Brain Responses to Symmetries in Naturalistic Novel Three-Dimensional Objects

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Background

Symmetries are prevalent in natural and man-made objects and scenes.

The literature on symmetry perception have mostly relied on patterns that are symmetrical in the image-plane[1]. However, during natural vision, symmetrical objects in the world are often distorted by perspective such that they do not produce image-plane symmetry on the retina.

Perspective-distorted symmetry creates weaker brain responses than image-plane symmetry[2], and EEG studies have found that distorted symmetry elicits Event-Related Potentials (ERPs) only when participants are engaged in symmetry-related tasks[3].

Motivation

We use a Steady-State Visual Evoked Potentials (SSVEPs) paradigm to investigate symmetry responses to naturalistic, novel objects. Our experiment design allows us to compare responses to symmetries in the image-level and perspective-distorted symmetry.

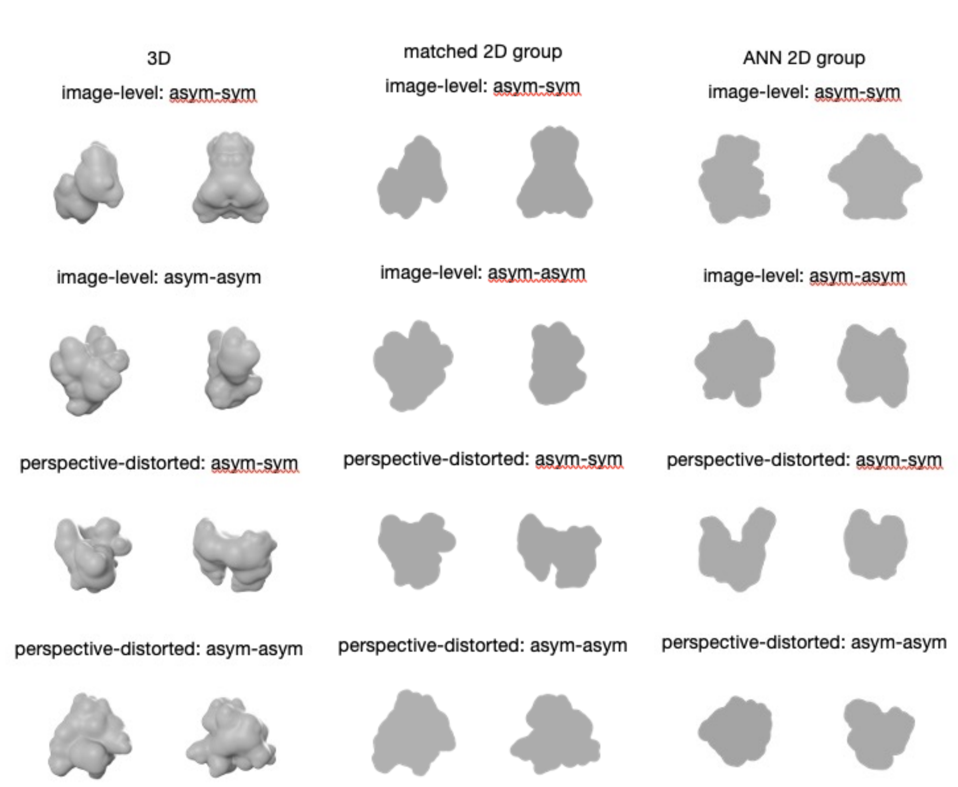
Methods

For Experiment 1, naturalistic, novel three-dimensional objects with (and those without) vertical reflection symmetry axes were procedurally generated in Blender, and rendered to produce images under two conditions:

1. Viewing direction orthogonal to object symmetry producing symmetries in the image-plane.
2. Objects rotated relative to viewing direction. Symmetries present in objects were distorted due to perspective.

We selected pairs of asymmetrical and symmetrical images, and pairs of two asymmetrical images that created similar activations in an artificial neural network (ANN) trained on object image classification, VGG-16[4]. Low to mid level features were equated across every pair.

Experiment 2 used two stimuli sets: one using 2D versions of the 3D images, another using a set of 2D images unrelated to the 3D, matched using VGG-16[4]. Both had the same conditions as Experiment 1. 2D images were created by eliminating the shading found in the 3D images such that no depth cues were present in the resulting image.



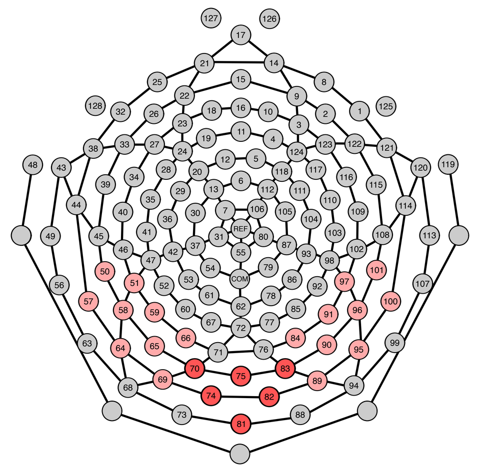
Participants (n=28 per experiment) passively viewed images from 10 image pairs. Each image in a pair was presented for 500 ms. One cycle consisted of presentations of each of the two images in a pair, for a stimulation frequency of 1 Hz.

For image-level and perspective-distorted sets, we ran separate conditions for asymmetrical-symmetrical pairs, and for pairs where both images were asymmetrical, resulting in a total of four conditions for each stimuli set.

We used high-density EEG (128 channels) to measure SSVEP responses.

Results: Topographies and ROI analysis

Electrode ROIs

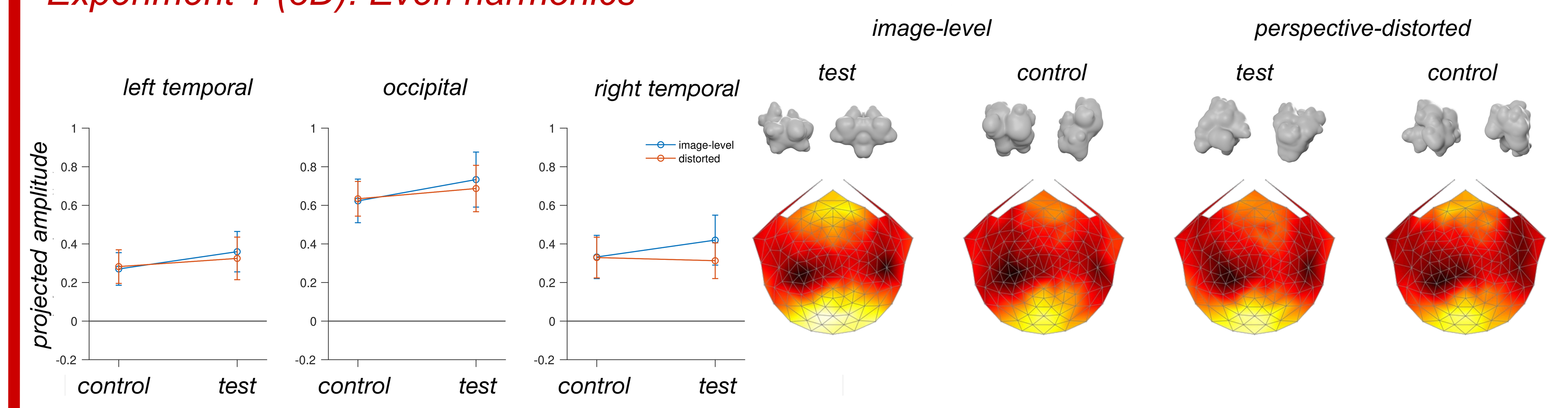


Below we are plotting coherent average amplitudes of the first and second harmonic from three distinct electrode ROIs, as well as whole-scalp topographies. Error bars indicate standard error of the mean over projected amplitudes computed for each participant. Electrode ROIs are based on a previous data set. Below, we will refer to our asym-sym conditions as the "test" condition, and asym-asym as the "control" condition. We expect to see a symmetry response in the former, but not in the latter.

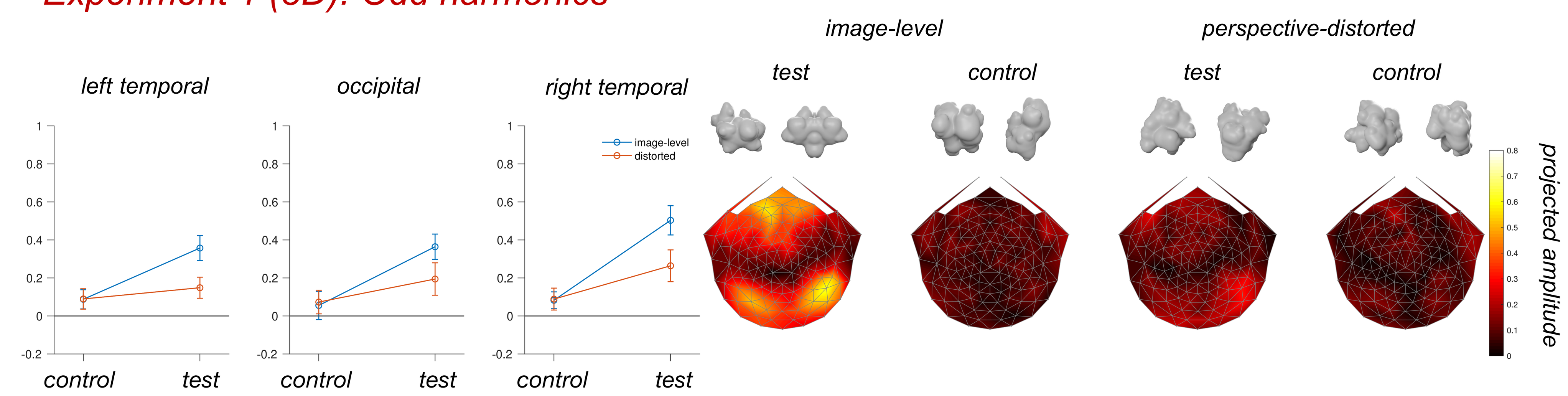
The ***even harmonics*** will capture image update responses driven by low-level changes in contrast. Data from the second harmonic are localized over occipital cortex and similar between the test and control conditions.

The ***odd harmonics*** will capture responses that are symmetry-specific and distinct from low-level contrast change[5]. The symmetry response can be quantified as the difference between the responses produced by the test conditions and control conditions.

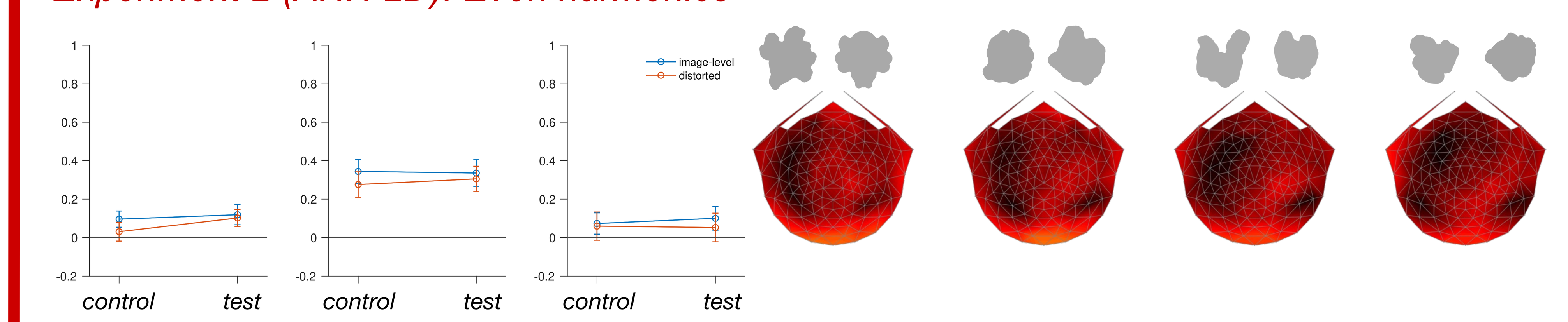
Experiment 1 (3D): Even harmonics



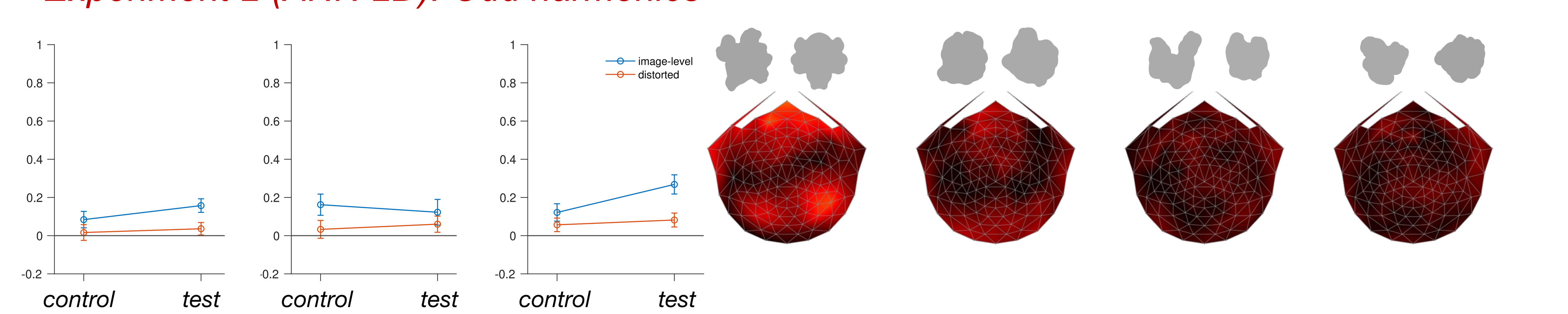
Experiment 1 (3D): Odd harmonics



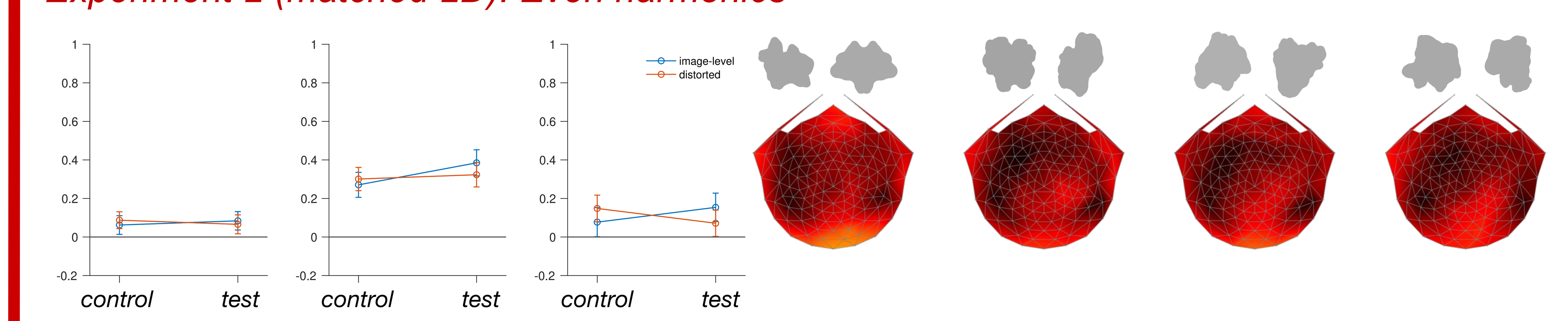
Experiment 2 (ANN 2D): Even harmonics



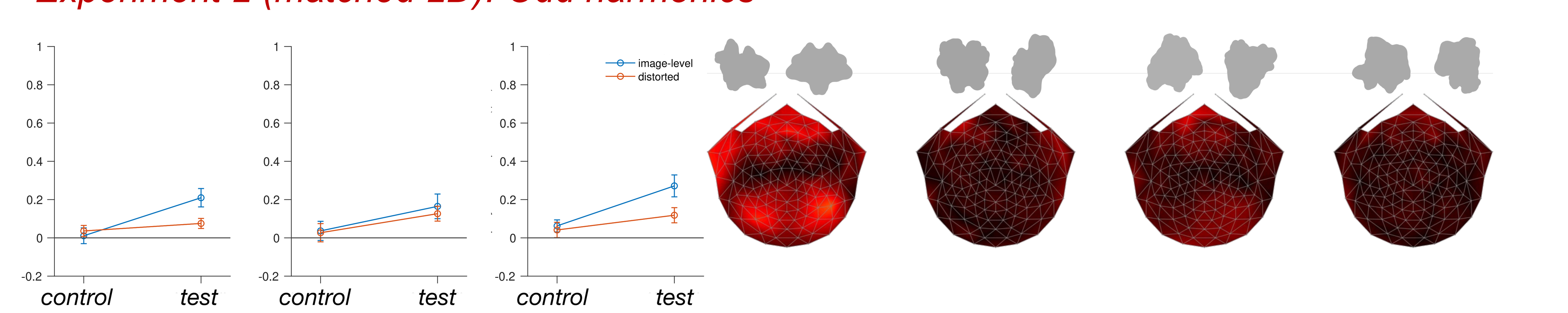
Experiment 2 (ANN 2D): Odd harmonics



Experiment 2 (matched 2D): Even harmonics

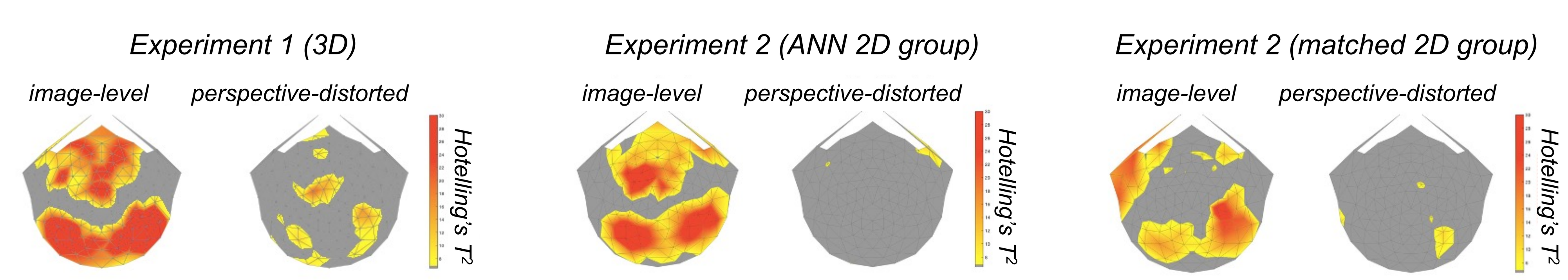


Experiment 2 (matched 2D): Odd harmonics



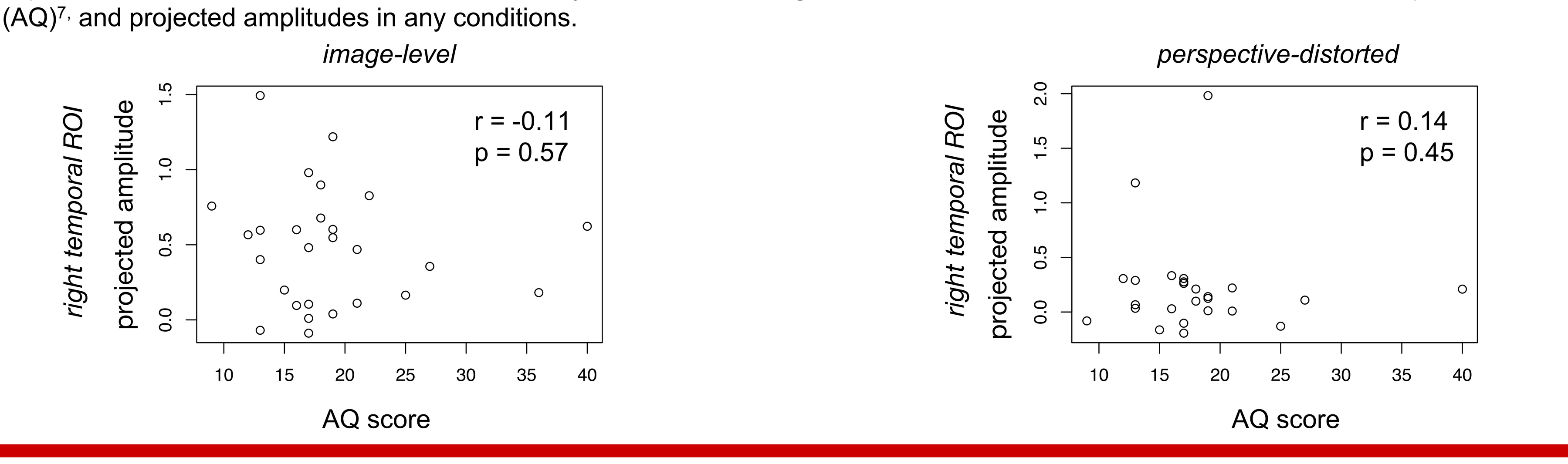
Results: Hotelling's T^2

Below is an electrode-by-electrode Hotelling's T^2 test incorporating both phase and amplitude, comparing test and control conditions. These maps display the significance at each electrode based on the first harmonic.



Results: Symmetry and ASD

A previous study found an association between brain responses to symmetry and developmental conditions that affect global processing, such as autism spectrum disorder[6]. However, in the current study, we did not see significant correlations between scores on the Autism Spectrum Quotient (AQ)[7] and projected amplitudes in any conditions.



Conclusion

- We found measurable SSVEP responses to symmetry during passive viewing for both image-level and perspective-distorted symmetry with the novel, naturalistic 3D stimuli.
- Perspective-distorted symmetry elicited weaker SSVEPs compared to image-level symmetry.
- 2D versions of the stimuli produced weaker SSVEP responses to image-level symmetry.
- We found no significant correlations between AQ scores and SSVEP responses to symmetry.

References

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