Functional MRI Encoding Model Reveals Population-Level Vibration Frequency Tuning in Human Cortex

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Introduction

- Vibration frequency perception is a crucial capacity that enables humans to recognize and manipulate objects.
- Vibration frequency sensing activates somatosensory areas, but a little is known about the neural representation of frequency in those areas.
- Here, we studied population-level vibration frequency representation using fMRI encoding model that predict BOLD response profile on a voxel-wise basis.

Questions

Q1. How is vibration frequency represented in the brain?

Q2. How is vibration frequency information combined over the hands?

Methods

- **Event-related fMRI experiment**: 5 subjects scanned in 3T scanner; 12 runs or 4560 volumes/subject in 2 sessions.
- **Task**: Respond to odd-ball events (middle vibration differs)
- **Data** preprocessing, analysis and visualization using AFNI, SUMA, and Python 3.
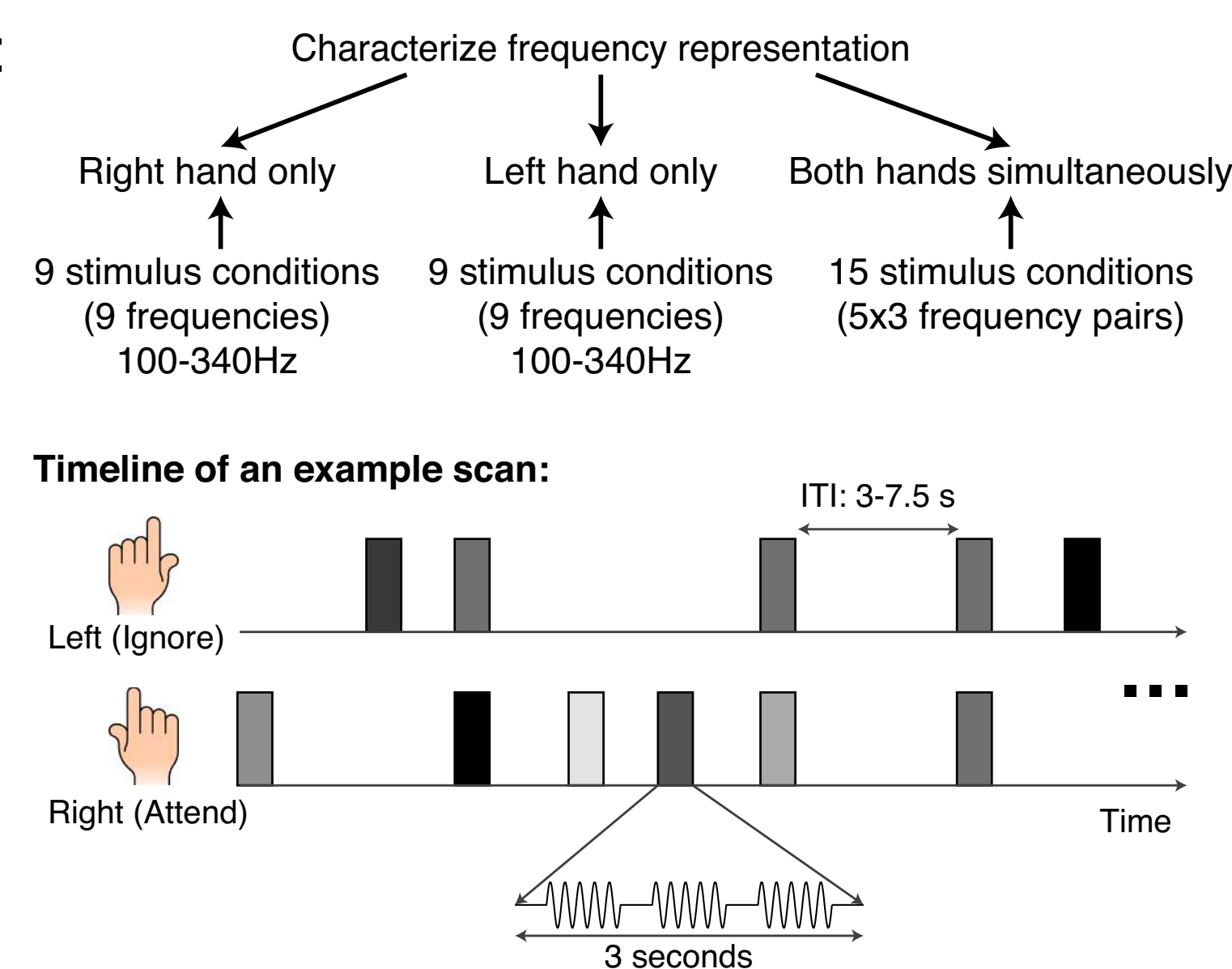- **Metrics**:

  Hand preference: $\sum_{i=1}^{\#basis} |w_i|$

  Frequency selectivity: $w_{max} - \frac{1}{\#basis - 1} \sum_{i=1}^{\#basis} w_i$, $\quad i \neq argmax(w)$
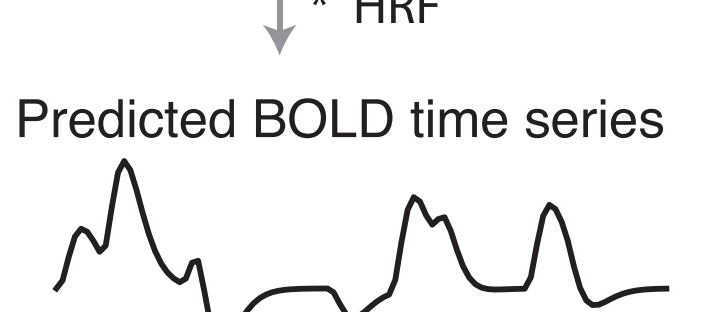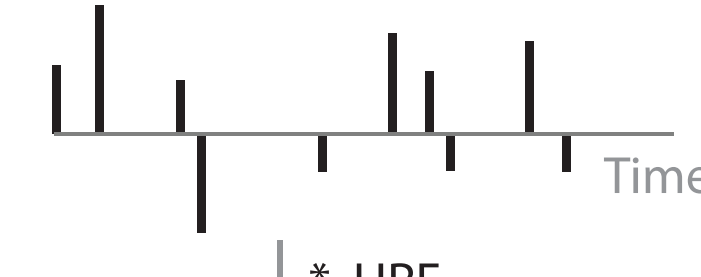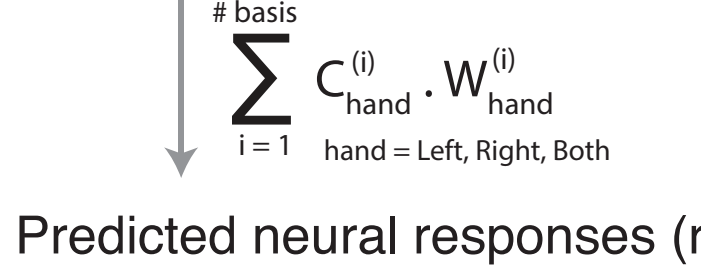
  w_i : weights associated with the stimulated hand and frequency-tuned basis functions.

Characterize frequency representation

Right hand only — 9 stimulus conditions (9 frequencies) 100-340Hz

Left hand only — 9 stimulus conditions (9 frequencies) 100-340Hz

Both hands simultaneously — 15 stimulus conditions (5x3 frequency pairs)

Timeline of an example scan:

Left (Ignore)

Right (Attend)

ITI: 3-7.5 s

3 seconds

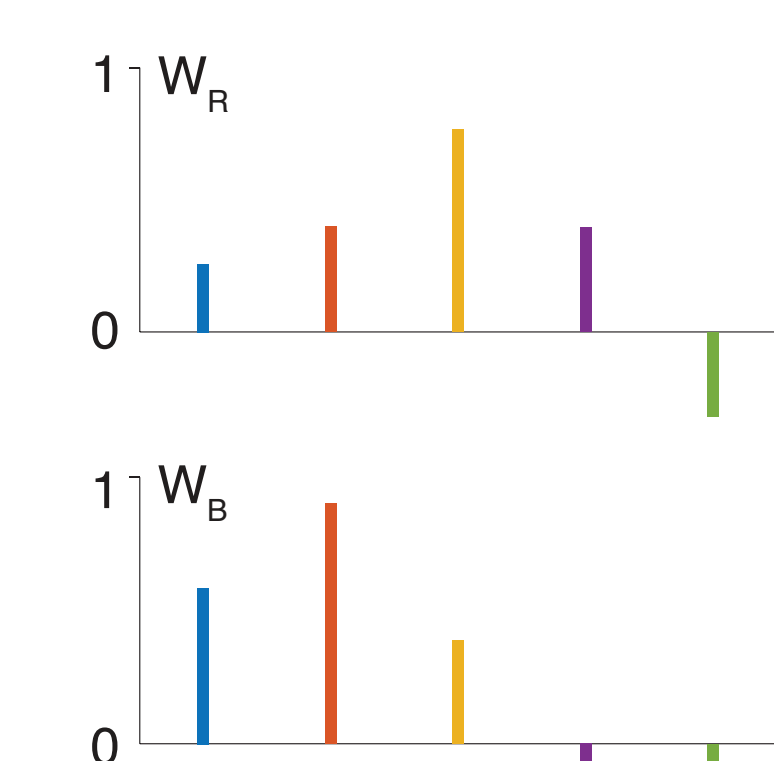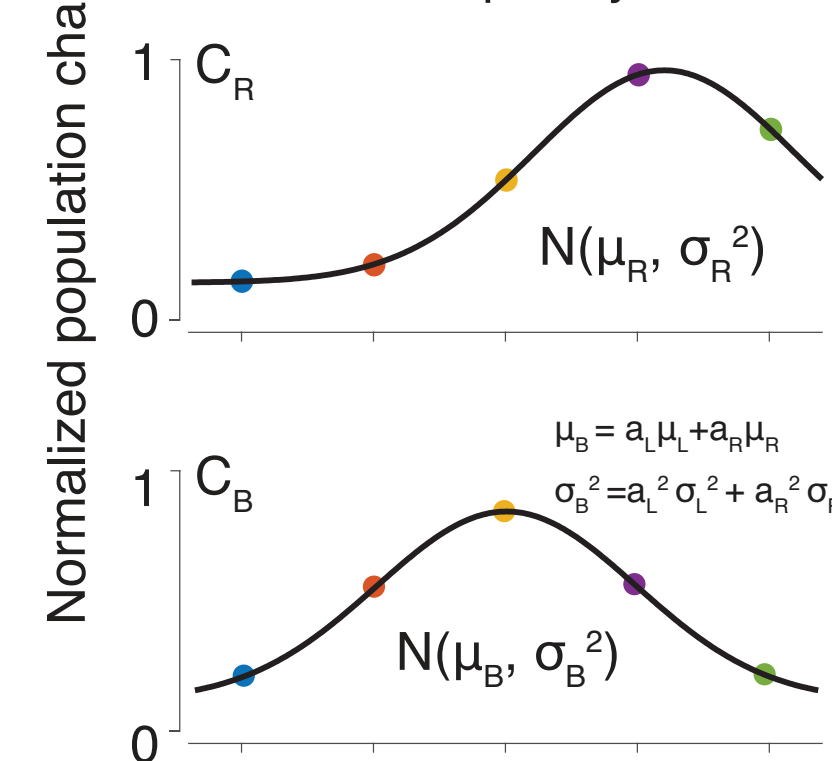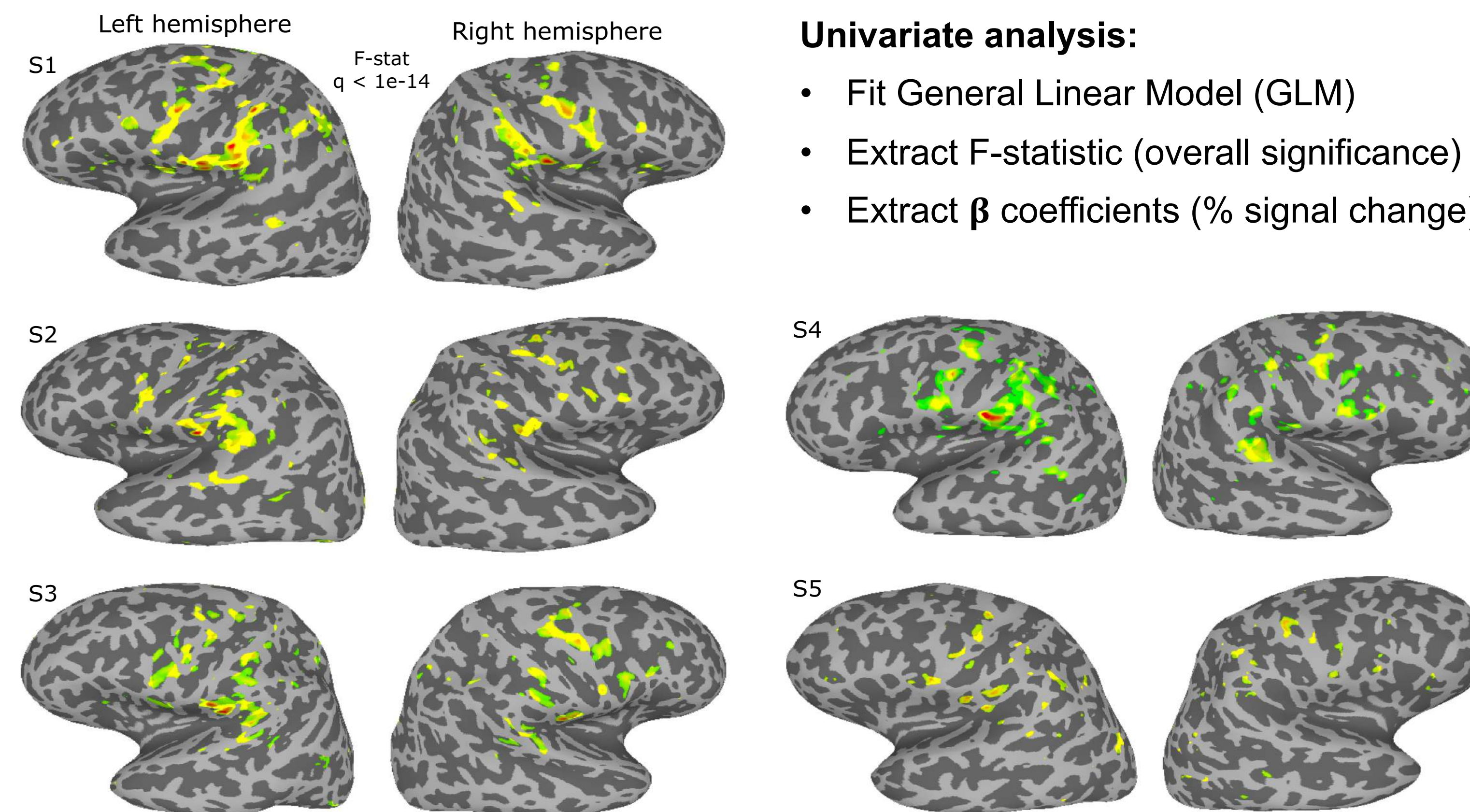## Encoding Model

Encoding model:

$$r = \sum_{i=1}^{\#basis} C_L^{(i)} \cdot W_L^{(i)} + C_R^{(i)} \cdot W_R^{(i)} + C_B^{(i)} \cdot W_B^{(i)}$$

Left — Right — Both

C_L : $N(\mu_L, \sigma_L^2)$

C_R : $N(\mu_R, \sigma_R^2)$

C_B : $N(\mu_B, \sigma_B^2)$

$\mu_B = a_L \mu_L + a_R \mu_R$
$\sigma_B^2 = a_L^2 \sigma_L^2 + a_R^2 \sigma_R^2$

W_L, W_R, W_B

Norm. population channel response : f_1 f_2 f_3 f_4 f_5 Frequency

Stimuli

$$\sum_{i=1}^{\#basis} C_{hand}^{(i)} \cdot W_{hand}^{(i)}, \quad hand = Left, Right, Both$$

Predicted neural responses (r)

* HRF

Predicted BOLD time series
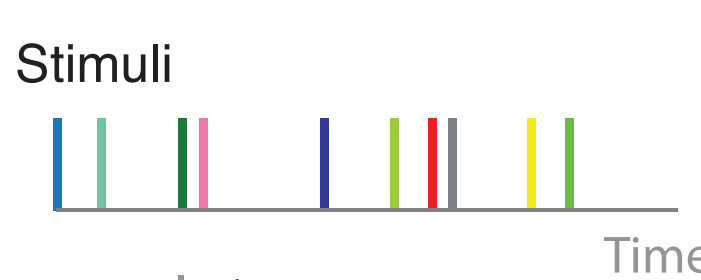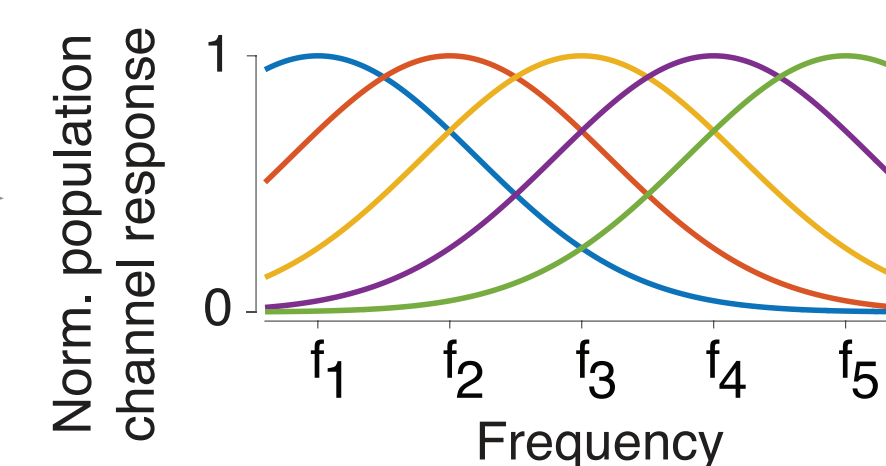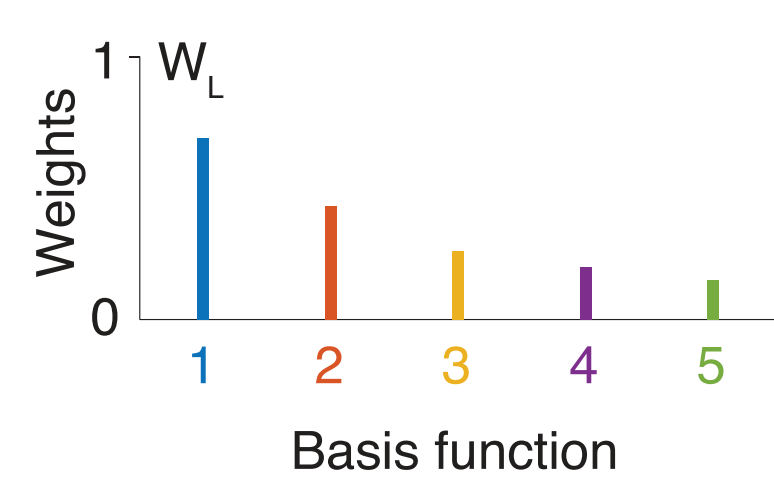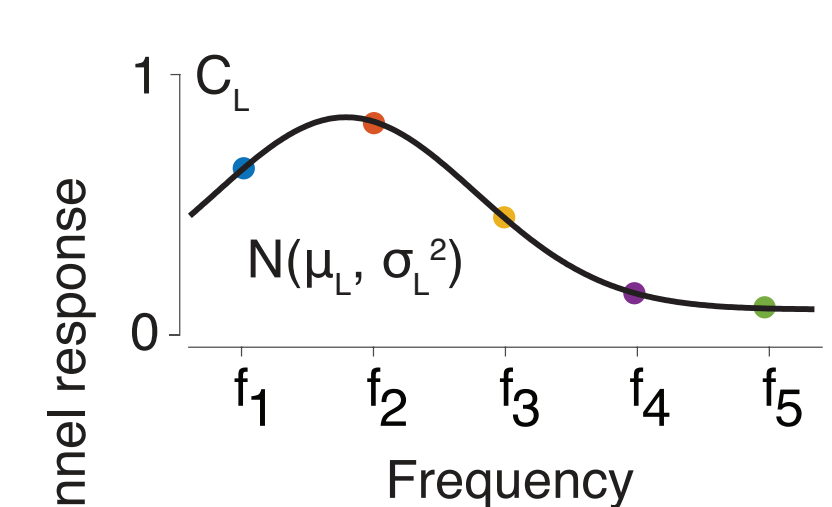
Sensorimotor areas respond to hand stimulation in a frequency-dependent manner

Left hemisphere — Right hemisphere
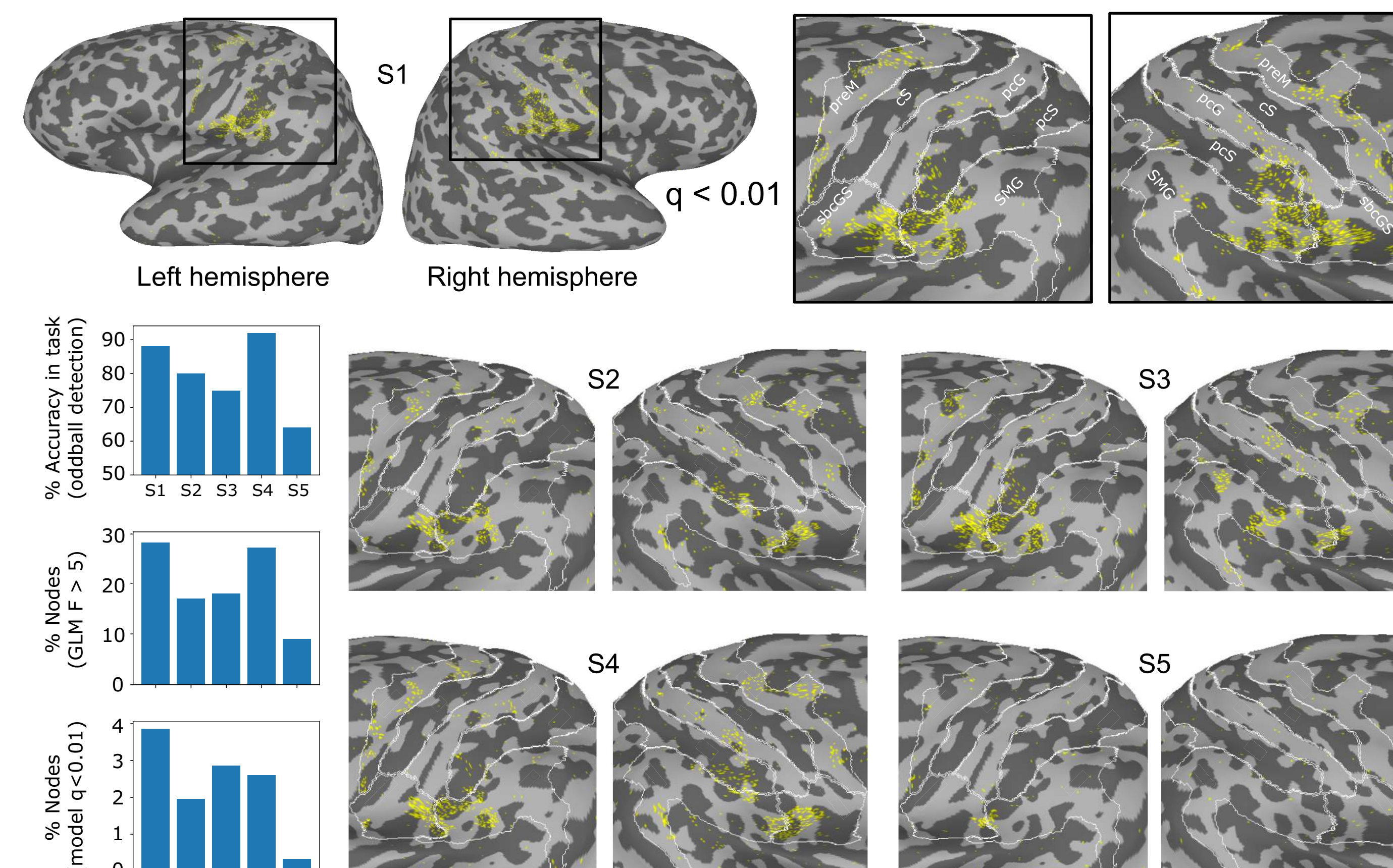
S1 — F-stat q < 1e-14

S2 — S4

S3 — S5

Univariate analysis:

- Fit General Linear Model (GLM)
- Extract F-statistic (overall significance)
- Extract β coefficients (% signal change)

% signal change — Frequency (Hz)

405 nodes, 357 nodes, 171 nodes, 98 nodes, 84 nodes, 57 nodes, 99 nodes, 185 nodes, 263 nodes

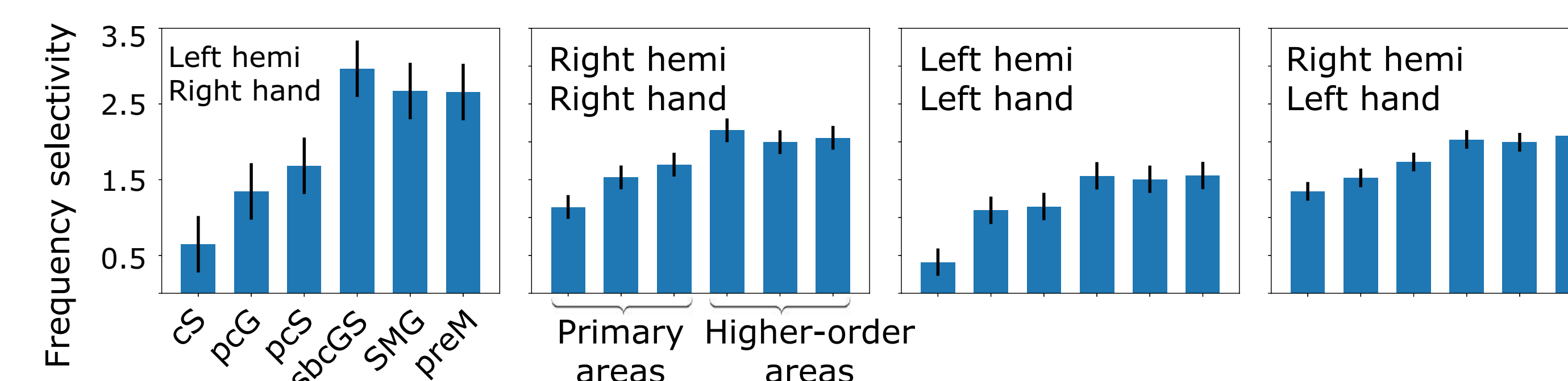Node counts (x 100) — Preferred frequency (Hz) — n = 5 subjects
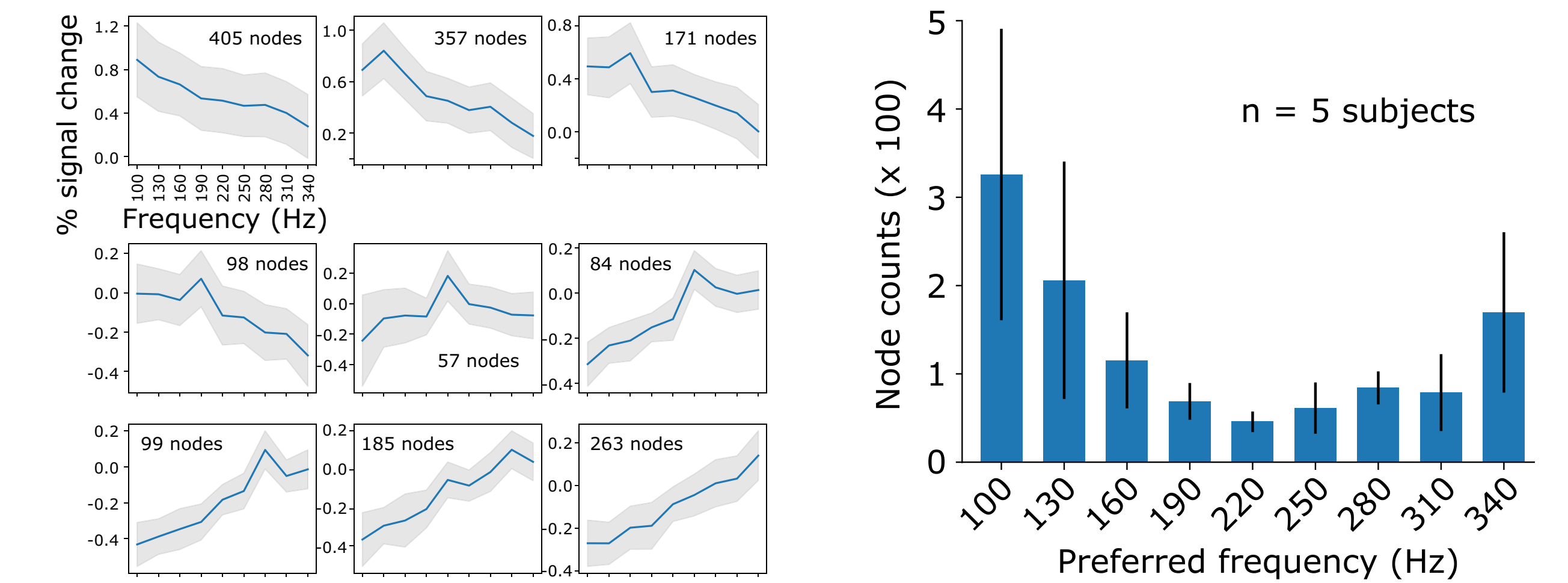
- Sensorimotor areas of each participant were activated by the vibration stimuli.
- Sensorimotor areas responded differentially to different vibration frequencies.
- More nodes responded to lower/higher frequencies, while fewer nodes responded to intermediate frequencies.

Encoding model indicates population-level vibration frequency tuning in sensorimotor areas

S1

q < 0.01

Left hemisphere — Right hemisphere

S2 — S3

S4 — S5

% Accuracy in task (oddball detection) — S1 S2 S3 S4 S5

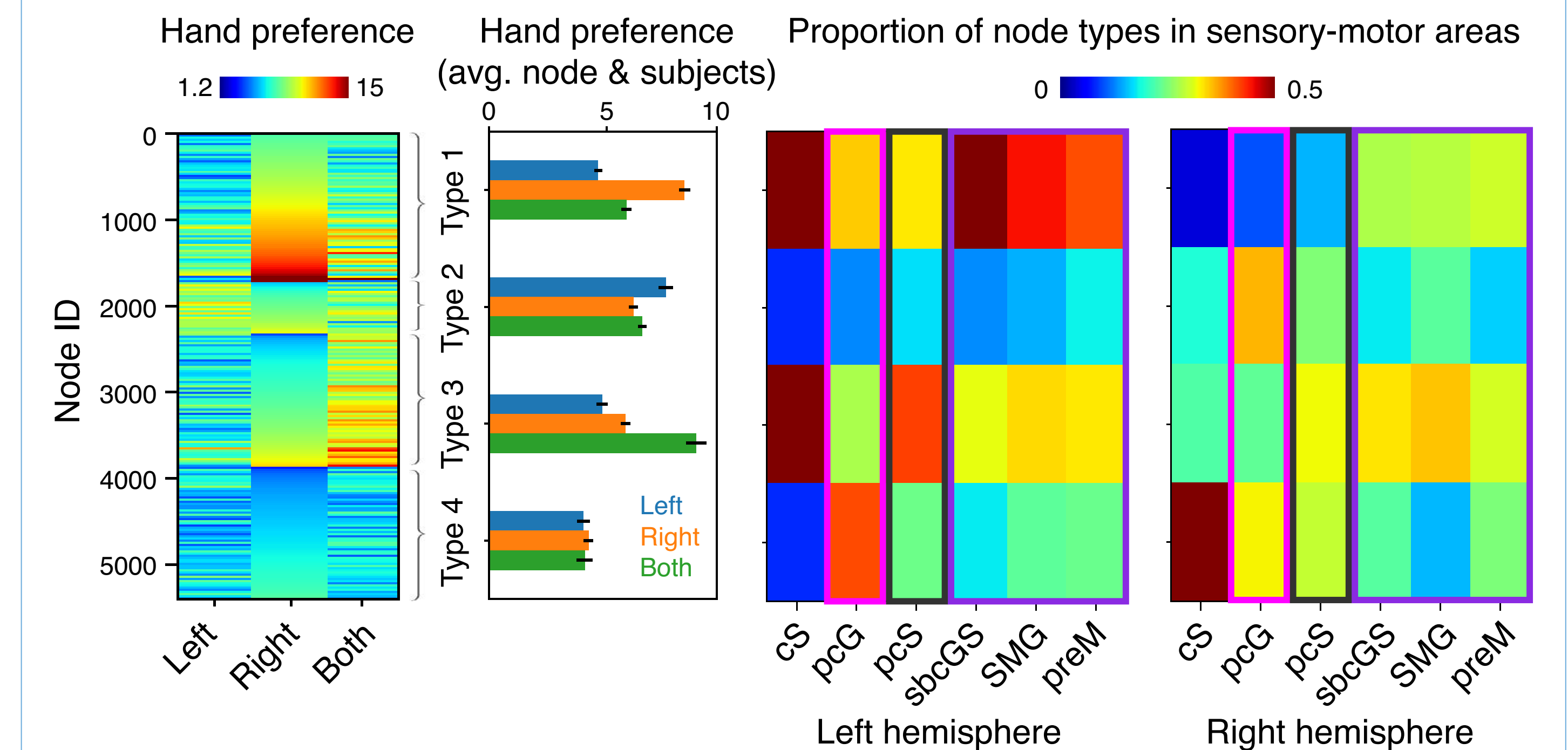% Nodes (GLM F > 5)

% Nodes (model q<0.01)

- Frequency-tuned basis functions can predict population neural responses.
- Vibration frequency information can be linearly integrated over the hands.

Higher-order areas are more selective for frequency

Frequency selectivity

Left hemi Right hand — cS pcG pcS sbcGS SMG preM

Right hemi Right hand — Primary areas / Higher-order areas

Left hemi Left hand

Right hemi Left hand

Response preferences for the two hands evolve over the somatosensory cortical hierarchy

Hand preference — 1.2 ... 15

Hand preference (avg. node & subjects)

Proportion of node types in sensory-motor areas — 0 ... 0.5

Node ID — Left Right Both

Type 1, Type 2, Type 3, Type 4

Left, Right, Both

cS pcG pcS sbcGS SMG preM — Left hemisphere / Right hemisphere

Summary

- Sensorimotor areas respond differentially to hands and vibration frequency.
  - Primary somatosensory areas are likely more selective to hands.
  - Higher-order areas are likely more selective to vibration frequency.
- Frequency-tuned basis functions can predict population neural responses.
- Vibration frequency information is linearly integrated over the hands.
- Preliminary results will be improved and confirmed by updating the encoding model with a overly completed basis functions.