

# Neural implementation of causal inference during multisensory processing in macaque brain

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# What is causal inference in multisensory processing?

Plato's cave



MatiasEnElMundo / Getty Images

Rubber hand illusions (RHI)



"It seemed as though the touch I felt was **caused** by the paintbrush touching the rubber hand."

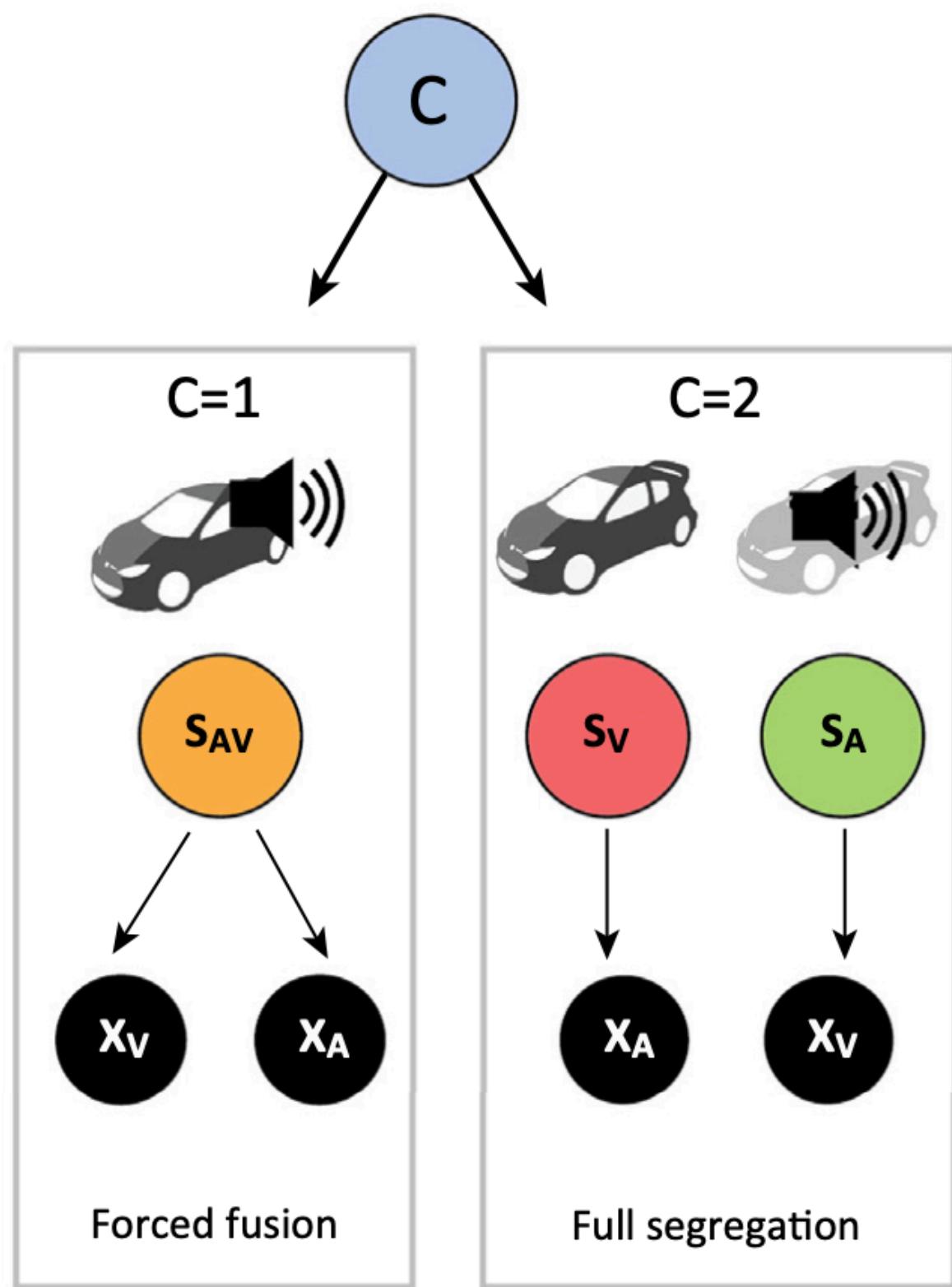
(Botvinick and Cohen, 1998; Kilteni et al., 2015)

- Perception is about making sense, that is, understanding what events in the outside world caused the sensory observations (Lochmann and Deneve, 2011).
- The brain must combine noisy information from multiple senses to create a coherent percept of the world (binding problem).
- Causal inference is the process of determining whether multiple sensory cues come from the same source (then integrate them) or different sources (otherwise segregate them).

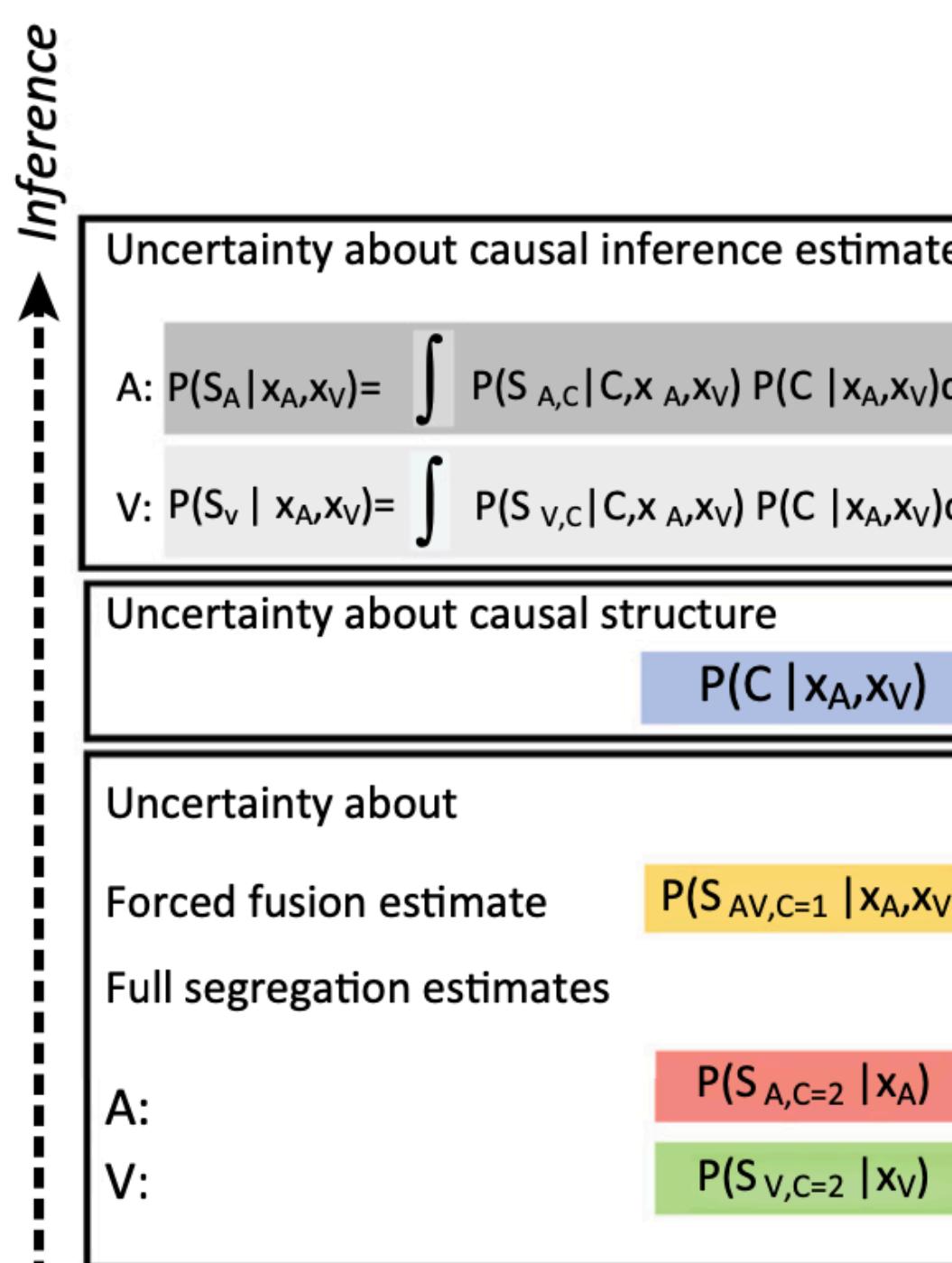
# What we do and do not know about multisensory causal inference?

## Computational Algorithm: Bayesian causal inference model

Generative model

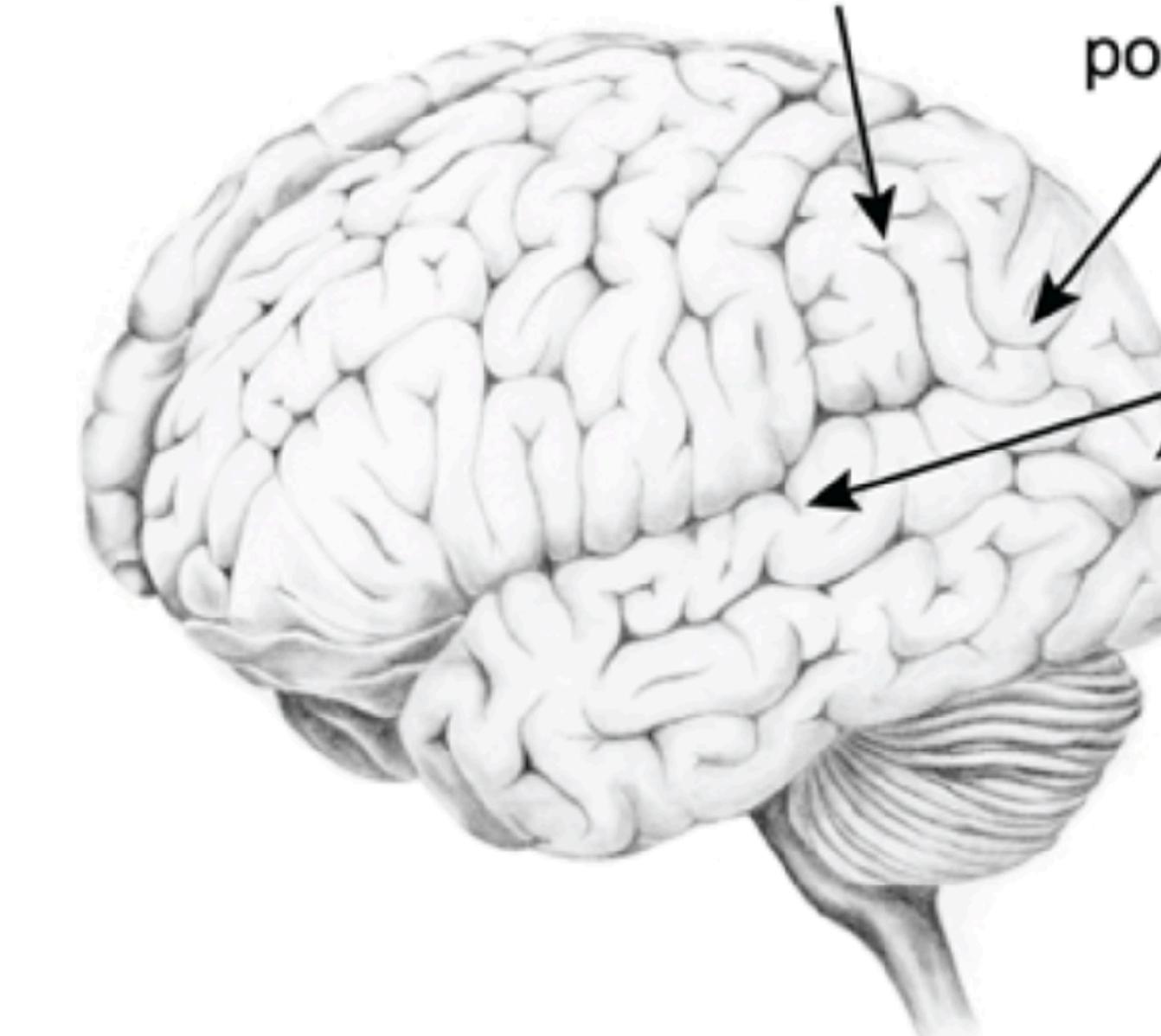


Inference model



## Neural correlates

Causal inference:  
anterior parietal  
regions



(Kayser and Shams, 2015)

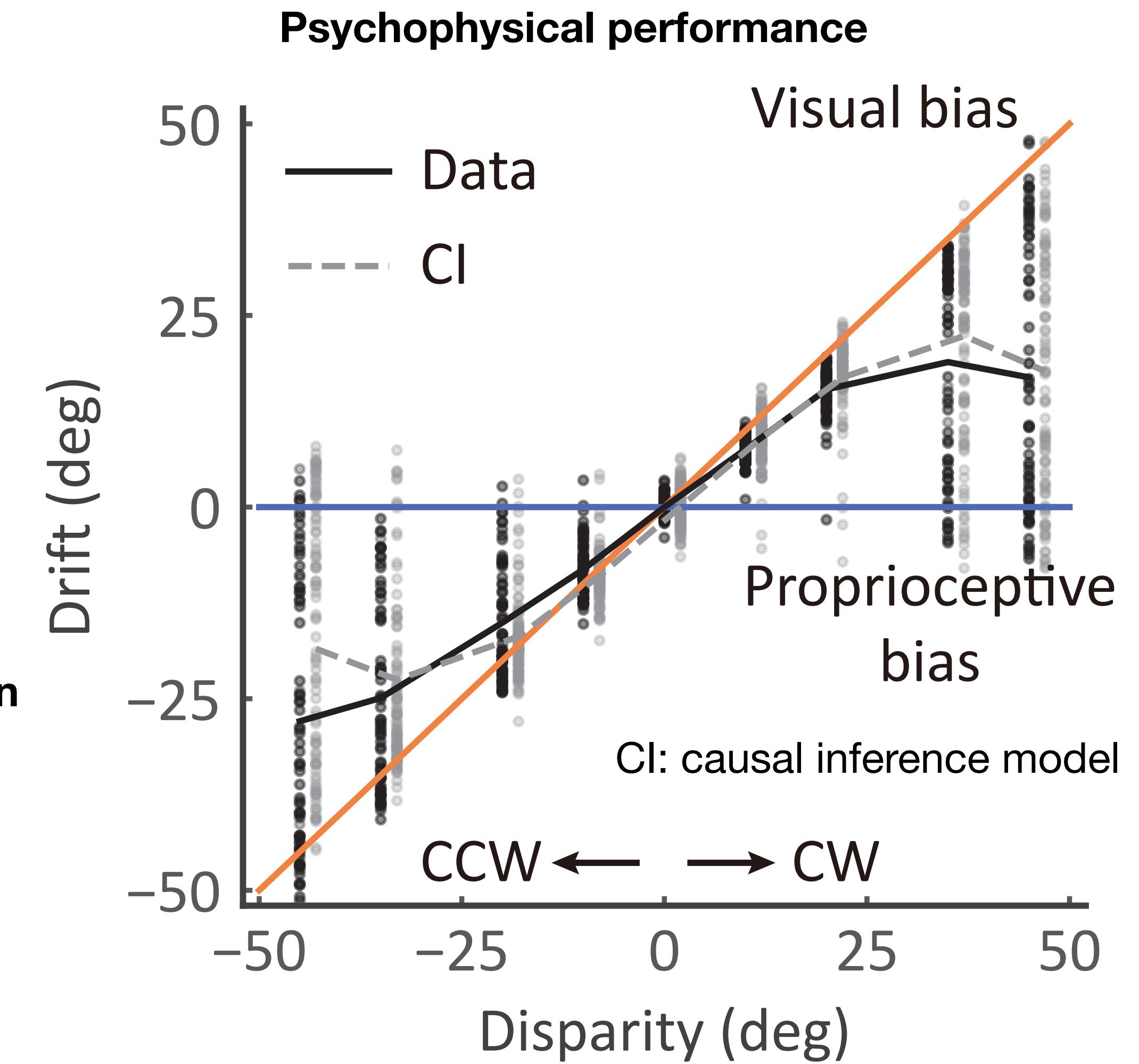
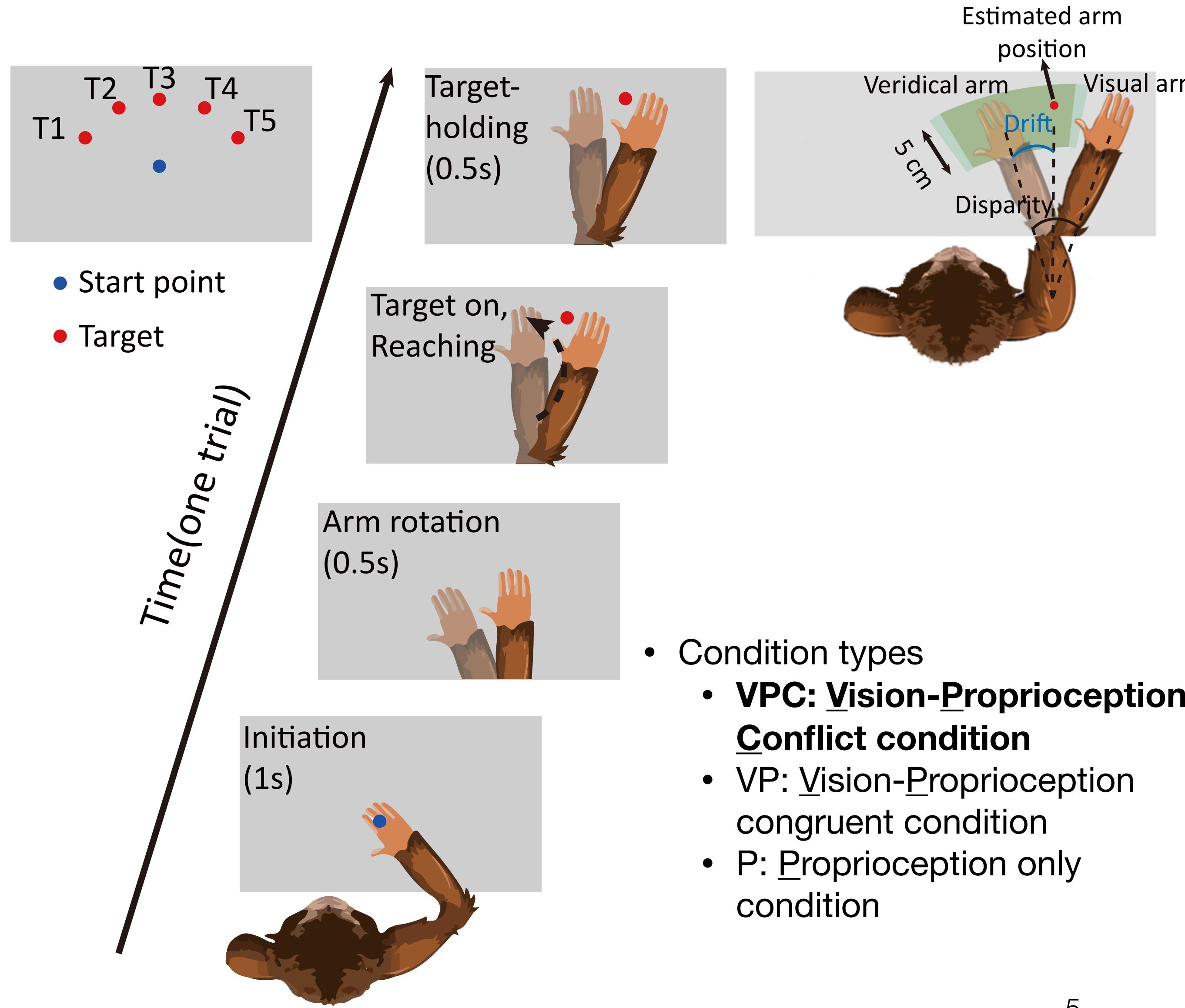
This distributed pattern of sensory representations demonstrates the progression of causal inference computations along the cortical hierarchy.

# What we do and do not know about multisensory causal inference?

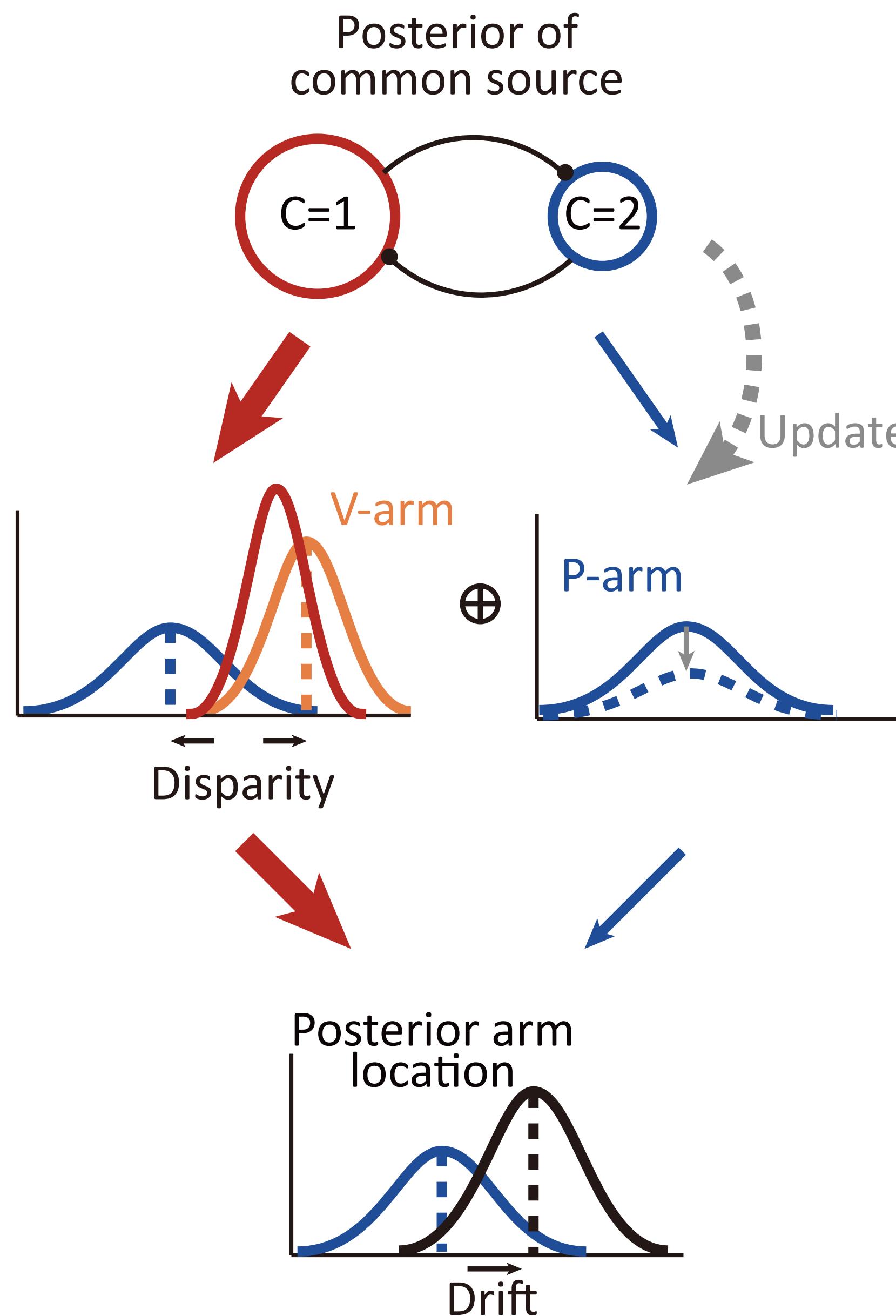
Key questions:

1. What are the **computational mechanisms** of representing and updating hidden causal structure?
2. What are the **frontal-parietal circuit** implementations of multisensory causal inference at single-neuron resolution?

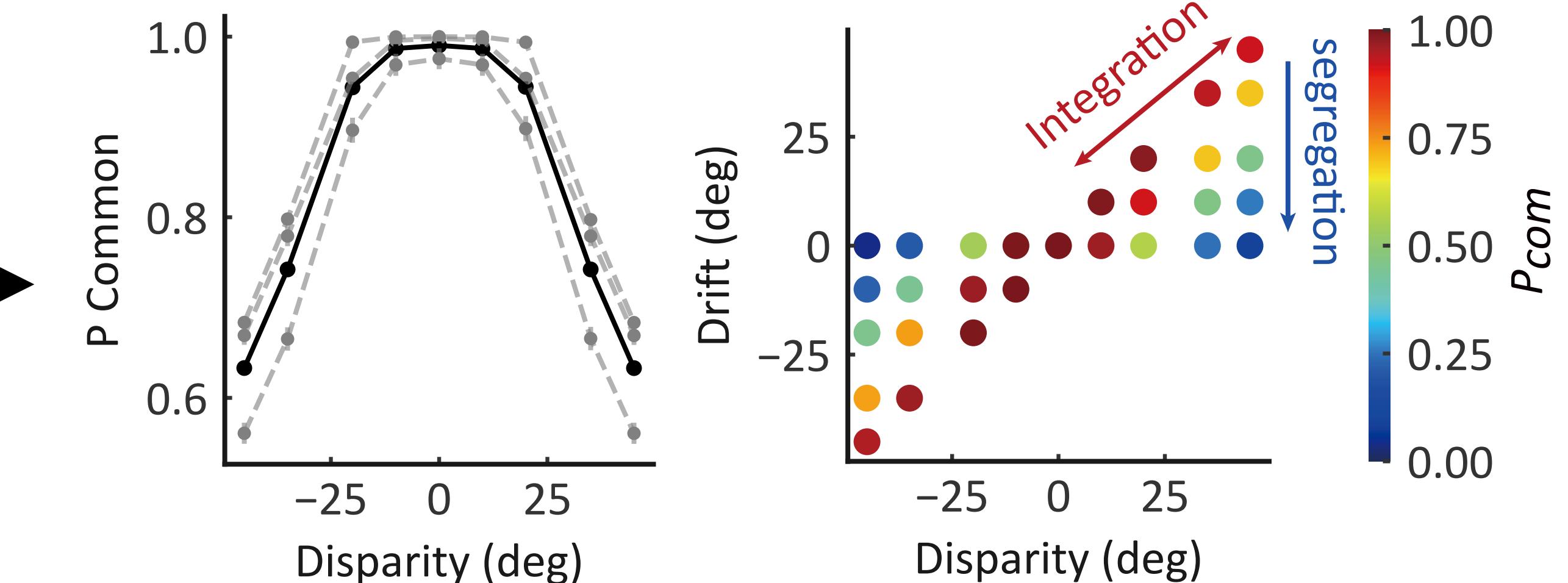
# Visual-proprioceptive causal inference task



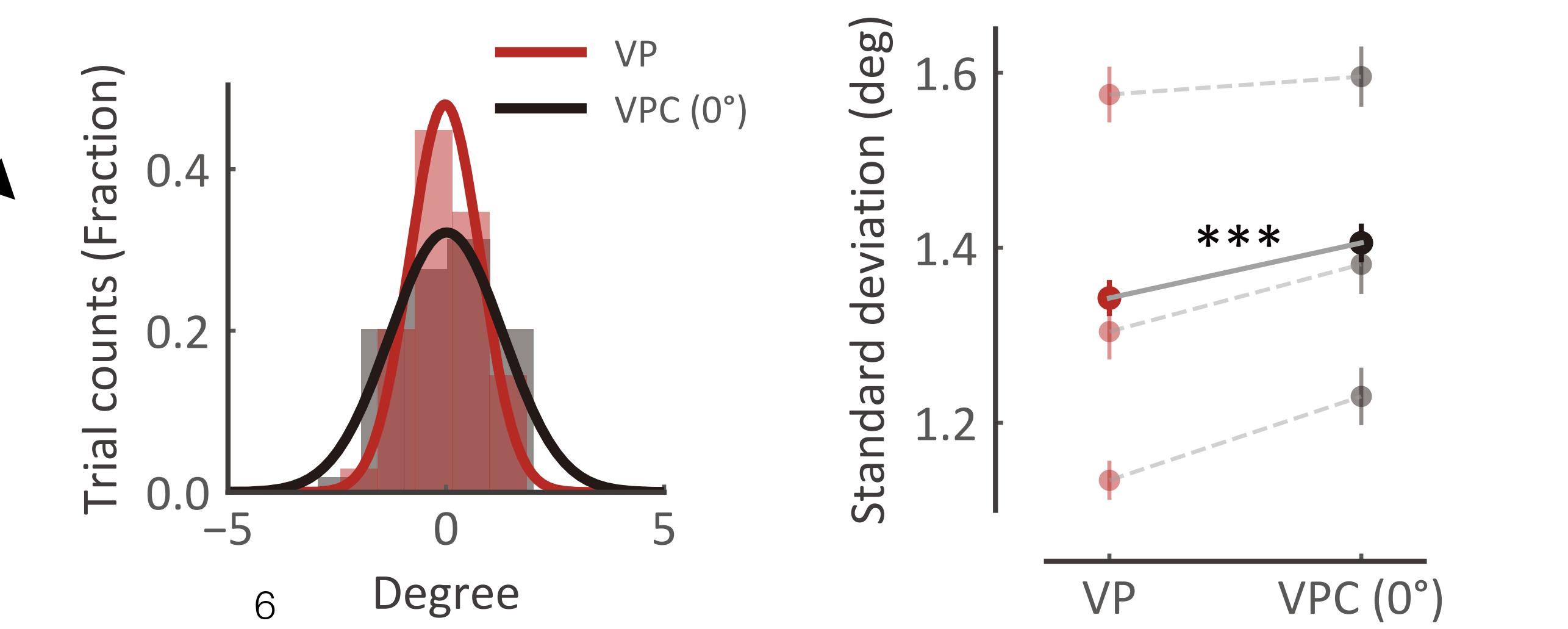
# Bayesian causal inference model predicts the behavior readout



## 1. Uncertainty about causal structure: the posterior probability of common source ( $P_{com}$ )

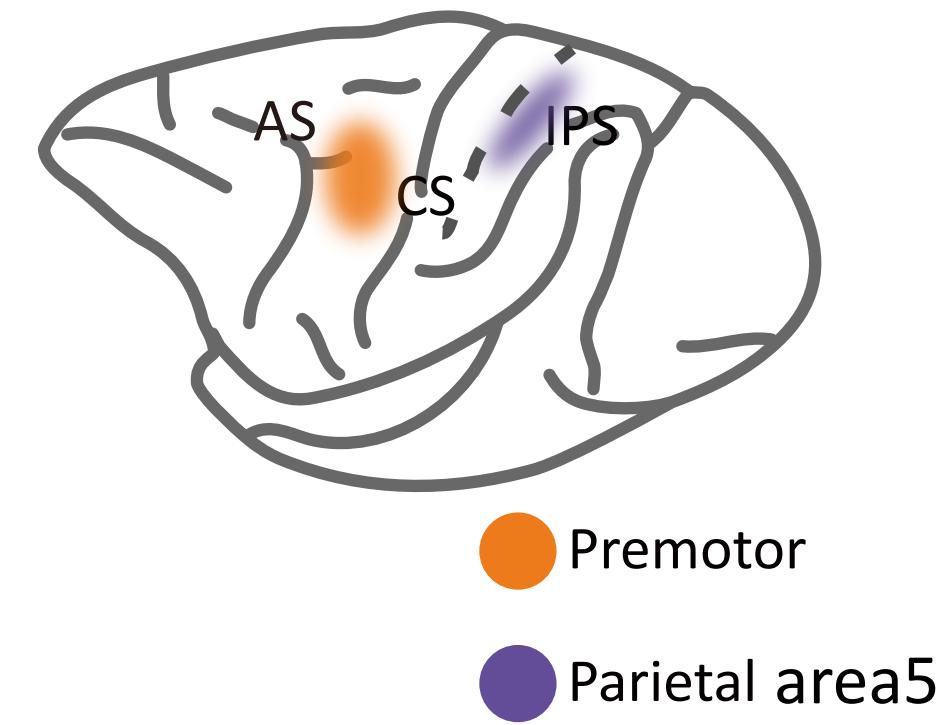


## 2. Uncertainty about proprioceptive representation

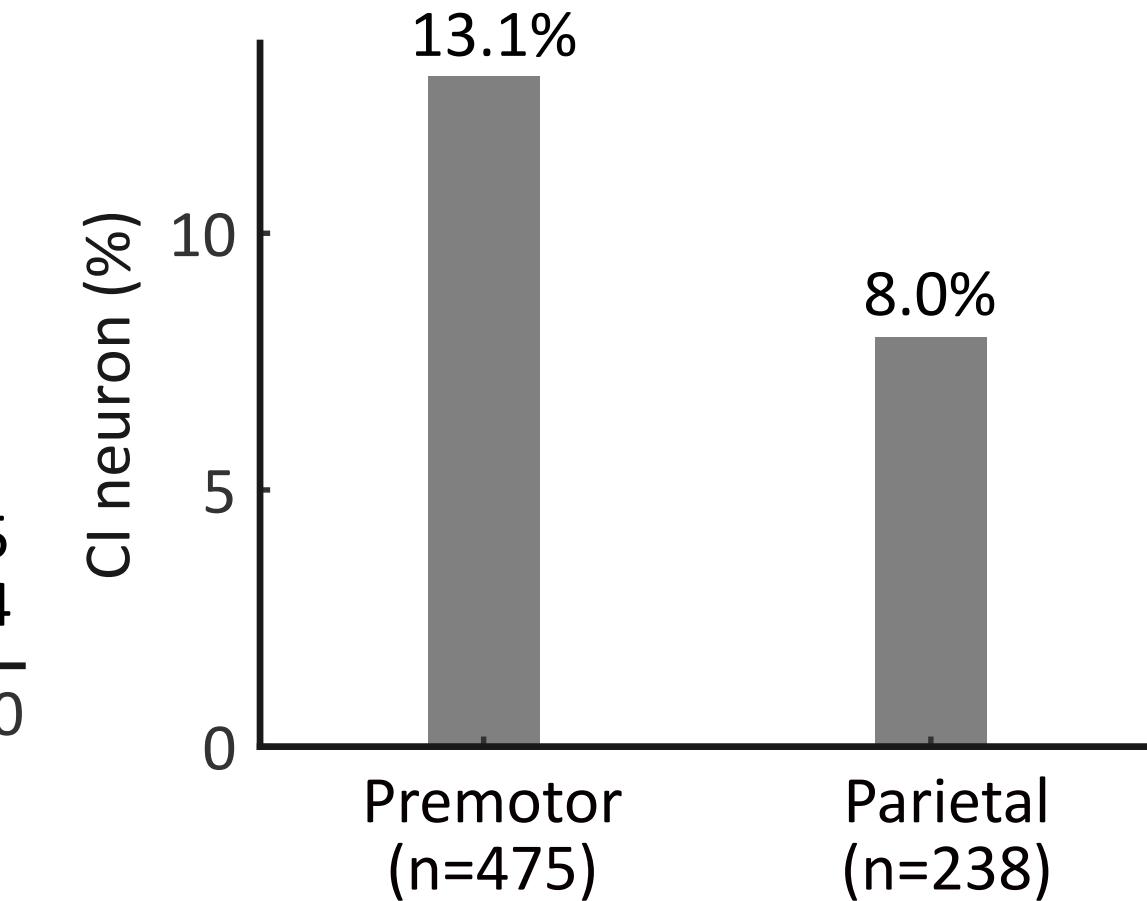
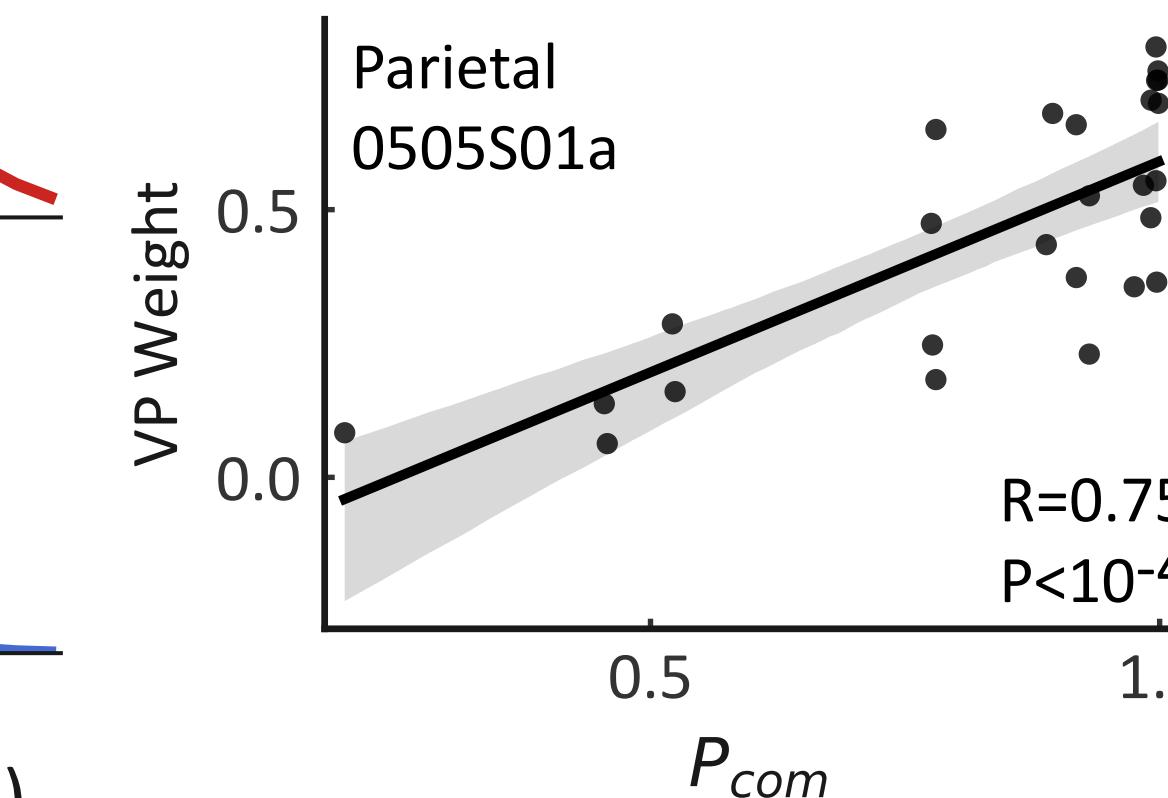
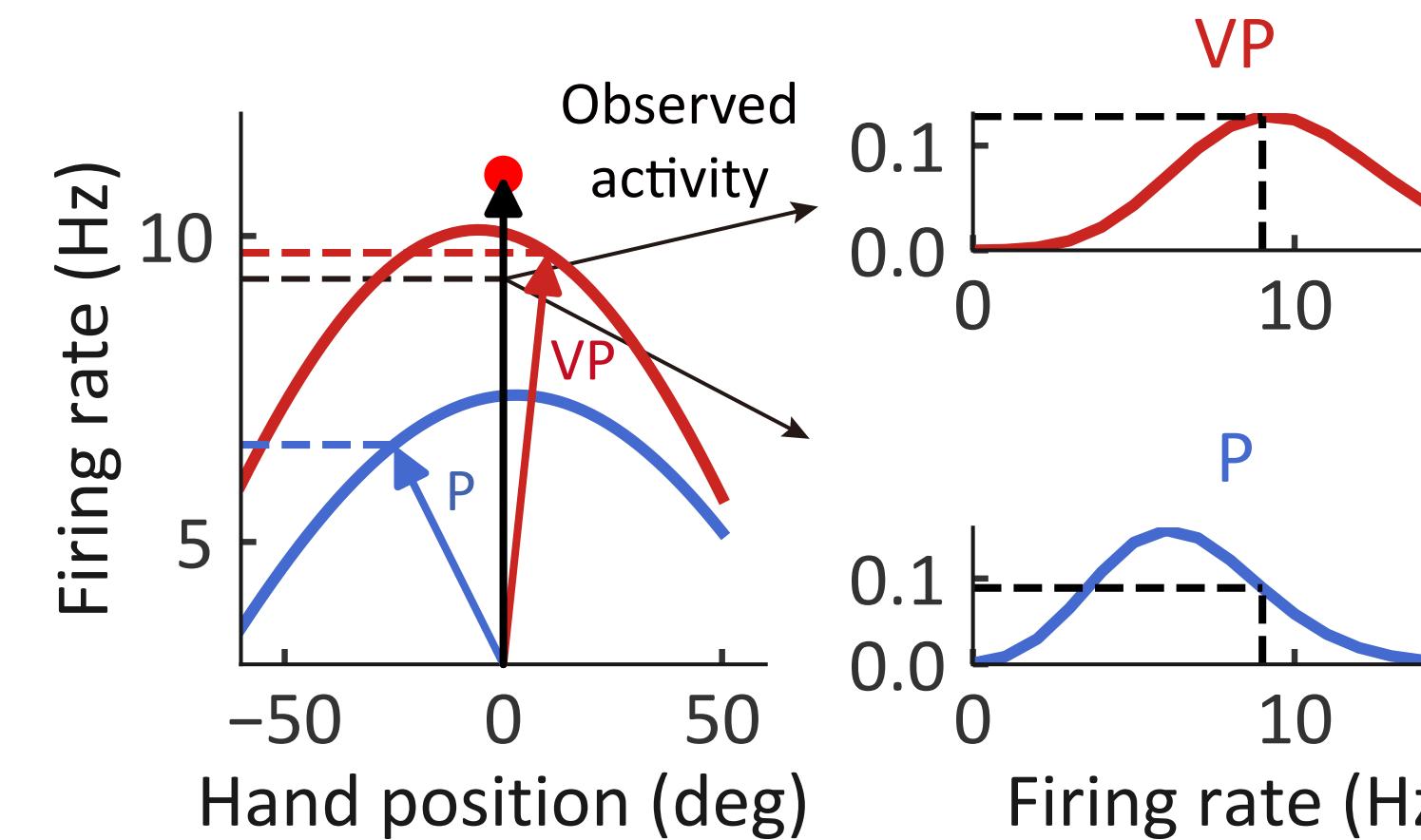


# Dynamic representation of causal inference in premotor-parietal circuit

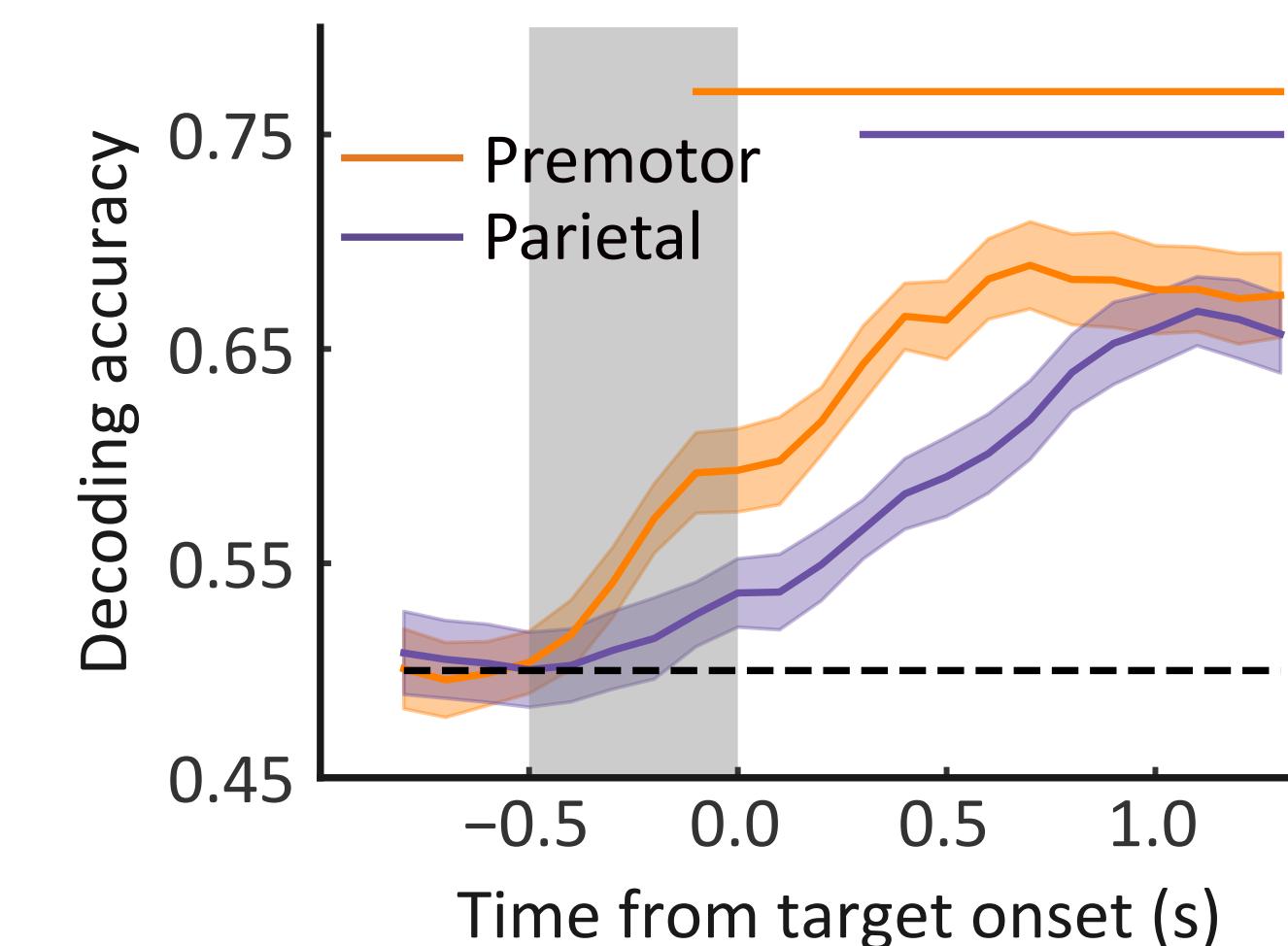
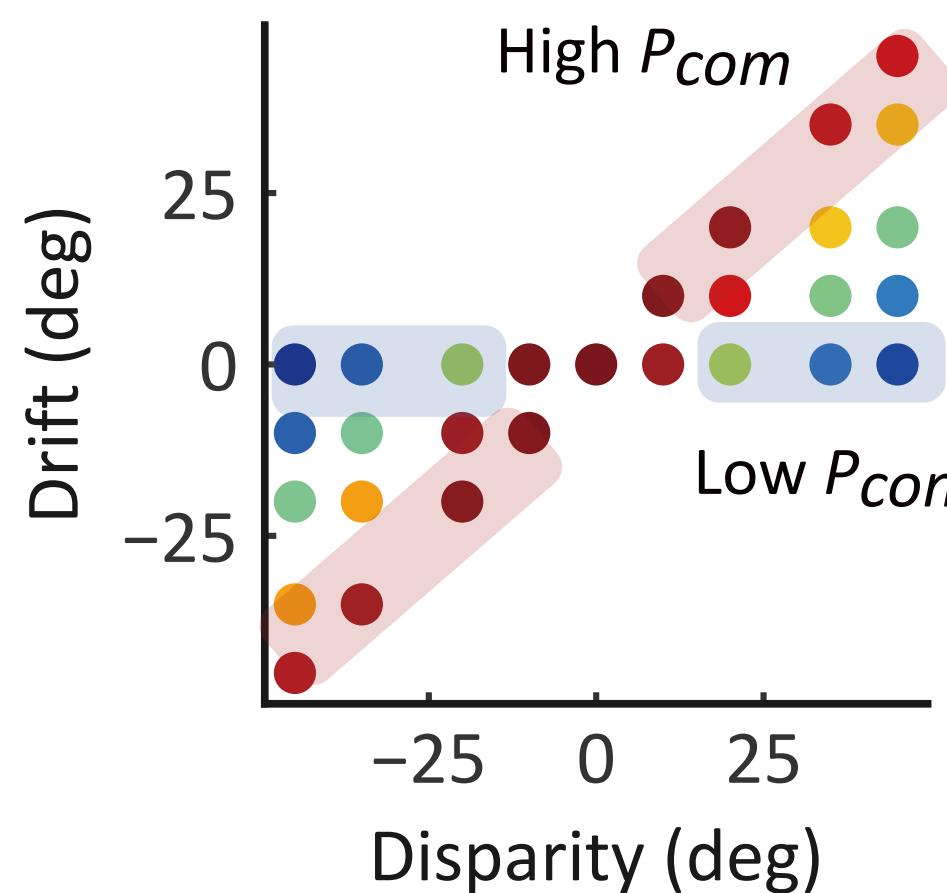
Single-unit recording in macaque monkeys



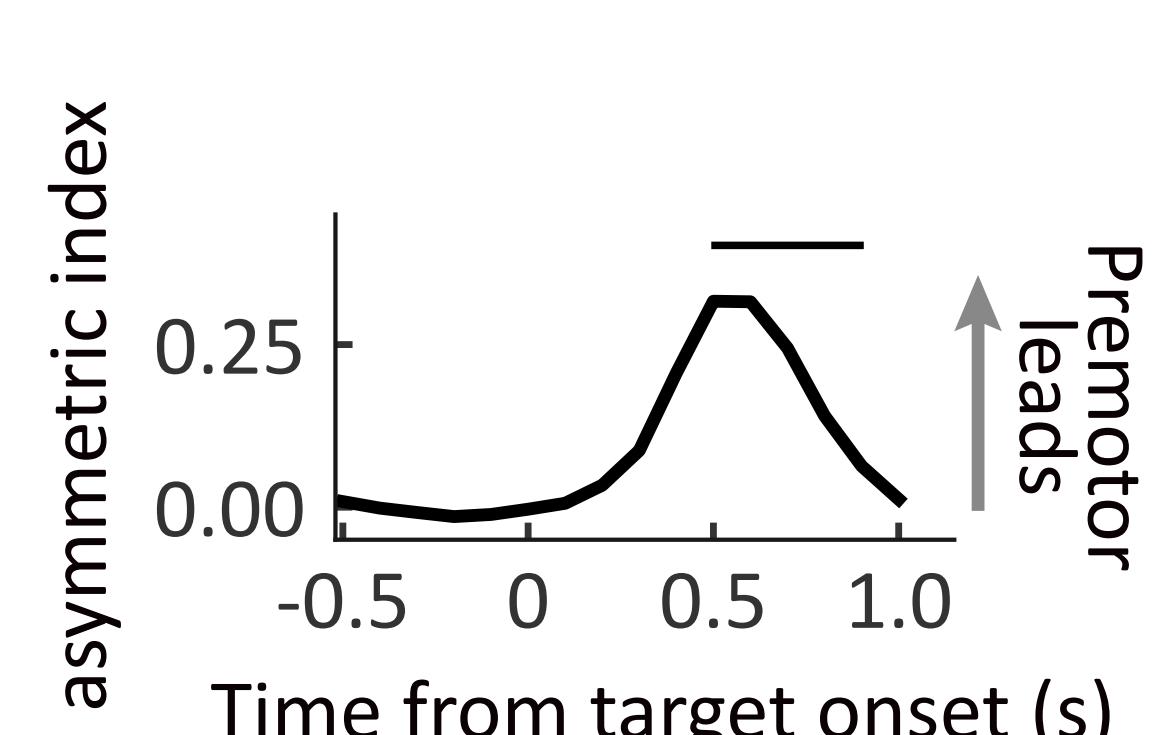
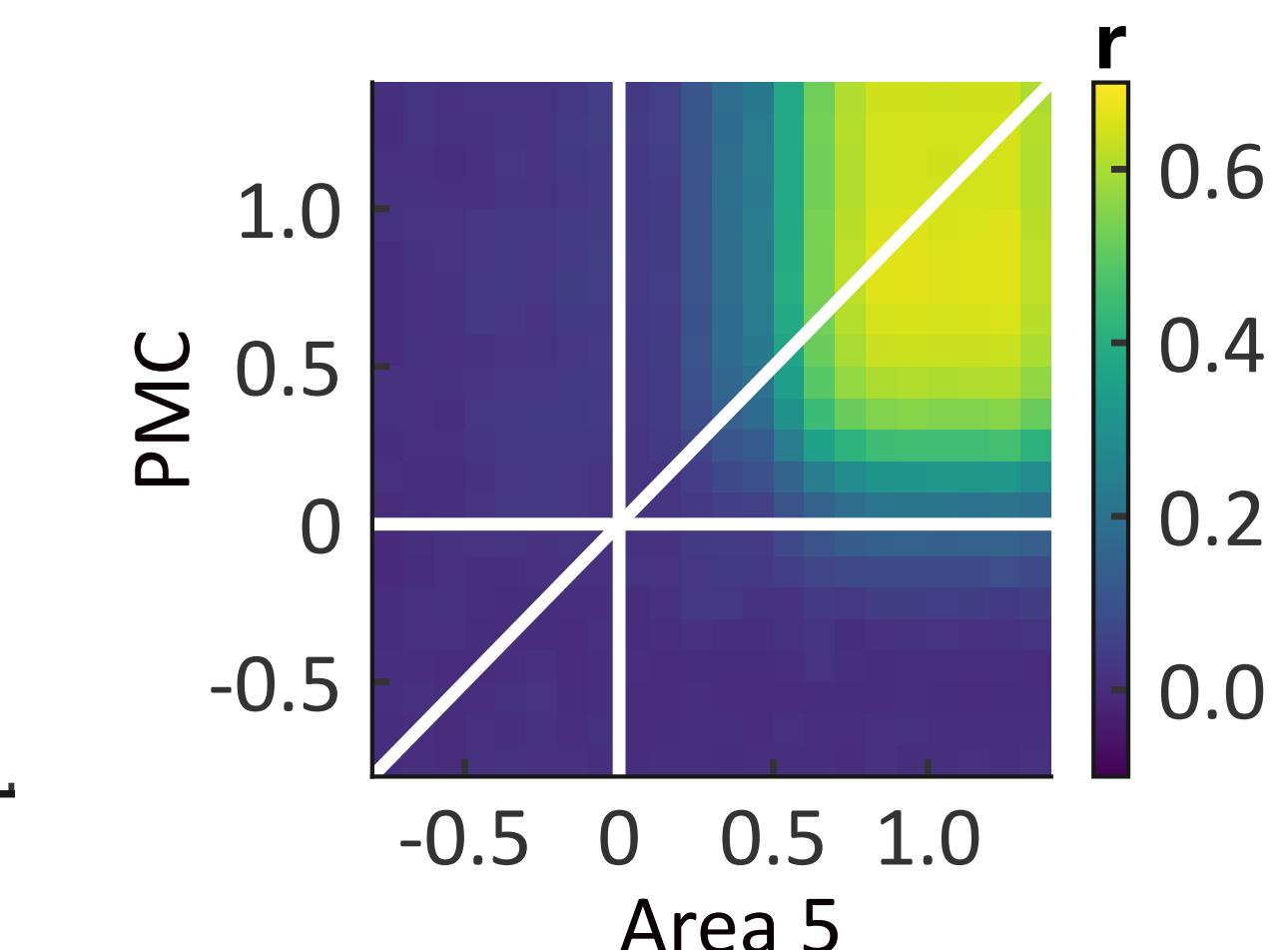
Normalized single neuron activity (VP Weight) predicted the uncertainty of causal structure ( $P_{com}$ )



Population decoding of  $P_{com}$



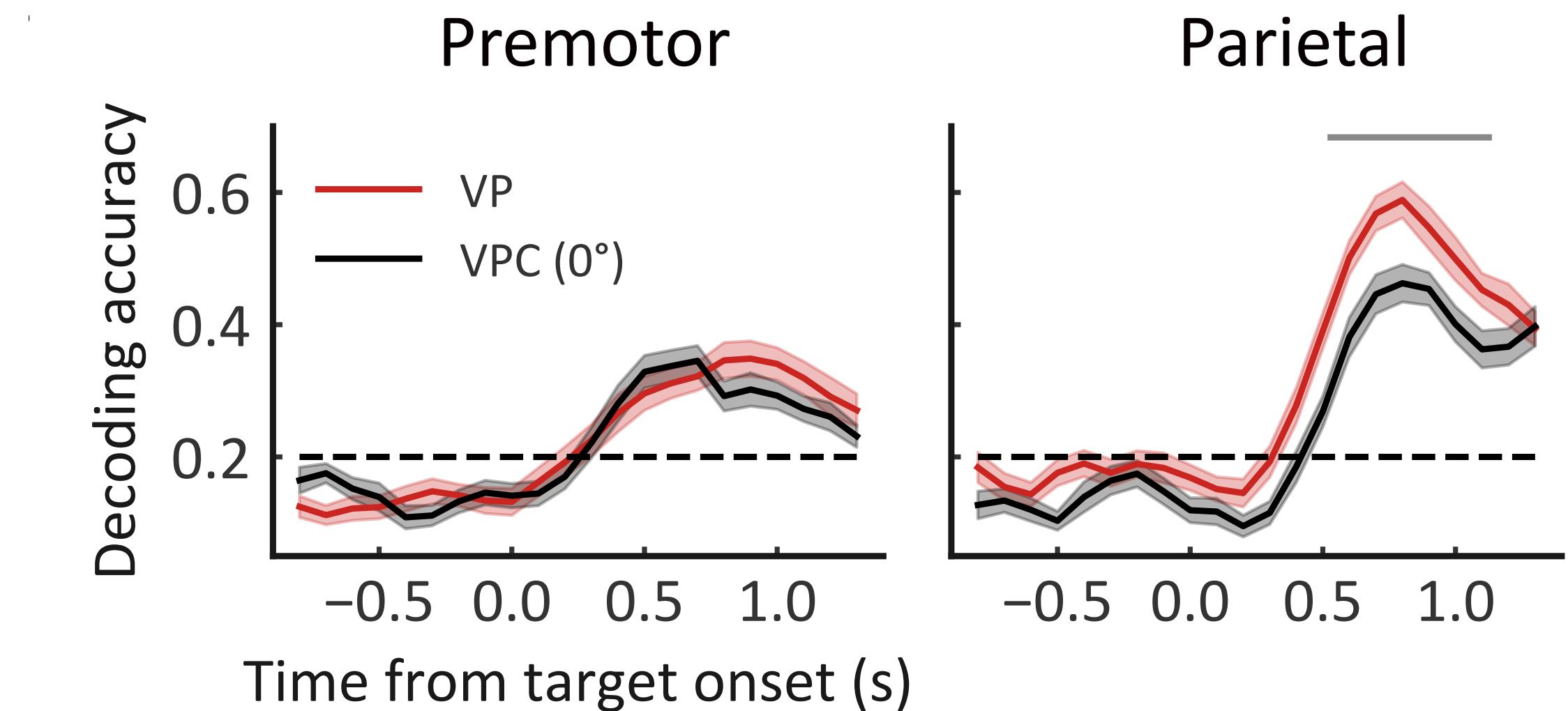
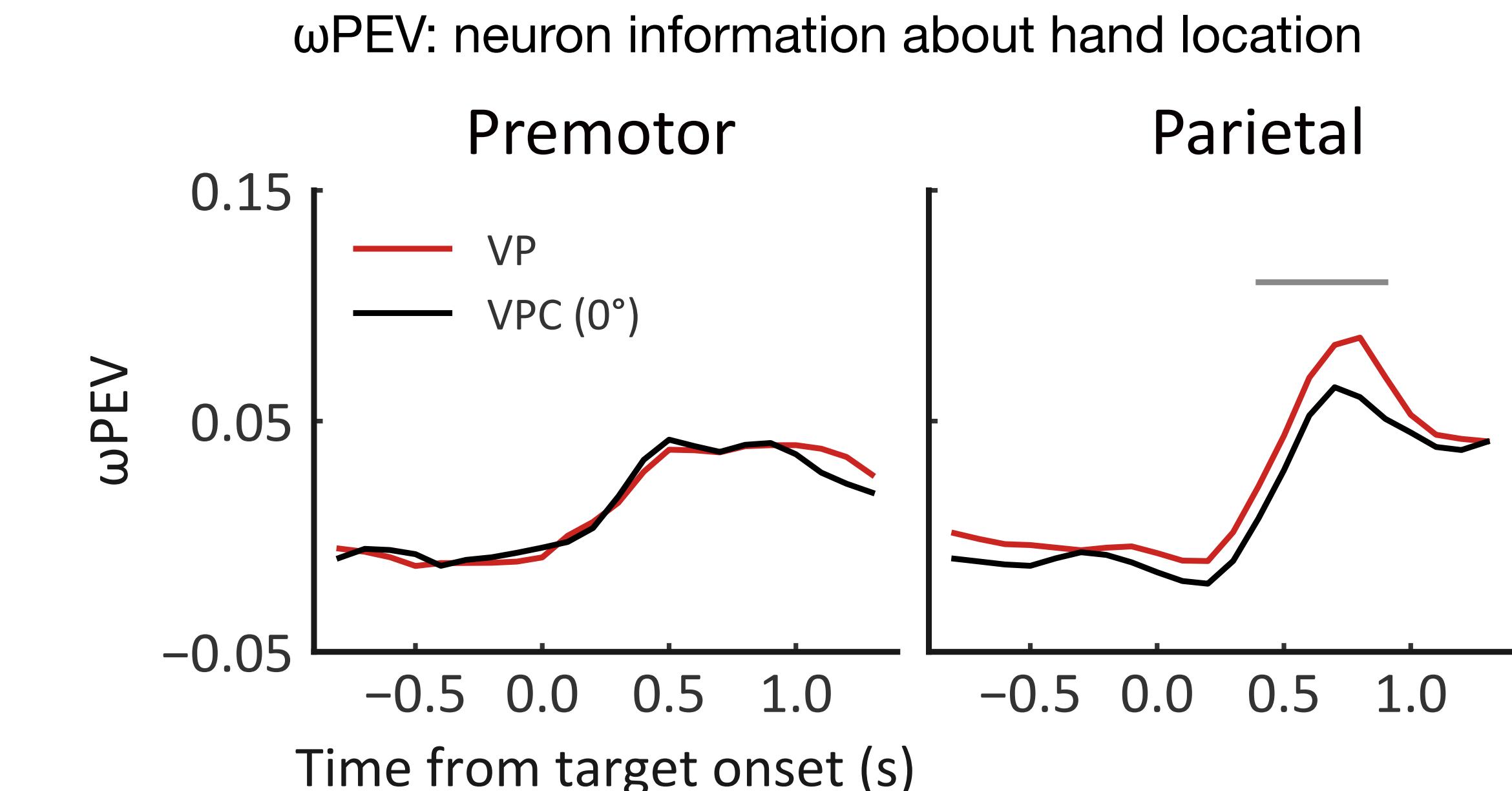
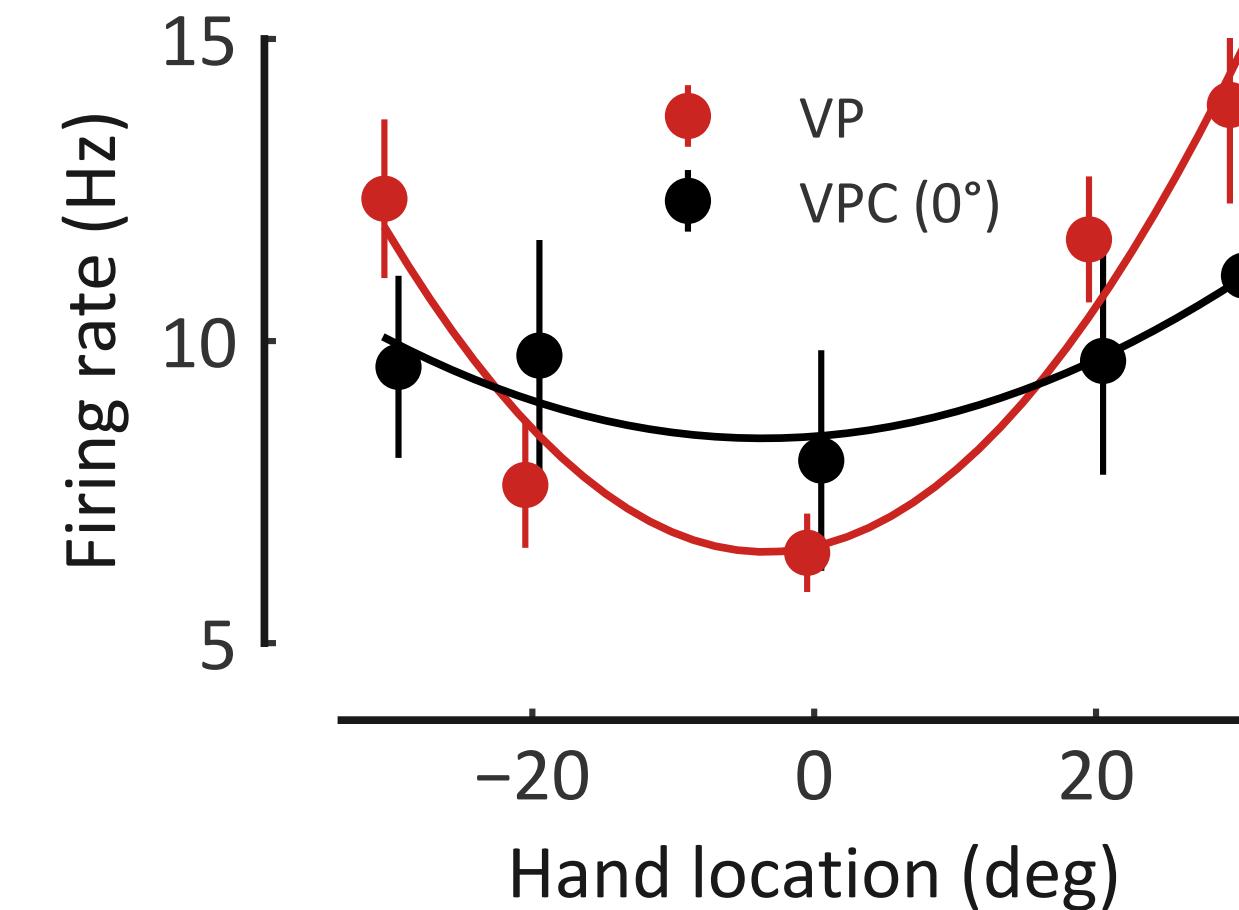
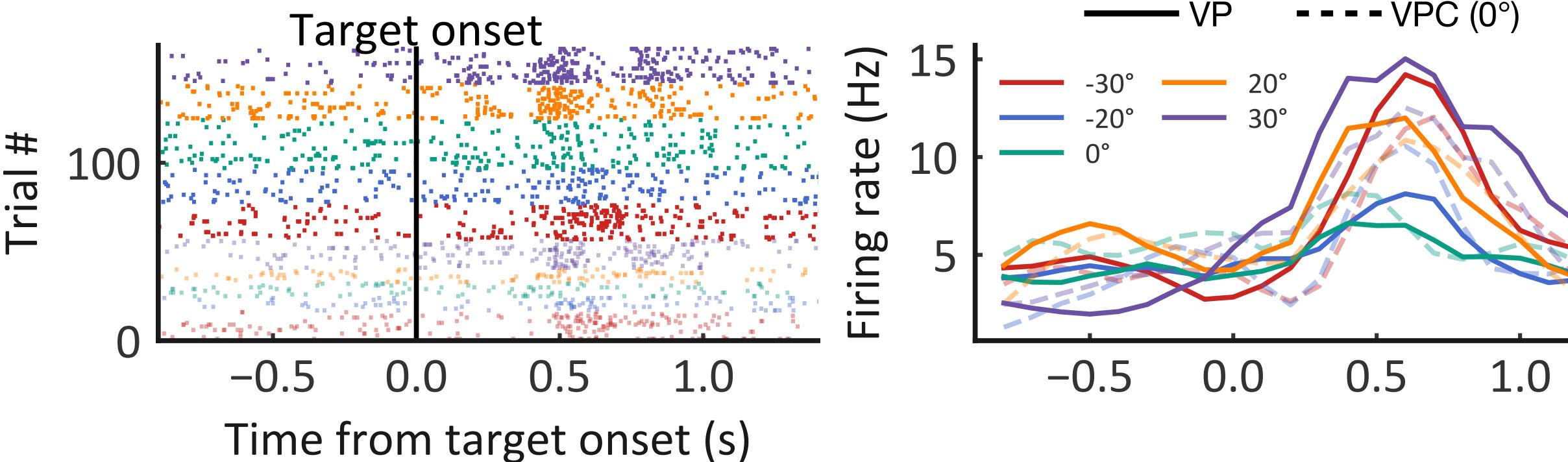
CCA results show that there is a communication subspace in frontal-parietal circuit



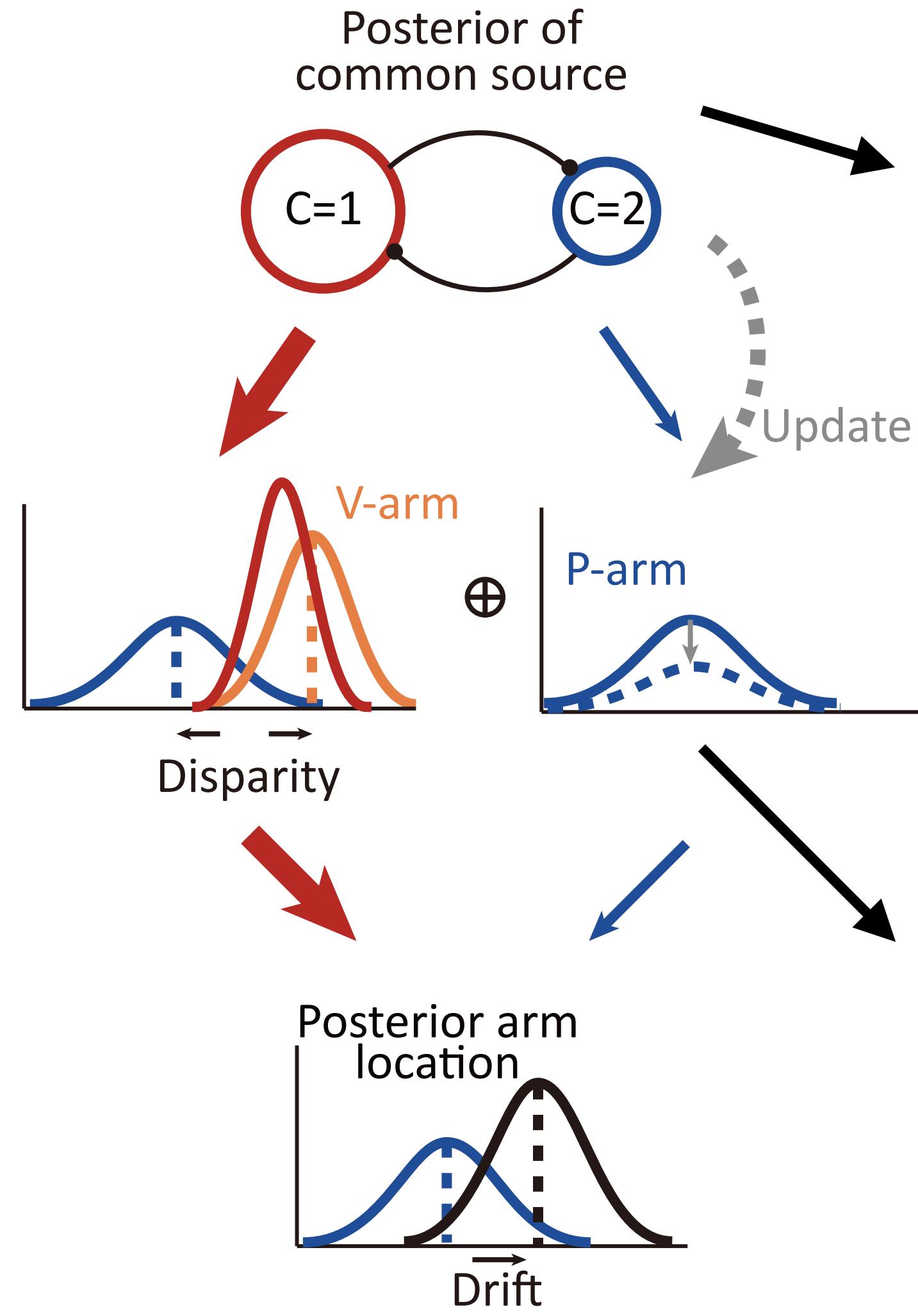
# Update sensory uncertainty of arm location in parietal cortex (area 5)

- Trade-off between CI and Prop
  - VPC: Vision-Proprioception Conflict condition
  - VP: Vision-Proprioception congruent condition

An example parietal Area5 neuron



# Summary

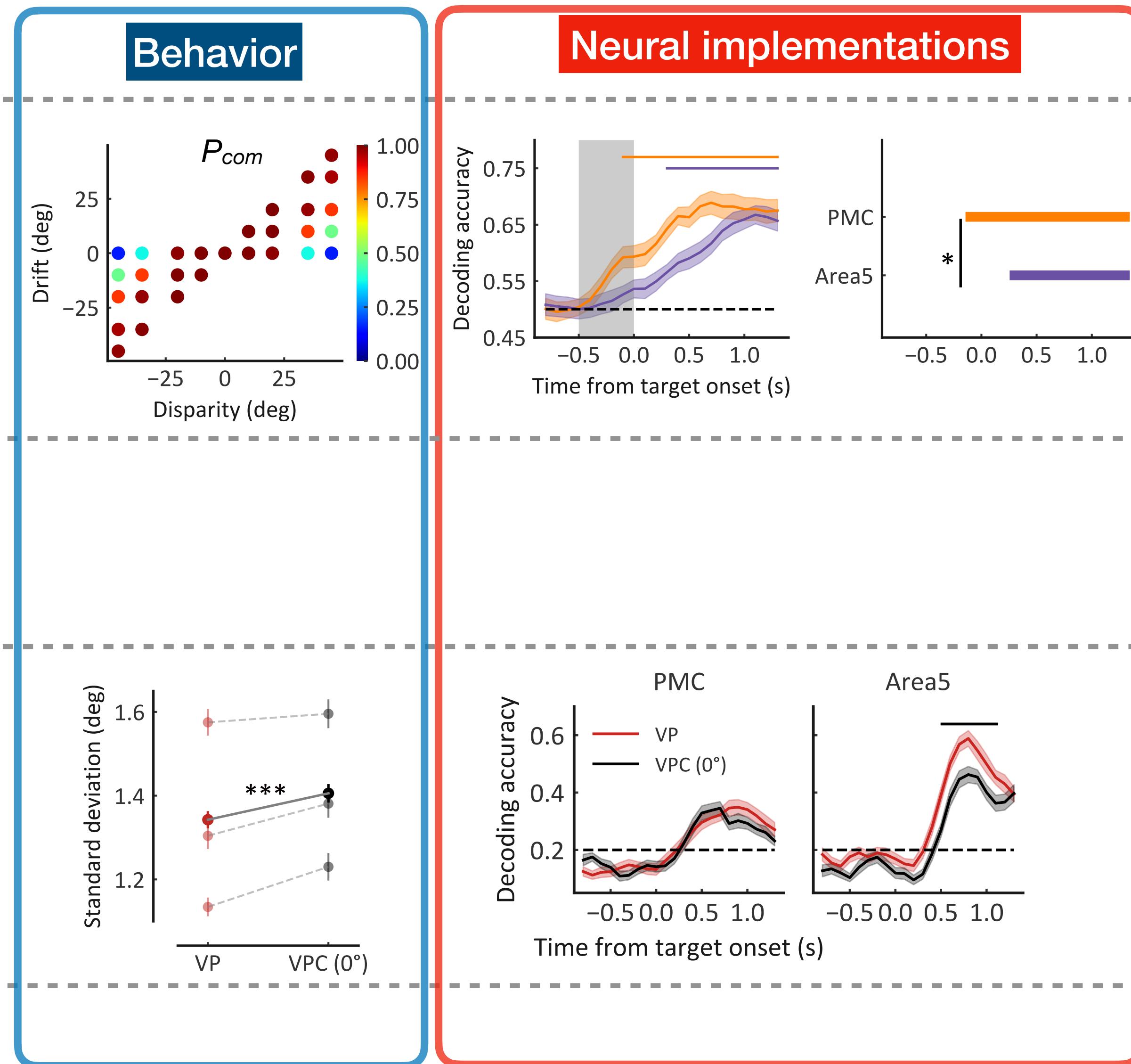


## $P_{com}$ representation

**Not only PMC but also Area5 represents the causal inference structure ( $P_{com}$ ) and PMC leads Area5.**

## Trade-off between CI and Prop

**Parietal Area5 updates the proprioception representation during causal inference.**



# Acknowledgements

Adviser:

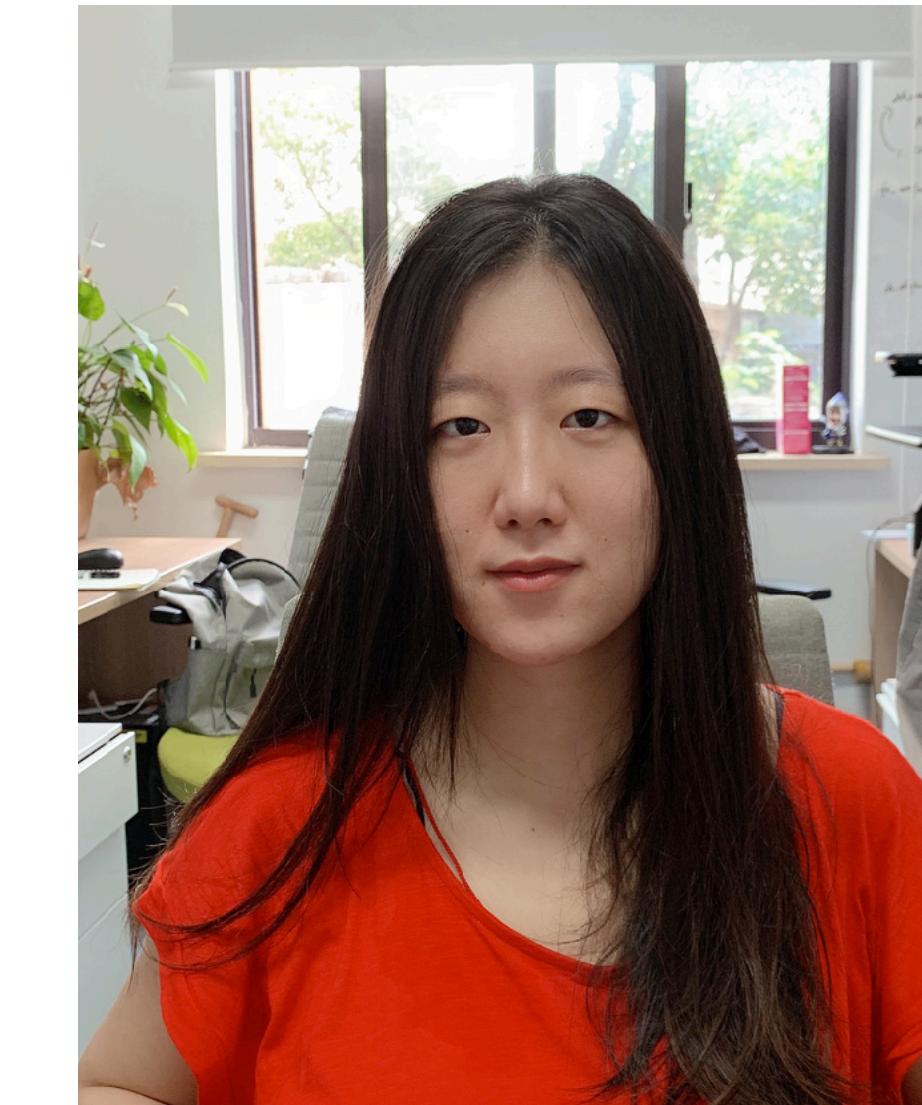


Dr. Liping Wang

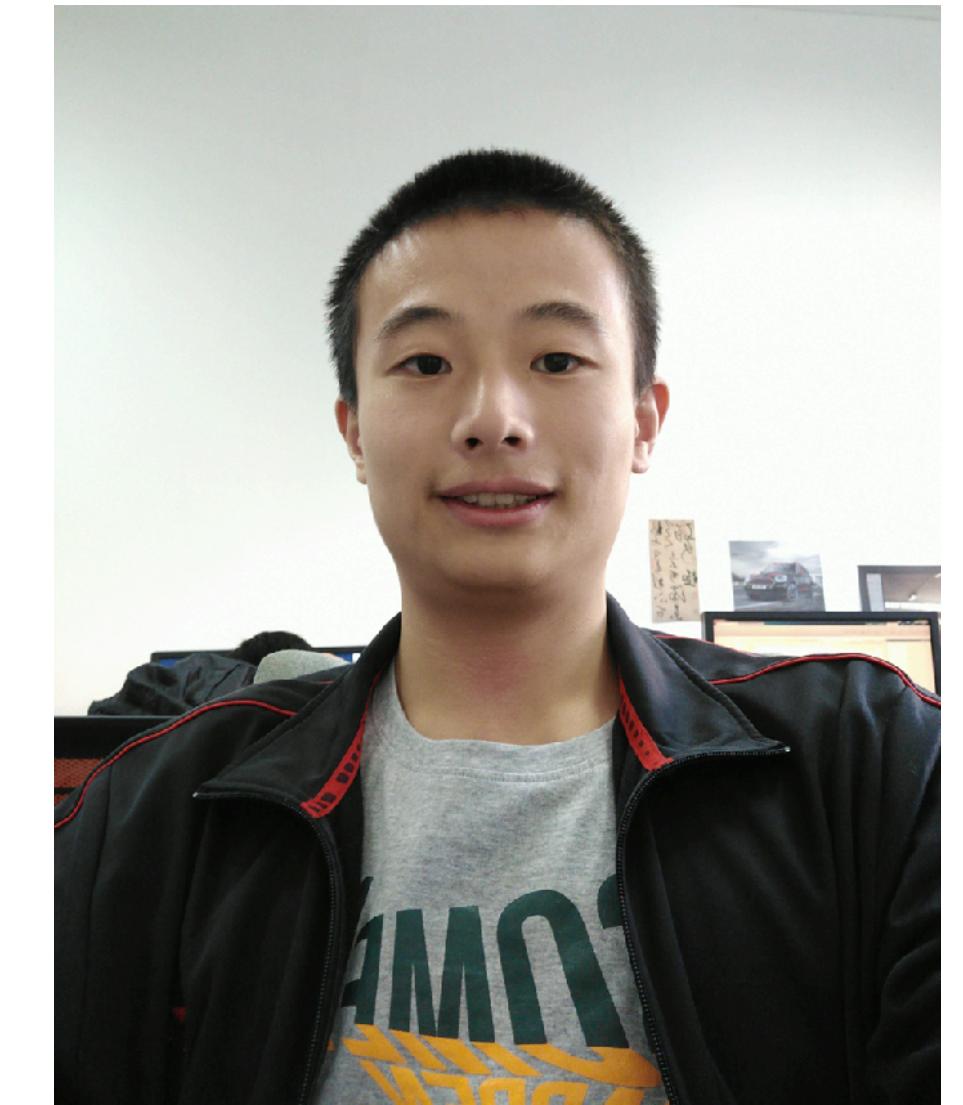
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