

Domain-General and Domain-Specific Patterns of Activity Supporting Metacognition in Human Prefrontal Cortex

Jorge Morales, Hakwan Lau, Stephen M. Fleming

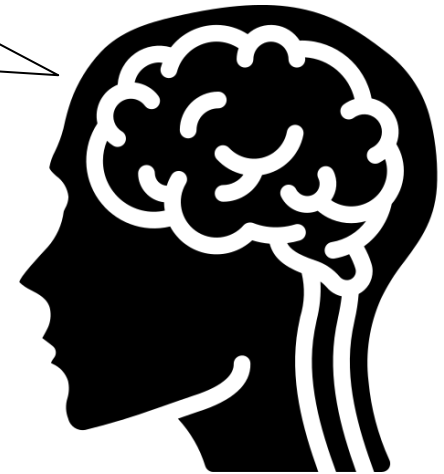
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Introduction

Metacognition the knowledge of one's cognitive process

Did I do well?

How confident am I that I was correct/right?



Objective Performance

Subjective Confidence

Introduction

Gap

- The neurocognitive architecture supporting metacognition
 - domain-general vs domain specific

Goal of the study

- Reveal coexistence of domain-general and domain-specific representation of metacognition.

Method

Participants

- 30 healthy subjects
- 24 subjects analyzed

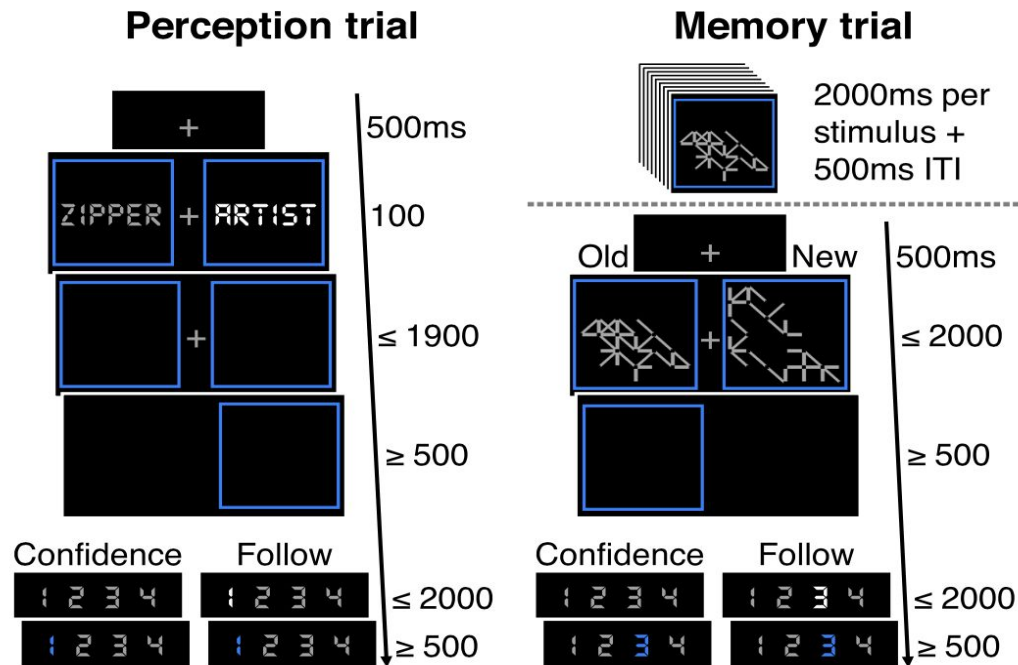
Experimental and task design

- Two-alternative forced choice (2-AFC)
- 2 x 2 x 2 design:
 - condition (confidence/follow)
 - task domain (perception/memory)
 - stimulus type (shapes/words)
- 6 runs, 8 of 9-trial miniblocks
→ total 432 trial

	Perception	Memory
word [9-trial of miniblock	9-trial of miniblock
	9-trial of miniblock	9-trial of miniblock
shape [9-trial of miniblock	9-trial of miniblock
	9-trial of miniblock	9-trial of miniblock
word [9-trial of miniblock	9-trial of miniblock
	9-trial of miniblock	9-trial of miniblock
shape [9-trial of miniblock	9-trial of miniblock
	9-trial of miniblock	9-trial of miniblock
	1 run	1 run

Method

Task design



Behavioral data analysis

Metacognitive efficiency _ log M-ratio

$$\log \left(\frac{\text{meta-}d'}{d'} \right)$$

d' : Type 1 sensitivity = ability to discriminate one stimulus from another.

meta- d' : metacognitive sensitivity

= ability to discriminate their own correct and incorrect responses

meta- $d' = d'$: ideal observers

meta- $d' < d'$: hypo-metacognitive sensitivity

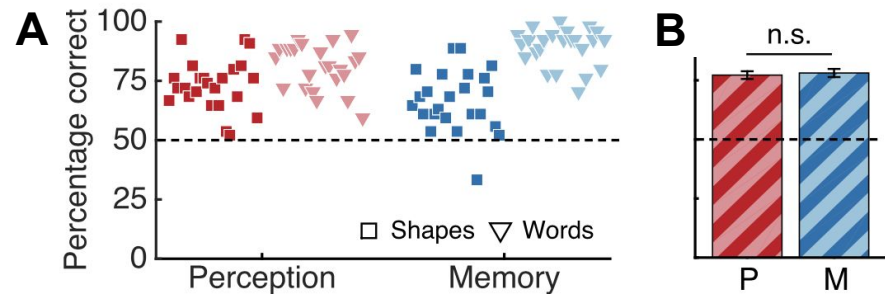
meta- $d' > d'$: hyper-metacognitive sensitivity

(Maniscalco and Lau 2014)

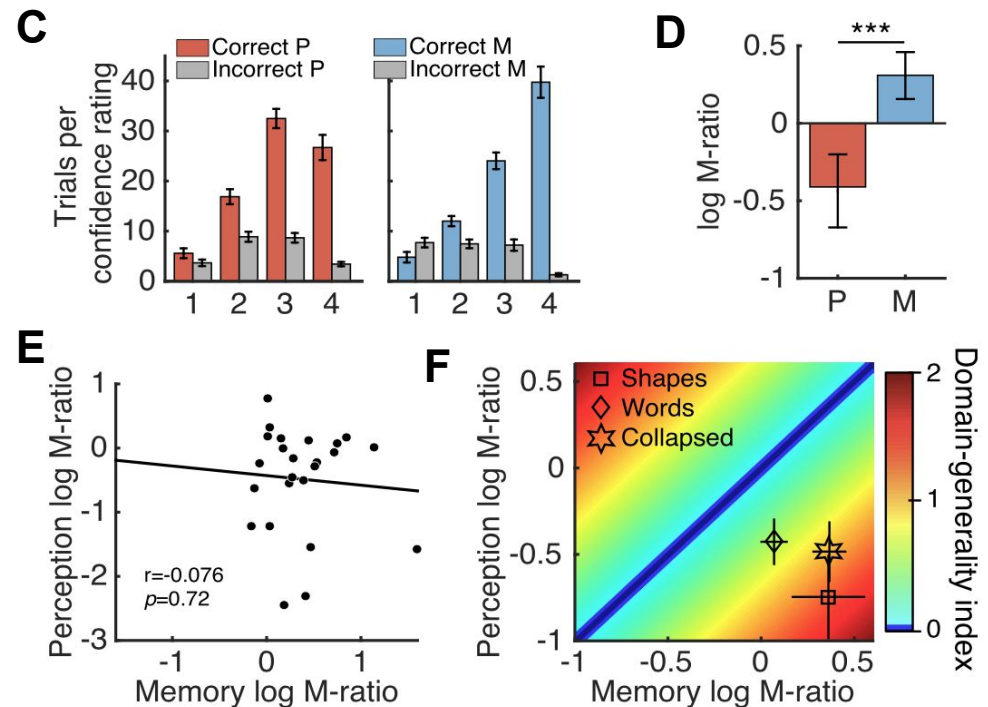
(Fleming and Daw 2017)

Behavioral data analysis

2-AFC Task performance



Metacognitive measures

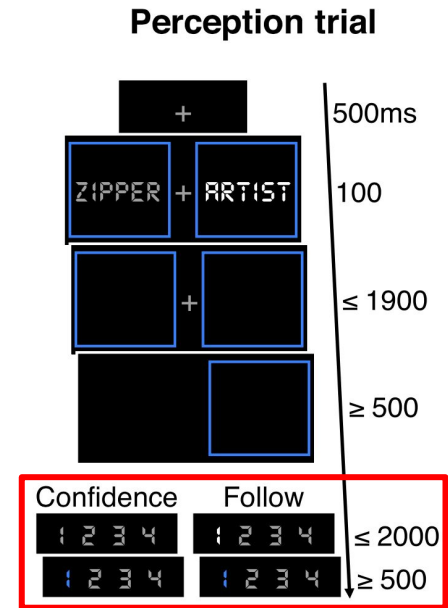


$$DGI = |\log M_P - \log M_M|$$

fMRI analyses

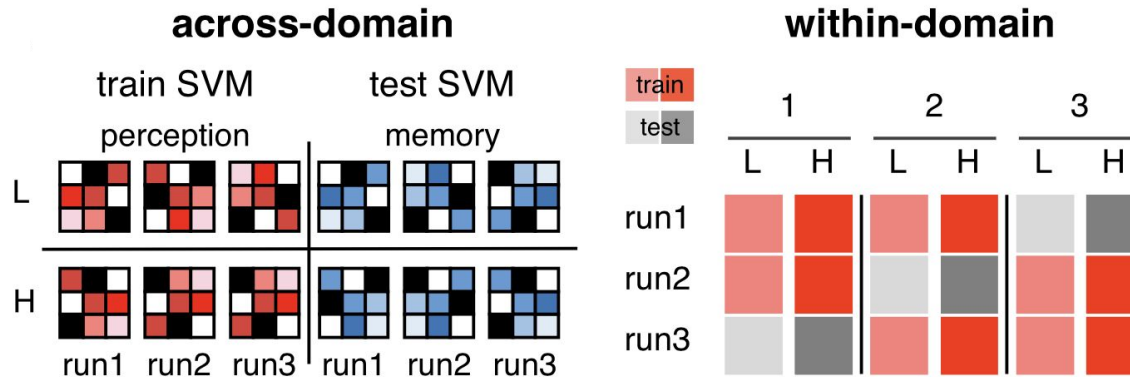
Univariate analysis

- GLM focus on the “rating period” of each trial
- **Judgement-related (JR) analysis**
 - the difference between confidence trials and follow trials
 - the confidence regressor & the follow regressor
- **Confidence-level-related (CLR) analysis**
 - the parametric relationship between confidence ratings (1-4) and neural activity
 - the confidence rating period & parametric modulation of 4 ratings
- ROI analysis from previous literature
 - Fleming et al, 2012: left rostrolateral PFC (L rlPFC), right rlPFC (R rlPFC), dorsal anterior cingulate cortex/presupplementary motor area (dACC/pre-SMA)
 - McCurdy et al, 2013: precuneus (PCUN)



fMRI analyses

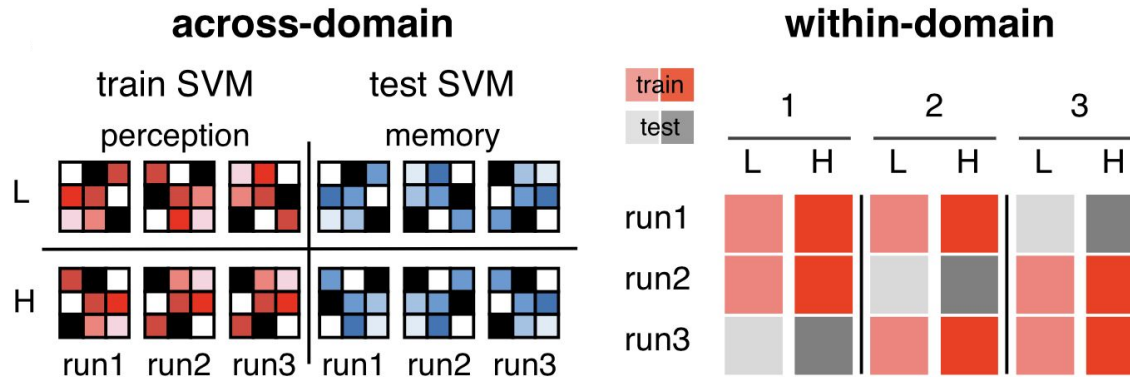
Multivoxel Pattern Analysis



- Judgement-related (JR) analysis
 - the difference between confidence trials and follow trials
- Confidence-level-related (CLR) analysis
 - binary classification of activity patterns: low-confidence category (ratings 1 & 2) / high-confidence category (ratings 3 & 4)

fMRI analyses

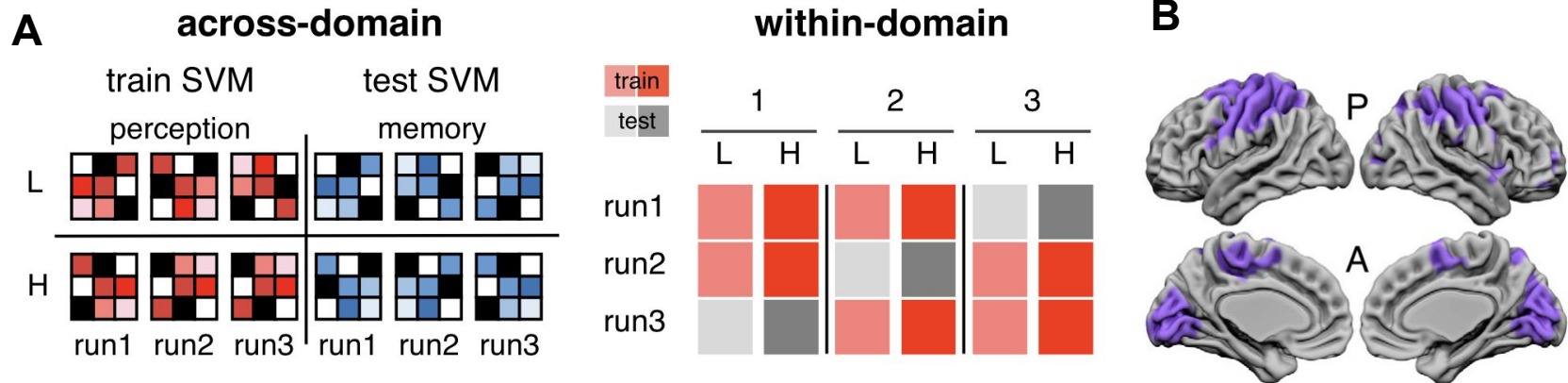
Multivoxel Pattern Analysis



- Support Vector Machine (SVM)
- **ROI analysis**
- **Whole-brain searchlight analysis**
- Across-domain / Within-domain
- The ability of confidence-related activity patterns to predict objective performance

fMRI analyses

Multivoxel Pattern Analysis



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fMRI analyses

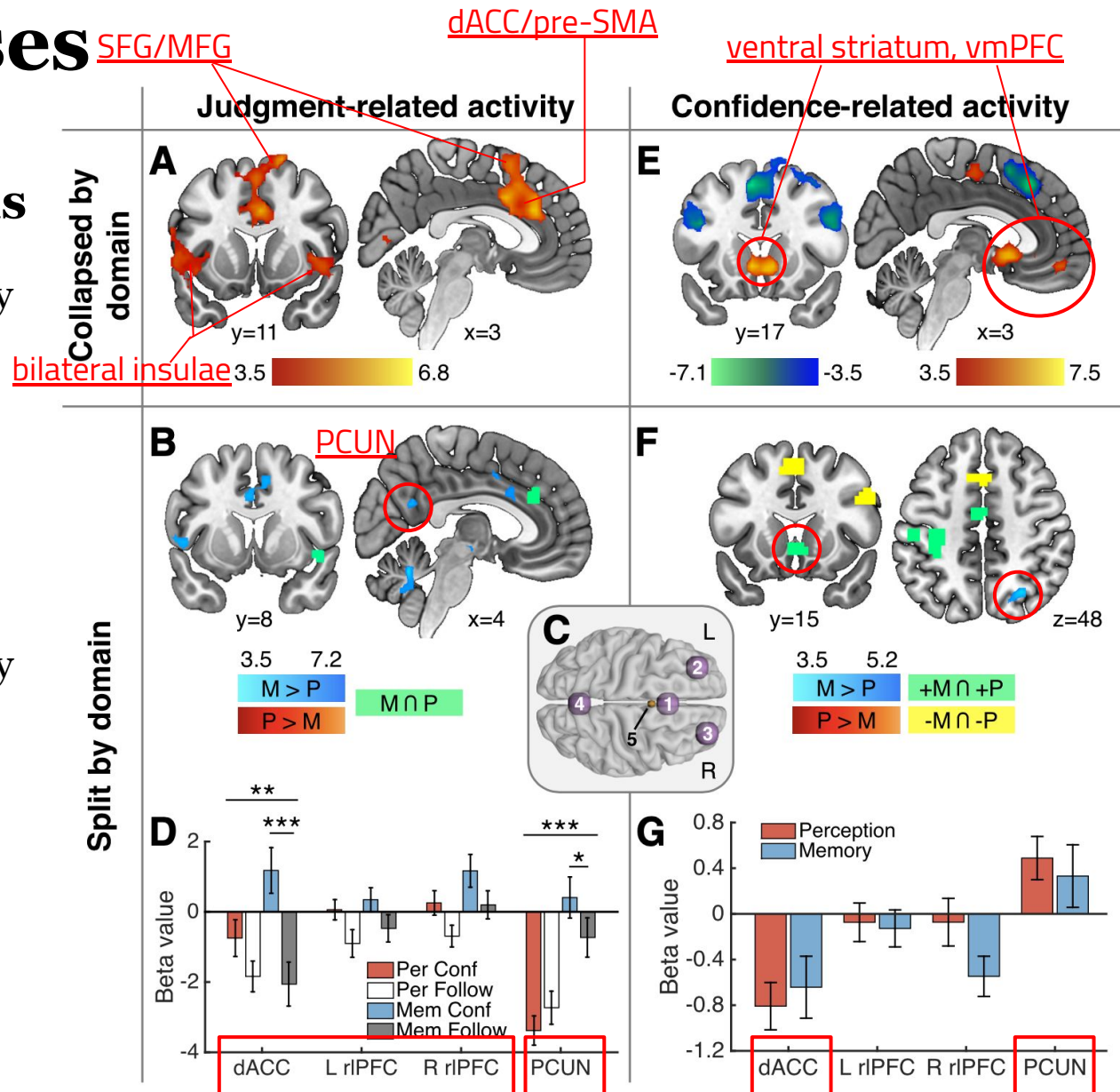
Univariate analysis

Judgement-related activity

- collapsed by domain
- split by domain
- ROI analysis

Confidence-related activity

- collapsed by domain
- split by domain
- ROI analysis



fMRI analyses

Multivoxel Pattern Analysis

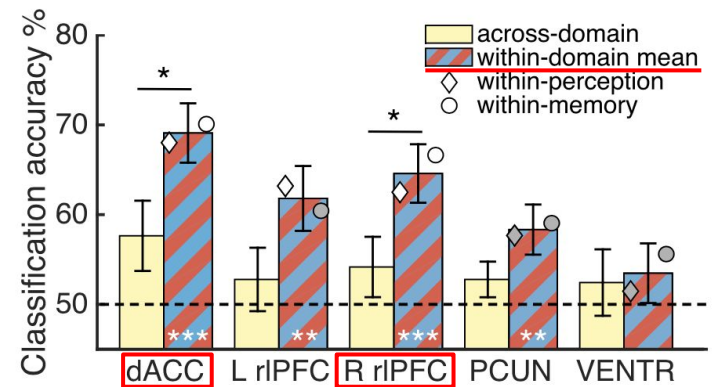
ROI analysis

- if domain general :
decoder in **perceptual trials**
→ **memory trials** (and vice versa)

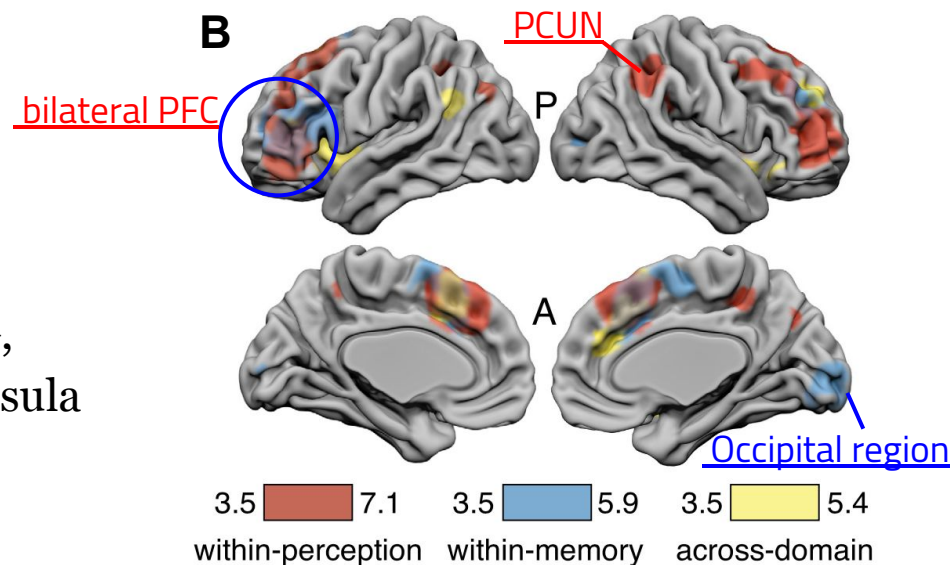
Searchlight analysis

- Within-domain
- Across-domain: dACC/pre-SMA, SFG, supramarginal gyrus, bilateral IFG/insula

A Judgment-related activity patterns



B



fMRI analyses

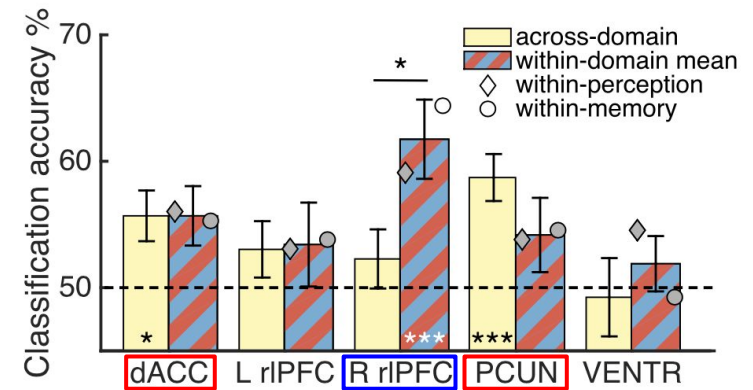
Multivoxel Pattern Analysis

ROI analysis

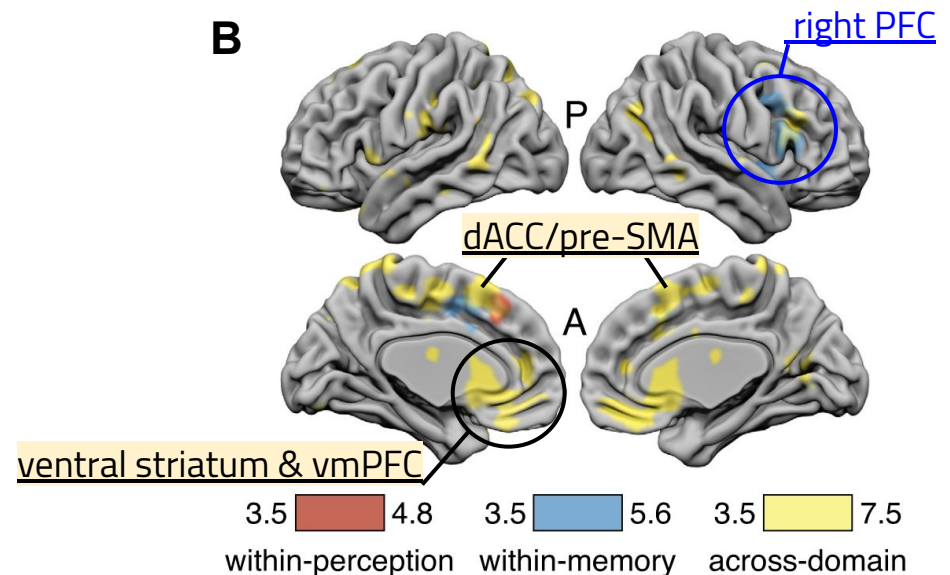
- if confidence level is domain general:
decoder to discriminate low (1-2) from
high (3-4) confidence rating patterns in
perceptual trials
→ **memory trials** (and vice versa)

Searchlight analysis

A Confidence-related activity patterns



B

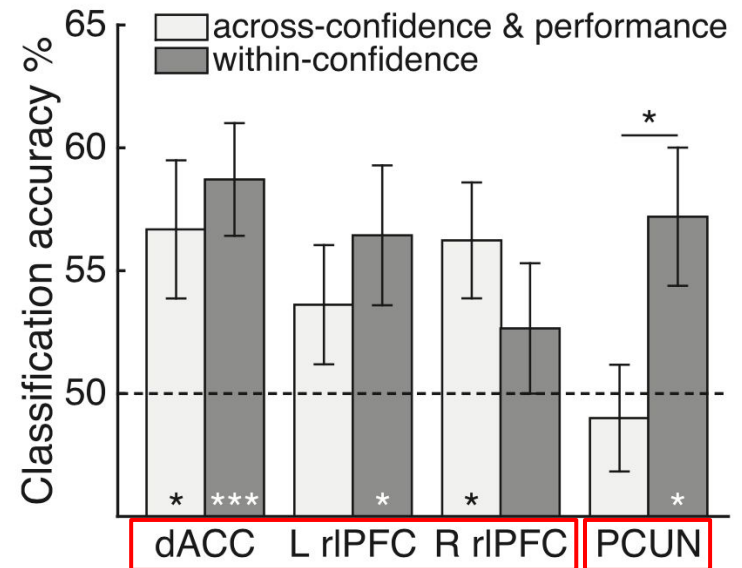


fMRI analyses

Multivoxel Pattern Analysis

Generalization of CLR activity to objective performance

- the relationship between objective task accuracy & confidence
- if the relationship exists:
decoder trained by CLR activity patterns
→ objective performance-related activity patterns
(and vice versa)



Discussion

Findings

- 1) convergent evidence from both univariate and multivariate analyses:
dACC/pre-SMA encodes a general signal predictive of confidence level and objective accuracy across memory and perceptual tasks.
- 2) In lateral anterior frontal cortex, activity patterns both for metacognitive judgements and level of confidence
 - lateral PFC
 - right rlPFC
- 3) convergent evidence that PCUN plays a specific role in metamemory judgements
- 4) domain-general signals in the ventral striatum and vmPFC were modulated by confidence level

Discussion

Limitations

- 1) Intertask leaks in confidence
 - favor domain-general confidence related patterns.

- 2) Assumption that visual perception and memory are distinct domains.
 - different modalities / difference aspects within single modality
 - closely related modalities could be part of a unified perceptual domain for metacognitive purposes.
 - further studies required

My interest

Metacognition modeling (Fleming and Daw 2017)

- First-Order Model / Postdecisional Model / Second-Order Model

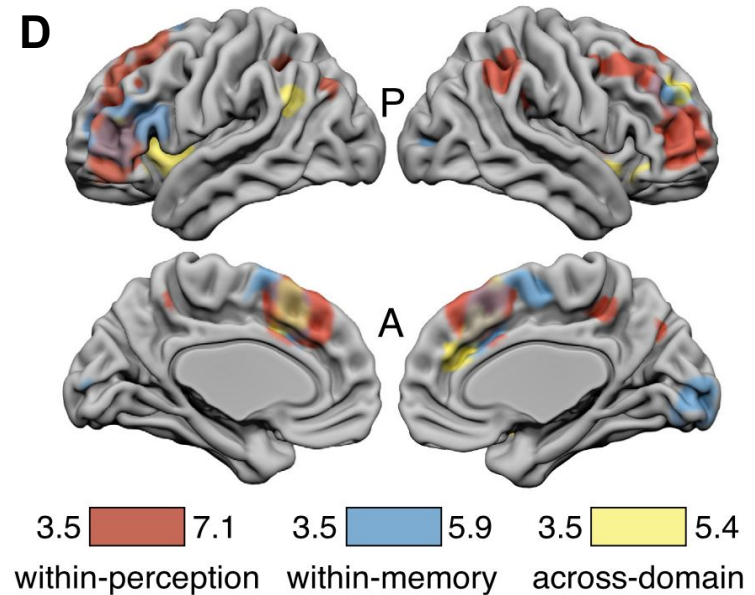
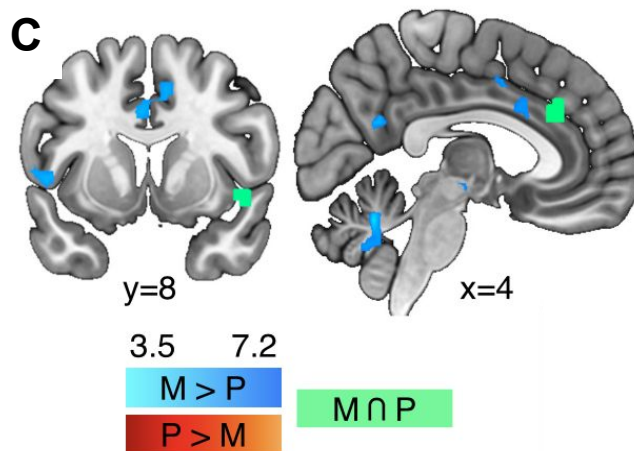
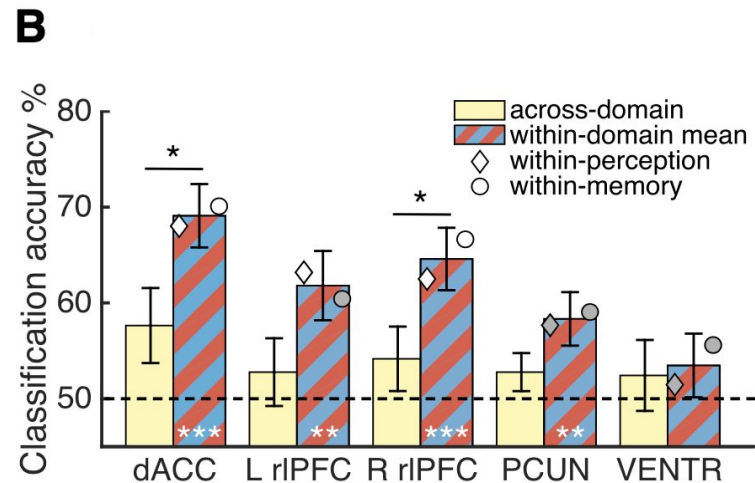
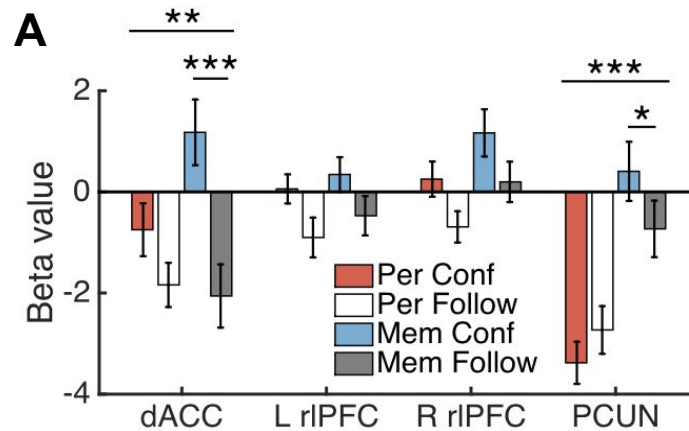
The relationship between metacognition and decision making (Fleming and Daw 2017)

- confidence and error detection
- influences of self-generated actions on confidence
- confidence and performance
- influence of choices on confidence judgements
- metacognitive monitoring and control

THANK YOU

JR	Domain-general	Domain specific
Uni-ROI	dACC/pre-SMA L rlPFC R rlPFC	PCUN (memory)
Uni-Whole brain	Anterior cingulate Right insula	PCUN (m>p) Middle cingulate gyrus Left insula Left hippocampus and cerebellum
Multi-ROI		dACC/pre-SMA L rlPFC R rlPFC PCUN
Multi-Whole brain	dACC/pre-SMA SFC Supramarginal gyrus Bilateral IFG/insula	PCUN (p) Bilateral PFC (p & m) Occipital region (m)
CLR	Domain-general	Domain specific
Uni-ROI	dACC/pre-SMA(-) PCUN	
Uni-Whole brain	Ventral striatum	Right parietal cortex (m>p)
Multi-ROI	dACC/pre-SMA PCUN	R rlPFC
Multi-Whole brain	dACC/pre-SMA vmPFC Ventral striatum	dACC/pre-SMA (m & p) Right PFC (m)

Judgement-related activity



Confidence-level-related activity

