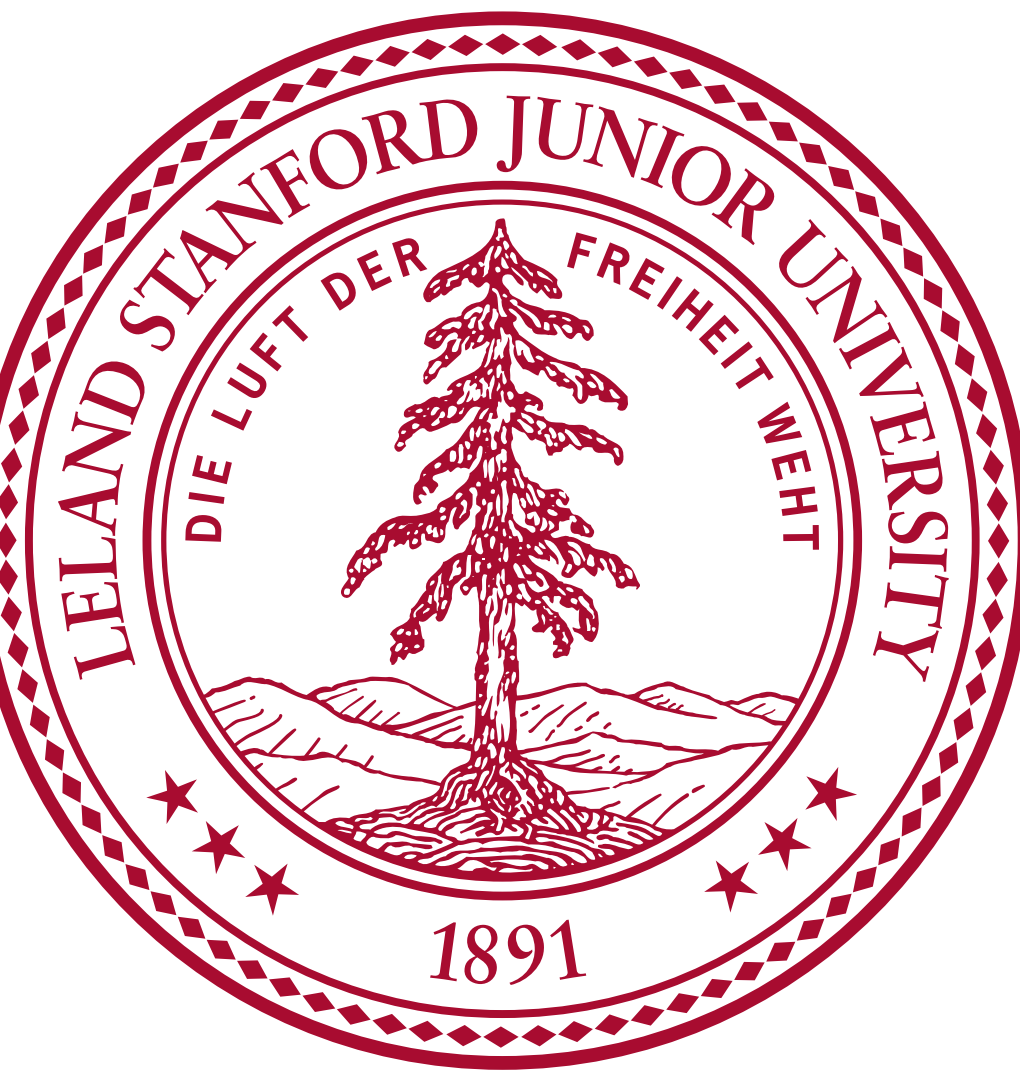# The Neural Response to Visual Symmetry in Wallpaper Patterns

P.J. Kohler[1], A.D.F. Clarke[2], J. Liu-Shang[3], A. Yakovleva[1], Y. Liu[4] & A.M. Norcia[1]

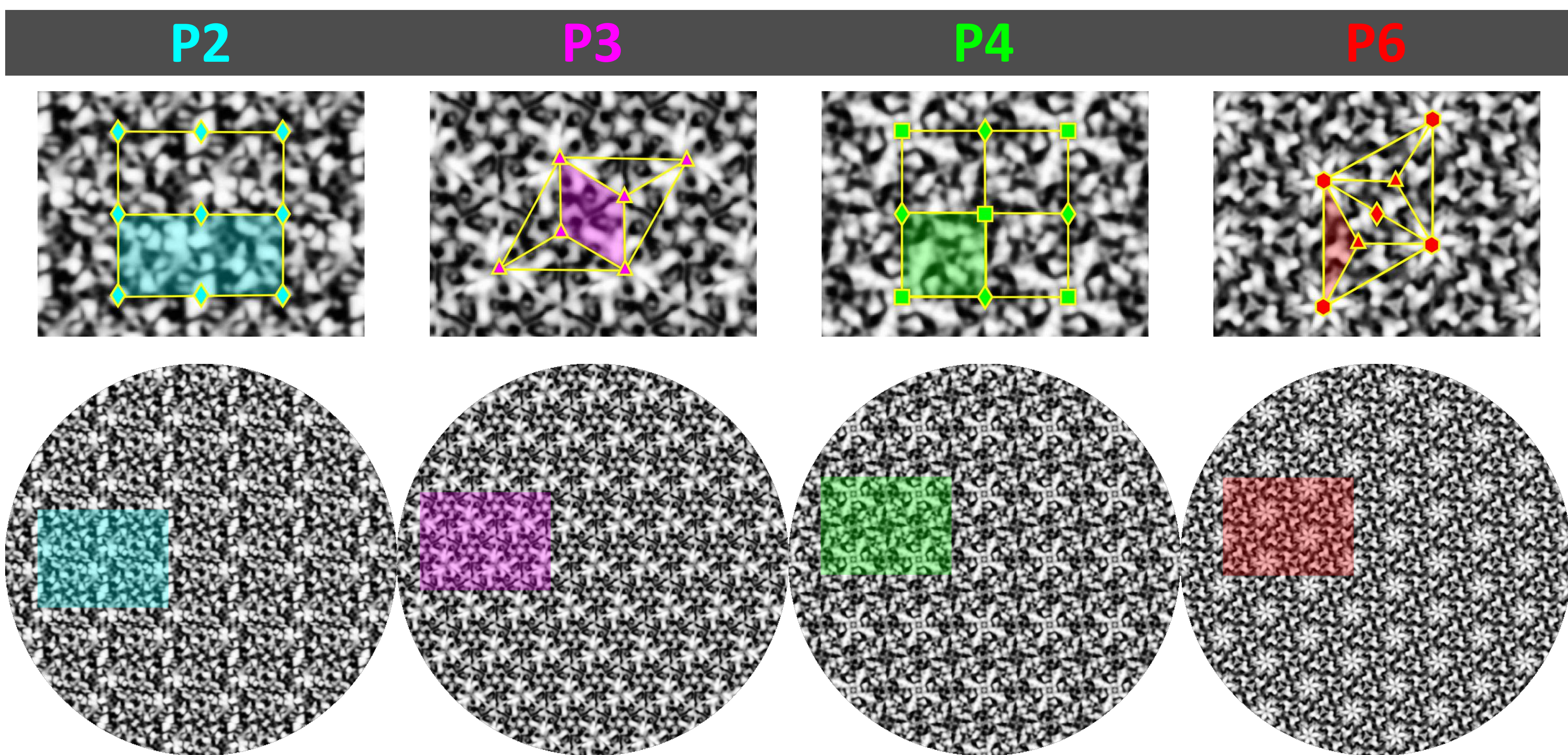[1]Department of Psychology, Stanford University   [2]ILLC, The University of Edinburgh   [3]Institute of Research in Psychology, University of Louvain   [4]College of Engineering, Penn State University
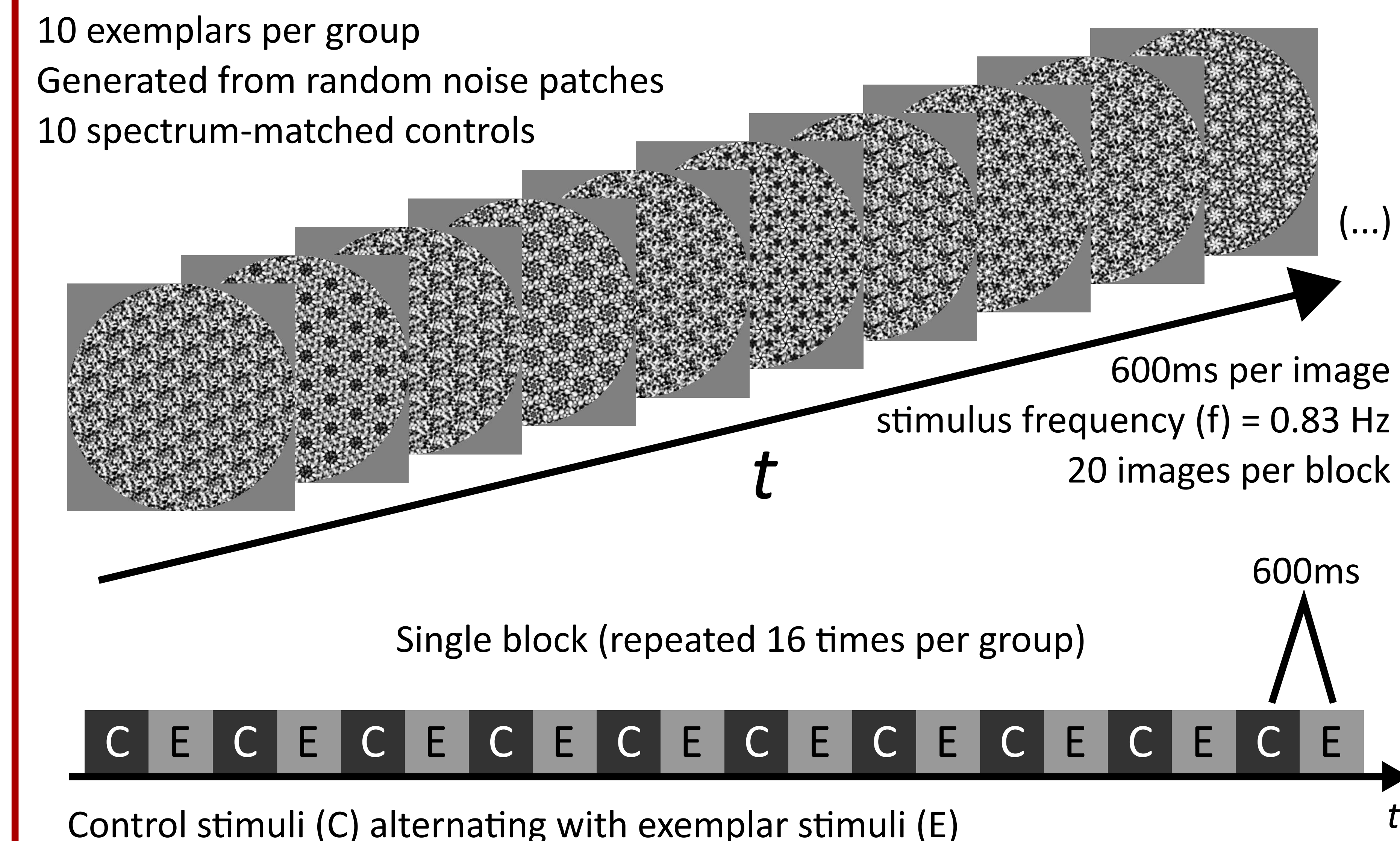
Background

Any periodic pattern belongs to one of 17 wallpaper groups based on its symmetries. Previous work has focused on mirror symmetry. Here we investigate rotation symmetry by recording EEG responses to 4 wallpaper patterns, each having a different number of rotation folds.

Rotation:
◆ 2-fold (180°)
▲ 3-fold (120°)
■ 4-fold (90°)
⬢ 6-fold (60°)

P2   P3   P4   P6

Stimulus

10 exemplars per group
Generated from random noise patches
10 spectrum-matched controls

600ms per image
stimulus frequency (f) = 0.83 Hz
20 images per block

Single block (repeated 16 times per group)

C E C E C E C E C E C E C E C E C E C E

Control stimuli (C) alternating with exemplar stimuli (E)

Analytical Approach

Test condition: P6 pattern alternates with random-noise pattern
Control condition: random-noise alternates with random-noise
Spectral analysis isolates a configural response evoked by the wallpaper group, that consists of odd harmonics.
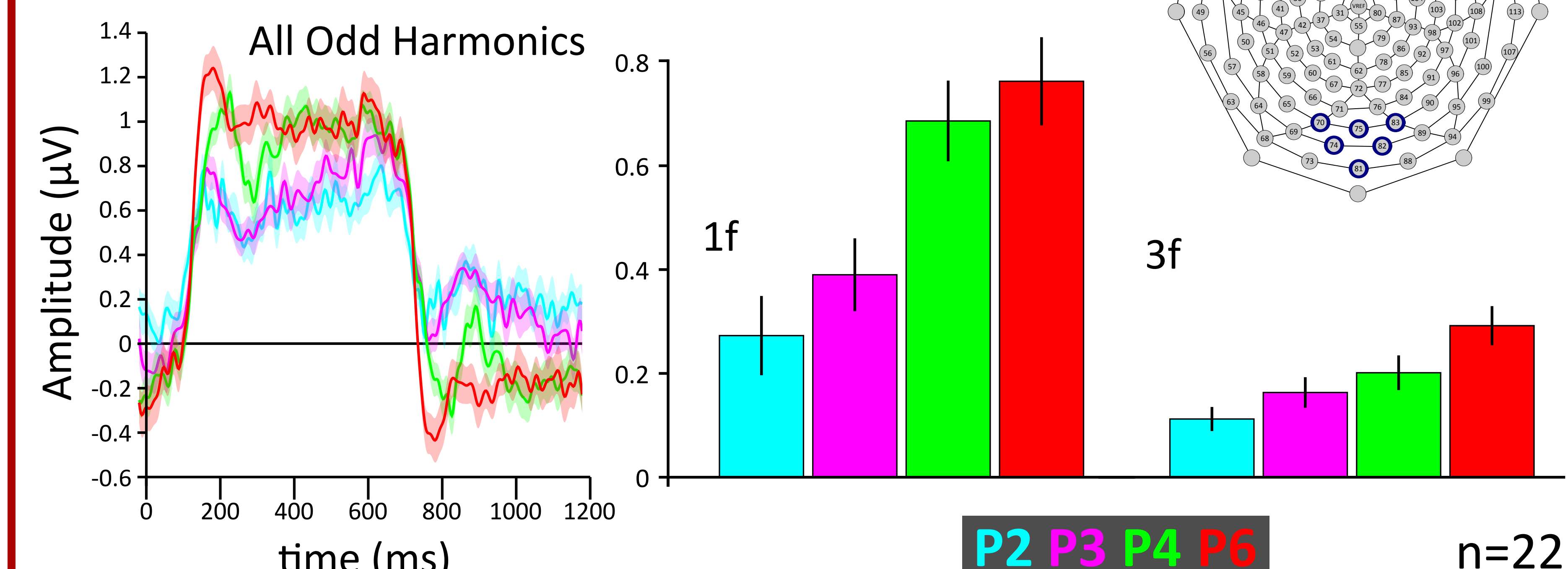
n=9

Test
Control

All Data   All Even Harmonics   All Odd Harmonics
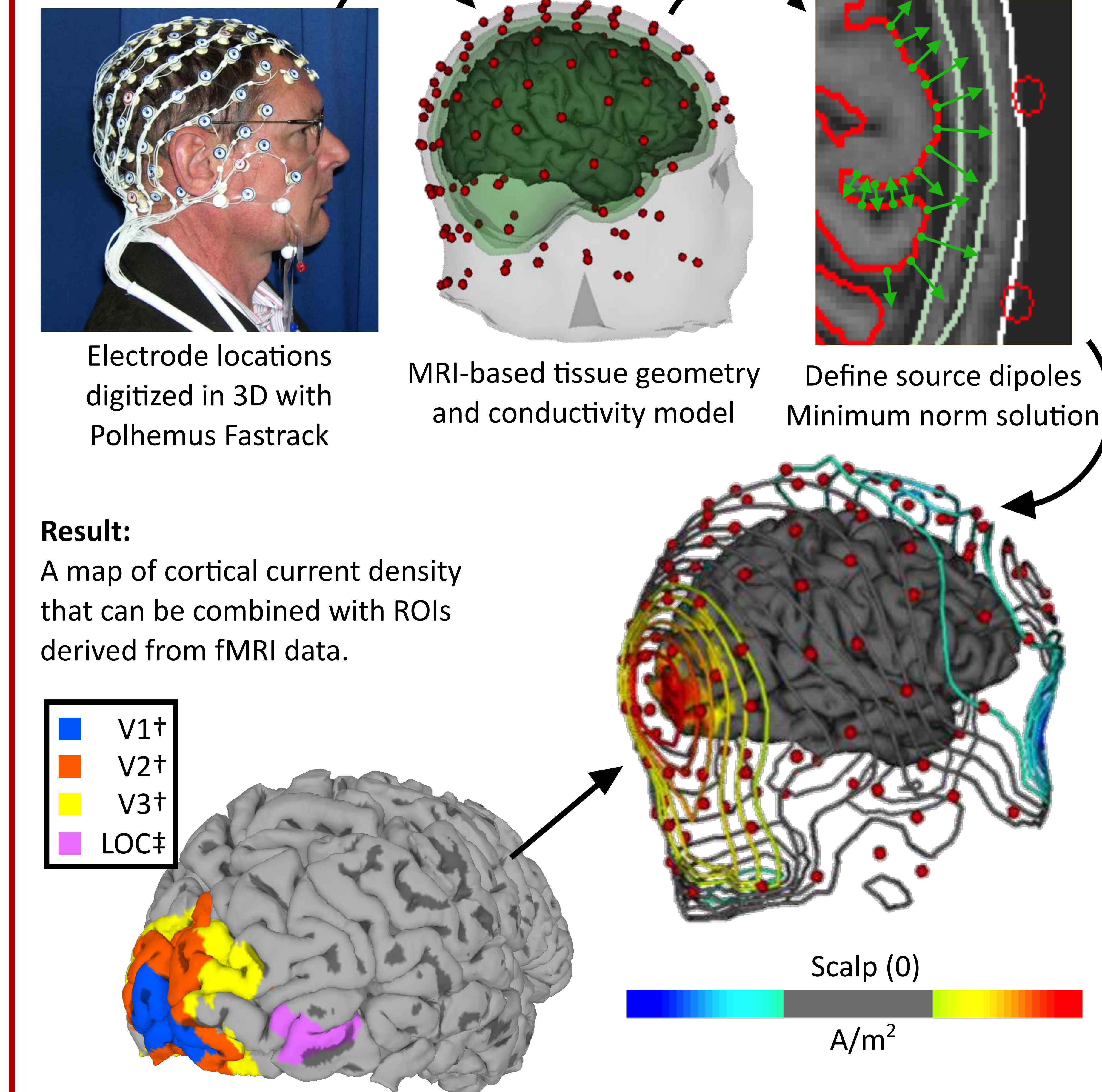
1f   2f   3f   4f
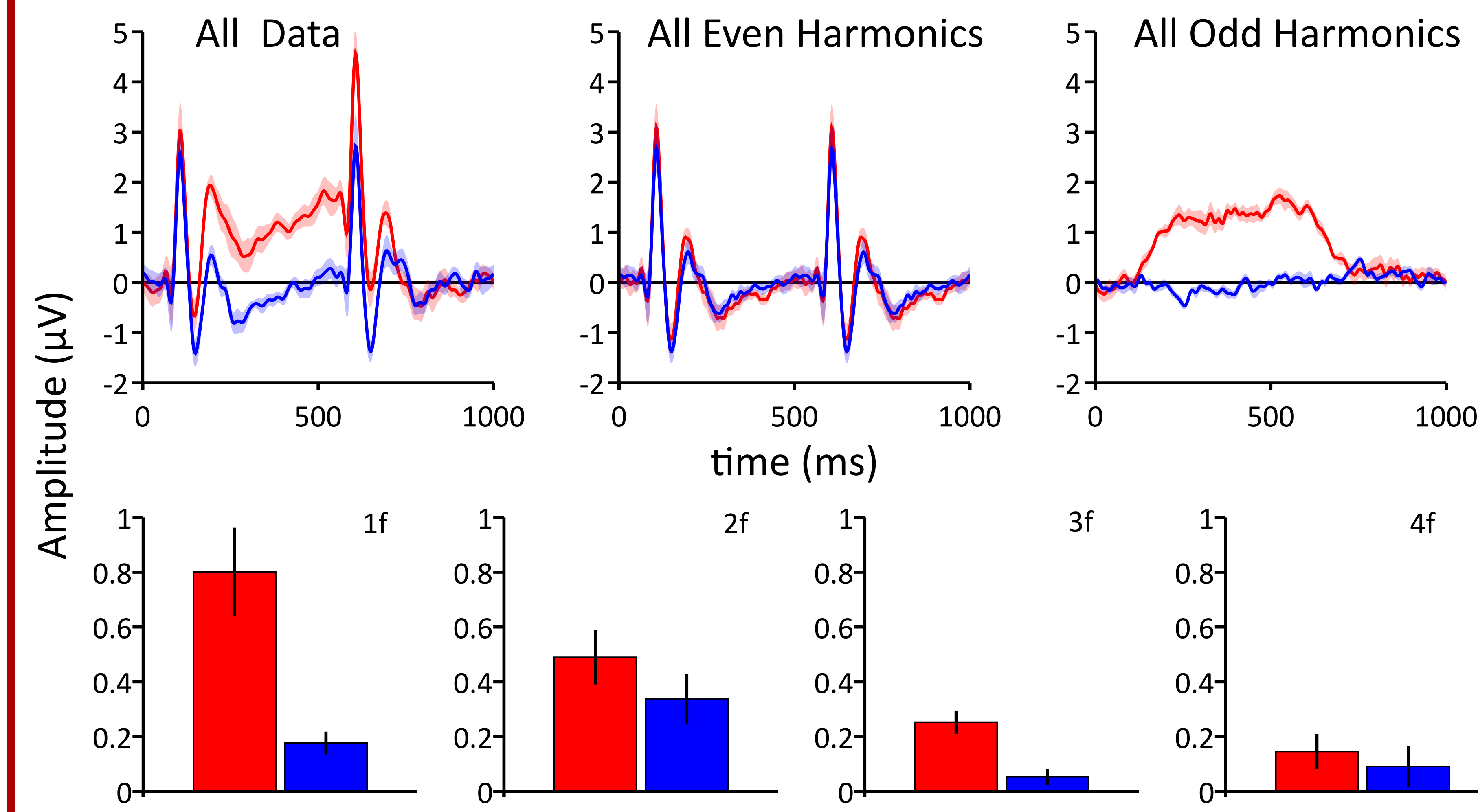
Sensor Space Results

We found a configural evoked response for all four wallpaper groups. The amplitude of this response increased linearly with the number of rotation folds.

Sensor selection

All Odd Harmonics

1f   3f

P2 P3 P4 P6   n=22

Source Imaging

What are the sources of neural activity that generates the signals we measure on the scalp?

Electrode locations digitized in 3D with Polhemus Fastrack

MRI-based tissue geometry and conductivity model

Define source dipoles
Minimum norm solution

Result:
A map of cortical current density that can be combined with ROIs derived from fMRI data.

■ V1†
■ V2†
■ V3†
■ LOC‡

Scalp (0)
A/m²

†Anatomically defined based on cortical surface reconstructions (Benson et al, 2014)
‡Functionally defined using standard functional localization method (Kourtzi, 2001)

Source Space Results

Configural evoked responses to the wallpaper groups were found in all 4 ROIs.

All Odd Harmonics
V1   V2   V3   LOC

P2 P3 P4 P6   n=10
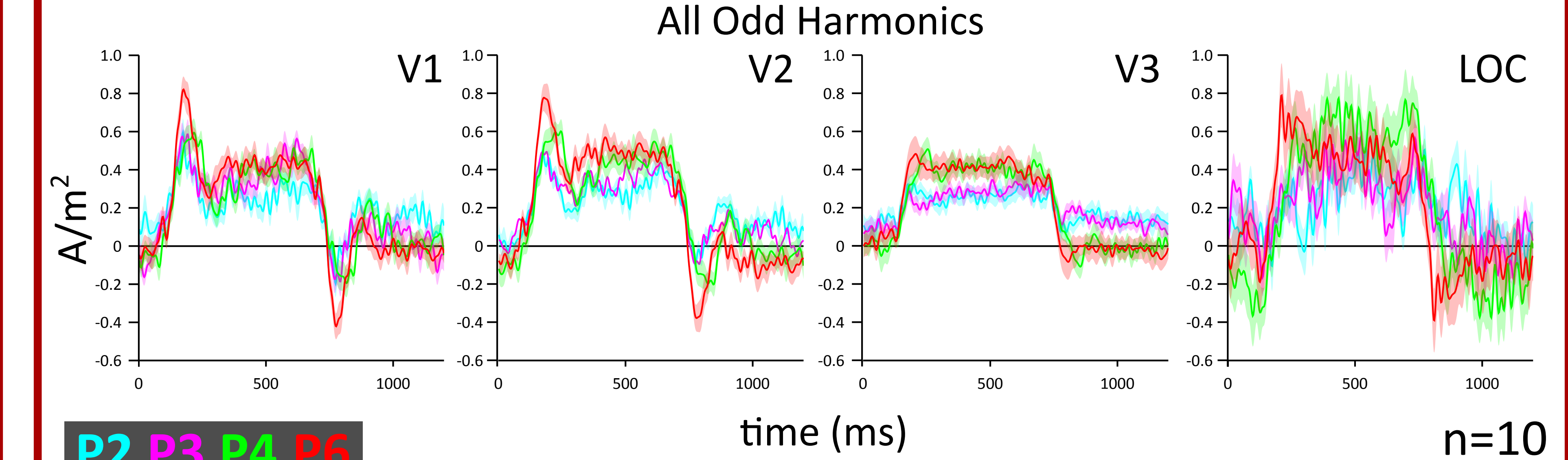
Activity scales with number of rotation folds at odd but not even harmonics.

V1   V2   V3   LOC

1f
2f
3f
4f
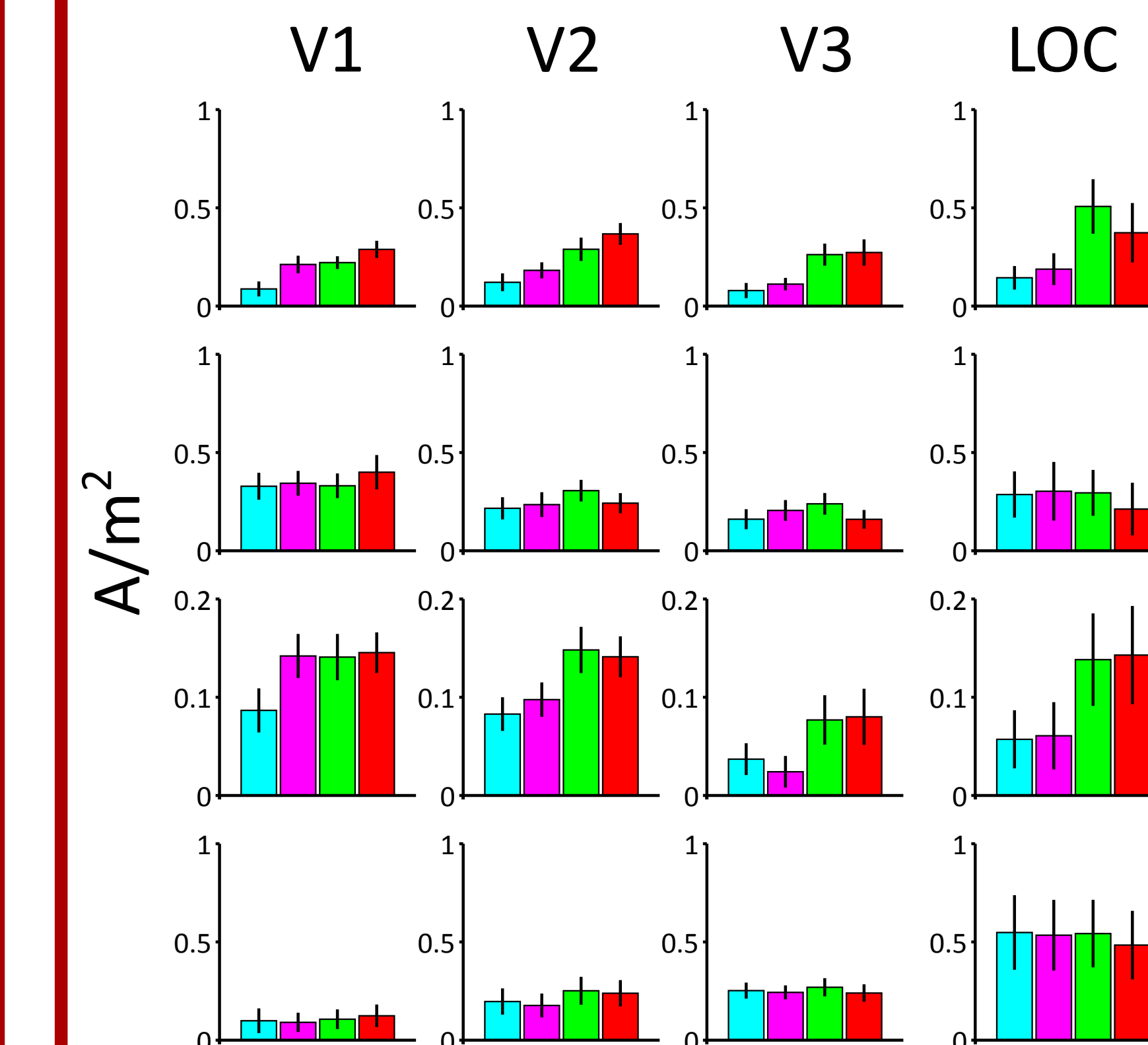
Responses are progressively delayed as the signals ascend the visual processing hierarchy.

Temporal response phase

1f
2f
3f

■ V1†
■ V2†
■ V3†
■ LOC‡
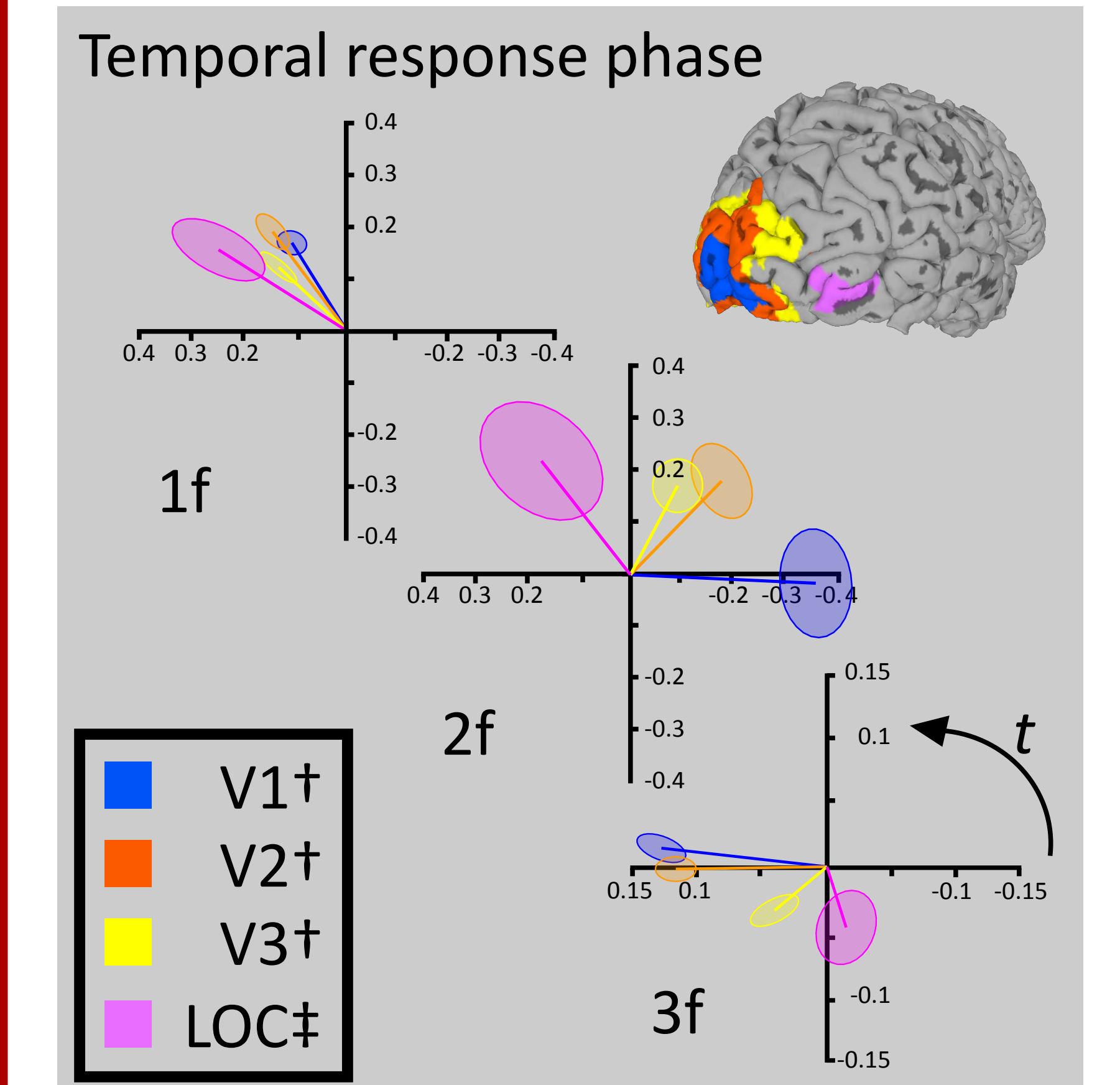
Conclusion

Configural evoked response amplitude increases linearly with the number of rotation folds in the wallpaper groups, indicating that the visual system parametrically represents rotation symmetry. Source localization suggests that this representation begins in early visual cortex.

References

Benson, NC et al. (2014). Correction of distortion in flattened representations of the cortical surface allows prediction of V1-V3 functional organization from anatomy. *PLoS Comput. Biol.*, 10(3).
Kourtzi, Z. & Kanwisher, N. (2001). Representation of perceived object shape by the human lateral occipital complex. *Science*, 293(5534), 1506-1509.