

# **Segregation and integration of cortical laminar information streams and their role in attention**

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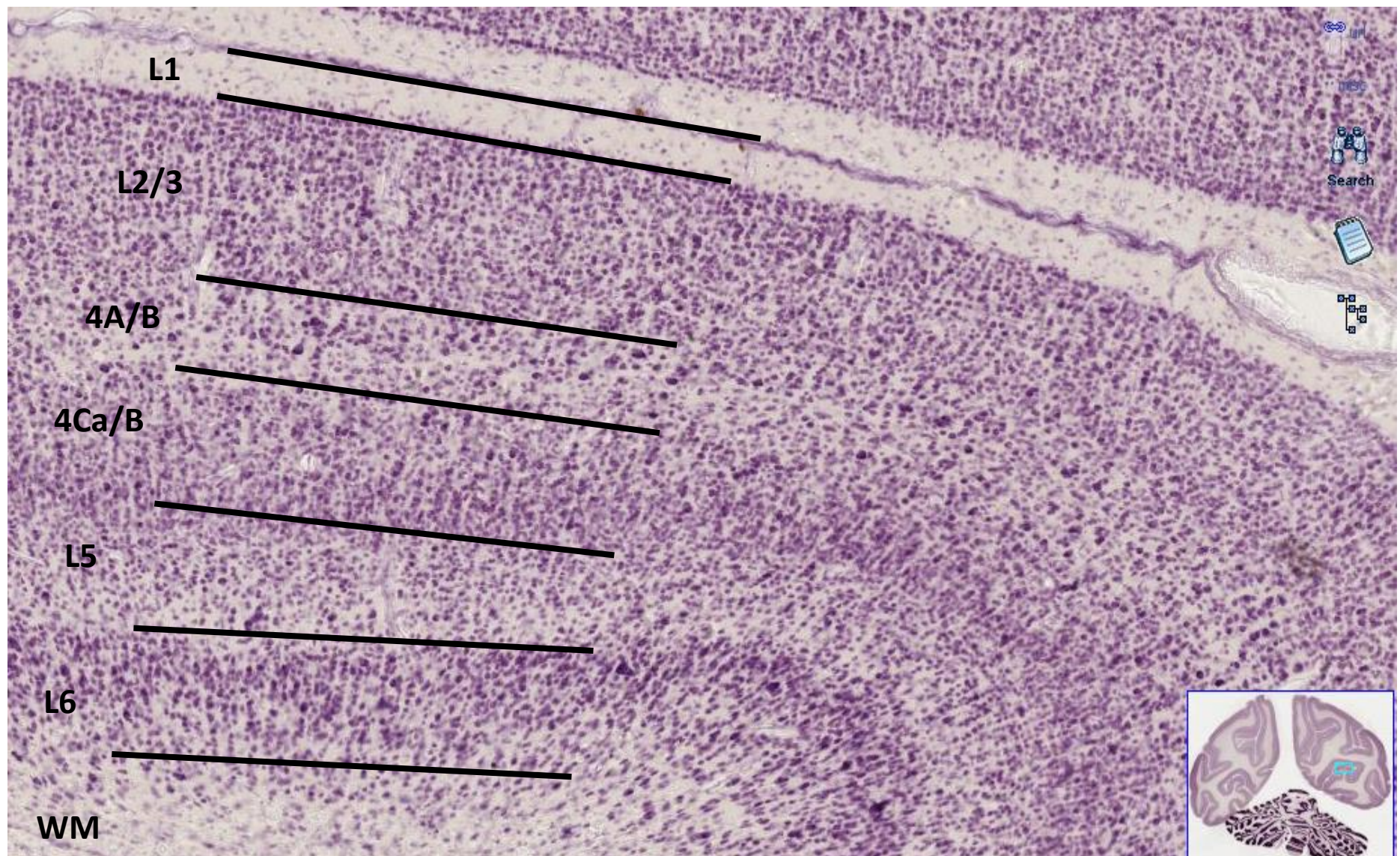
July 30<sup>th</sup>, 2014

ICON, Brisbane

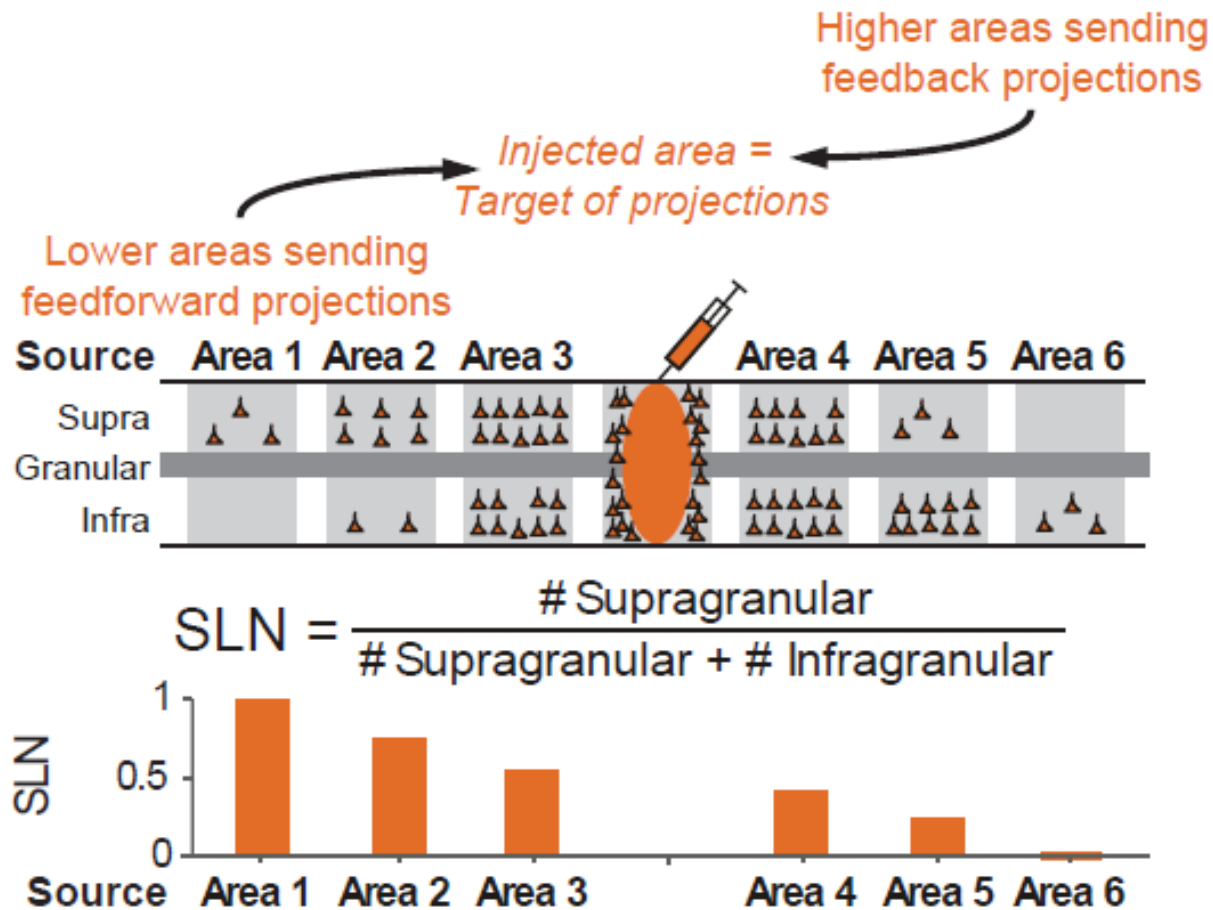
# Introduction

- Top-down and bottom-up processing
  - Cognitive distinction (“endogenous” vs. “exogenous”)
  - Anatomical distinction (“feedforward” vs. “feedback”)
- These asymmetries define a cortical hierarchy
- Points to a key computational challenge of cortical networks: functional segregation and functional integration
- What is the putative role of distinct cortical laminae in these processes?

# Cortical lamina in monkey area V1

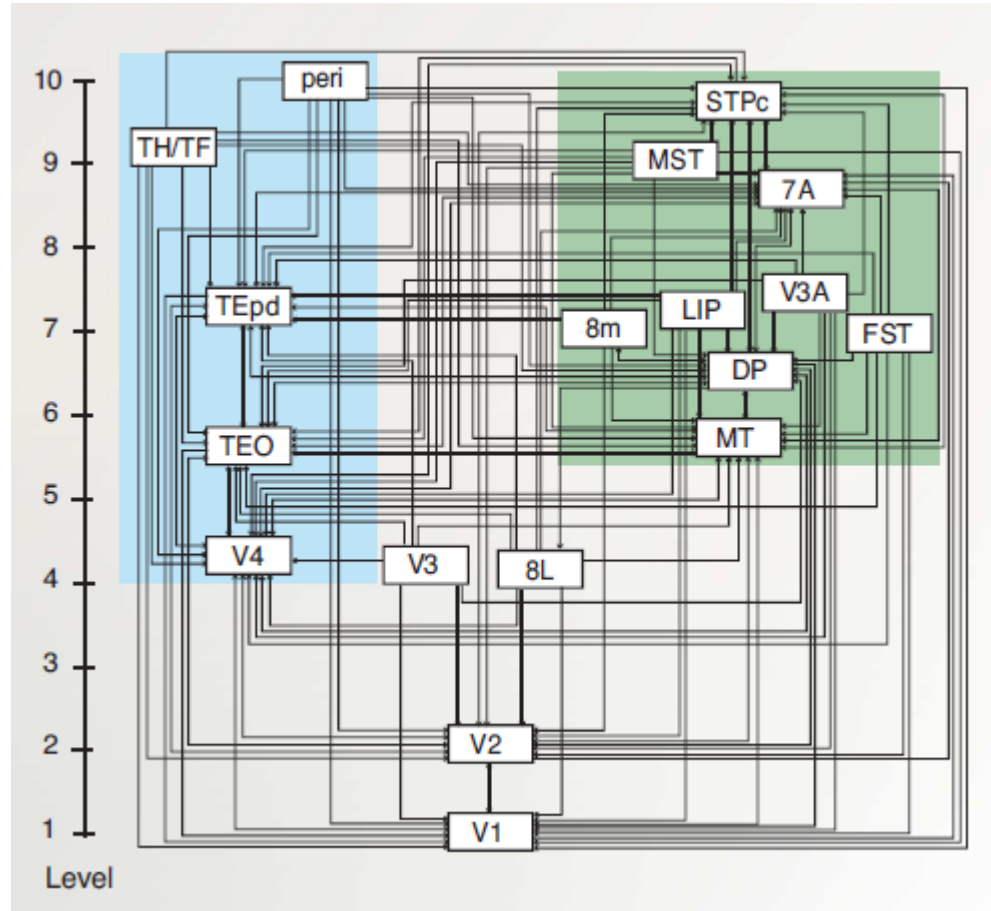


# Anatomy of hierarchy

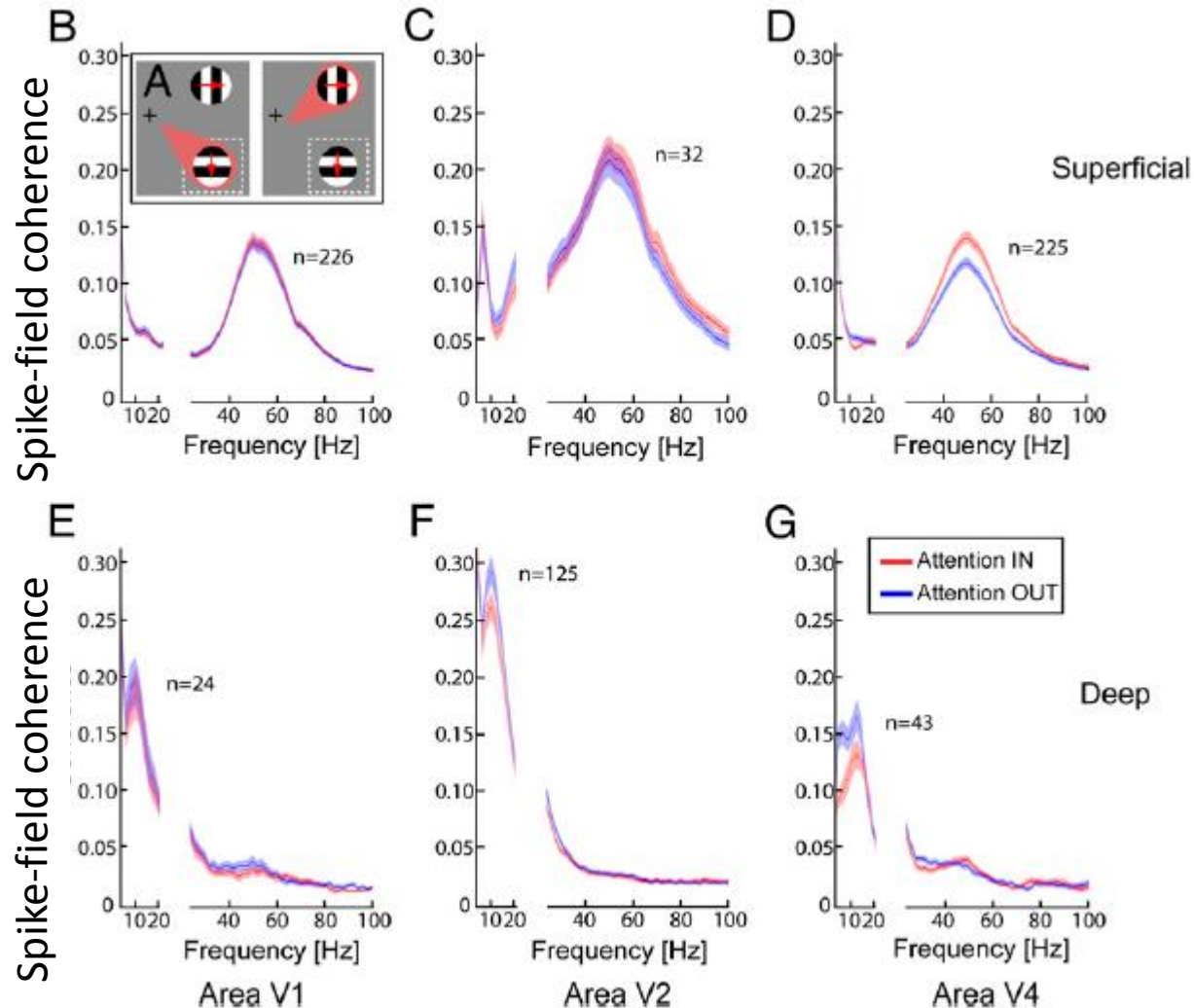




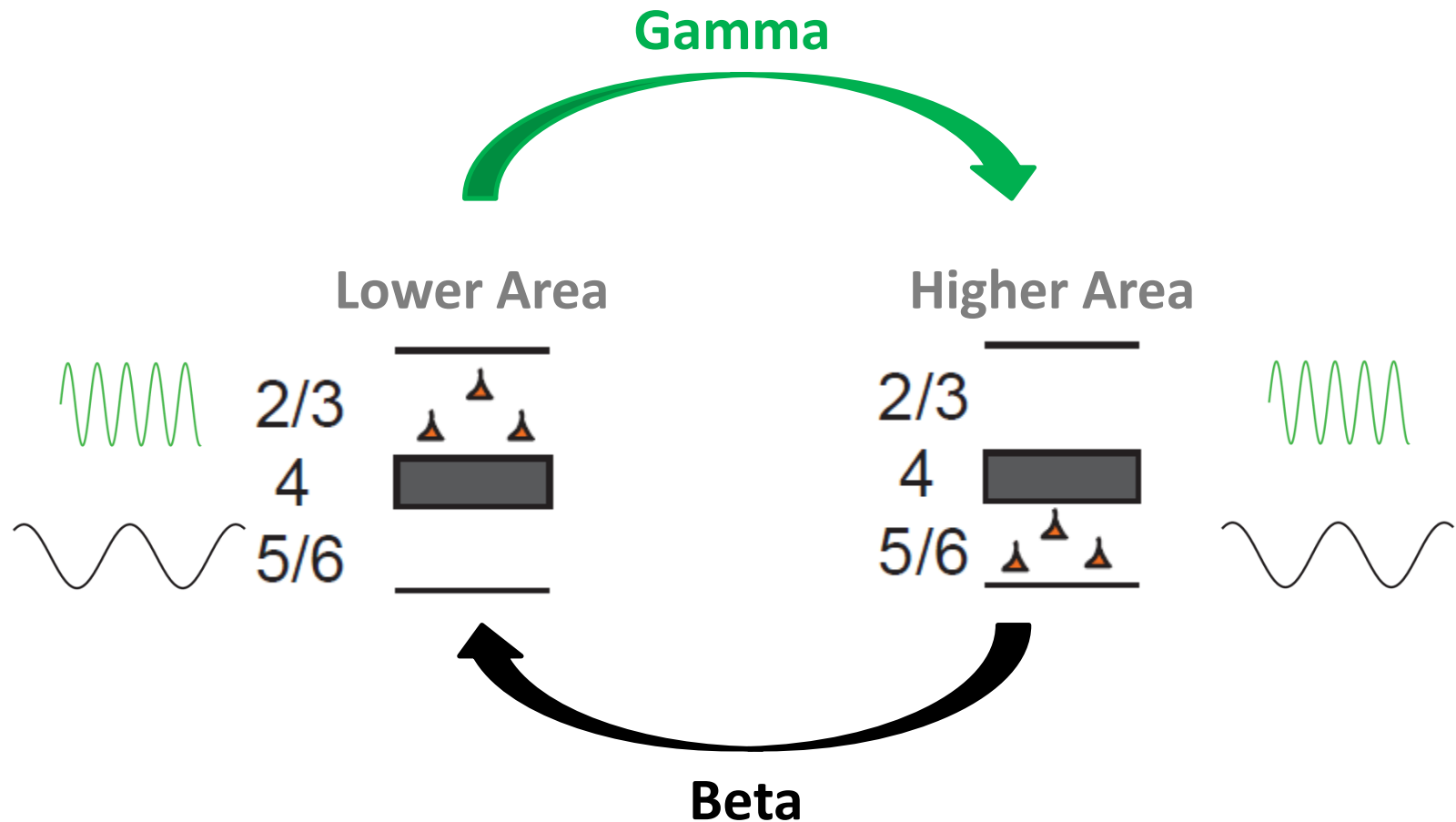
# Feedforward and feedback counterstreams define a cortical hierarchy



# Gamma synchronization is superficial, beta synchronization is deep

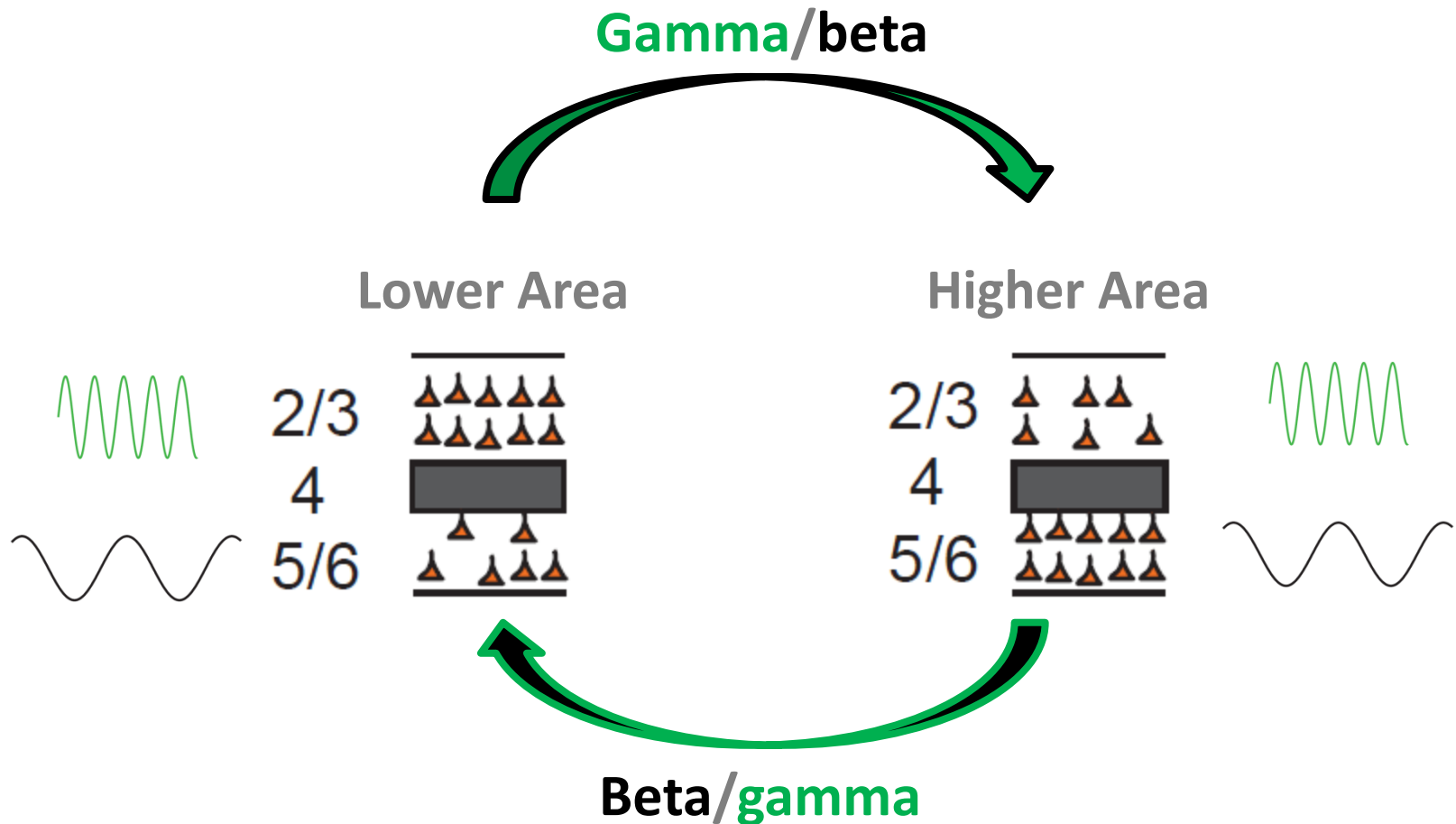


# Hypothesis for strong *anatomical* asymmetries



Prediction: strong *functional* asymmetry between gamma and beta

# Hypothesis for weak *anatomical* asymmetries

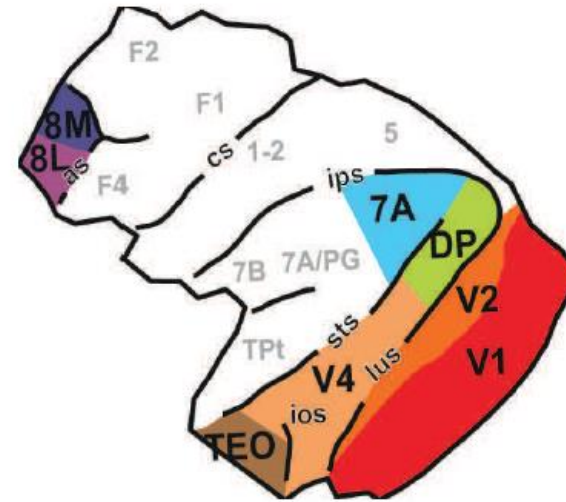
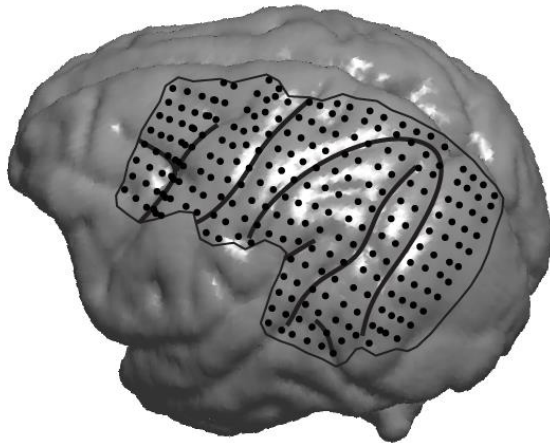


Prediction: weak *functional* asymmetry between gamma and beta

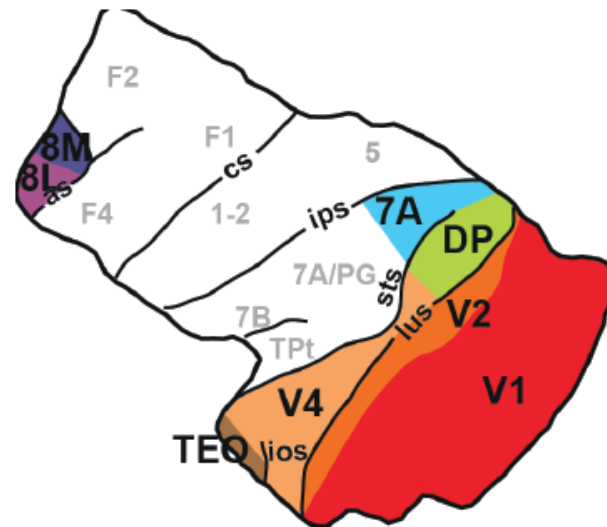
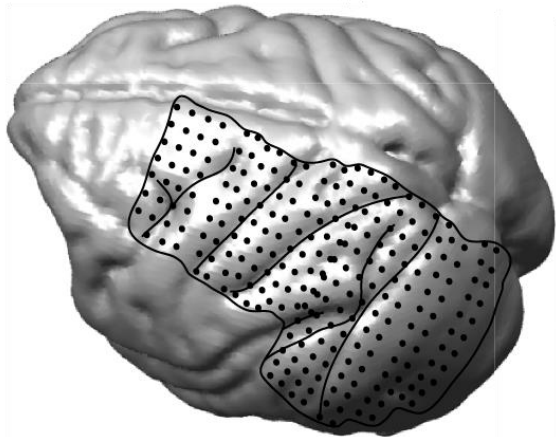


# Coverage of large-scale, high-density monkey ECoG recordings

Monkey 1

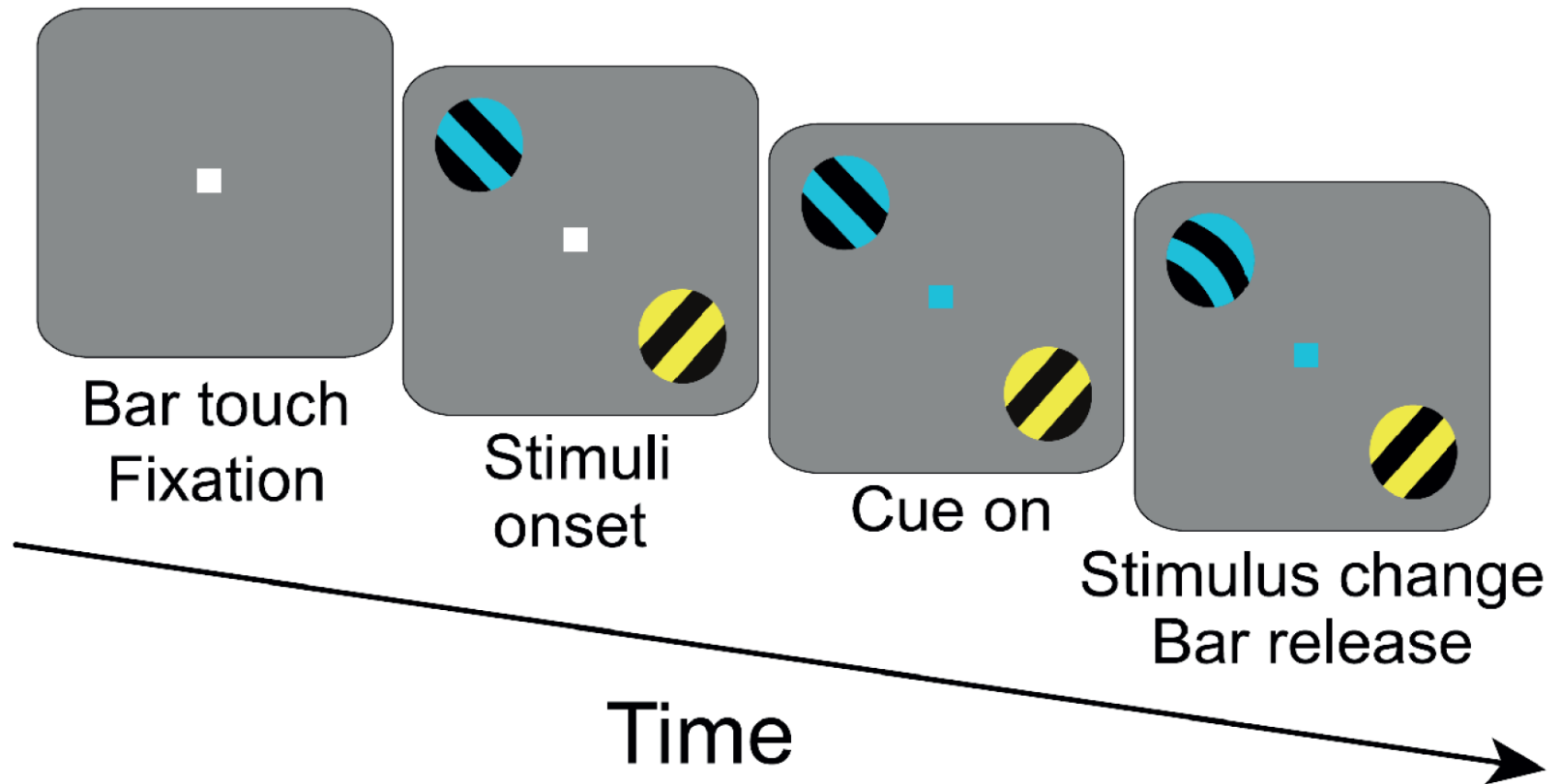


Monkey 2

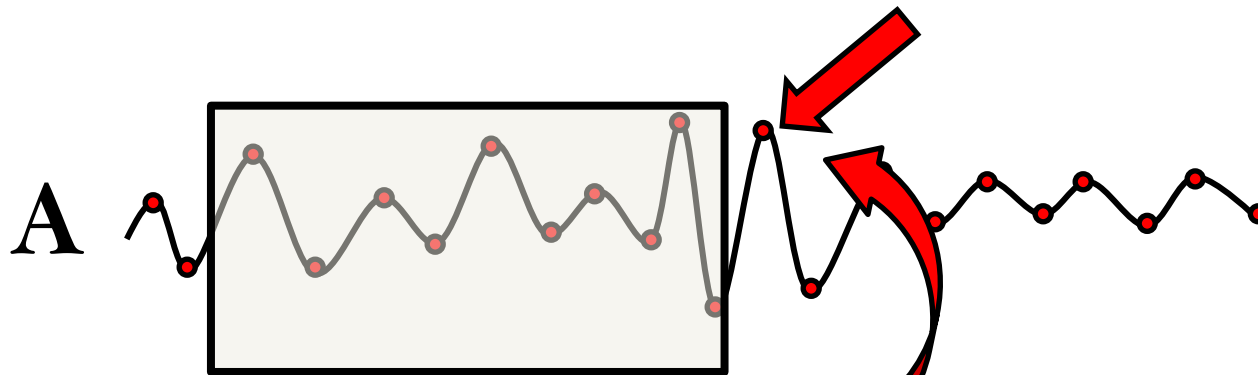


Increasing hierarchical level  
↑  
7A  
8M  
TEO  
DP  
V4  
8L  
V2  
V1

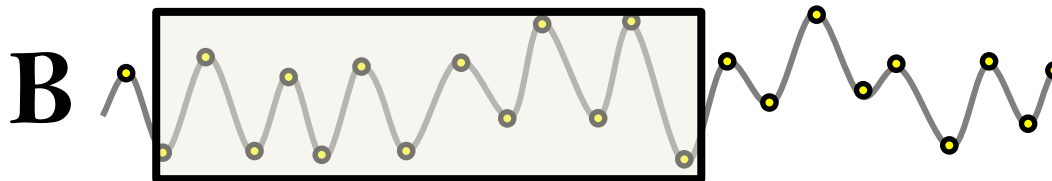
# Visual attention task



# Measuring directed influences with Granger causality



- *AR model used to predict  $A_{t+1}$  based on the past terms of  $A$*

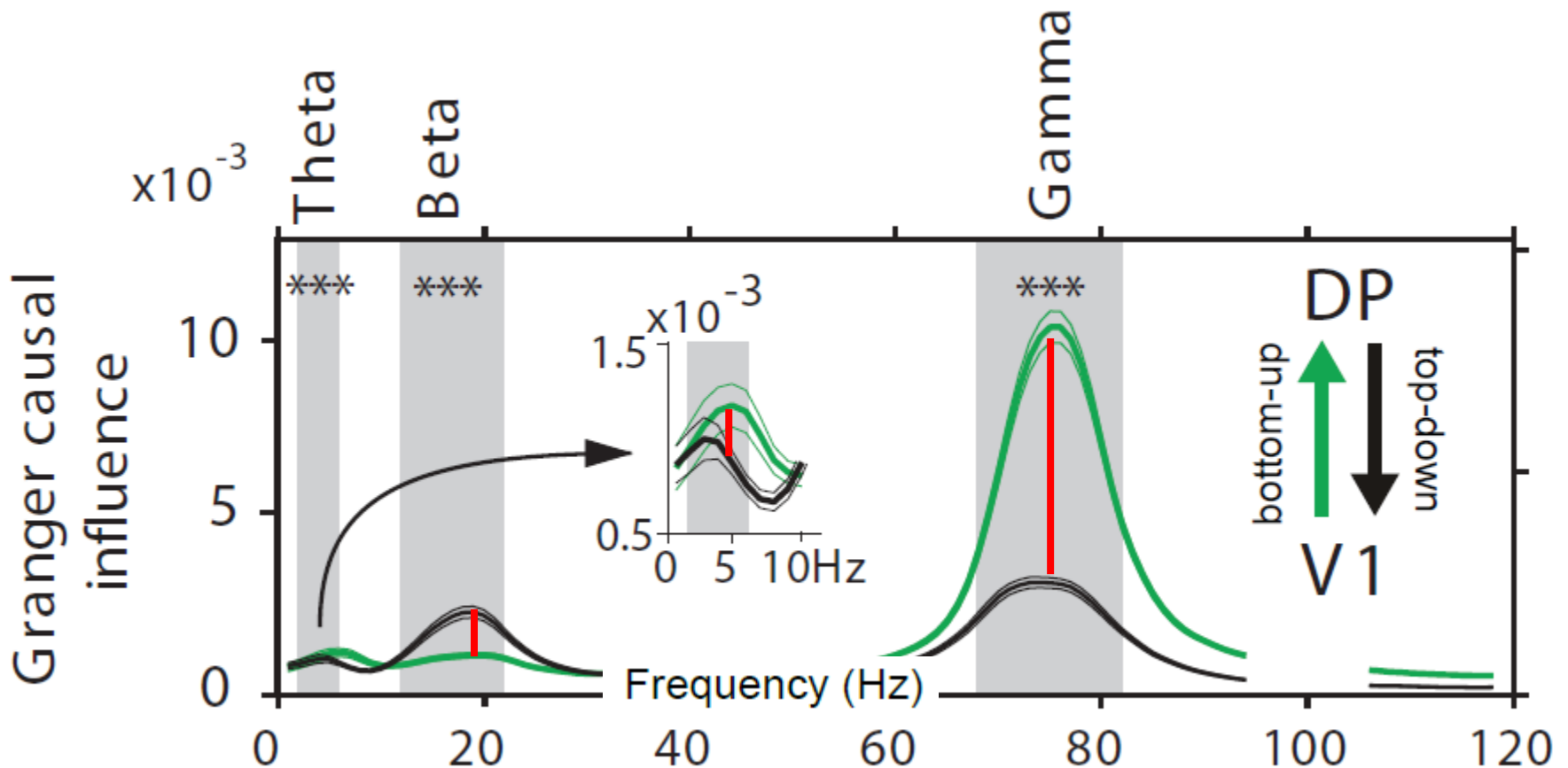


- *if past terms of  $B$  can improve prediction of  $A_{t+1}$  compared to prediction from past terms of  $A$  alone  $\rightarrow B$  granger-causes  $A$*

*Spectral GC*

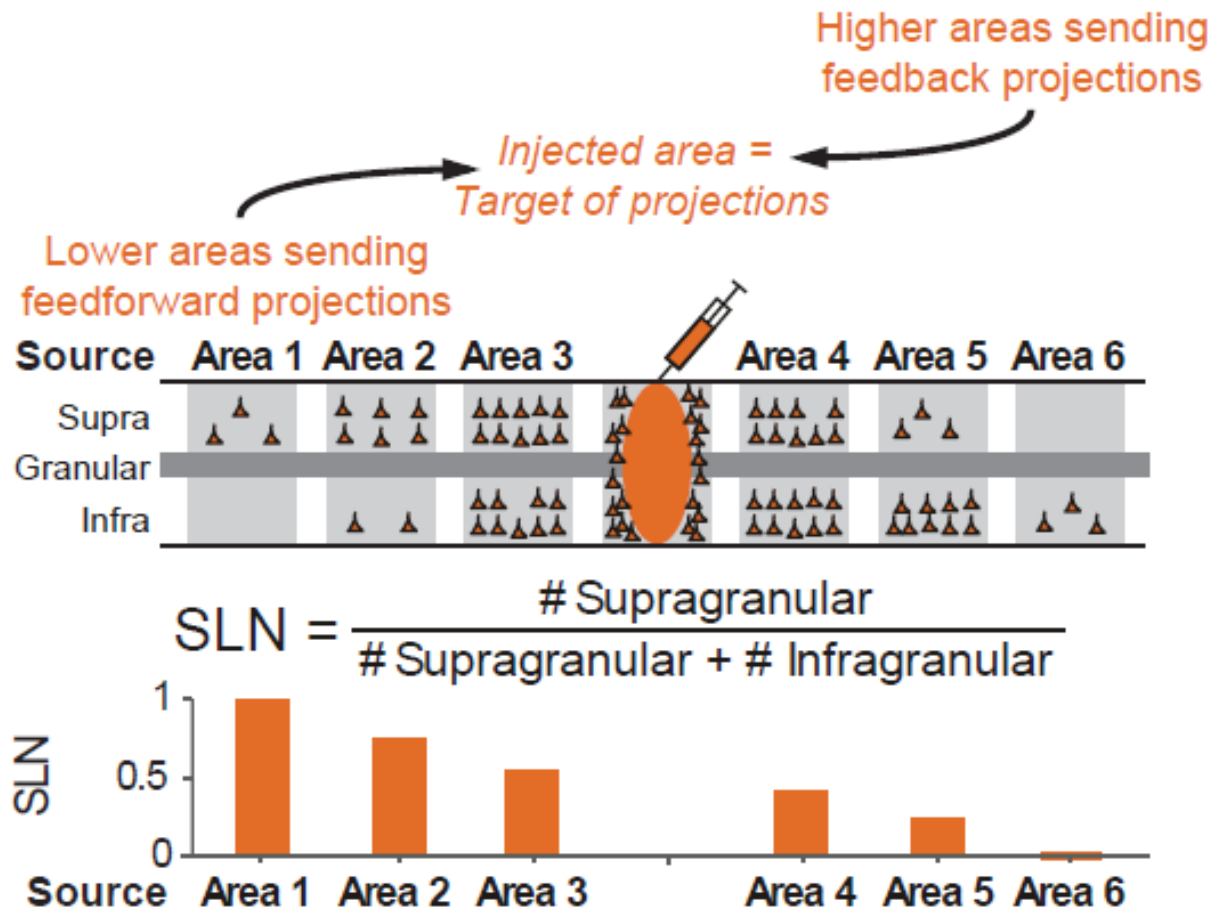
*fraction of total power at a frequency  $f$  of  $A$  is G-caused by  $B$*

# Quantifying functional asymmetries

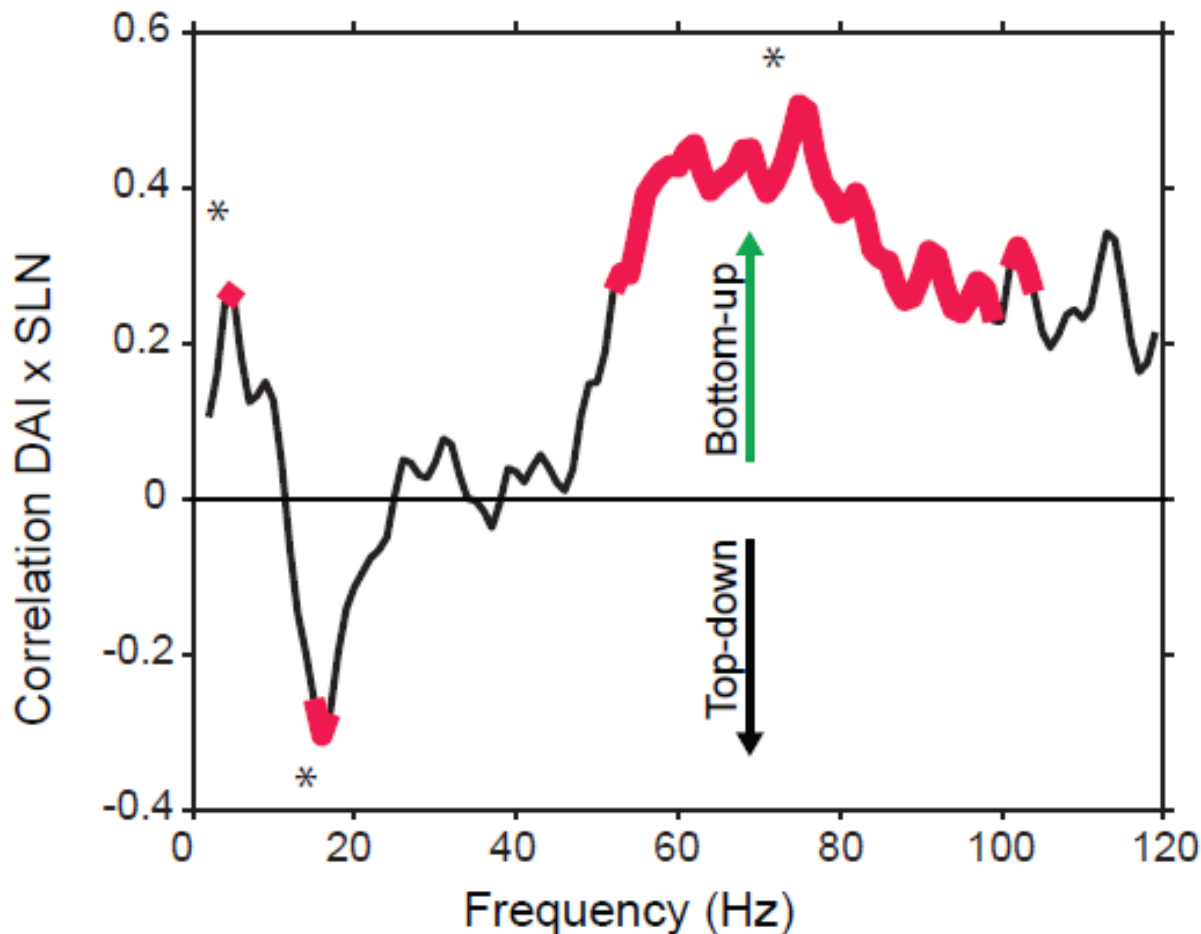


$$DAI(\text{frequency}) = \frac{\text{outflow} - \text{inflow}}{\text{outflow} + \text{inflow}}$$

# Anatomy of hierarchy

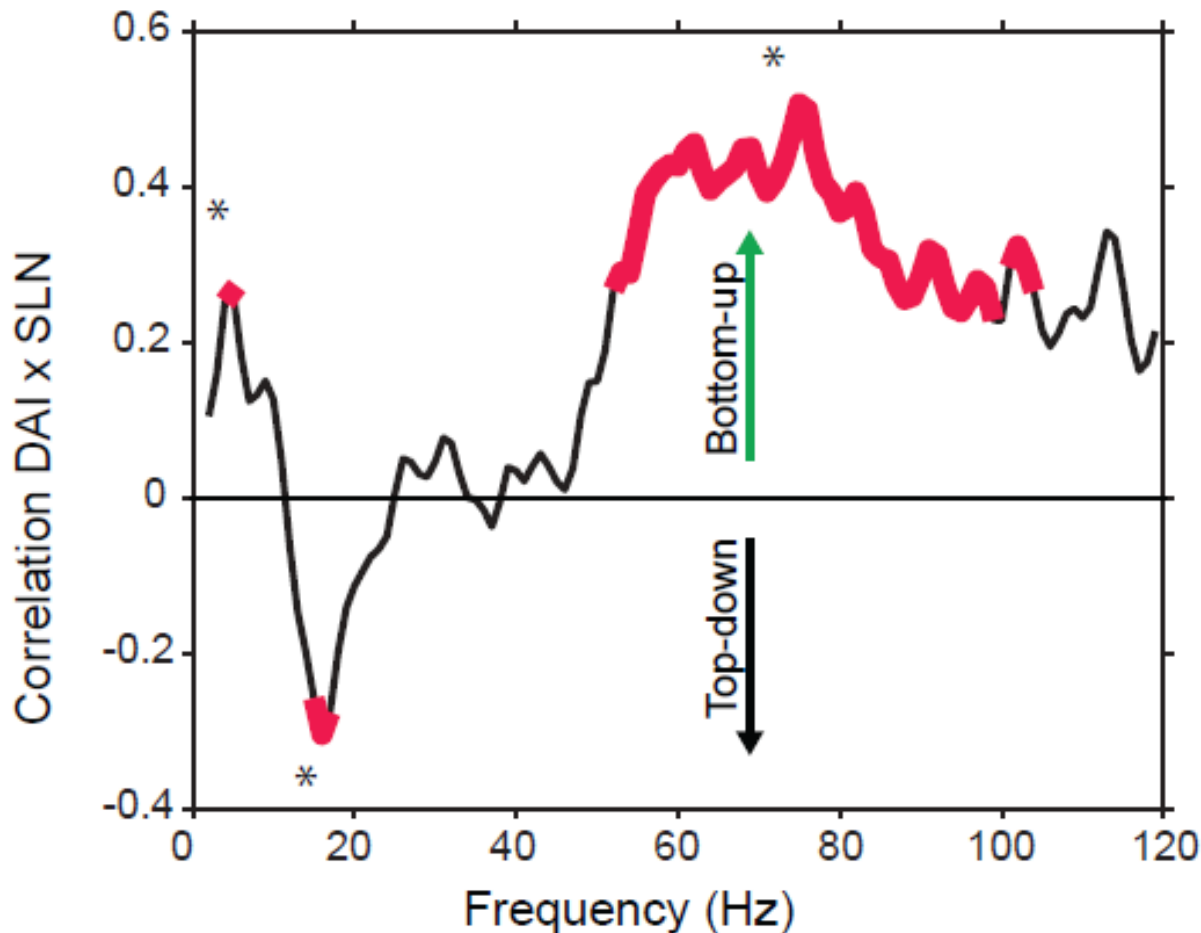


# Correlation between anatomical and functional *graded* asymmetries





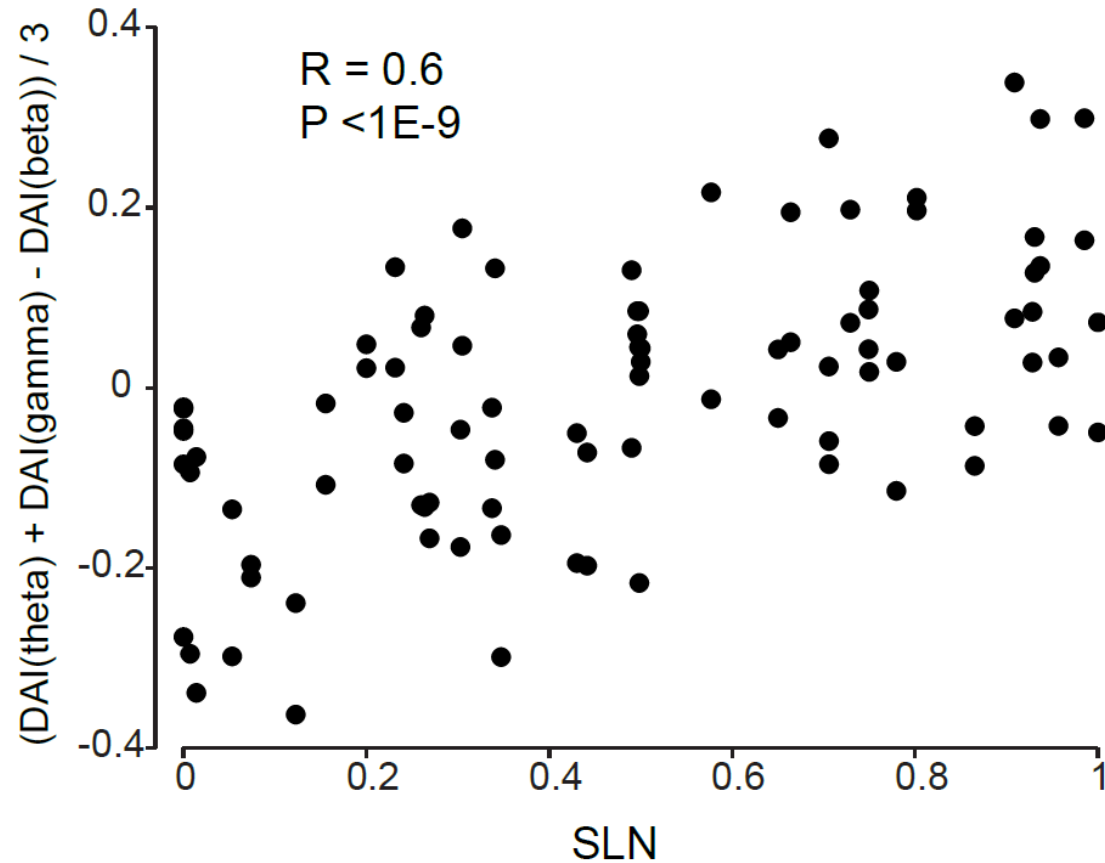
# Correlation between anatomical and functional asymmetries



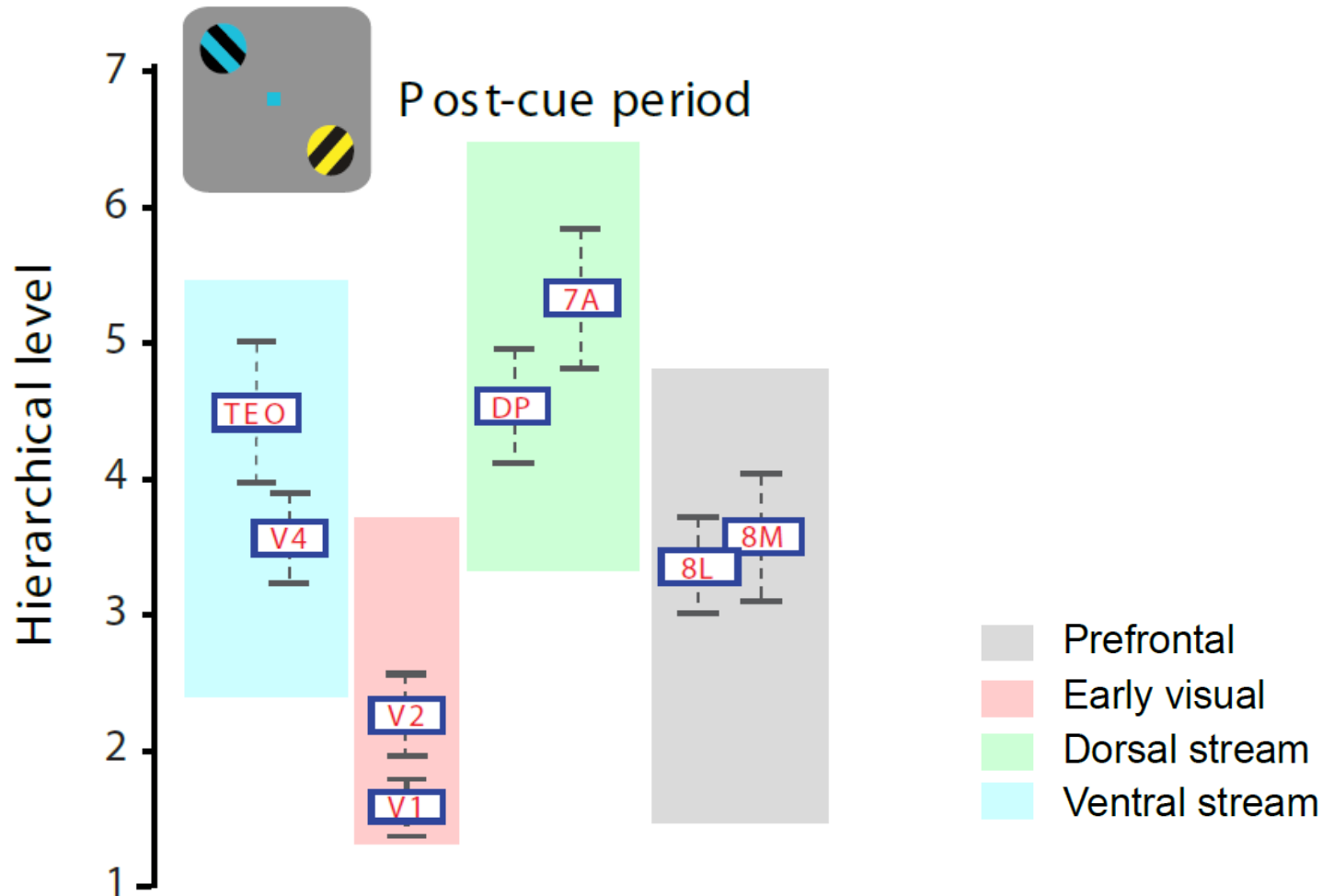
$$DAI(\text{frequency}) = \frac{GC \text{ outflow} - GC \text{ inflow}}{GC \text{ outflow} + GC \text{ inflow}}$$

$$SLN = \frac{\# \text{ neurons labeled supragranular}}{\# \text{ neurons labeled infra} + \# \text{ neurons labeled supragranular}}$$

# Graded-ness of anatomy and function are correlated

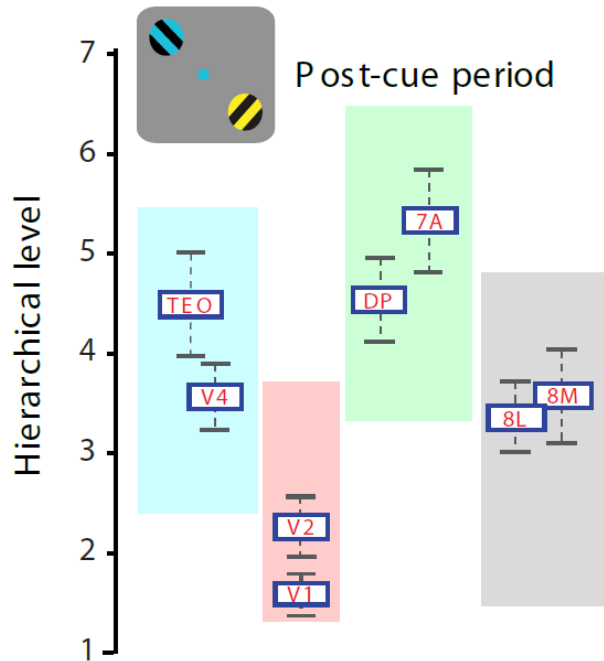


# The functional visual cortical hierarchy

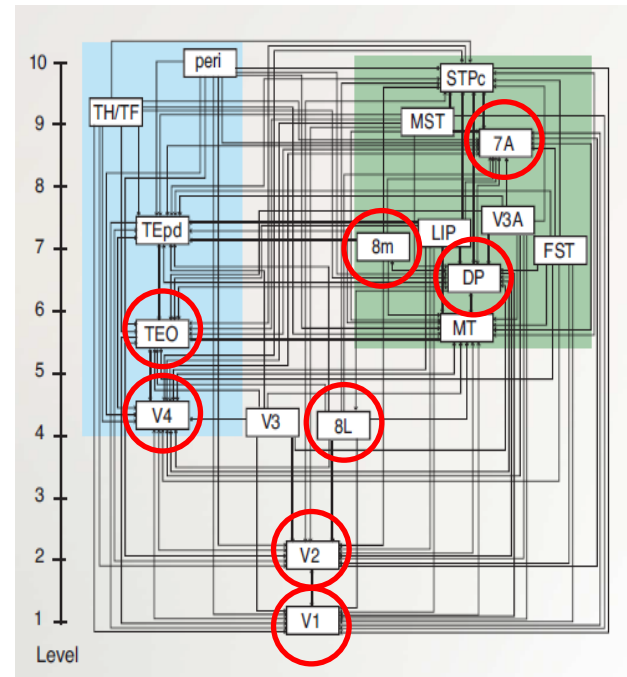


# Comparing hierarchical models

Functional Hierarchy Model

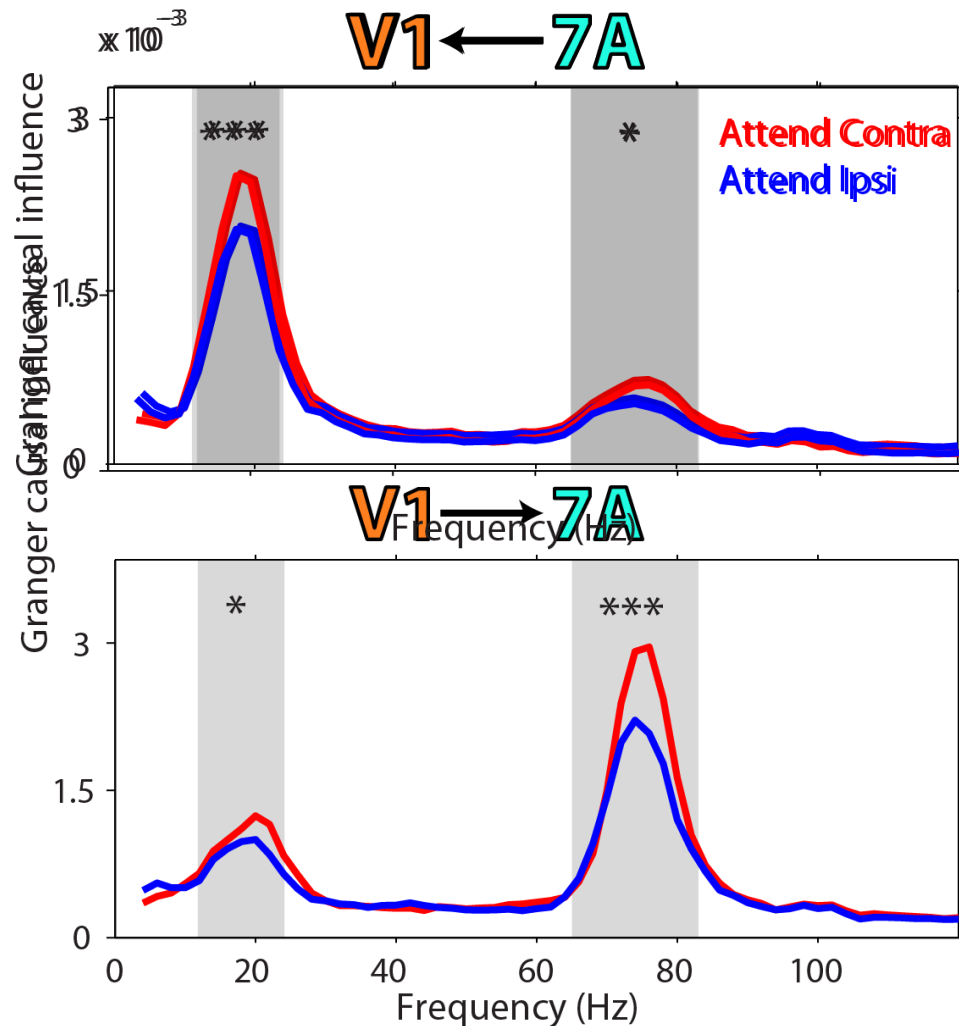


Anatomical Hierarchy Model (Kennedy)

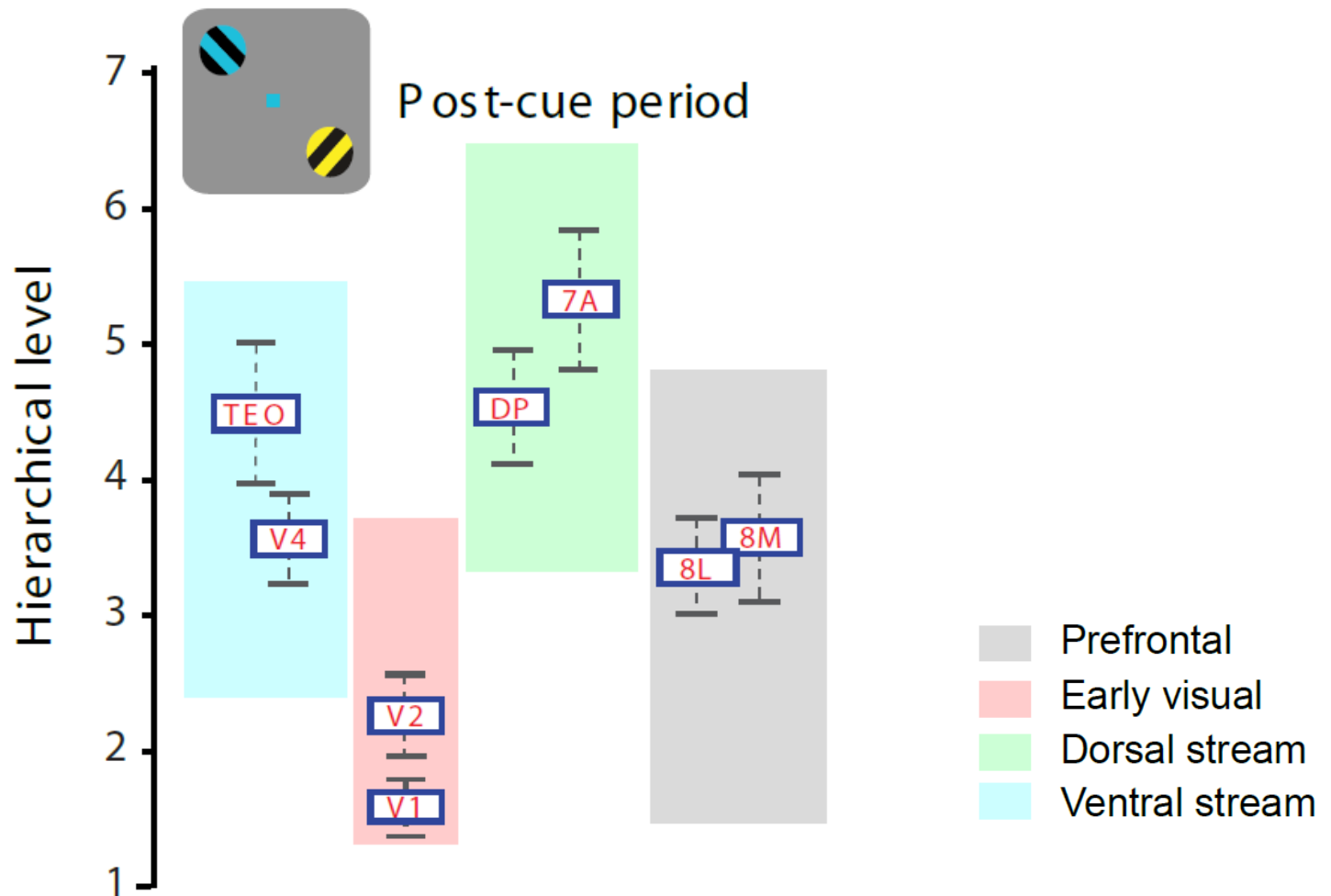


$R=0.94, p=0.0005$

# Attentional modulation of inter-areal GC influences

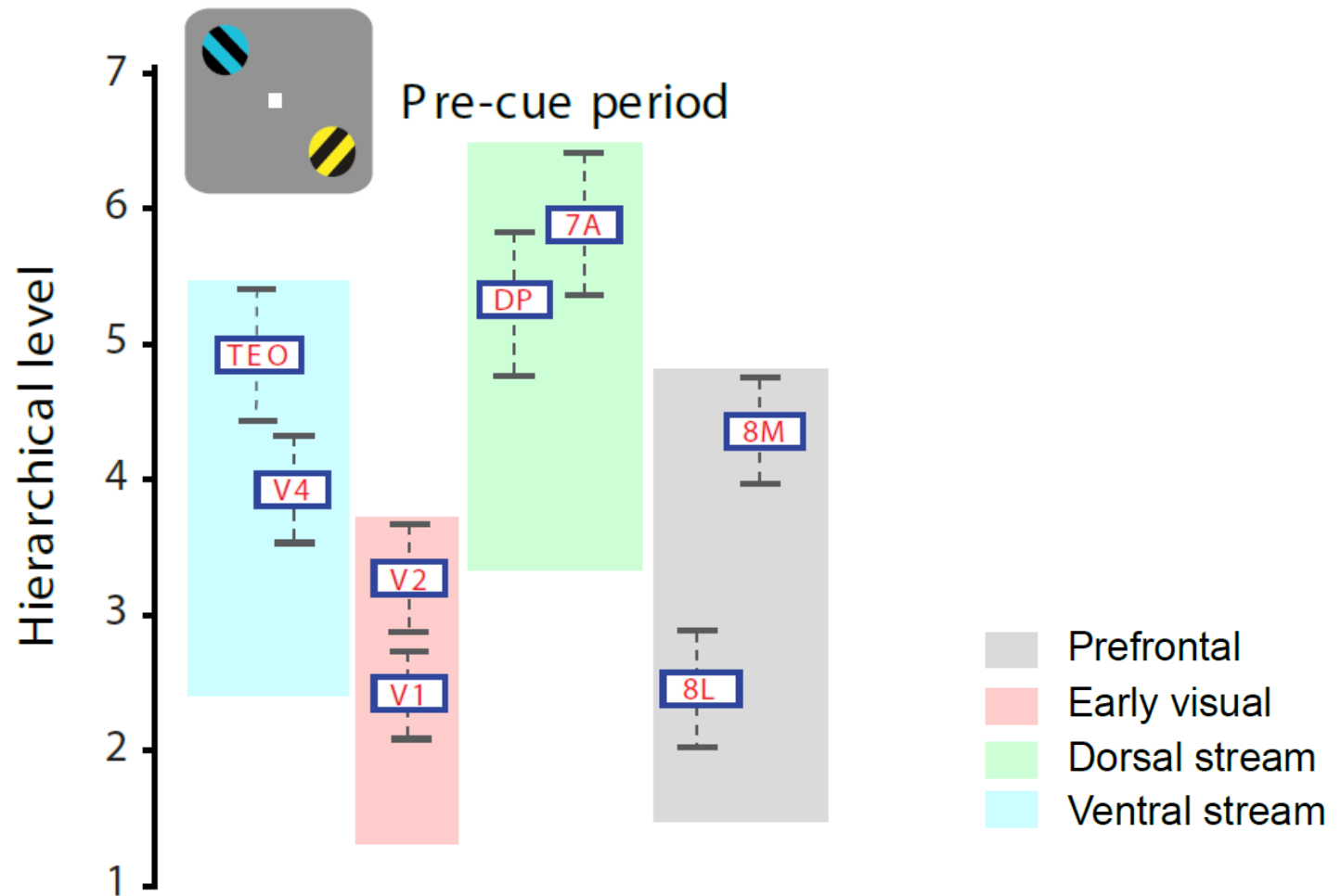


# Is the functional hierarchy dynamic?

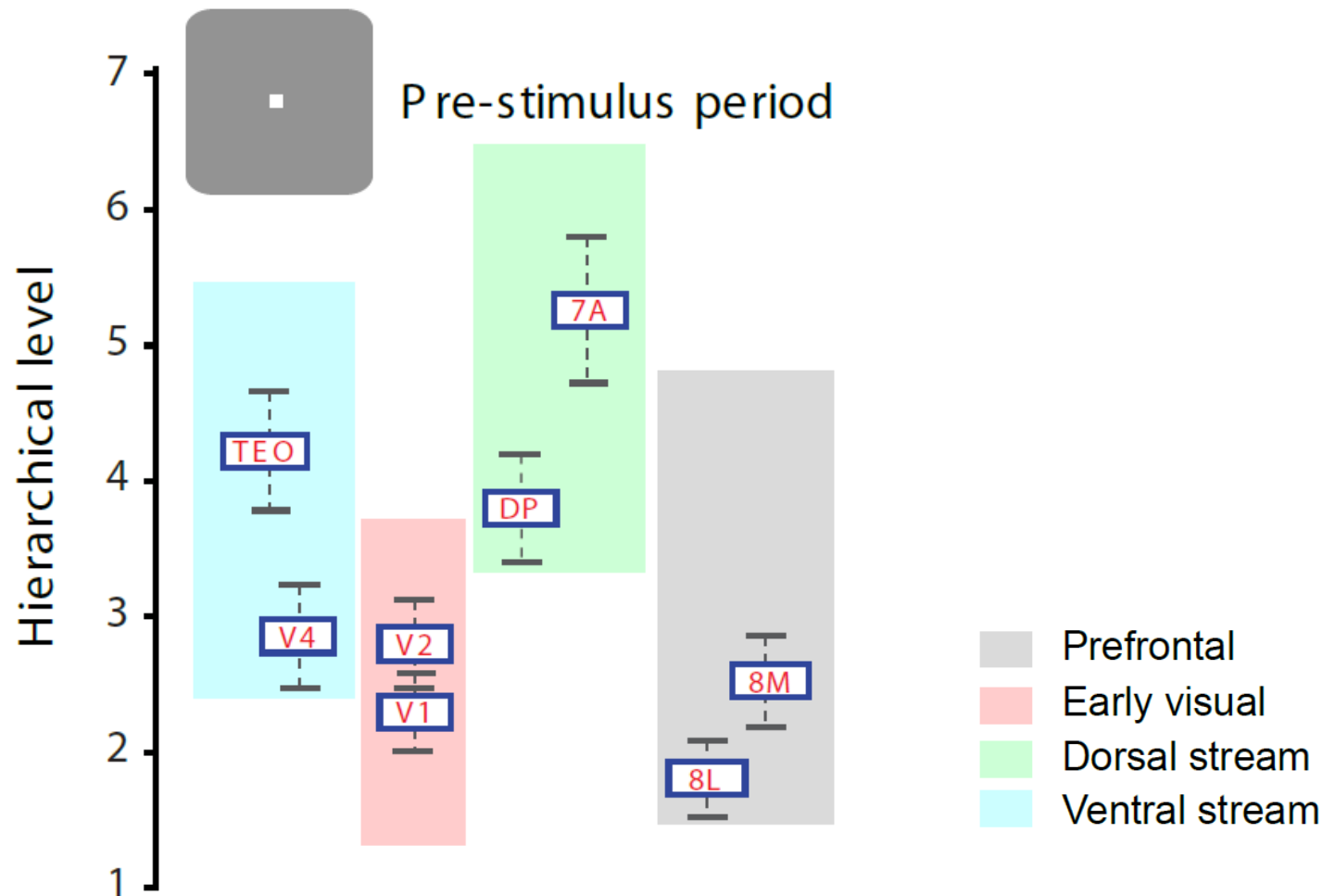




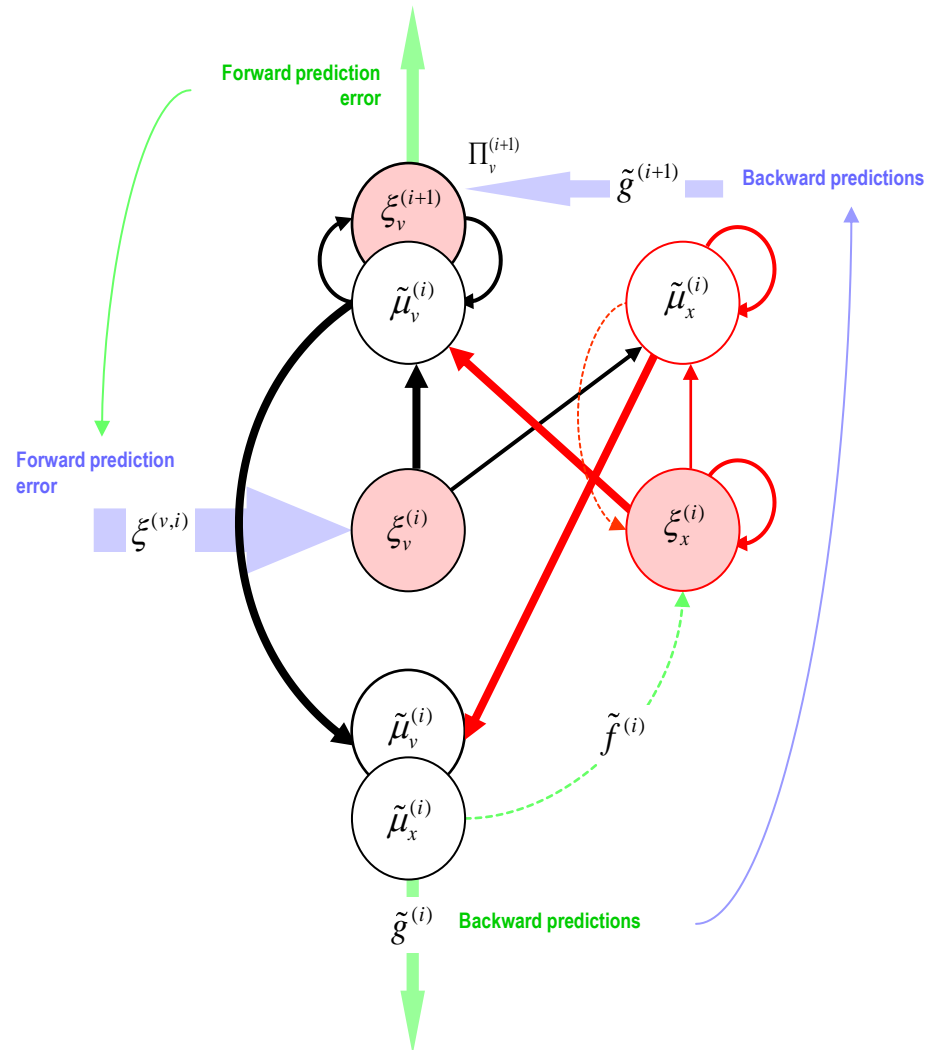
# Is the functional hierarchy dynamic?



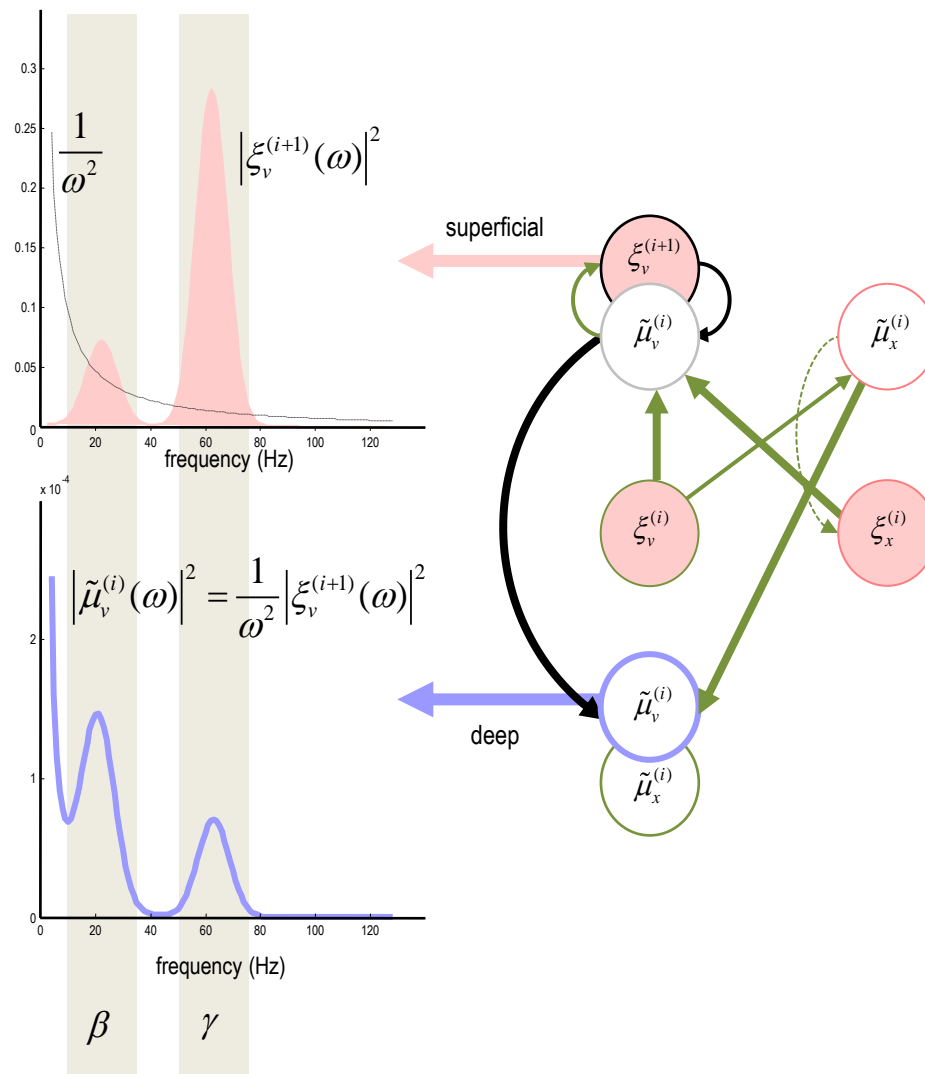
# Is the functional hierarchy dynamic?



# Canonical microcircuits for predictive coding?



# Spectral asymmetries between superficial and deep cells



# Conclusions

- Feedforward and feedback anatomical connections are segregated in different layers
- Functionally, feedforward and feedback communication are segregated in different frequencies
- These communication “rules” define a functional hierarchy
- Beta and gamma influences are likely related to the underlying laminar anatomical connectivity and oscillatory profile of different areas
- Inter-areal synchronization at beta and gamma frequencies is enhanced with selective visual attention
- Changes in inter-areal GC influences over task periods reveal a dynamic functional hierarchy
- These patterns may underlie a basic circuit motif of canonical microcircuits

# Acknowledgements

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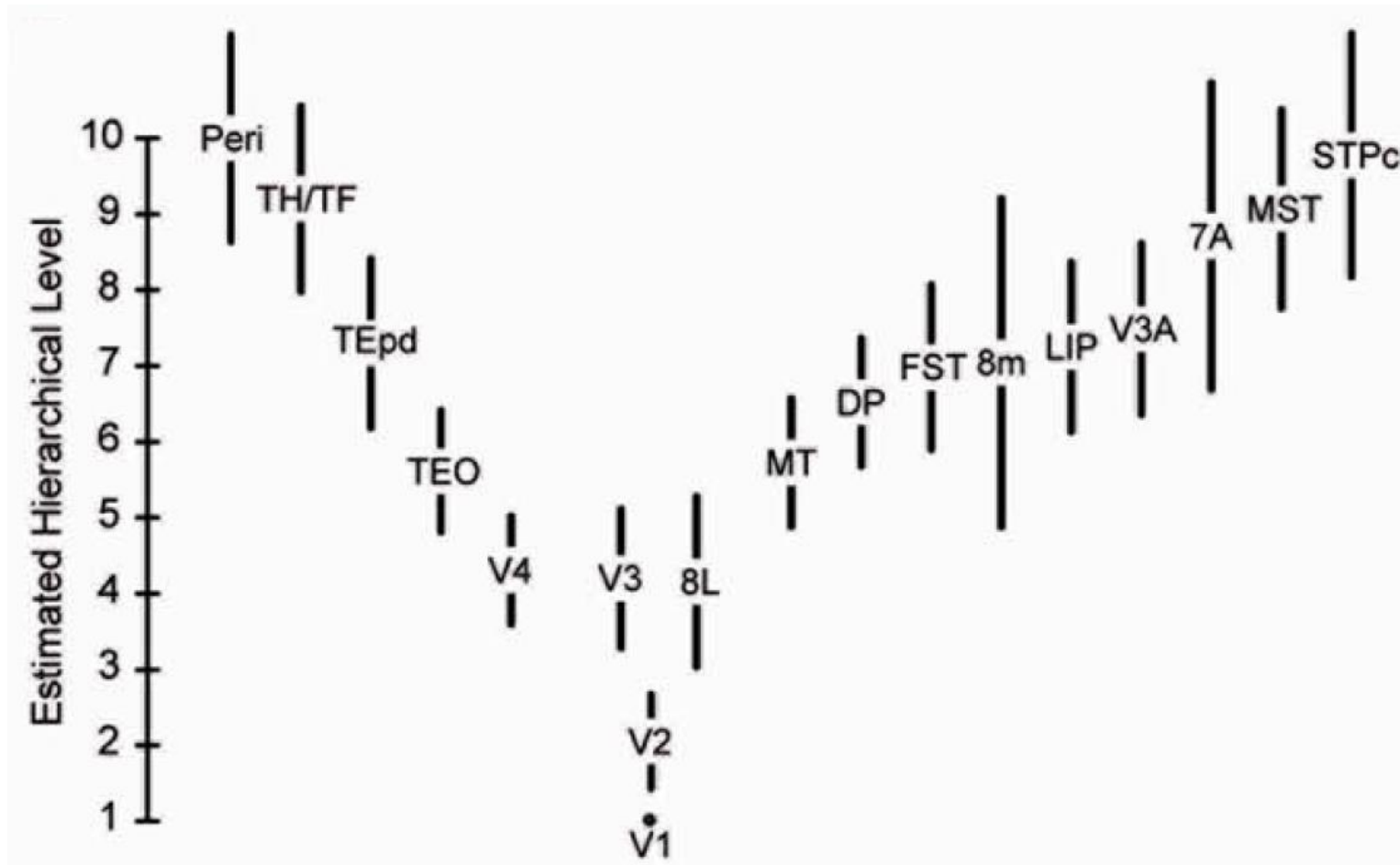
**Pascal Fries**



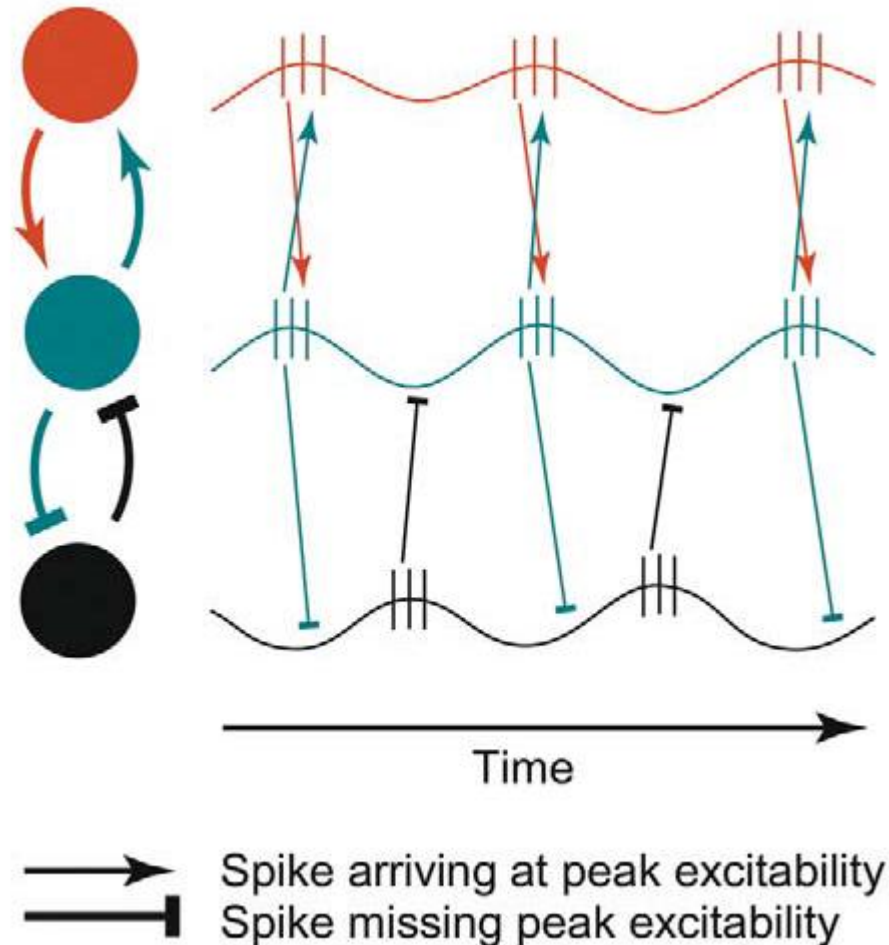
# Future questions

- If top-down and bottom-up processing are segregated in layers and frequencies, then what mechanism(s) mediate their functional integration?
- Cross-frequency interactions: how does top-down beta lead to bottom-up gamma modulation?
- Cortical hierarchical organization in the human brain?

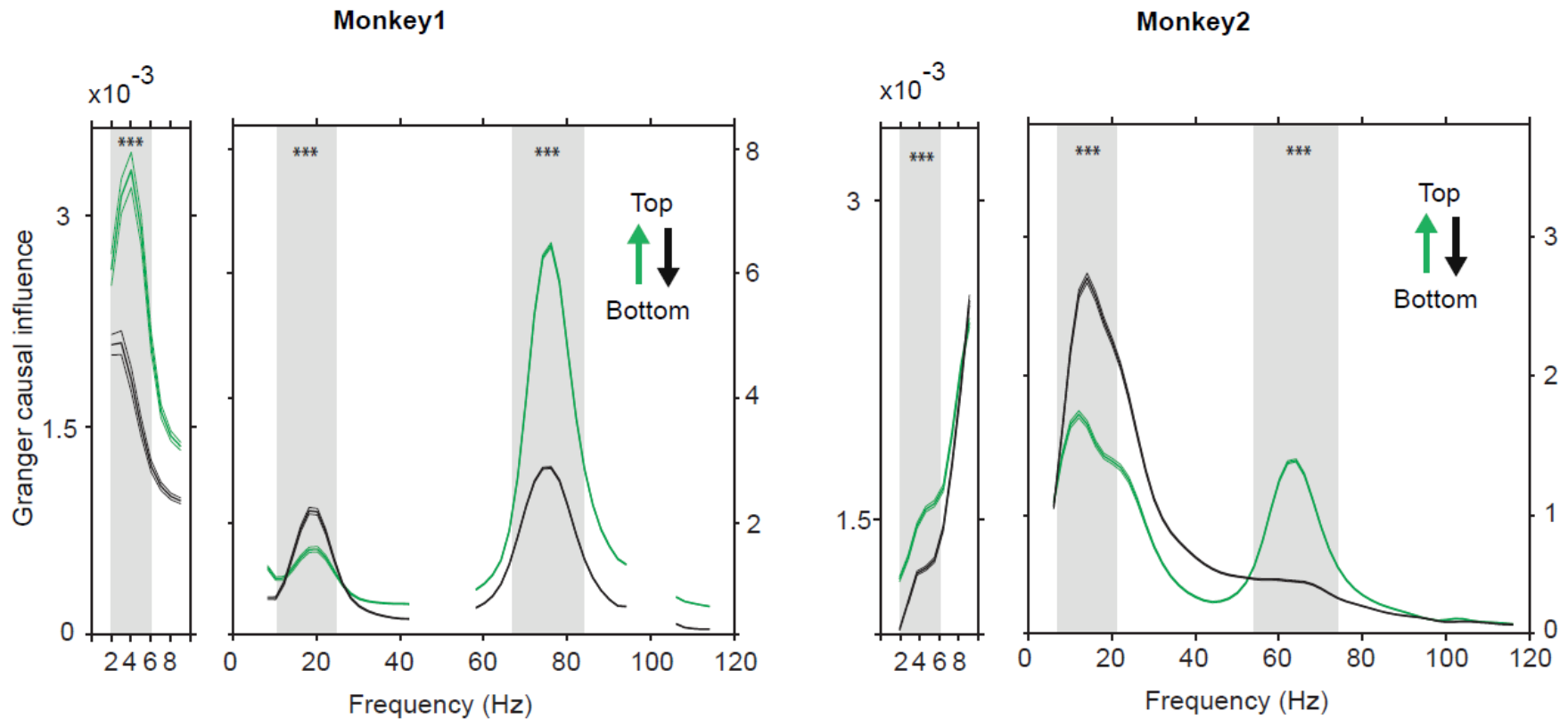
# The hierarchy has some intrinsic variability



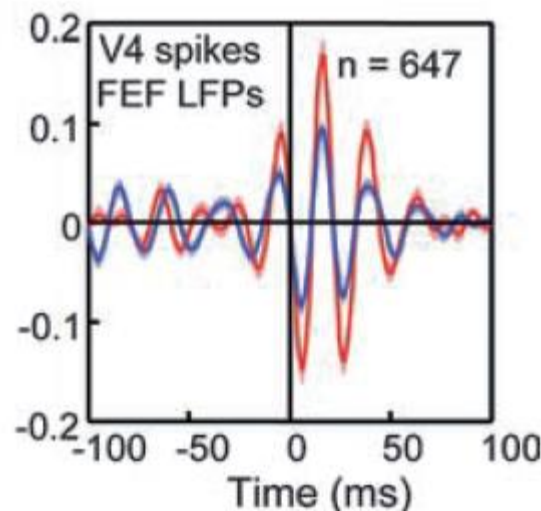
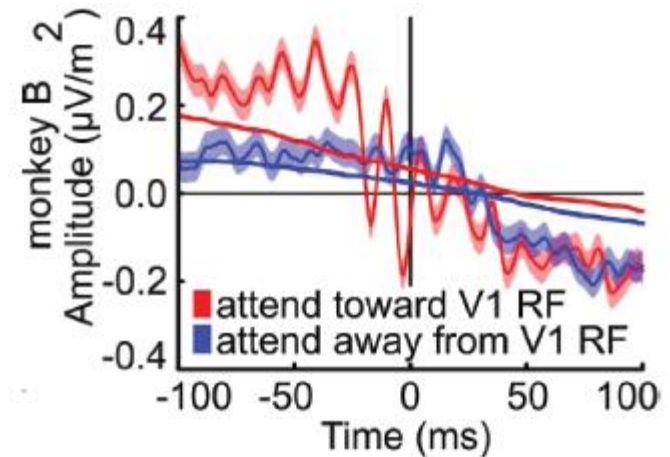
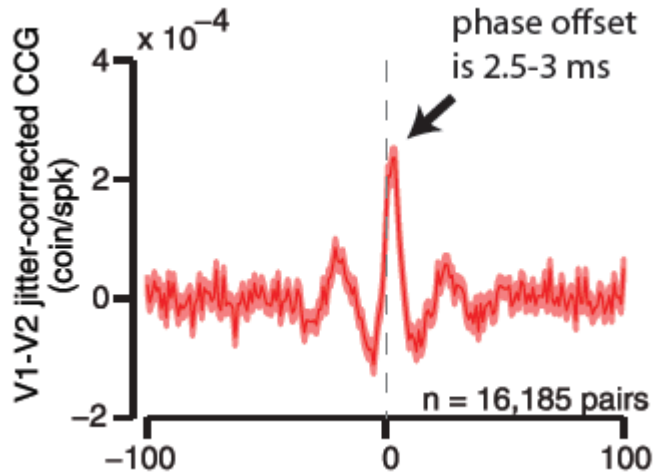
# Original Communication-through-coherence hypothesis



# Theta and gamma are feedforward, beta is feedback

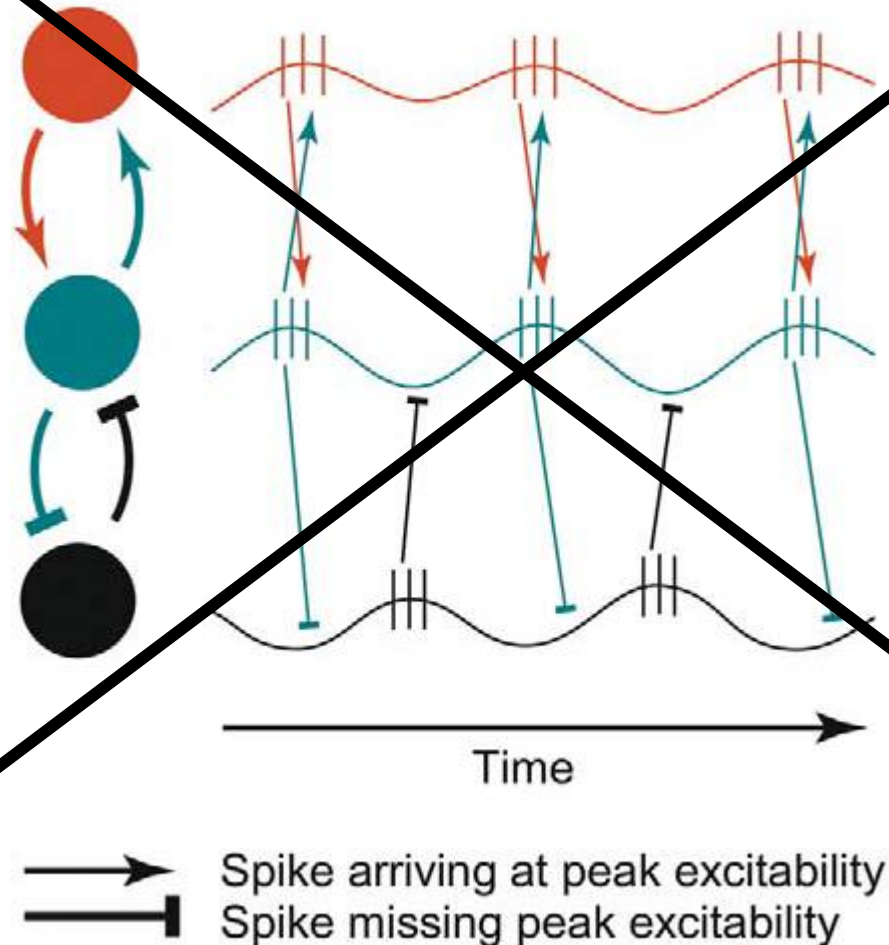


# Inter-areal synchronization exists *predominantly* at non-zero phase



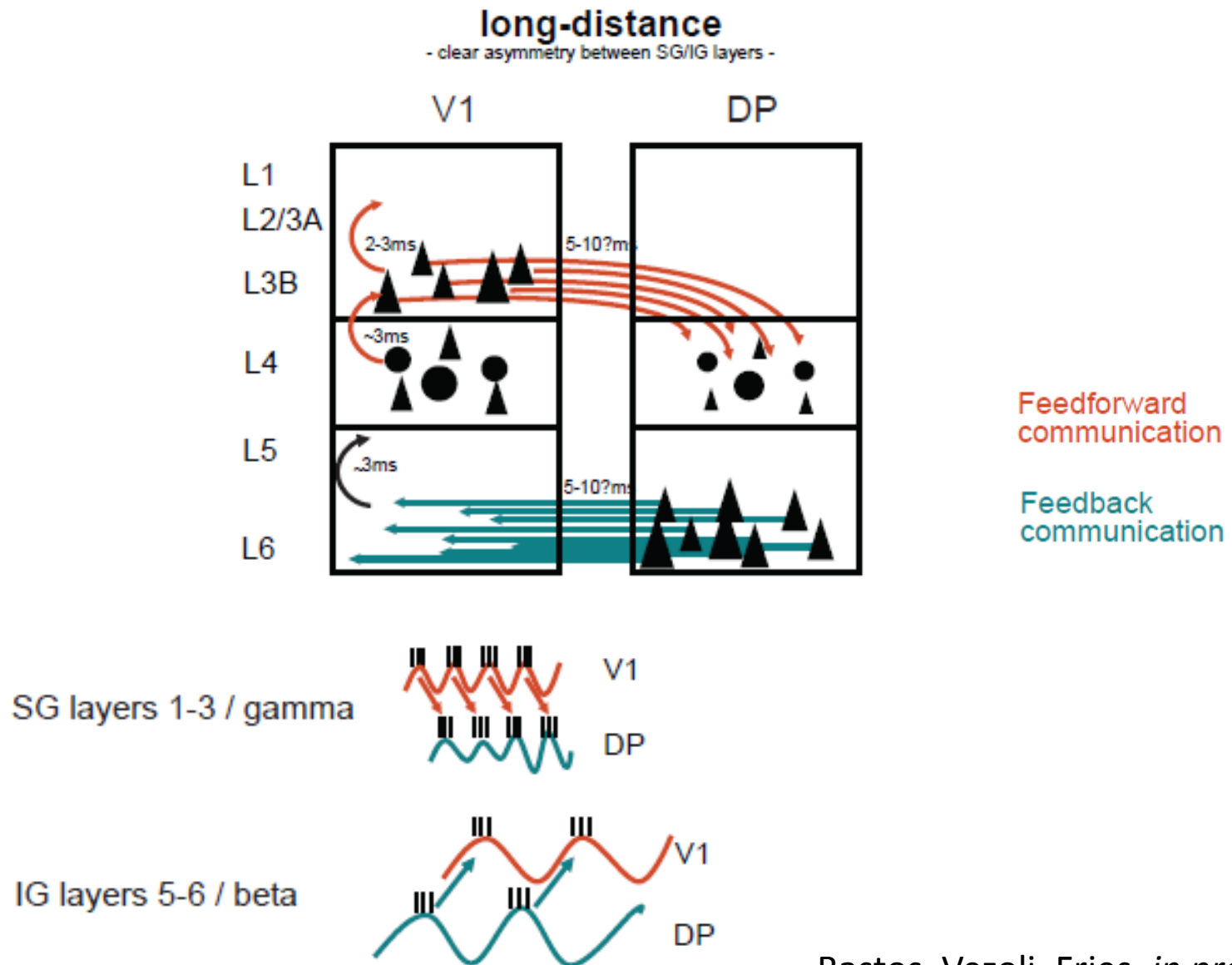
Jia et al., 2013  
Grothe et al., 2012  
Gregoriou et al., 2009

# Original Communication-through-coherence hypothesis





# CTC through frequency and anatomical segregation



# CTC through frequency and anatomical segregation

