Supplemental Data

Individual Differences among Grapheme-Color Synesthetes: Brain-Behavior Correlations

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Supplemental Data 1

Defining hV4 versus V4/V8

The organization of V1-V4v in the ventral visual pathway of humans is widely agreed upon, and the results of previous phase-encoded retinotopy studies have found a consistent organization of these early visual areas (see Figure S1). However, there is currently a debate about the organization of human visual area V4 (see Hadjikhani et al., 1998; Wade et al., 2002). Early studies using phase-encoded retinotopy methods clearly identified visual areas V1-V4v (Engel et al., 1994; Sereno et al. 1995), but did not identify retinotopic visual areas beyond V4v. Subsequent studies of retinotopy beyond V4v have yielded inconsistent results. Hadjikhani et al. (1998) have suggested that there is an additional color-selective visual area beyond V4v, which is composed of a separate fovea, oriented 90° away from the confluent foveal representation for V1-V4v, and representing an entire hemifield. However, more recently Wade et al. (2002) have re-examined this issue, and suggest that, rather than being composed of separate representations for V4v and V8, the previously defined V4v is simply the ventral portion (representing the upper visual field) of a full hemifield representation that shares a confluent fovea with V1-V4v, which they have dubbed hV4. Crucially, both Hadjikhani et al. and Wade et al. agree about the location and organization of V4v. The only point of disagreement is whether there exists an additional retinotopic area beyond V4v, or whether V4v is simply a part of a full hemifield representation, hV4.

In order to clarify these issues, we examined retinotopic maps in the occipito-temporal junction for all of our subjects. In order to minimize any distortions due to the unfolding procedure, we unfolded a small potion of cortex (radius 60–70 mm) centered on the fovea of V4v, as defined by our original retinotopy scans. When we examined our retinotopic data, we find a full 180° sweep, beginning at the V3/V4v boundary, and extending anteriorly (Figure S1). This full hemifield representation shares its foveal representation with the confluent representation of V1-V4v, consistent with the characterization of hV4 by Wade et al. (2002).

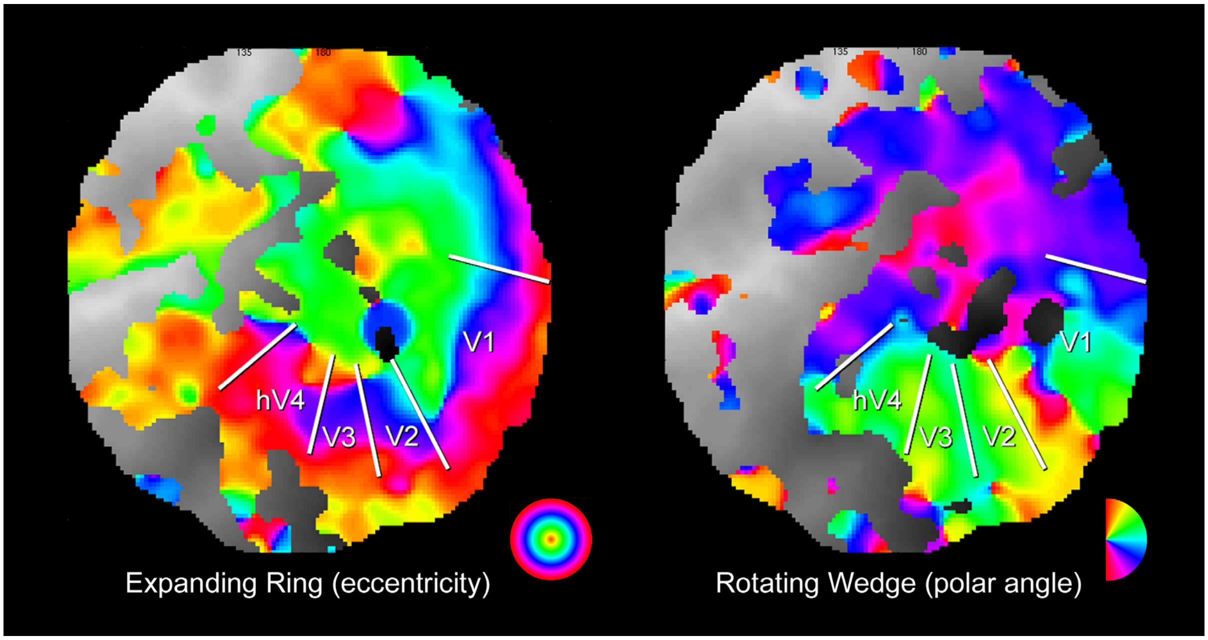

Figure S1. Retinotopic maps to expanding ring stimulus (left) and rotating wedge stimulus (right). Position in the visual field is indicated by the legends in the lower right corner of each portion of the figure. Visual area boundaries are indicated in white. Note the full 180° sweep defining hV4, and the absence of a clear second foveal representation. These retinotopy data are inconsistent with Hadjikhani et al. (1998), but are consistent with the proposed organization of hV4 (Wade et al., 2002).

Supplemental Data 2

Shown below is the raw time series data for each of the ROIs in each of three conditions, Letters, Numbers, and Non-Linguistic Symbols, averaged across all 12 subjects. The raw hemodynamic response is shown in blue. As can be seen here, the hemodynamic signal increases at the onset of each condition, and rises to a peak four to six seconds after the onset of the stimulus (consistent with previous literature, Boynton et al., 1996).

We then fit these raw hemodynamic responses with a sinusoid. The period of the sinusoid was fixed to be 40 seconds (one complete cycle in our experiment) and the amplitude and phase were the fit using an iterative least-squares algorithm. Best fitting sinusoids are shown in red. The amplitudes are reported in the main results section of our paper, broken down by group (synesthete and non-synesthete). The mean phase of the best fitting sine was 32.38° (corresponding to a hemodynamic lag of 3.60 seconds) and ranged from 19.01° to 50.30° (2.11 to 5.59 seconds).

Although these are somewhat short latencies for the hemodynamic response, it should be noted that the actual peak of the response was in the more traditional range. However, best fitting sinusoids tended to be slightly earlier than the peak because, as can be seen here, responses in the second half of each 20 second period were less than responses in the first half of each 20 second period, possibly due to adaptation.

Also, note that the amplitude of the responses in the grapheme area is clearly greater than the amplitude of the responses in other, earlier visual areas, especially in the case of numbers.

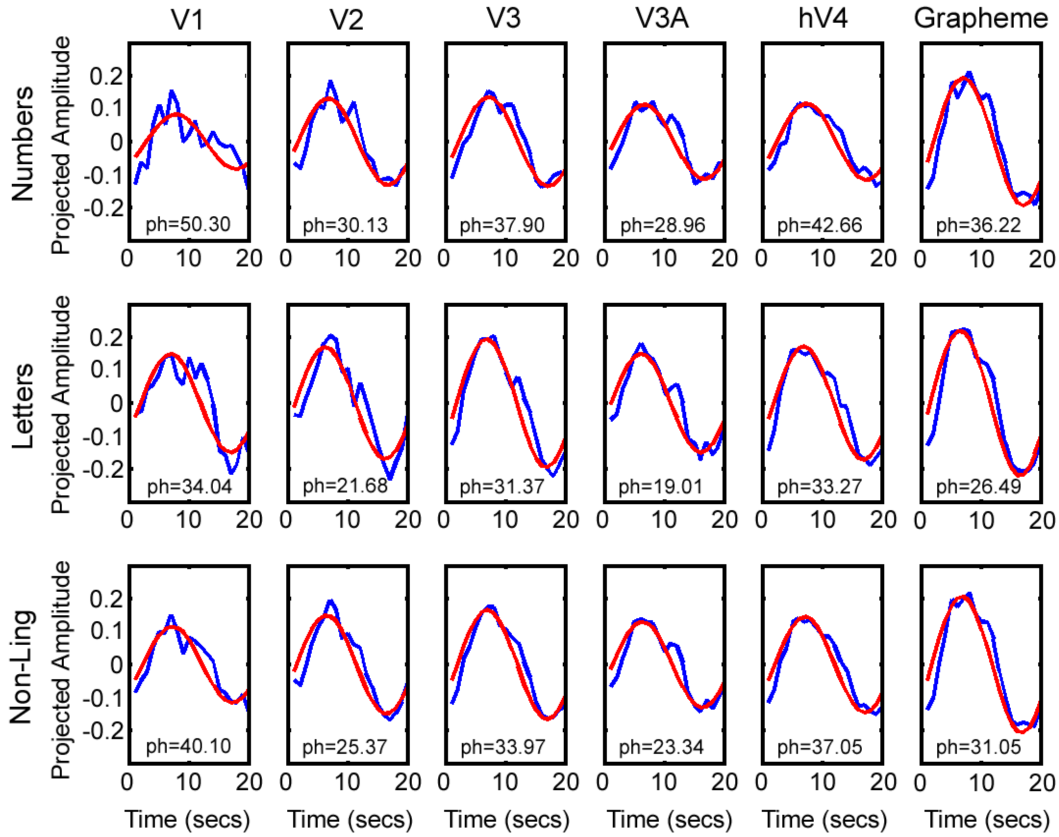

Figure S2. Hemodynamic time series data for our predefined regions of interest (ROIs), V1, V2, V3, V3A, hV4 and the grapheme area. The raw hemodynamic responses are indicated in blue, and the best fitting sine waves are indicated in red. The phase of the best fitting sine for each condition and each ROI is given in the center bottom of each plot. These data clearly show that our hemodynamic responses were within the normal range for computation of projected amplitudes, consistent with our use of a fixed reference phase of 35º.

Supplemental References

Boynton, G.M., Engel, S.A., Glover, G.H. and Heeger, D.J. (1996). Linear systems analysis of fMRI in human V1. J Neurosci *16*, 4207-4221.

Engel, S.A., Rumelhart, D.E., Wandell, B.A. and Lee, A.T. (1994). fMRI of human visual cortex. Nature *369*, 525.

Hadjikhani, N., Liu, A. K., Dale, A. M., Cavanagh, P., and Tootell, R.B.H. (1998). Retinotopy and color sensitivity in human visual cortical area V8. Nat Neurosci *1*, 235-241.

Sereno, M.I., Dale, A.M., Reppas, J.B., and Kwong, K.K. (1995). Borders of multiple visual areas in humans revealed by functional magnetic resonance imaging. Science *268*, 889-893.

Wade A.R., Brewer A.A. Rieger J.W., and Wandell B.A. (2002). Functional measurements of human ventral occipital cortex: Retinotopy and colour. Philos T Roy Soc B *357*, 963-973.