CHARACTERIZATION OF CORTICAL VISUOTOPY IN HUMAN AND MACAQUE: QUANTITATIVE SIMILARITIES ACROSS SUBJECTS AND SPECIES*

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Abstract

Topographic maps of sensory and motor spaces exist throughout the brain, and the visuotopic maps in cerebral cortex provide the basic datastructure for vision. Their most striking feature is a strongly space-variant geometry: in macaques and humans the central visual field is over-represented relative to the periphery by up to four orders of magnitude in solid angle. Although observations of cortical topography are commonplace in brain imaging, much less attention has been paid to quantitatively measuring the visuotopic map, making it difficult or impossible to perform cross-individual and cross-species comparative analyses.

Cortical visuotopy has frequently been inadequately characterized in terms of cortical magnification factor along the eccentricity coordinate. This one-dimensional characterization ignores the two-dimensional nature of the mapping. Perhaps as a result, existing attempts at characterization in both human and macaque show wide variance across studies. Furthermore, magnification factor is dependent on the physical size of the given visuotopic area, which varies significantly across subjects and species.

In previous work, we demonstrated that the shape of anatomically-defined V1 within flattened cortex is remarkably similar across subjects for both macaque and human, and that the shapes in macaque and human are nearly identical [1]. This regularity of the V1 layout validates efforts to characterize the visuotopic maps across a population of subjects—as well as across humans and macaques.

Here, rather than cortical magnification factor, we use a generalization of the standard complex logarithm or $w = \log(z + a)$ model for cortical visuotopy—the *wedge–monopole* model—which provides a quantitative model for our *a priori* knowledge of multi-area topographic layout. This model provides a two-dimensional mapping with a small number of parameters that *jointly* models the topographic structure of V1, V2, and V3. The model parameter a serves to characterize the percentage of cortex devoted to representing the fovea within the V1–V2–V3 complex. This alternative characterization is independent of the size of the areas, unlike cortical magnification factor.

To measure the visuotopic maps in human, we collected fMRI data from four subjects. For surface-based visuotopic map analysis, we flattened the mesh representation of the visual cortex into the plane using a novel quasi-isometric flattening algorithm that introduces much less geometric distortion than current flattening methods [2]. Although for many applications cortical flattenings are used for visualization only, here flattening provides global coordinates for the cortical surface in which we fit our topographic model, and it is therefore crucial for an accurate, quantitative analysis—independent of variance in the gross cortical folding pattern—to minimize metric distortions induced by flattening.

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To obtain accurate model fits, we employed robust techniques to avoid fitting artifacts and performed cross-validation analysis to assess the parameter value reliability. The resulting fits exhibited low parameter variance across subjects and low cross-validation error, indicating good agreement with the data.

We compared our human fMRI results with fits to two sets of macaque visuotopy data: V1 2DG data collected in our lab, and publicly-available V1–V2 electrophysiology data from the Van Essen lab. All aspects of the visuotopic maps were quantitatively similar between human and macaque, up to global scaling. In particular, the a parameter was in the range of 0.6 to 0.7° in both human and macaque.

The macaque visual cortex has often served as a model for human, and our study demonstrates that, for visuotopy, this practice is justified. Furthermore, the low parameter variance across human subjects—and similarity of parameter values to macaque—suggests convergence on an accurate characterization of human visuotopy.

References

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