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 using using Event-Related Potentials (ERPs) have found that distorted symmetry elicits symmetry responses only when participants are engaged in symmetry-related tasks[3].

Motivation

The current study uses 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

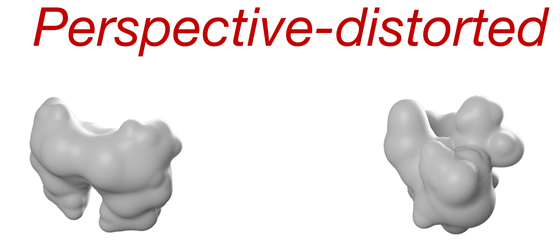
Naturalistic, novel three-dimensional objects with vertical reflection symmetry axes were procedurally generated in Blender (a 3D graphics software) and rendered to produce images under two conditions:

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

Asymmetrical objects were produced and rendered using the same approach. Pairs of asymmetrical and symmetrical images, and pairs of two asymmetrical images were selected so that low to mid level features were equated across every pair in all sets. We selected pairs of images for each of these conditions that created similar activations in an artificial neural network trained on object image classification.

Image-level

Perspective-distorted

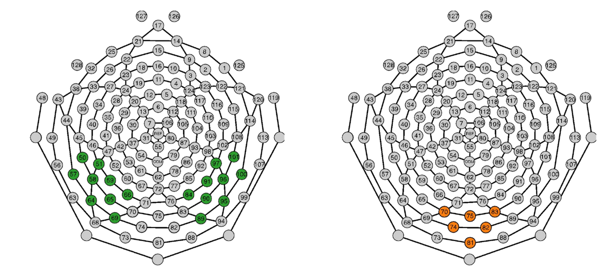


In each trial of the experiment, participants (n=30) passively viewed images from 10 image pairs. The first image in each pair was presented for 500 ms, followed by the second image for another 500 ms. One cycle consisted of two image presentations, for a stimulation frequency of 1Hz. For both image-level and perspective-distorted image sets, we ran separate conditions for asymmetrical-symmetrical image pairs, and for image pairs where both images were asymmetrical, resulting in a total of four conditions.

We used high-density EEG (128 channels) to measure SSVEP responses. Our paradigm produces characteristic peaks in the frequency domain at harmonics of the stimulation frequency.

Results: Topographies

Image update responses driven by low-level changes in contrast will be captured by the even harmonics, while responses that are symmetry-specific and distinct from low-level contrast change will be isolated in the odd harmonics of the stimulation frequency[4]. Below we are plotting whole-scalp topographies based on the coherent average of the odd harmonics of individual participant amplitudes. The symmetry response can be observed as the difference between the topographies produced by the symmetry conditions and the control conditions. Electrode rois are based on the first data set.



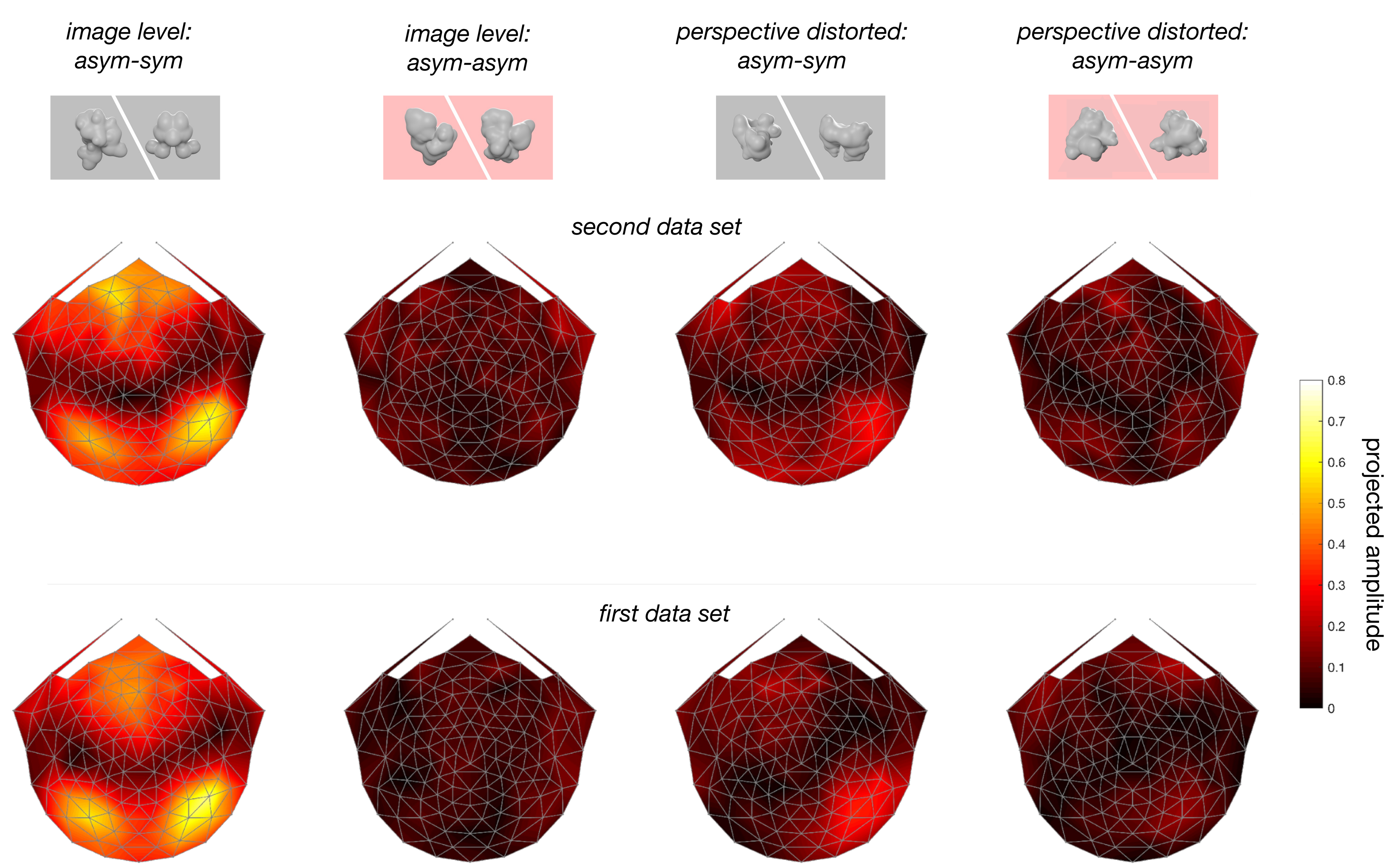
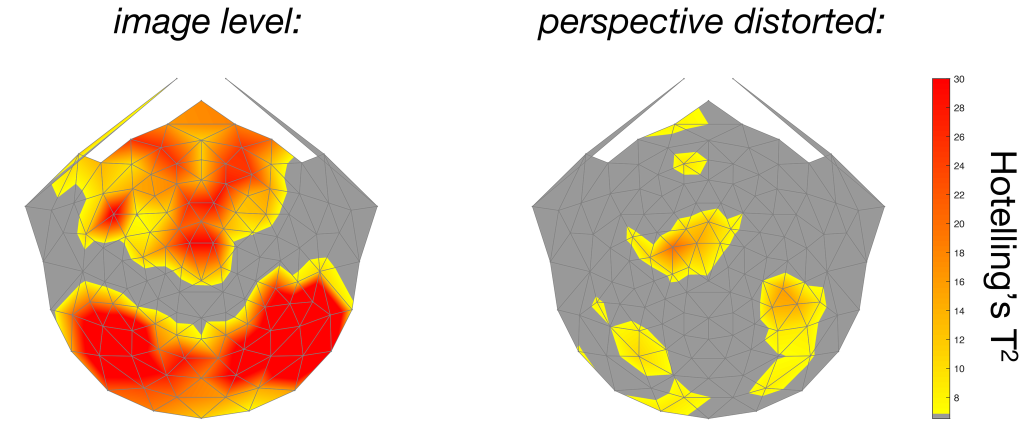


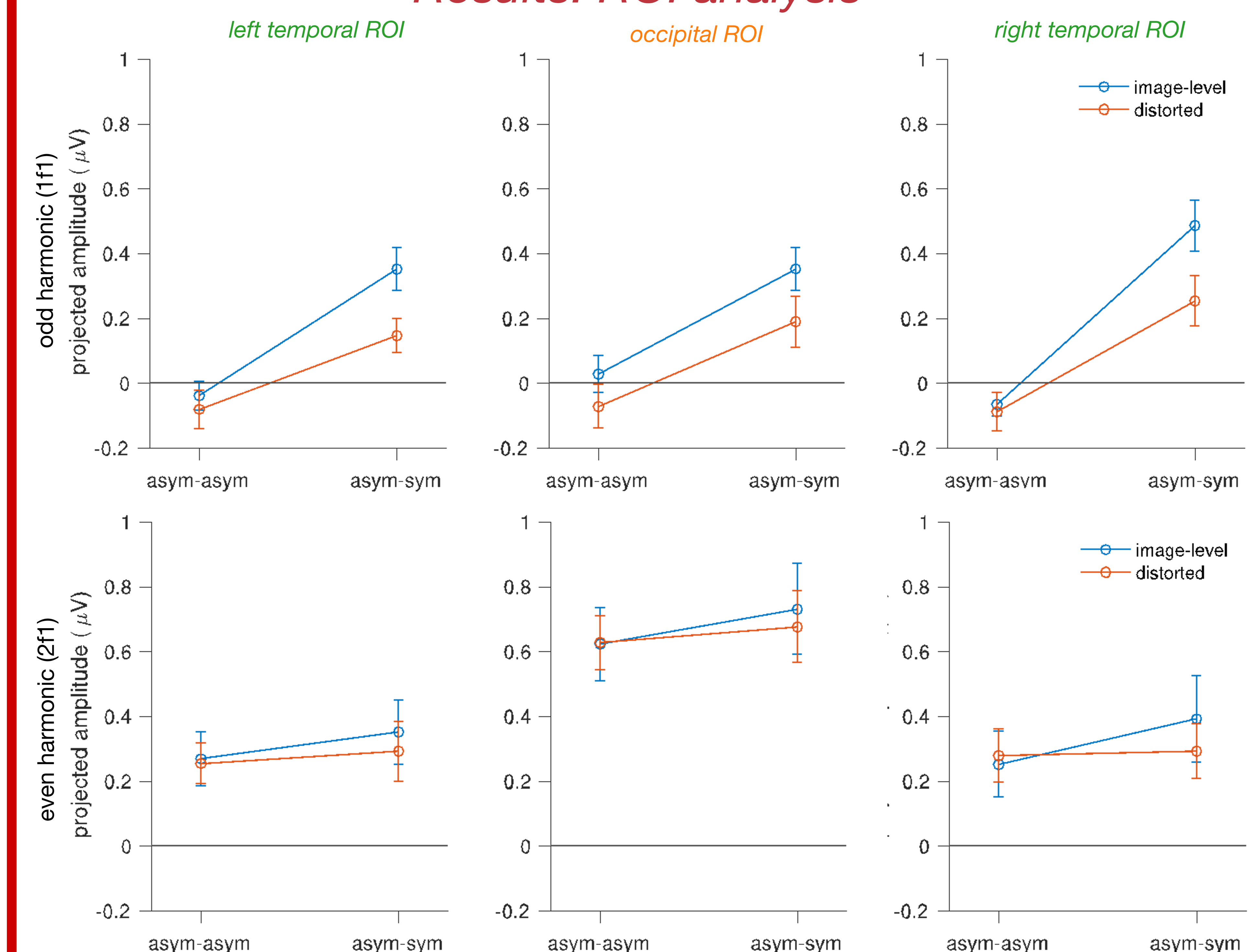
Image-level symmetry elicits strong responses in broad regions including sites associated with occipital and left and right temporal cortex. For perspective-distorted symmetry, the response is more right-lateralized, and is weaker in the posterior locations associated with occipital cortex.

Results: Whole scalp statistics



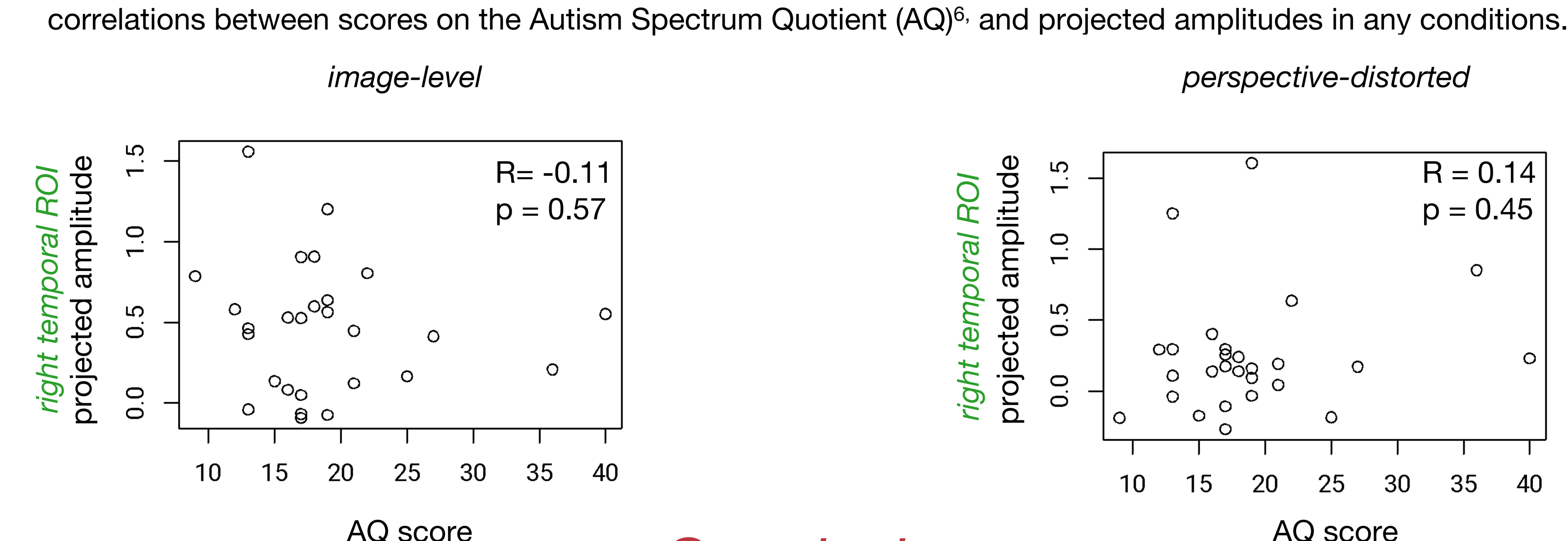
Above is an electrode-by-electrode Hotelling's T^2 test incorporating both phase and amplitude, comparing test and control conditions (asym asym vs asym sym). These maps display the significance at each electrode based on the first harmonic.

Results: ROI analysis



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[5]. However, in the current study, we did not see significant correlations between scores on the Autism Spectrum Quotient (AQ)[6] and projected amplitudes in any conditions.



Conclusion

ROIs were determined using data from a pilot study in which perspective distorted symmetry elicited SSVEPs comparable to those elicited by image level symmetry during passive viewing, but strongly right lateralized and only in more anterior scalp regions likely driven by activity in higher level visual cortex, such as in the temporal cortex. A follow up study showed similar results, with a slightly weaker right lateralization effect. There were no significant correlations between AQ scores and projected amplitudes in any conditions.

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