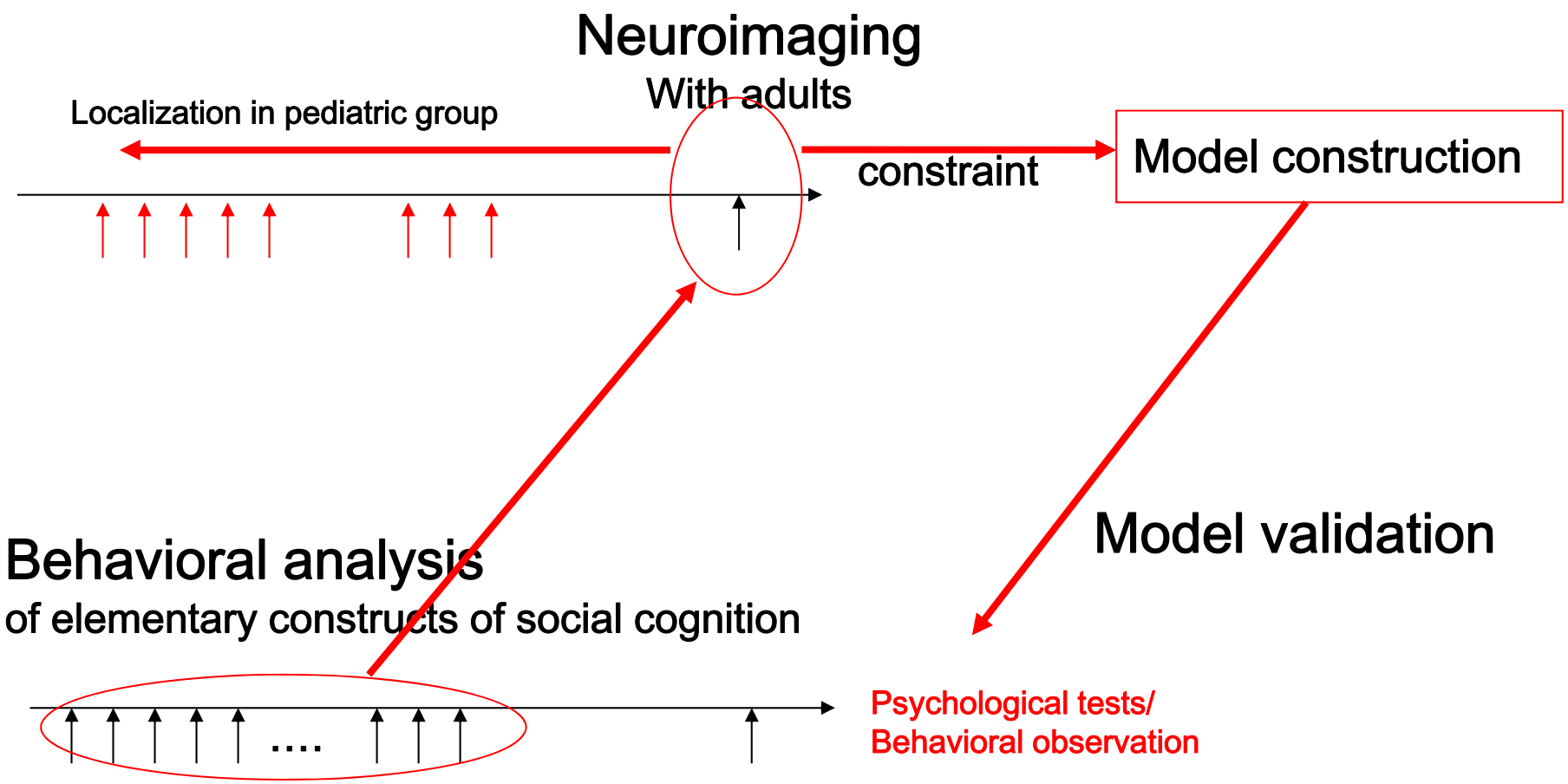
The Third International Workshop on Linguistics of *BA*
13:25 – 14:25 (60 min)
March 26th, 2016
Meeting Room on the 3rd Floor of Building 8
Waseda University
Nishi-Waseda 1-6-1, Shinjuku-ku,
Tokyo 169-8050,
Japan

Key question

How do we become social beings?

Approaches to Social Cognitive Development with Neuroimaging technique



Development of social cognition

age	milestone behavior
0 m	neonatal imitation
4 m	social contingency
9 m	joint attention
1.5 y	self recognition
4.5 y	theory of mind
school	metaphor / sarcasm
	white lie
	moral
	empathy
	prosocial behavior

Definition

Social cognition

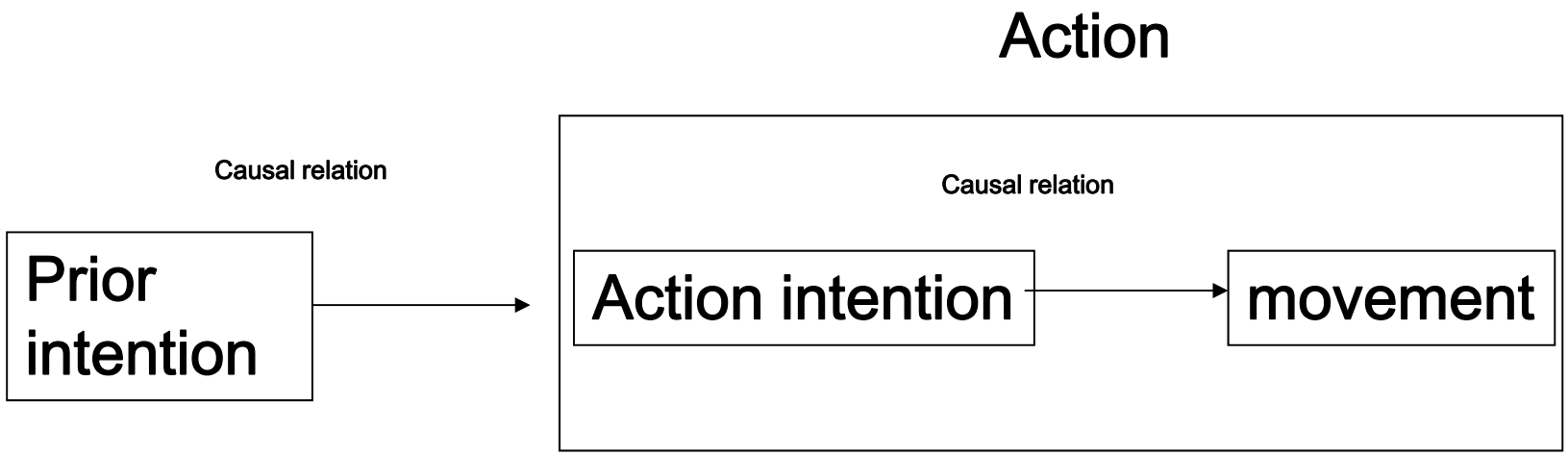
The processing of information which culminates in the accurate perception of the dispositions and intentions of other individual.

(Brothers, 1990)

→ implies prediction of action

Intention and Action

Searle (1983)



Intention and action

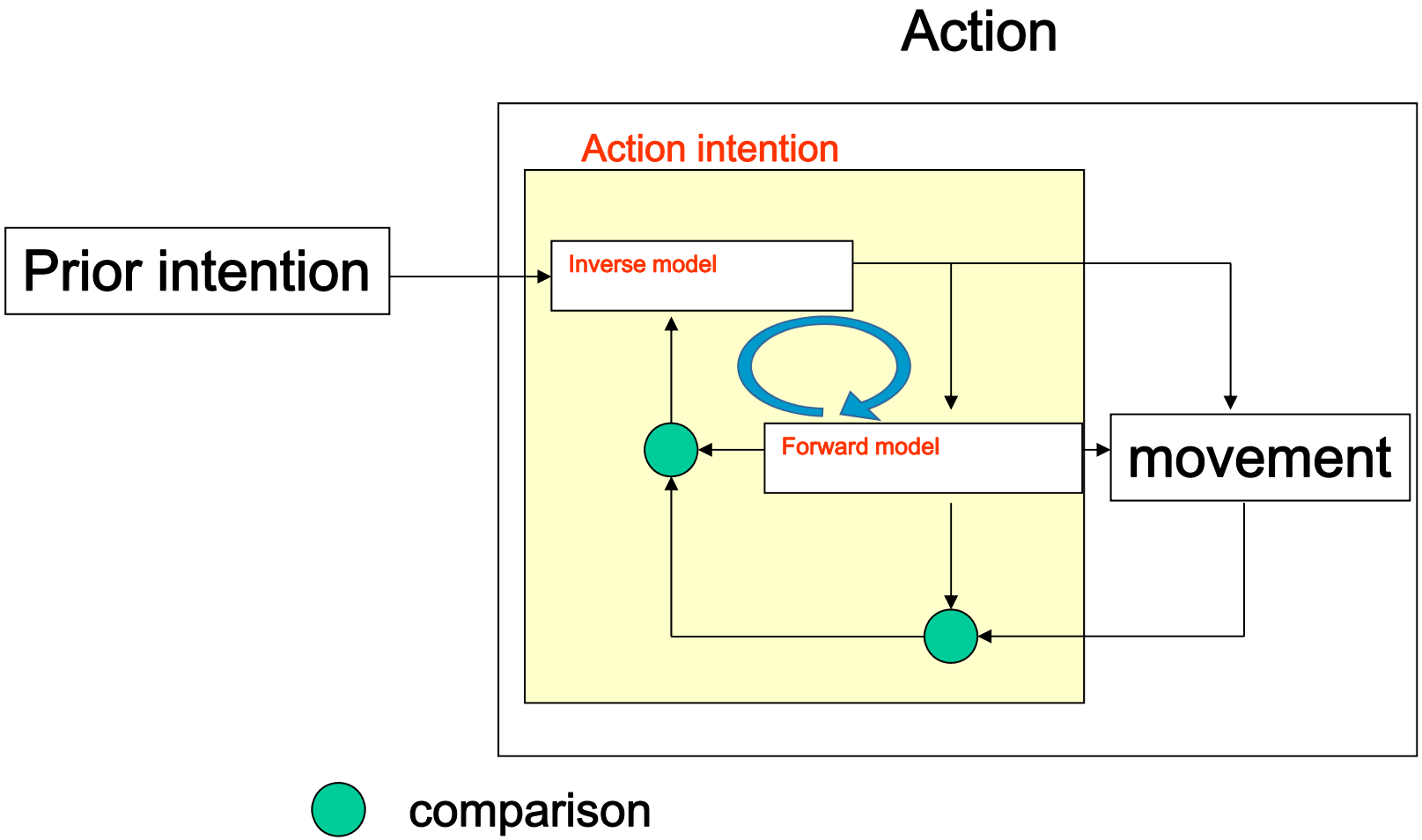
(Searle, 1983）

- “When I raise my arm, my arm goes up. And the problem arises: what is left over if I subtract the fact that my arm goes up from the fact that I raise my arm?” (Wittgenstein 1953)

- = Action intention
- “trying”

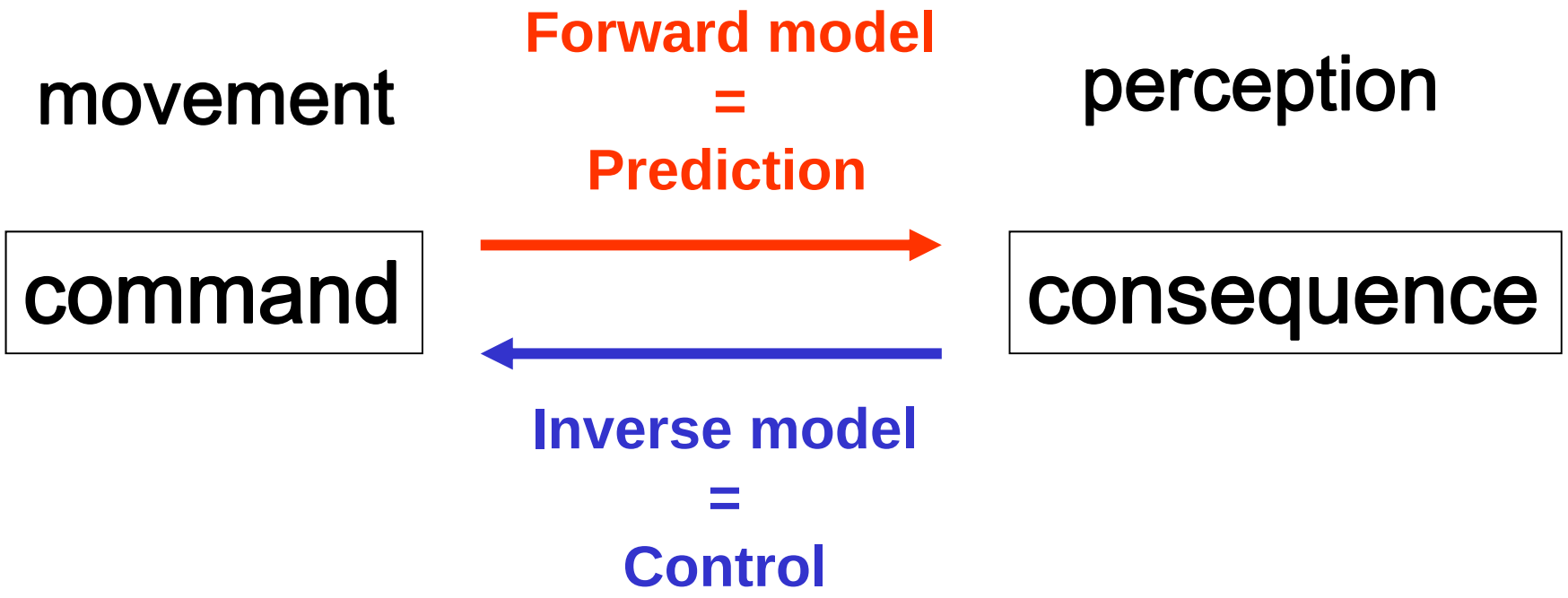
Intention and Action

Jeannerod (2006)



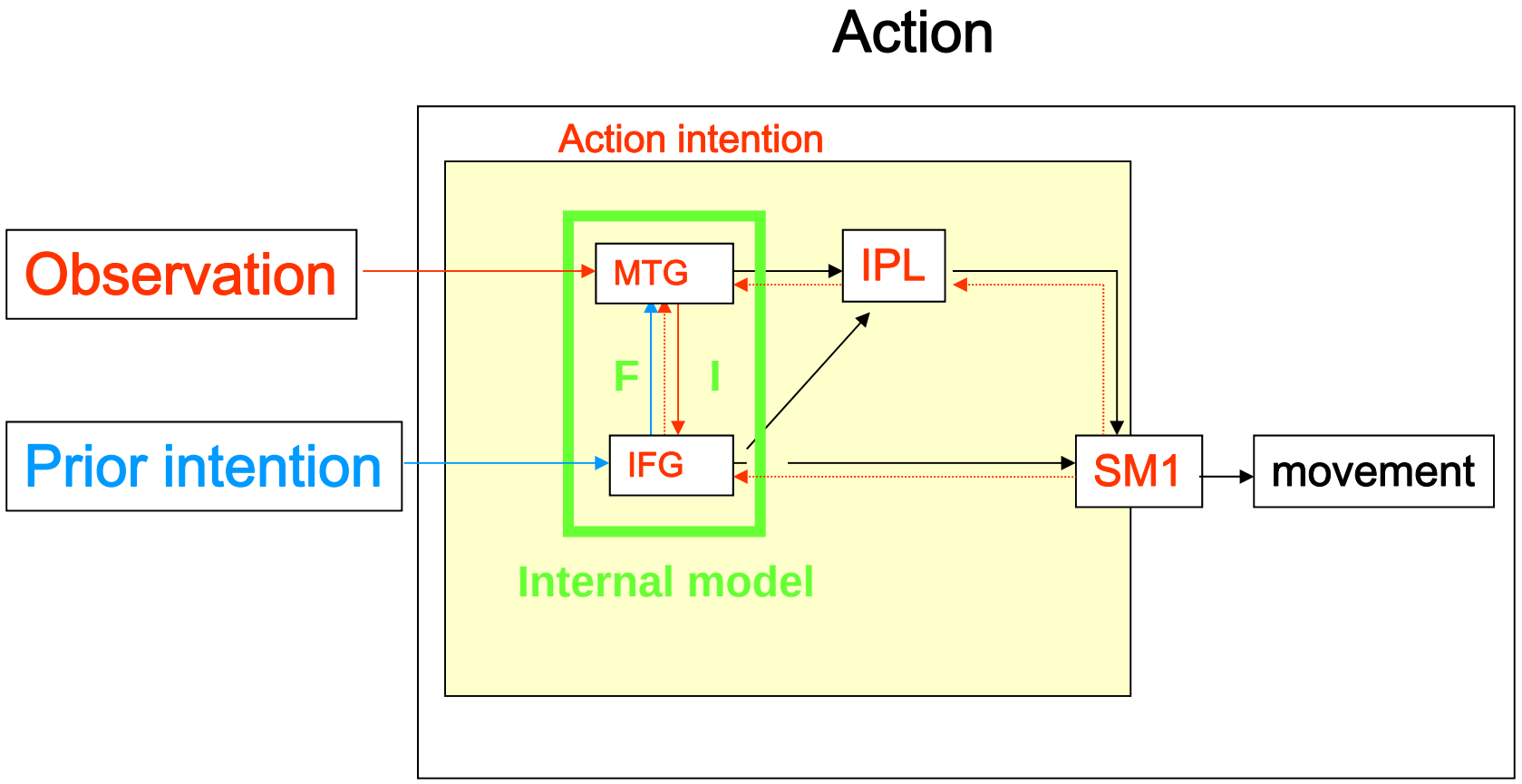
Model of motor control

(Wolpert et al. 2003)

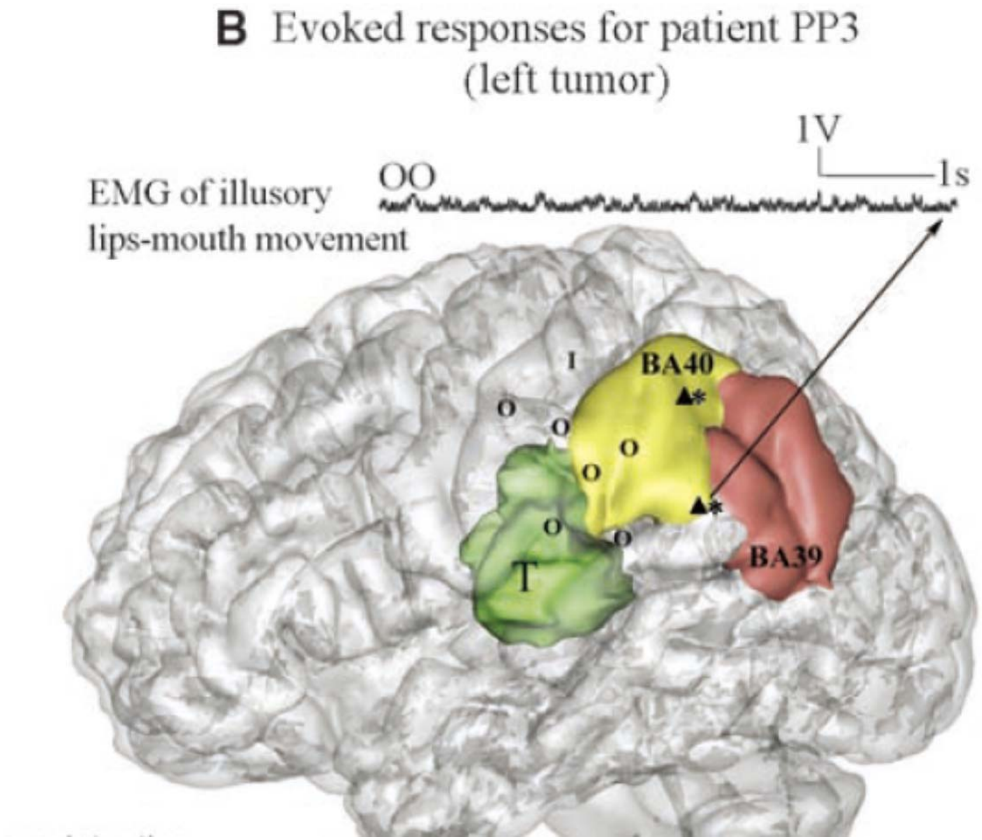


Observation and Action

Jeannerod (2006)



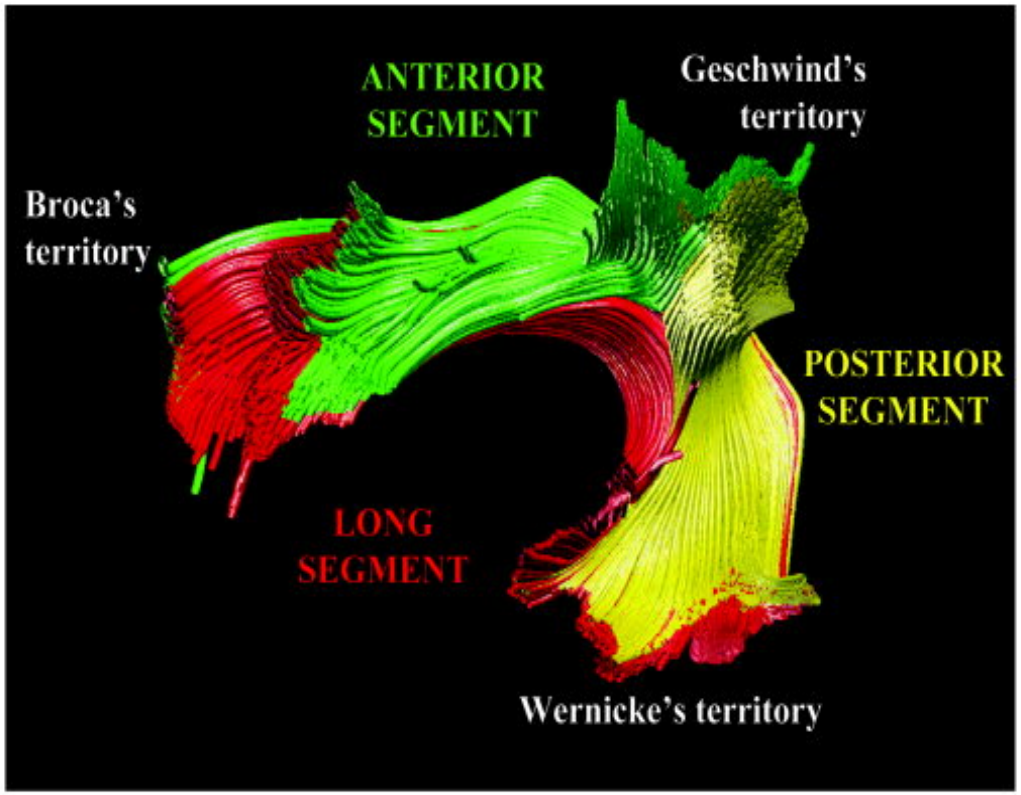
Electrical stimulation of the inferior parietal cortex provoked intention to move
= neural substrates of action intention



When stimulation intensity increased, motor intention was replaced by illusory movement awareness.
"The signal we are aware of when making a movement … emerge from the predictions we make about the movement in advance of action"

(Desmurget et al. 2003)

In human brain, direct connection between MTG and IFG does exist



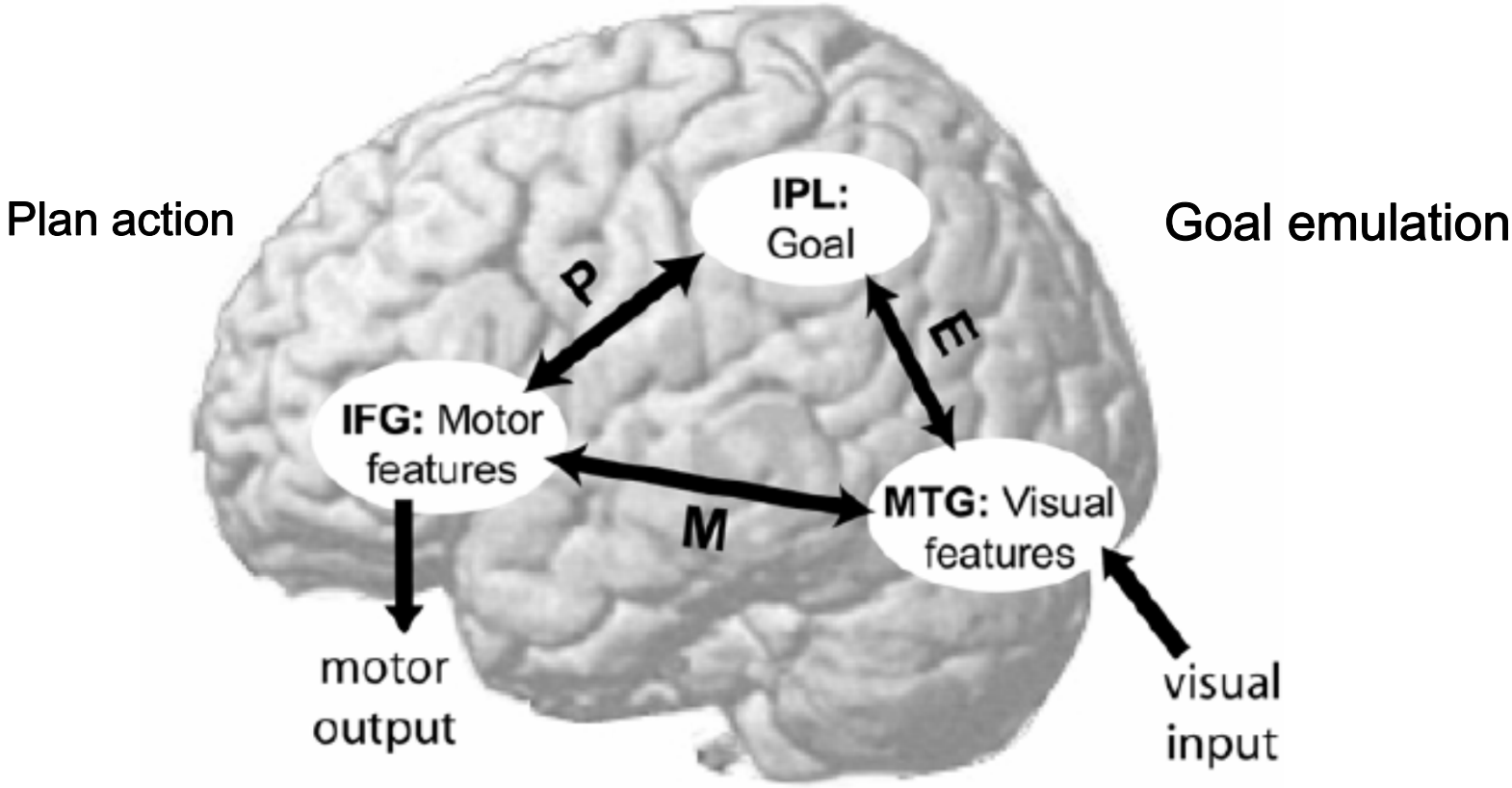
(Catani, et al. 2005)

DTI revealed direct route between MTG and IFG, between MTG and IPL (posterior segment) , and between IPL and IFG (anterior segment)

Annals of Neurology
Volume 57, Issue 1, pages 8-16, 13 DEC 2004 DOI: 10.1002/ana.20319
http://onlinelibrary.wiley.com/doi/10.1002/ana.20319/full#fig3

Dual pathway hypothesis of putative Mirror Neuron System EP-M model (Hamilton, 2008)

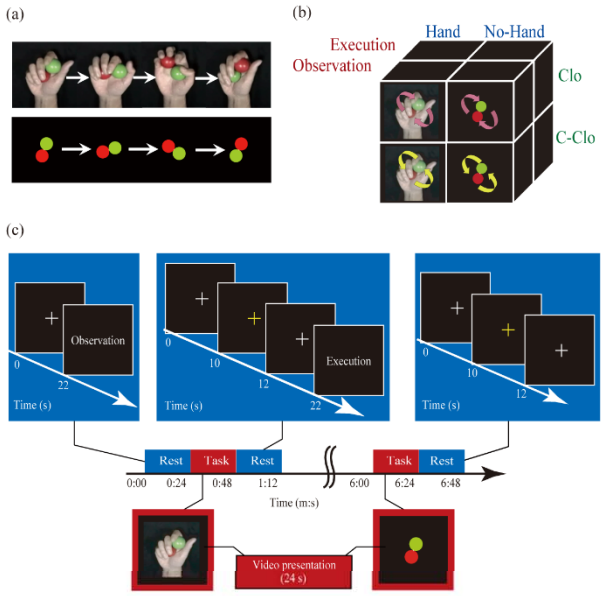
EP (MTG-IPL-IFG) Understanding of goal directed action
M (MTG-IGF) Automatic mimicry of actions without goals

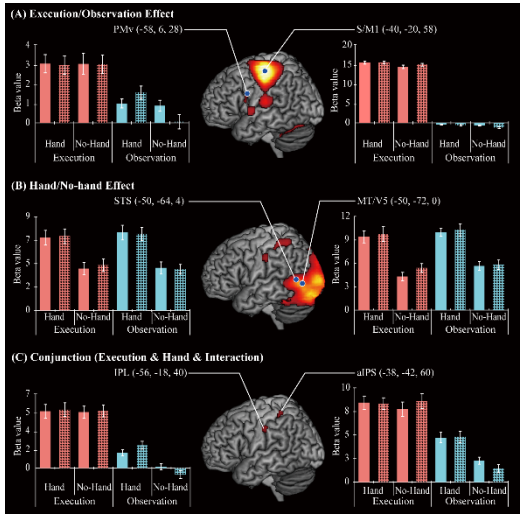


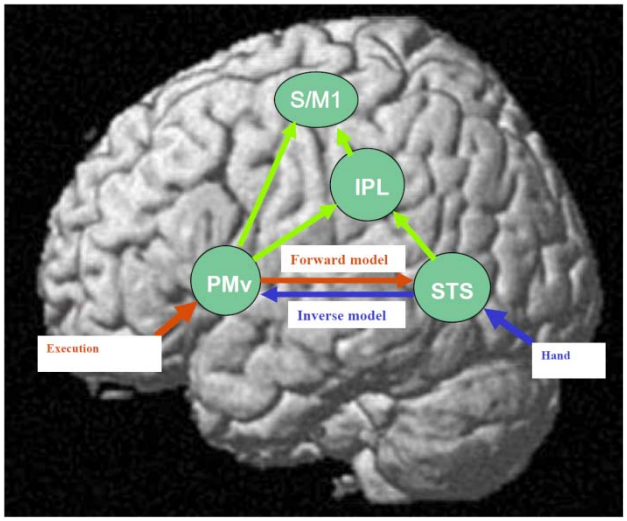
(automatic) Mimicry

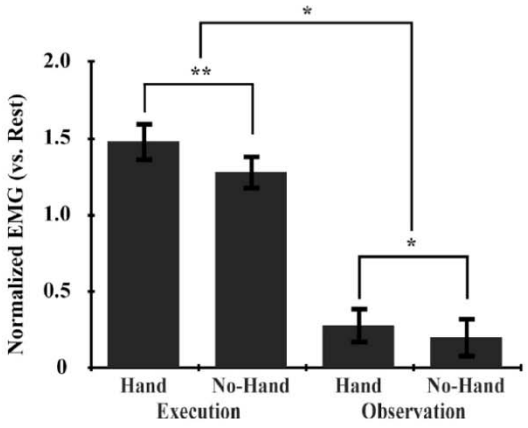
Neural Networks of automatic mimicry

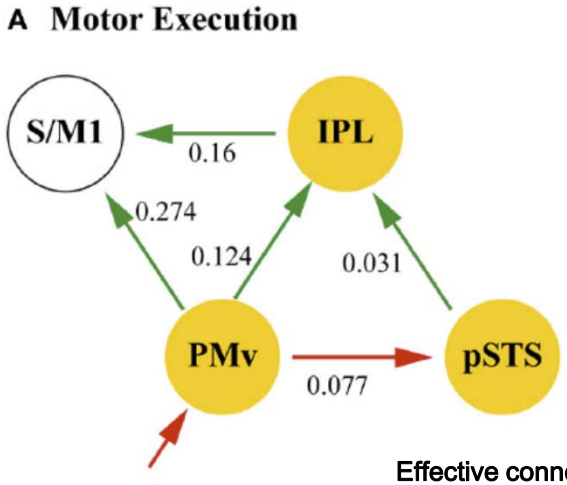
Constituting 2 x 2 (Execution x Hand observation) factorial design

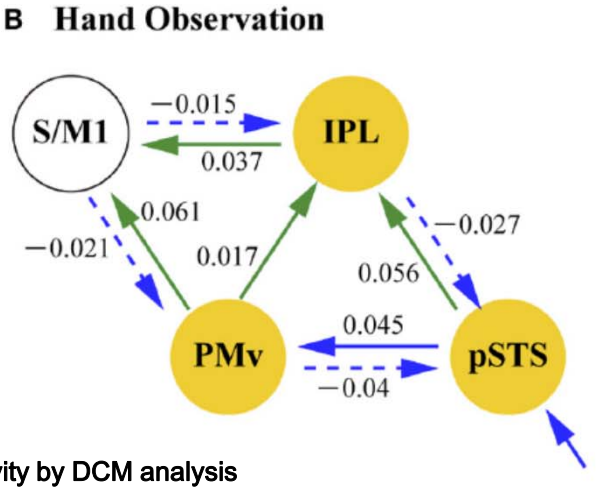












Effective connectivity by DCM analysis

Action representation implemented as the dynamic interaction of putative mirror neuron system and the primary sensori-motor cortex (Sasaki et al. 2012)

Development of social cognition

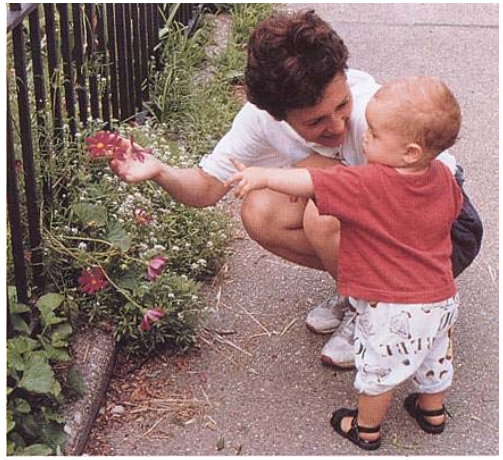
age	milestone behavior
0 m	neonatal imitation
4 m	social contingency
9 m	joint attention
1.5 y	self recognition
4.5 y	theory of mind
school	metaphor / sarcasm
	white lie
	moral
	empathy
	prosocial behavior

Joint attention

- To coordinate attention
- between interactive social partners
- with respect to objects
- to share an awareness of the objects

Joint attention

- Emerges around 6 to 12 months of age
- Through eye gaze
- Precursor of Theory of Mind
- Essential for language acquisition
- Lack of JA is an early sign of autism
- Eye-contact is prerequisite for JA



Eye-contact and JA play an important role for typical development of social behavior

Live interaction is critical for language acquisition

a Foreign-language exposure

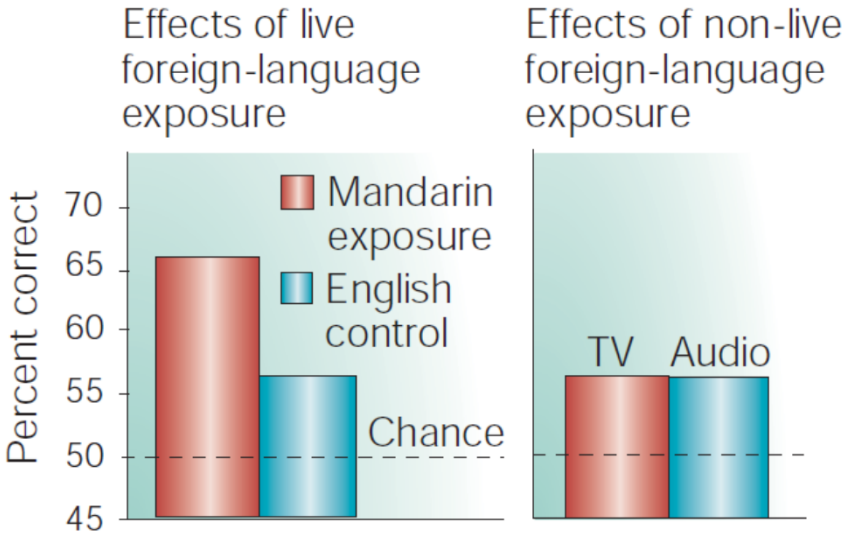
Live exposure

Auditory or audiovisual exposure

b Phonetic perception test

Head-turn procedure
Test stimuli: Mandarin Chinese phonetic contrast

c Phonetic learning



- 9 m.o. infants
- Exposure to Mandarin (L2)
- Learned from live exposure,
- Not from video exposure

(Kuhl, 2004)

Eye-contact

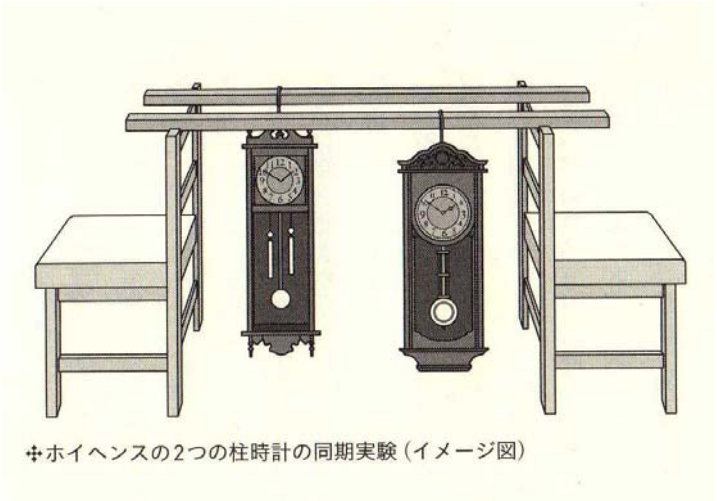
- Sharing psychological states (Travarthen, 1979)
  - intention (I am looking at you)
  - attention (I am paying attention to you)
  - emotion (proto-conversation)

Making inter-subjectivity possible

How to depict the neural substrates of “sharing”

Synchronization as the result of interaction of multiple systems

C. Huygens (1629-1695)



✣ホイヘンスの2つの柱時計の同期実験（イメージ図）

非線形問題解決集団
池口研究室
NONLINEAR DYNAMICAL SYSTEM

メトロノーム同期 (2個，大)
Synchronization of two metronomes (Large)

2010年10月11日，池口研究室にて撮影
Filmed at Ikeguchi Laboratory, on October 11, 2010.

How to depict the neural substrates of “sharing”

- Perspect of individual brain function
  （Llinas, 2001)
  - Input-output system
    - Driven by interaction with the external world
    - External factors determine the system operation
    - Similar inputs produce similar output
    - Regular task-related functional MRI
  - Operating-on-its-own system
    - Intrinsically driven
    - External factors modulate system operation
    - Studies of spontaneous activity for the evaluation of functional connectivity (inter-regional correlation)

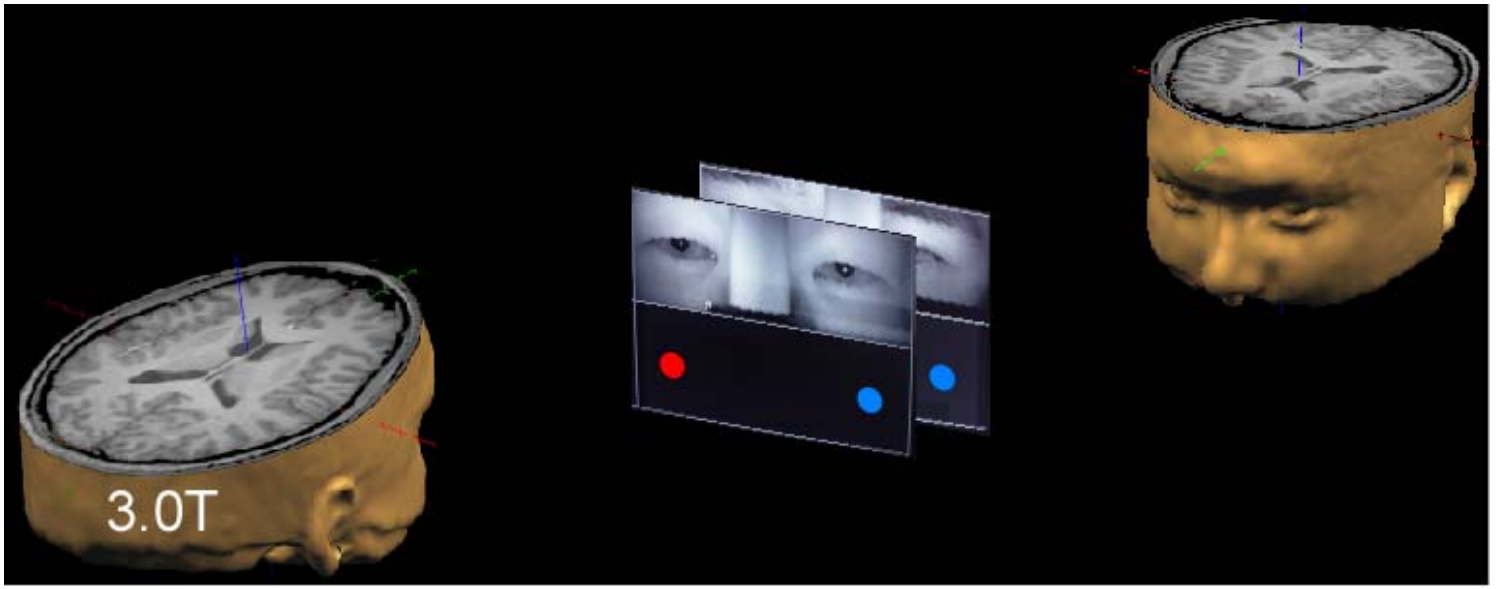
How to depict the neural substrates of “sharing”

- Perspect of paired brain function
  （Llinas, 2001)
  - Input-output system
    - Driven by interaction with the external world
    - External factors determine the system operation
    - Similar inputs produce similar output
    - Regular task-related functional MRI: difficult to depict pair specific findings (because tasks are common)
  - Operating-on-its-own system
    - Intrinsically driven
    - External factors modulate system operation
    - Studies of spontaneous activity for the evaluation of functional connectivity (inter-**subject** correlation)

Our approach to the neural substrates of joint attention & eye contact

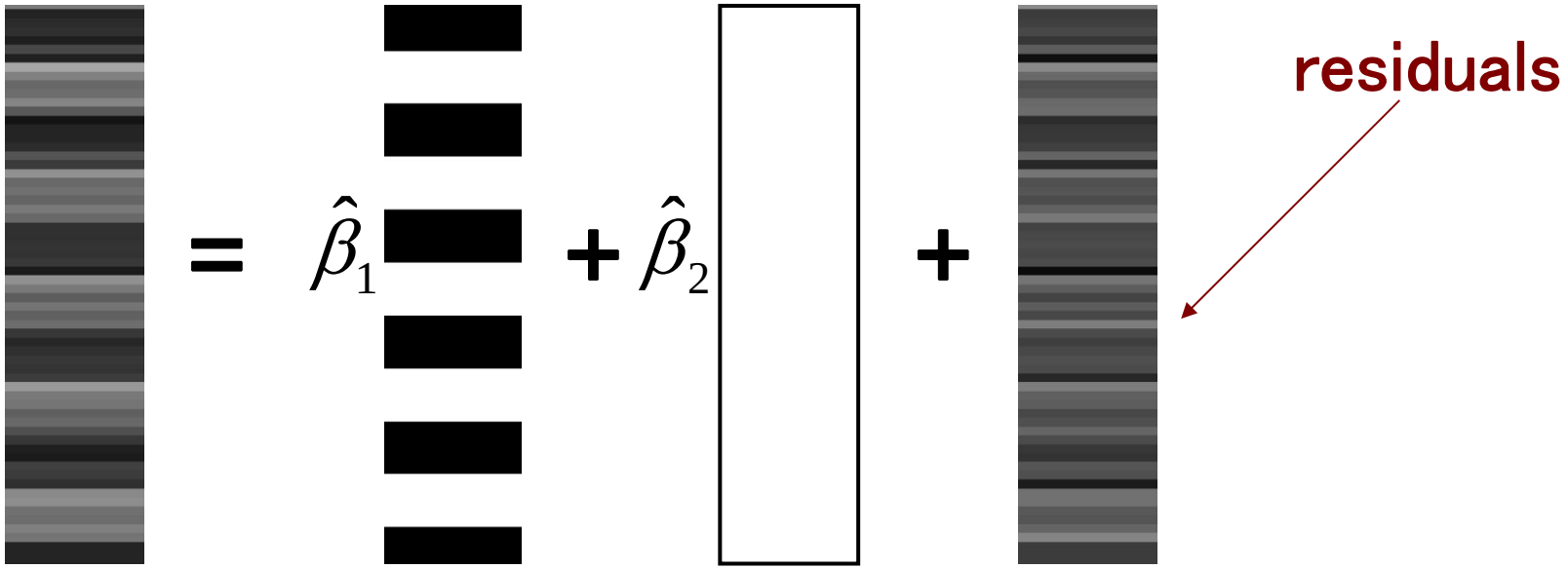
- **Joint attention**
  - Eye-cue based input-output system
- **Eye contact**
  - Synchronization of two “Operating-on-its-own” system
    - Sharing psychological states
    - Inter-subjective synchronization of the residual time series after model-out of the task-related activity

Hyperscanning fMRI during joint attention task



Using Dual fMRI system (prototype: 3.0T – 1.5T @Fukui Med School)

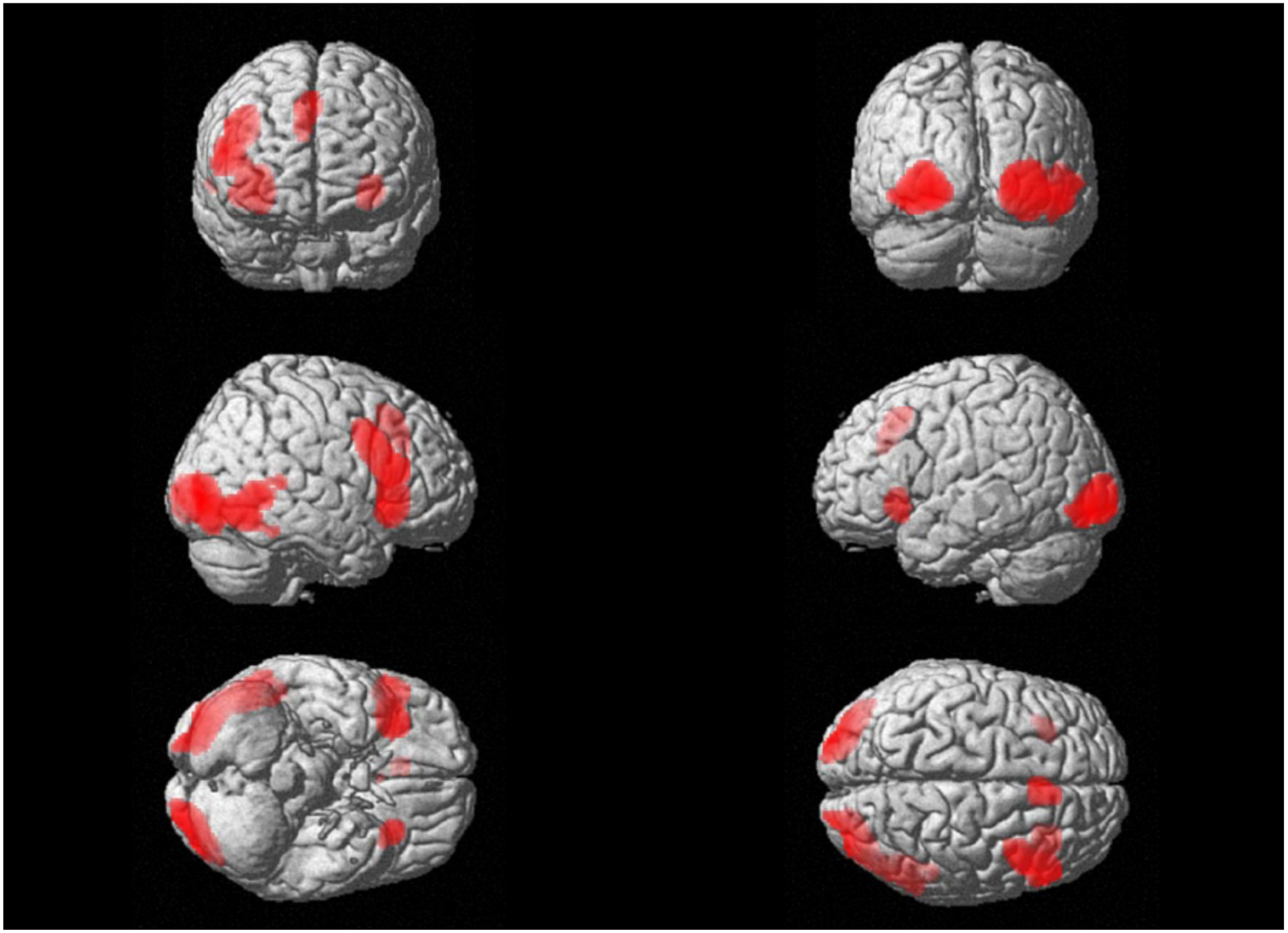
How to obtain *state-related* activities



$$Y = \hat{\beta}_1 x_1 + \hat{\beta}_2 x_2 + \hat{\varepsilon}$$

The residual time series after model-out of the task-related

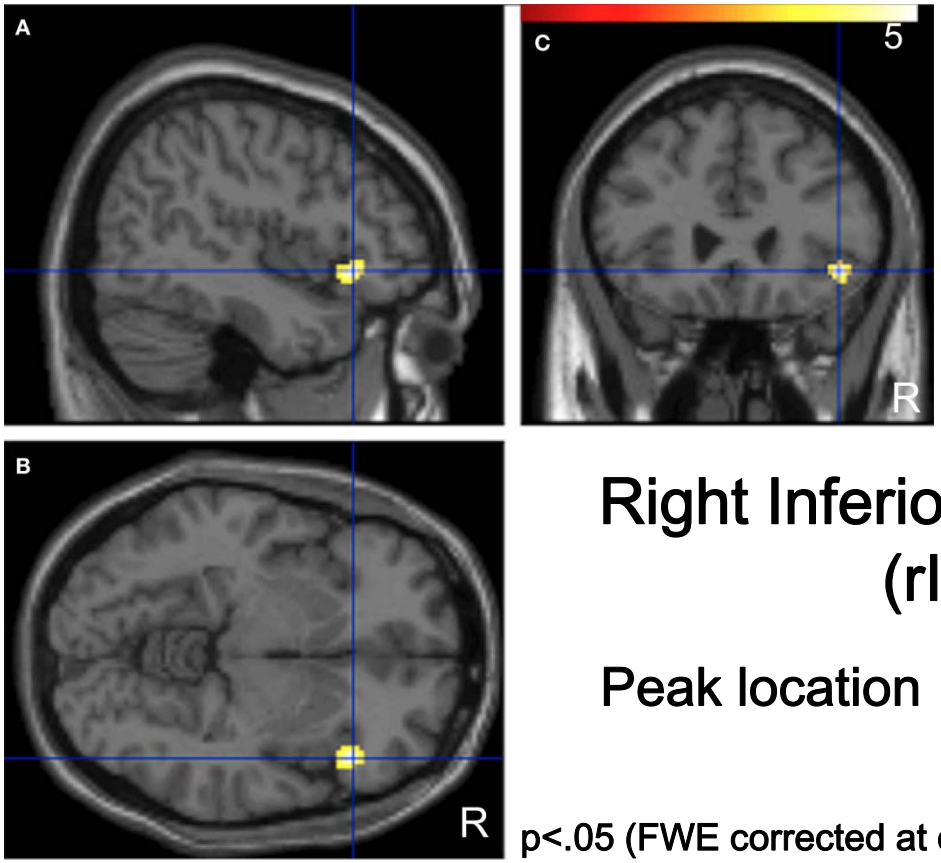
Eye Cue effect (Eye – Object)



P<0.05 FWE corrected

Inter-subject correlation in the rIFG

High correlation in pair (Pair – NonPair)



Right Inferior frontal gyrus (rIFG)

Peak location (46,26,-6)

p<.05 (FWE corrected at cluster level)

Saito & Tanabe et al (2010)

Questions

- What does the synchronization represent?
- Could the synchronization be learned?
- What is the role of the right IFG?

Blink

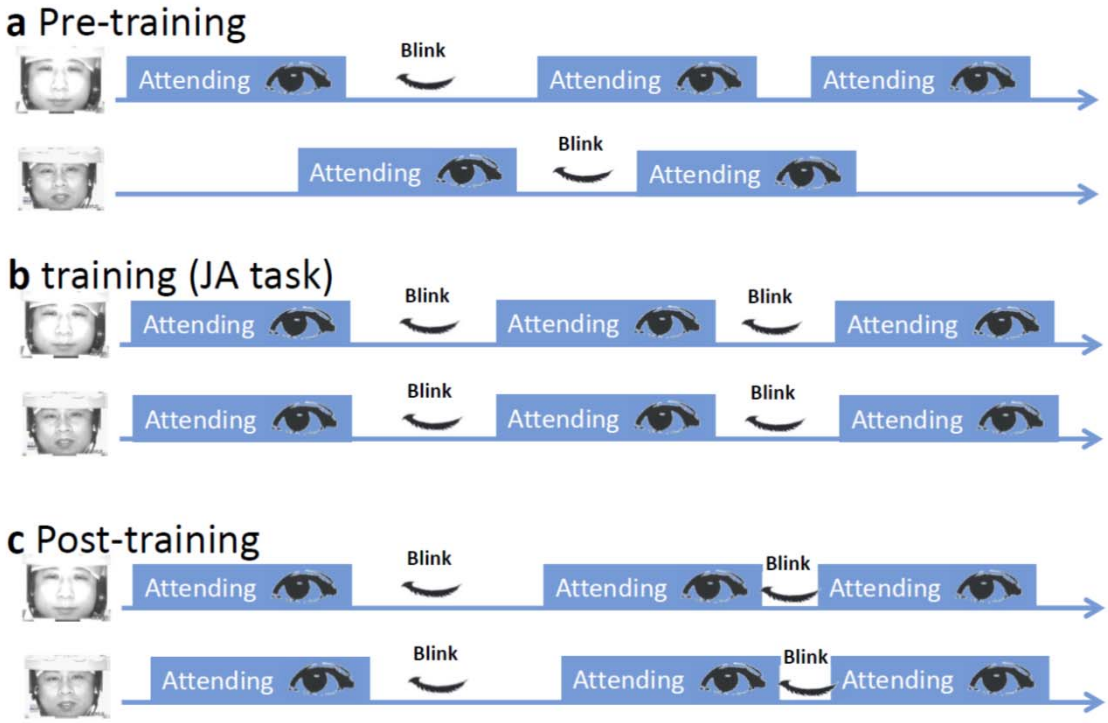
- Blink of the speaker and listener are entrained at the pause of the conversation

  （Nakano and Kitazawa, 2010）

- → Synchronization of blink may represent the shared attention

Hypothesis

- Joint attention synchronizes the attentional window
- Joint attetntion task enhances shared attention through Hebbian learning
- Right IFG is where Hebbian learning occurs



Serial hyperscanning fMRI (mutual gaze –JA mutual gaze)
To evaluate the inter-subject connectivity *per se*

Day 1

Day 2

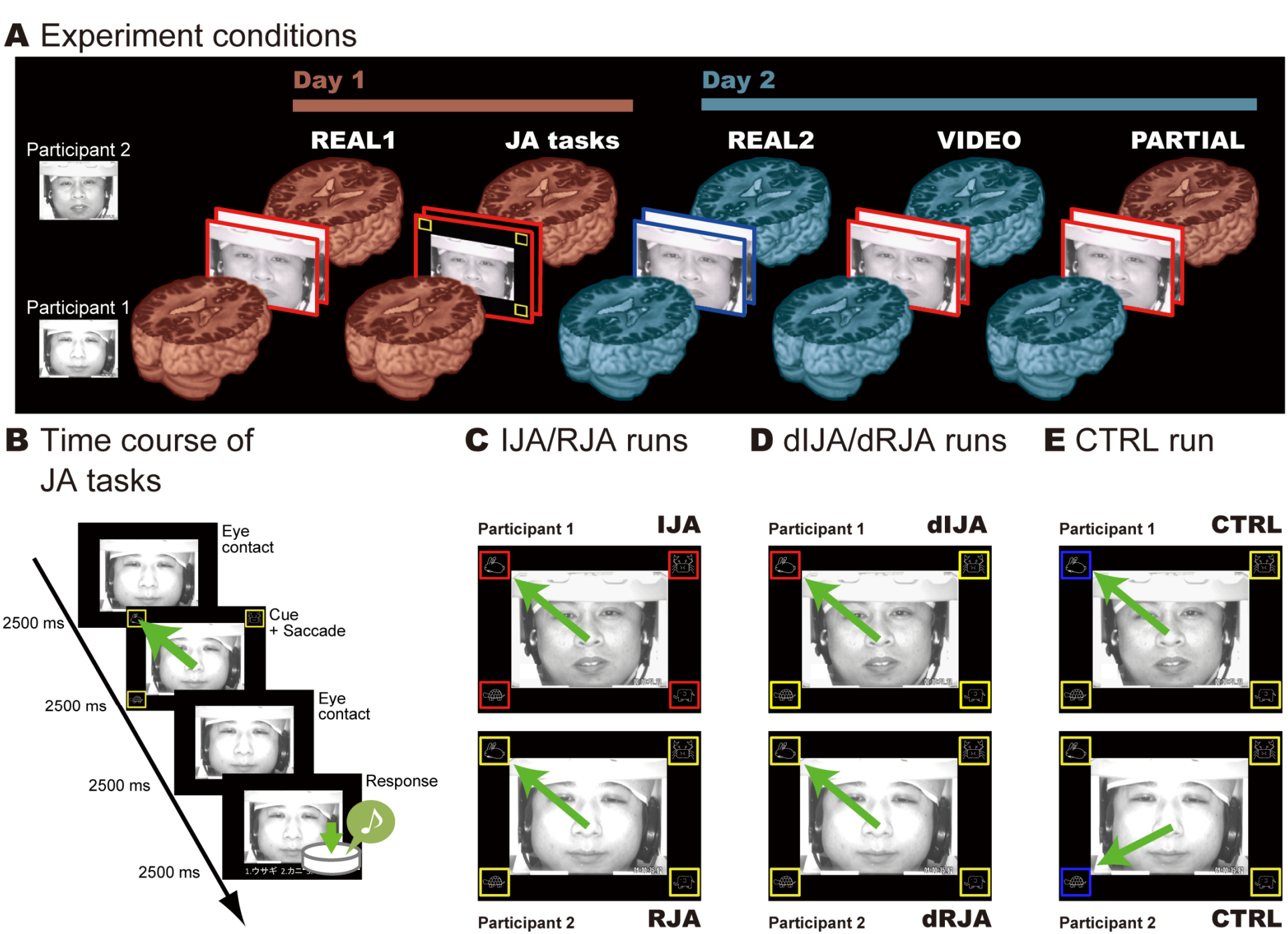
Live mutual gaze

JA tasks

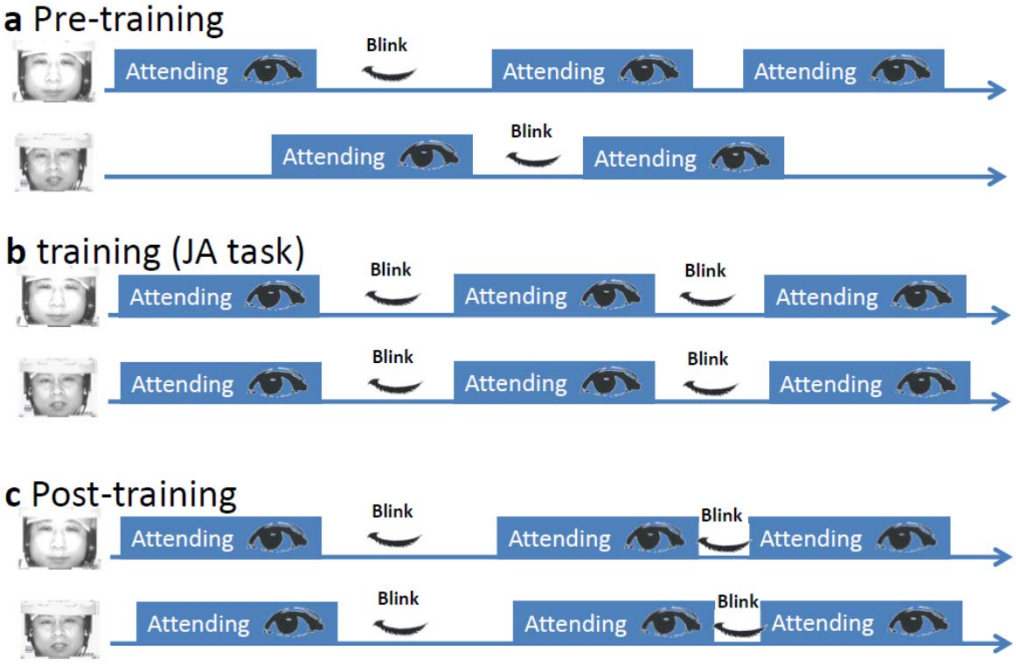
Live mutual gaze
+
Control condition (video)

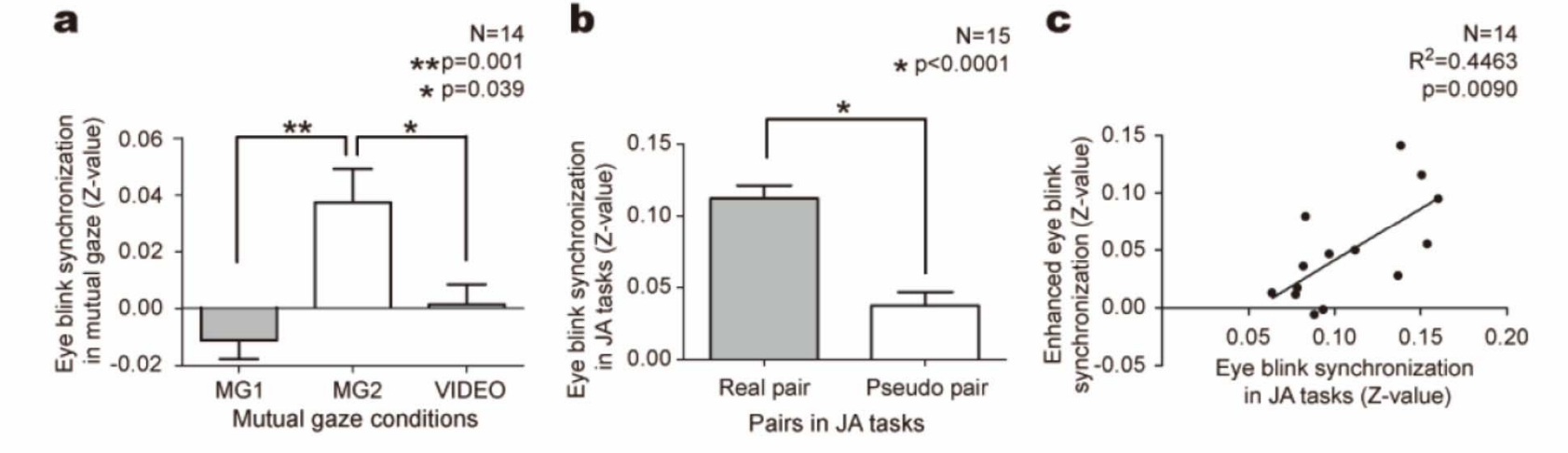
Using Hyperscanning fMRI system (3T-3T) @ Okazaki

Expectation

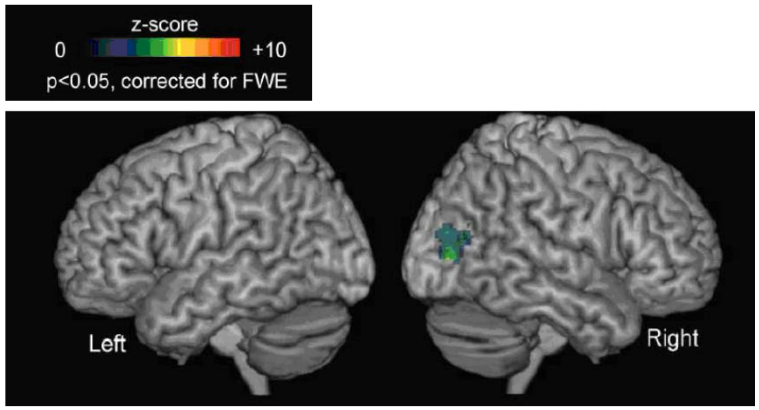

A Experiment conditions
Day 1
Day 2
REAL1
JA tasks
REAL2
VIDEO
PARTIAL
Participant 2
Participant 1
B Time course of JA tasks
Eye contact
Cue + Saccade
Eye contact
Response
2500 ms
2500 ms
2500 ms
2500 ms
C IJA/RJA runs
D dIJA/dRJA runs
E CTRL run
Participant 1
IJA
Participant 2
RJA
Participant 1
dIJA
Participant 2
dRJA
Participant 1
CTRL
Participant 2
CTRL

Enhanced blink synchronization during JA
Persisted at post-training mutual gaze

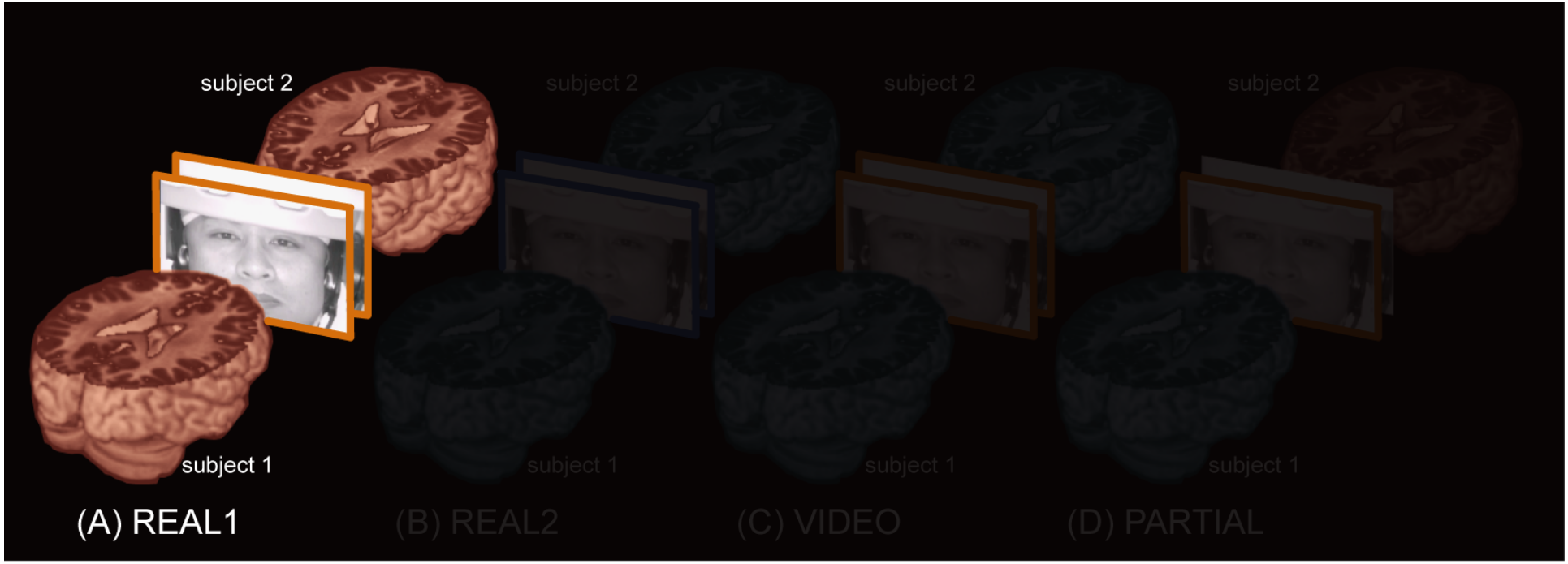




Real mutual gaze condition day 1 (REAL1)

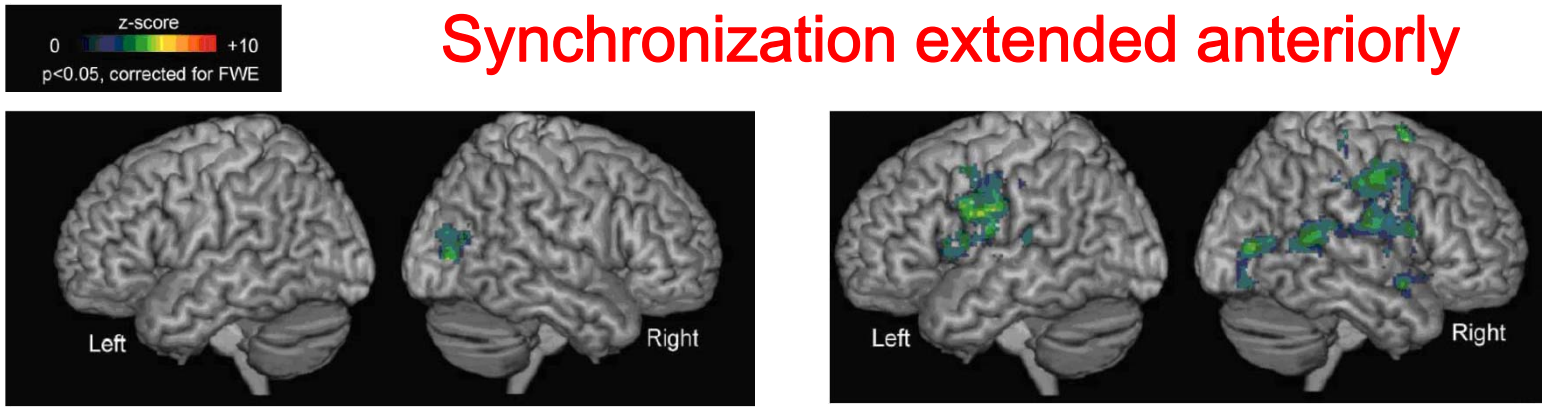


Synchronization confined to the right MTG



Real mutual gaze condition day 2 (REAL2)

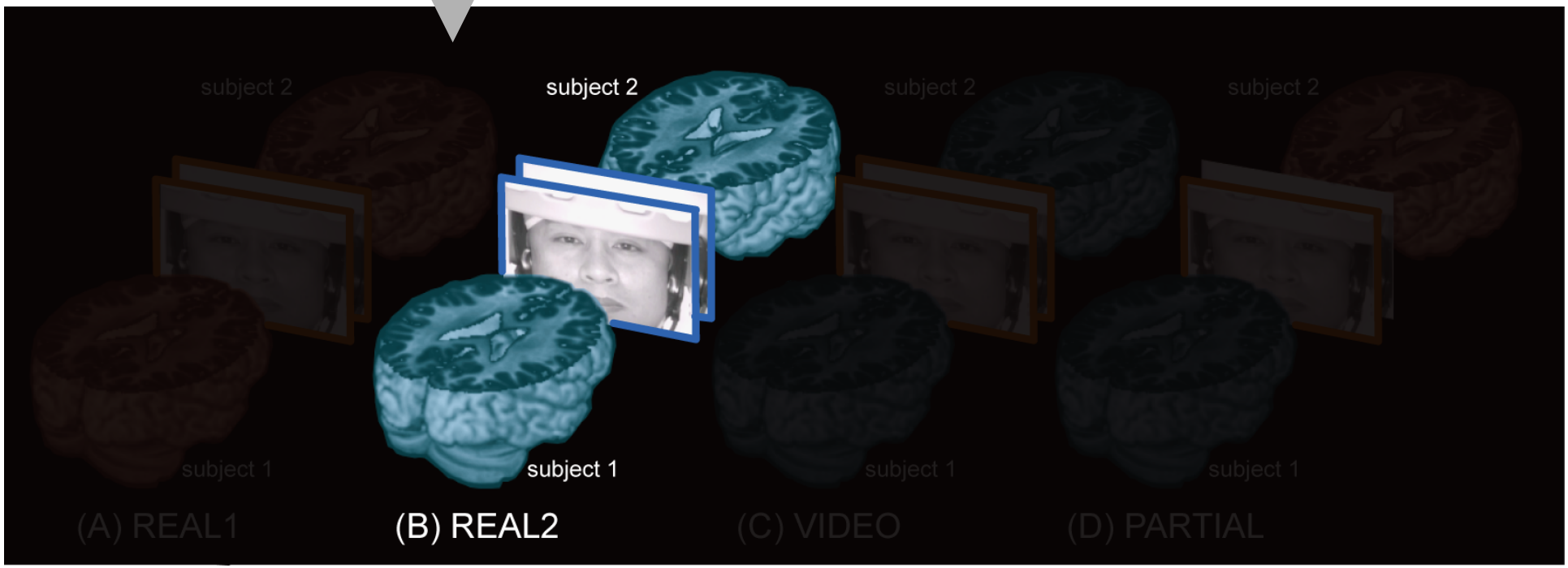
Synchronization extended anteriorly



Day 1

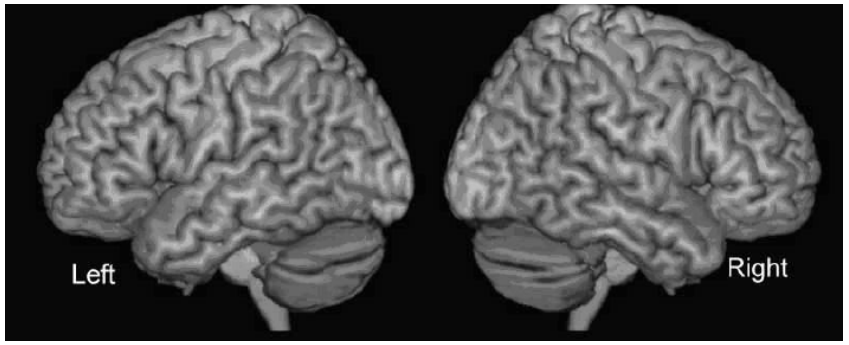
JA task Day 1

Day 2



Fake mutual gaze condition day 2 (VIDEO)

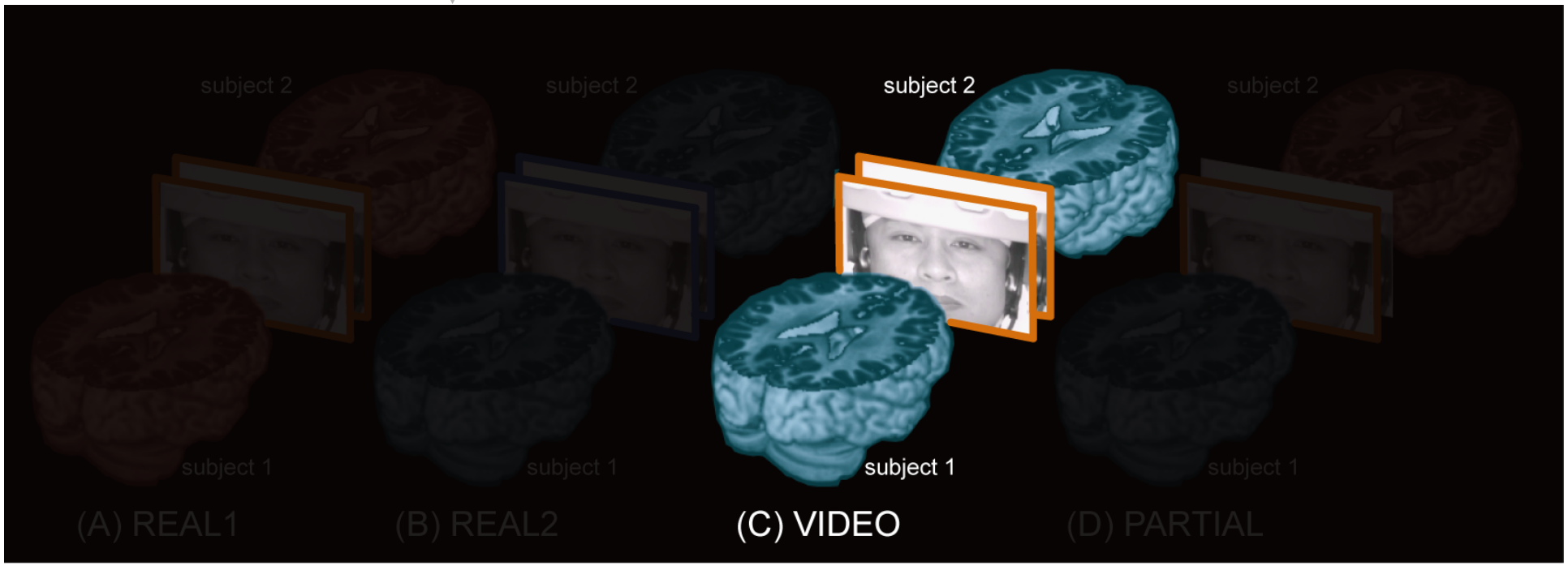
No synchronization through VIDEO



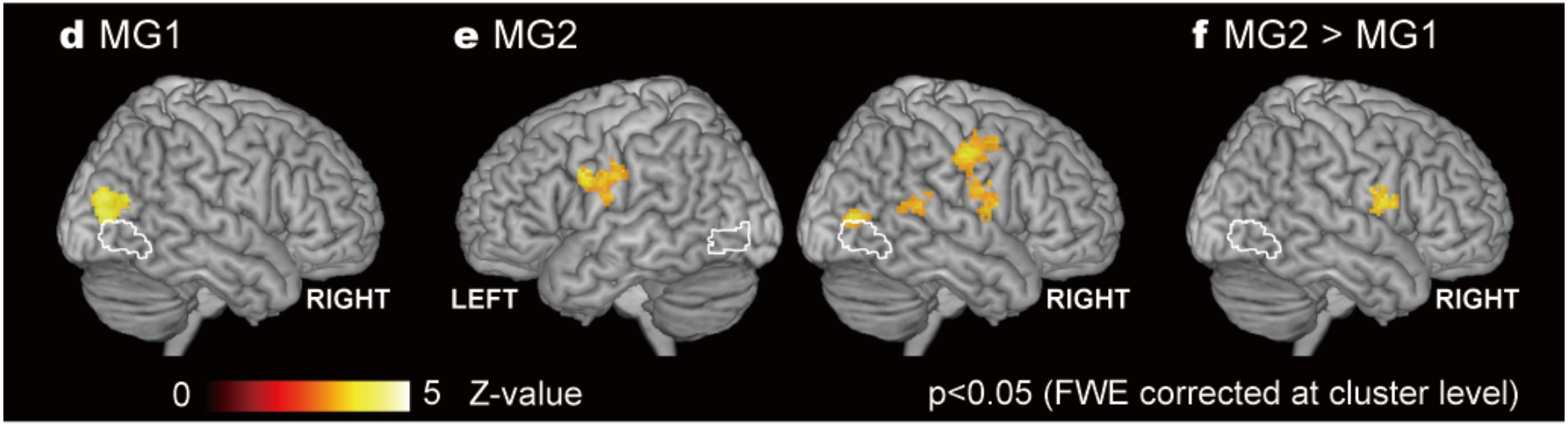
JA task Day 1

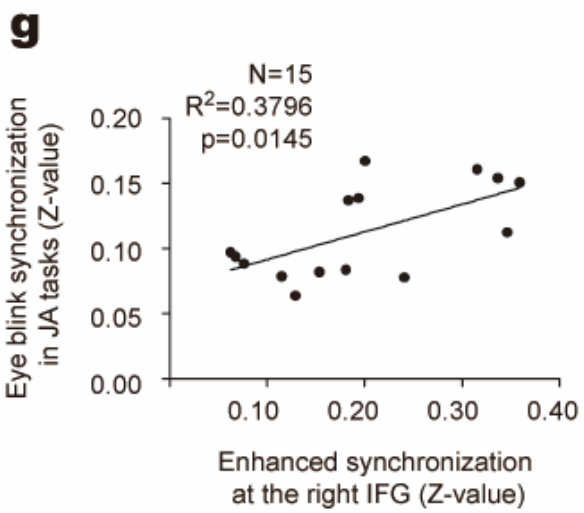
Day 1

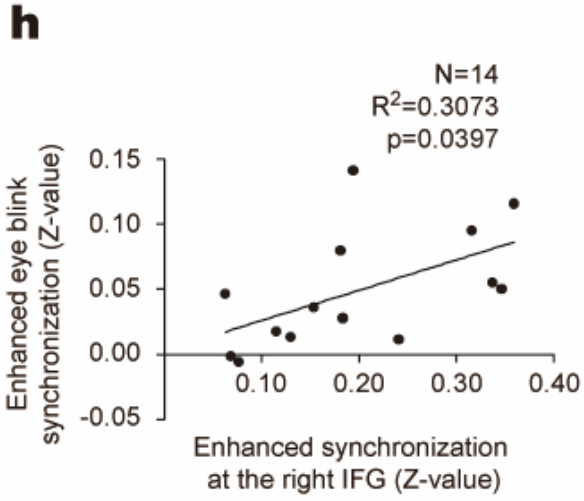
Day 2

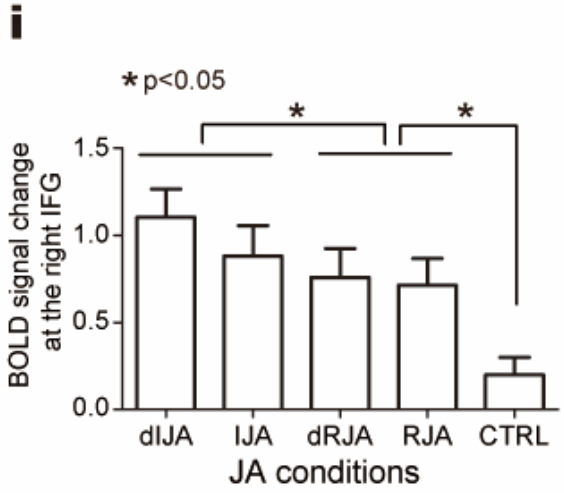


Neural synchronization of the right IFG represents enhanced sharing attention









Koike & Tanabe et al. (submitted)

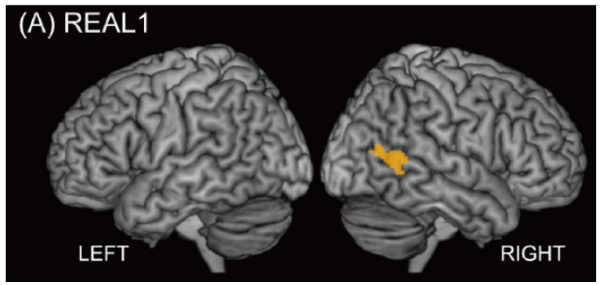
No JA, no change in synchronization

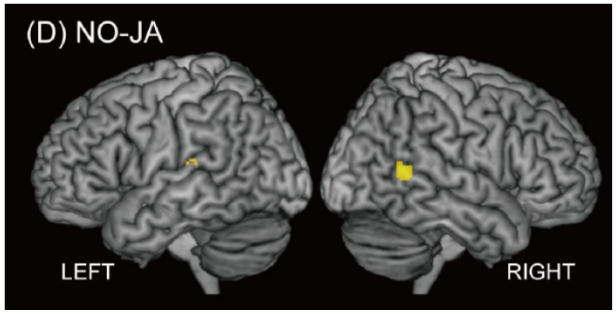
Day 1 | **Day 2**

Live mutual gaze

~~JA tasks~~

Live mutual gaze





Anteriorly extended synchronization is JA specific

With different partner, no change in synchronization

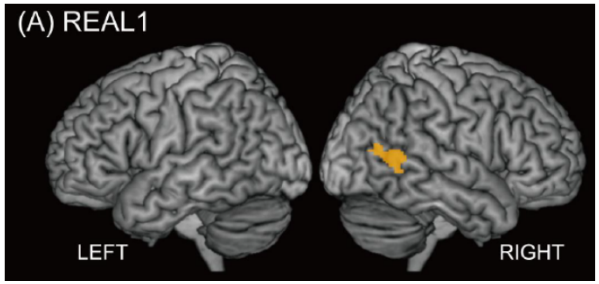
Day 1 | **Day 2**

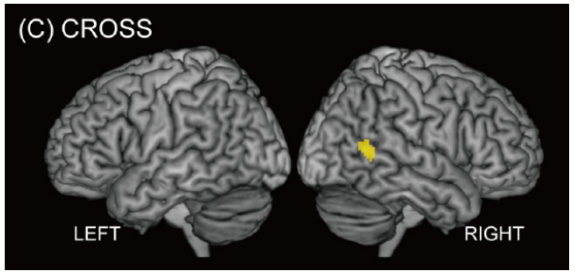
Eye contact

JA tasks

Eye contact

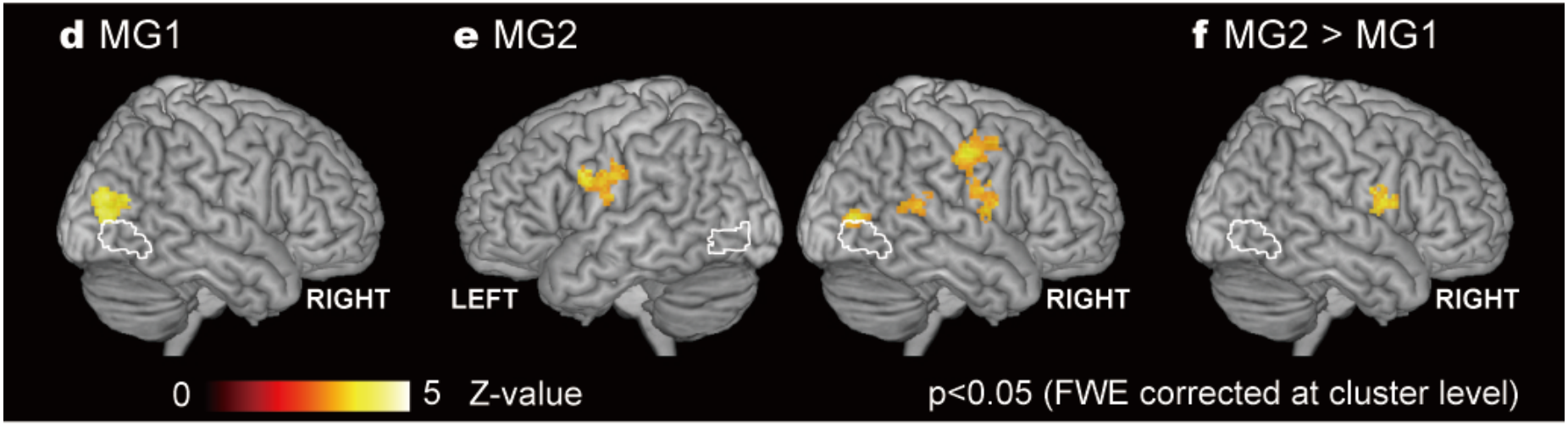
With different partner

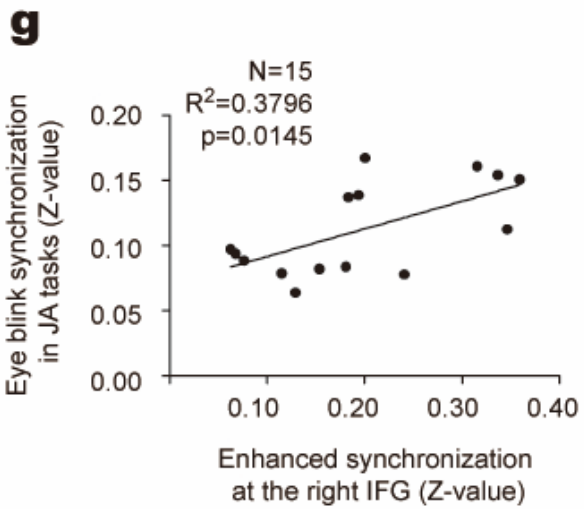


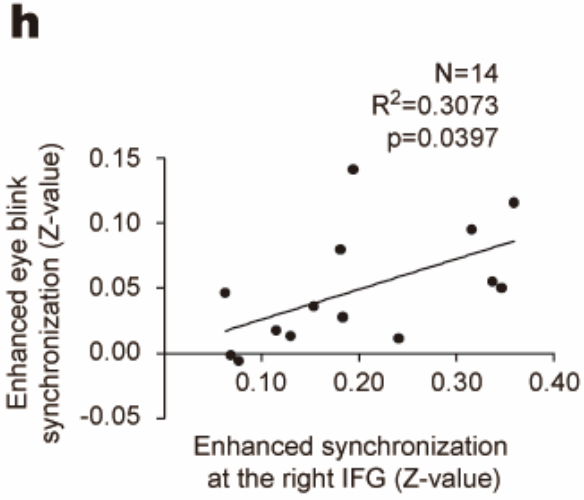


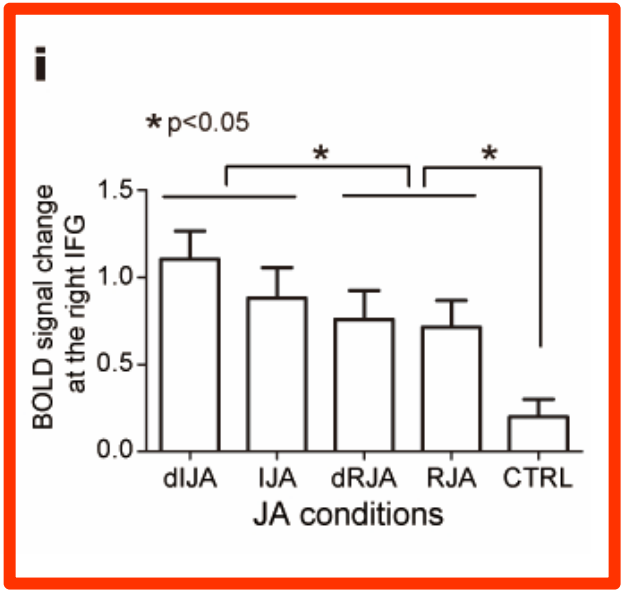
Anteriorly extended synchronization is partner specific

Neural synchronization of the right IFG represents enhanced sharing attention



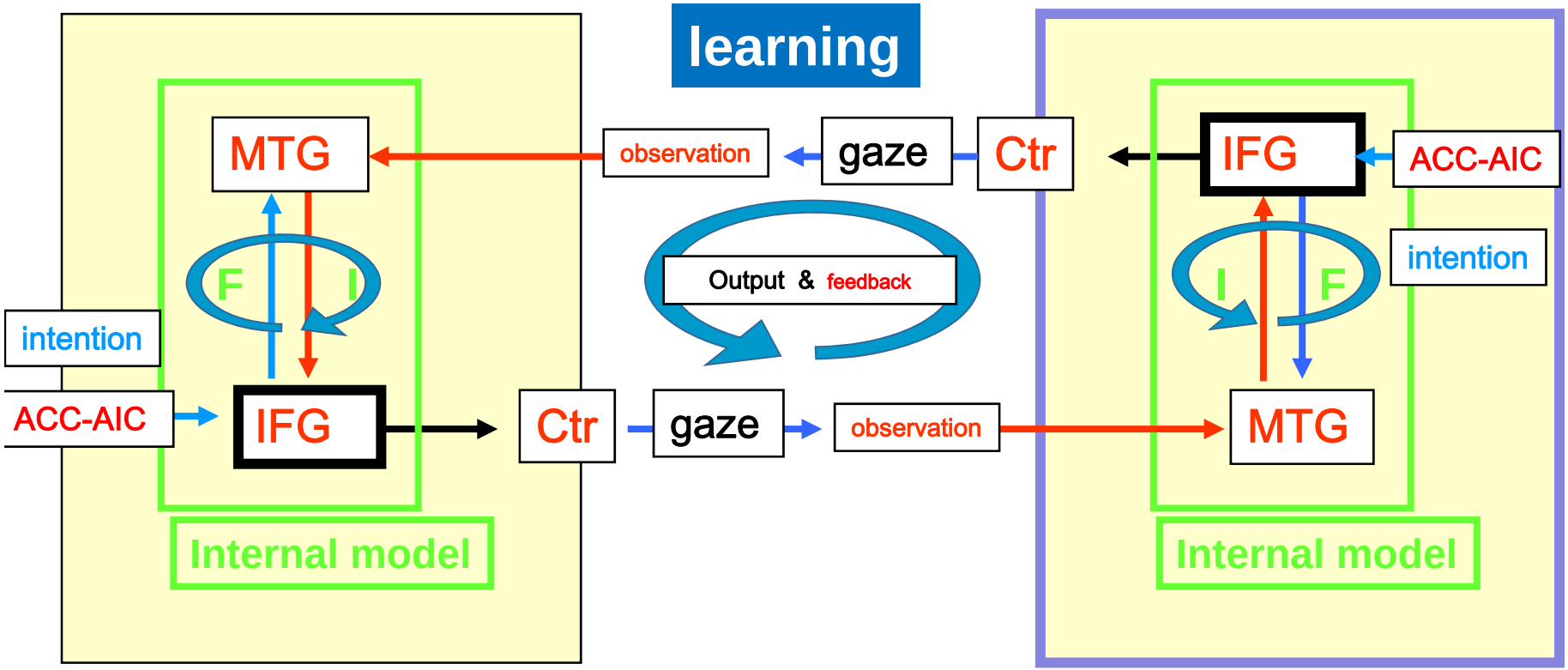






Koike & Tanabe et al. (submitted)

“Sync” model representing inter-subjectivity during face-to-face communication

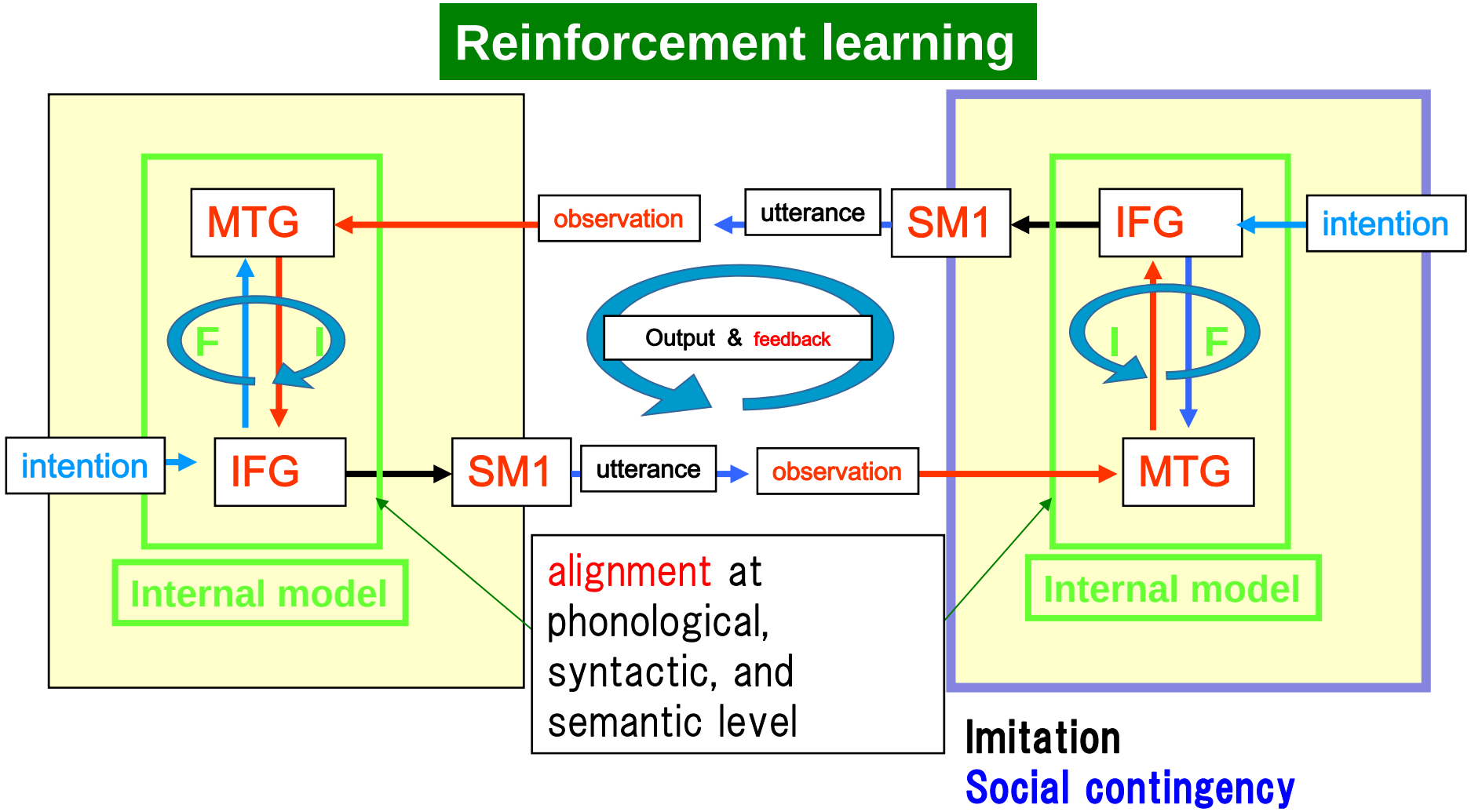


Sharing attention is established by the internal model formation through *cross-individual Hebbian learning* during joint attention task

Summary

Hyperscanning functional MRI showed the inter-brain effect of enhanced sharing attention emerged from the joint attention that cannot be reduced to the individual.

Extension to the dialogue and linguistic learning



Shared action representation of language formed in BA that includes the third object

Development of social cognition

age	milestone behavior
0 m	neonatal imitation
4 m	social contingency
9 m	joint attention
1.5 y	self recognition
4.5 y	theory of mind
school	metaphor / sarcasm
	white lie
	moral
	empathy
	prosocial behavior

https://www.youtube.com/watch?v=1KppOC33Mfw

Thank you for your attention!