



KEY CLAIM

By reading structured neural distortion of individuals with Color-Vision deficiency (CVD), we invert it into a personalized color-correction filter

BACKGROUND & GAP

- Health phenotypes (cardiac¹, gene-expression²) are often structured distortions.
- Such distortions **vary across individuals** even within a diagnostic category.
- Prior work simulates the loss or applies population-level fixes.
 - Inverting a person's own distortion for intervention is under-explored

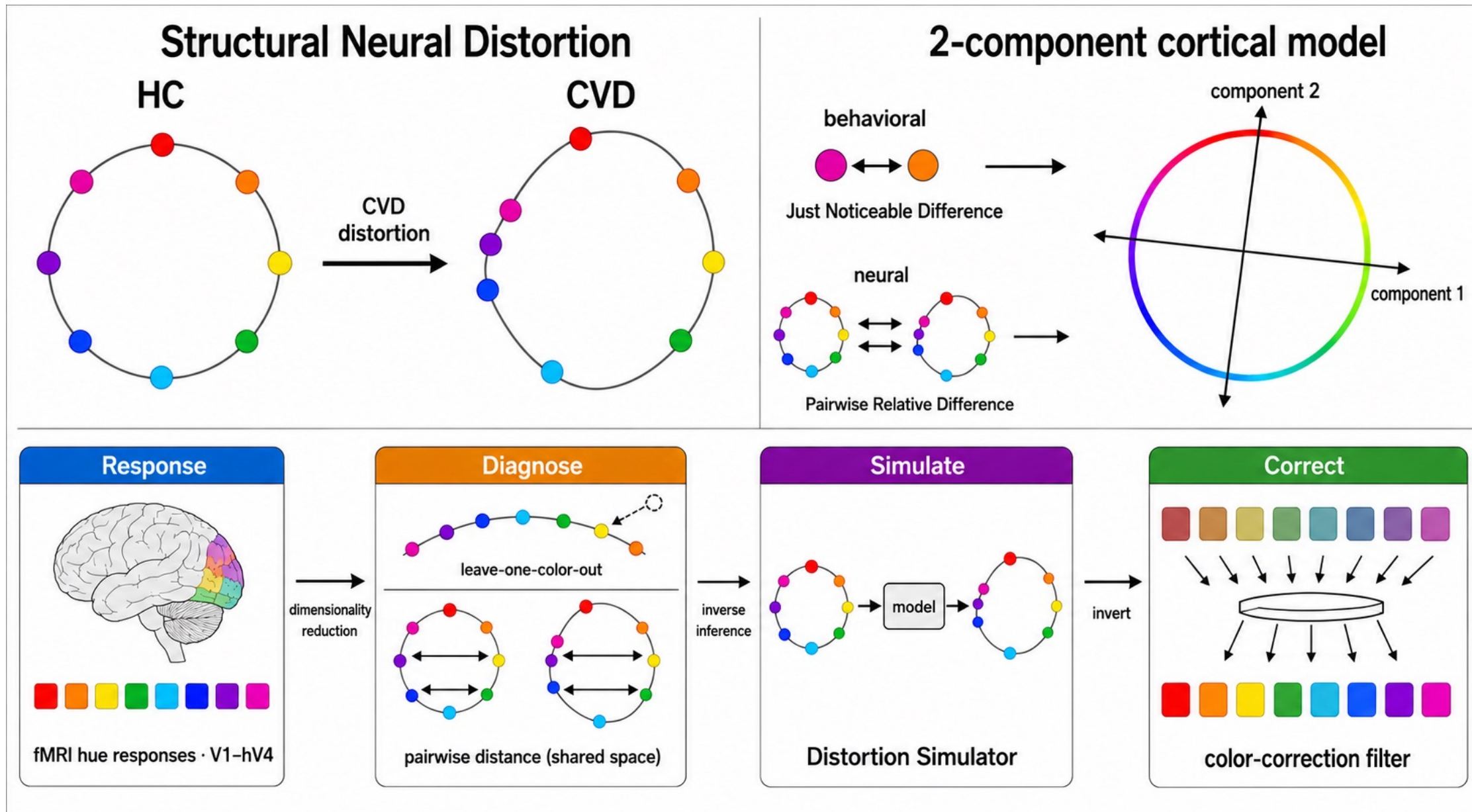
Contributions

- We represent CVD as a distortion of the brain's hue-representation geometry
- We fit a cortical model per person by combining behavioral & neural losses
- We invert each person's fitted model into their color-correction filter

METHODS – EXPERIMENT & ANALYSIS

- Participants (N = 10)**: 7 Healthy Controls (HC) + 3 CVD (two deutan, one protan)
- fMRI Experiment**: 8 isoluminant hues, 6 runs, ROIs V1-hV4
- LOCO (leave-one-color-out)**: can a held-out hue be rebuilt from the other seven?
 - Forward-Encoding model maps hue → 6 channels → neural responses
 - Tests **continuous hue structure** in neural hue representations
- RDM (relative distances)**: how far apart are hue pairs in the brain representation?
 - Shared Response Model (SRM) projects HC & CVD into a **shared low(4)-dim space**
 - $\Delta\text{RDM} = \text{CVD} - \text{HC}$ = which pairs are **relatively merged or split**

FRAMEWORK & MODEL - LOSS



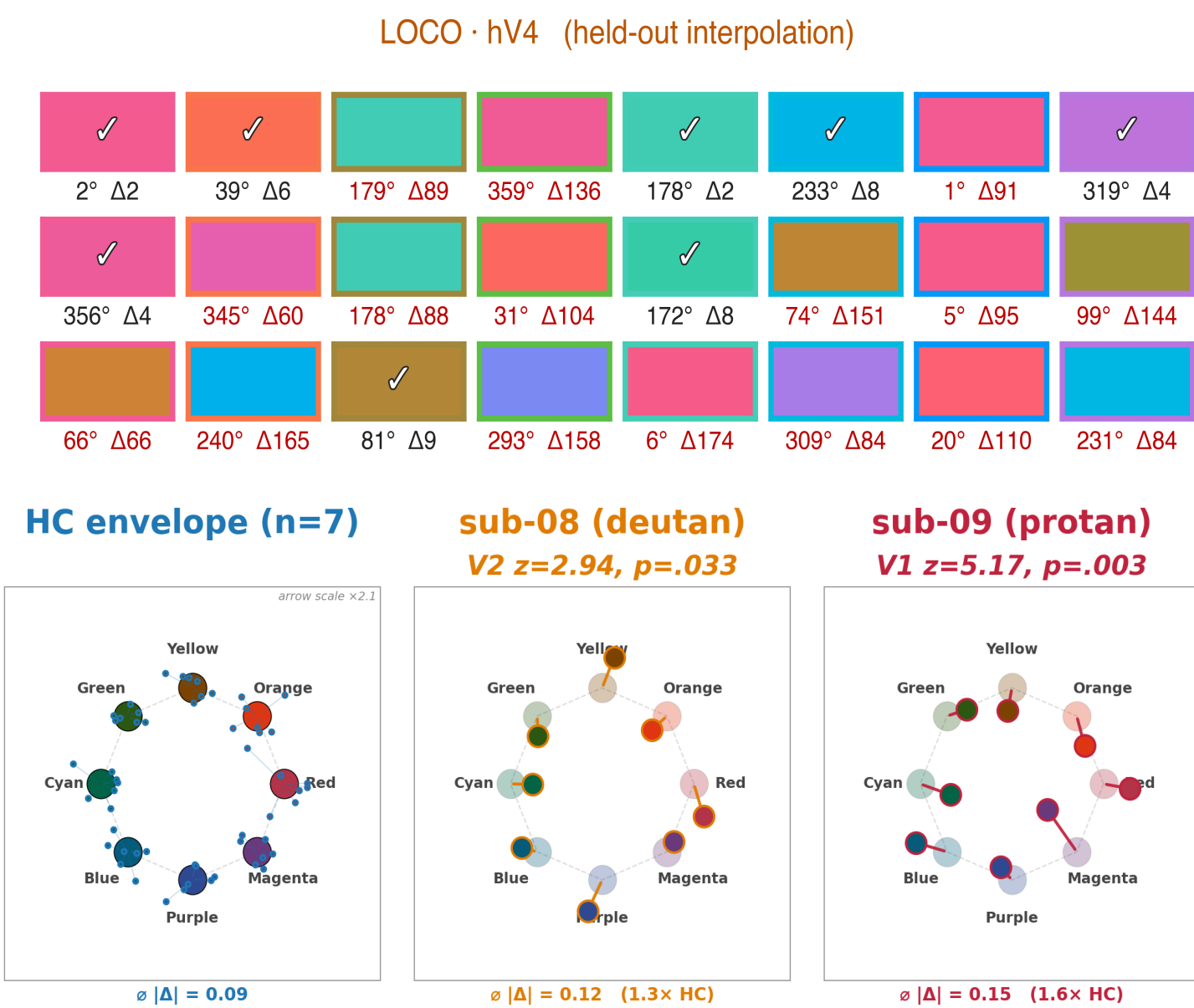
Diagnose each person's hue distortion, fit a cortical model as a deficiency simulator, then invert it into a color-correction filter.

Model mechanism	Parameters	Form
Retinal Cone-Shift ⁶	1	$\Delta\lambda$
Retinal + Cortical compensation	1	$\delta\theta = (2-g) \cdot \delta\theta_{\text{Machado}}$
Cortical two-component	2	$\theta' = \theta + \beta_s \cos(\theta - 90^\circ) + \beta_c \cos(\theta - \theta_{\text{conf}})$

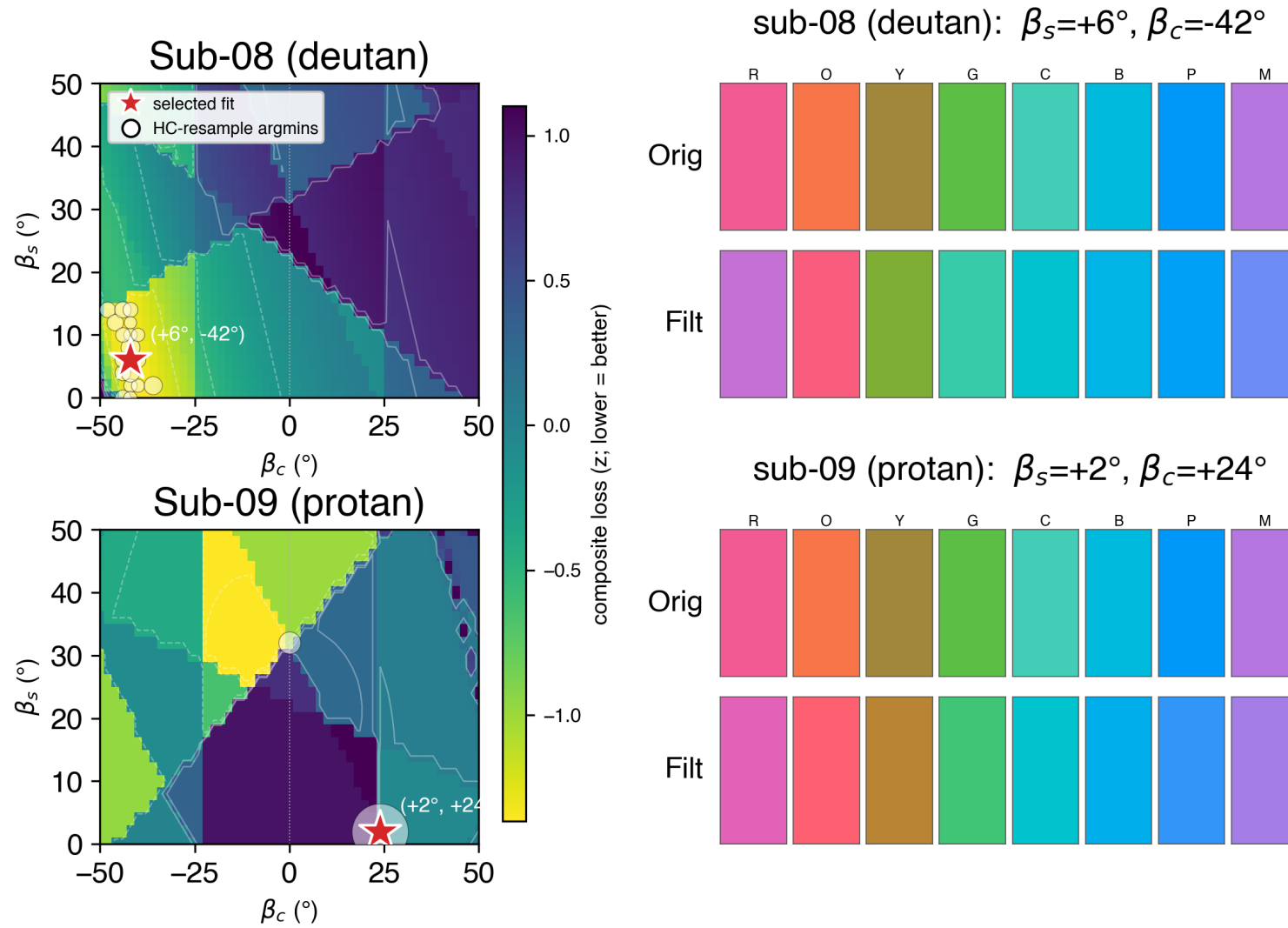
Loss = behavioral JND (Ly) + V1,V2 ΔRDM (L_RDM) + hV4 LOCO (L_LOCO);
selected by held-out generalization

RESULTS

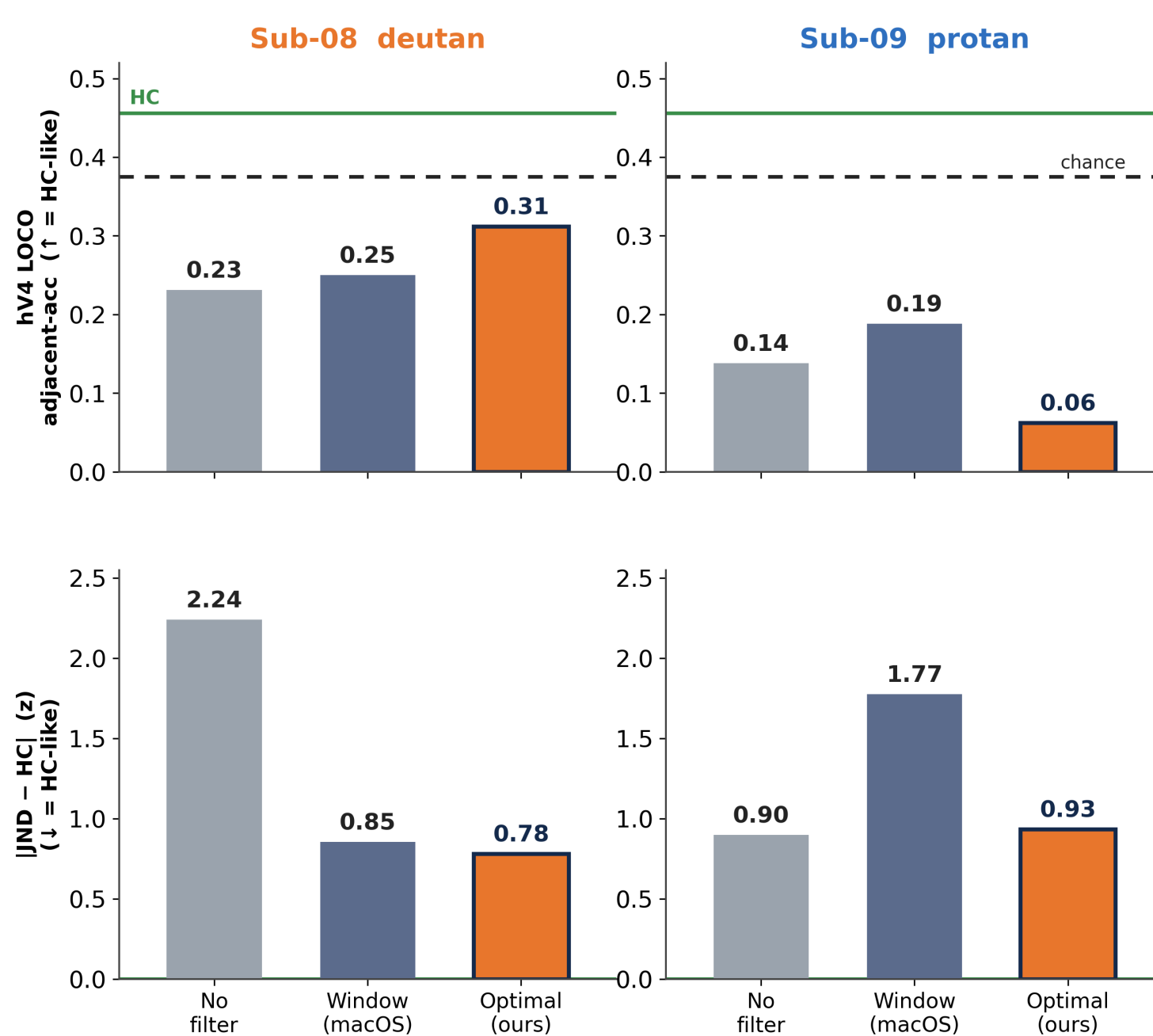
A. Represent · A structured distortion



B. Fit · Deficiency modeling



C. Validation (2nd-MRI, Exploratory)



Category discrimination preserved

- LOCO accuracy difference: $p=0.668$
- Every hue stays decodable.

But continuous interpolation collapses in LOCO

- LOCO Accuracy: HC 0.47
- Deutan 0.25 ($p=.082$) / Protan 0.13 ($p=.024$)

The distortion localizes to a subject-specific ROI

- Deutan V2 $p=0.040$, Protan V1 $p=0.007$

Retina models failed:

- Overcompensation, non-invertible

Result (β_s , β_c ; final loss):

- Deutan: (+6°, -42°); $L = \gamma_{\text{OY}} + \Delta\text{RDM_V2}$
- Protan: (+2°, +24°); $L = \gamma_{\text{all}} + \Delta\text{RDM_V1}$

Neural loss stabilizes parameters

- Deutan: β_c sign stable, no zero-crossing
- Protan: decisive only with neural

(3/7 → 7/7)

CONCLUSIONS

End-to-end framework:

- Structured distortion → Analytic inversion fit → personalized filter

Behavioral HC-likeness favors the personalized filter; exploratory neural effects

- Limits**: N=2; heterogeneous results across metrics/subjects
- Next**: a unified geometry target (integration across metrics, ROIs), larger N

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