Supplementary Materials for

A twisted visual field map in the primate dorsomedial cortex predicted by topographic continuity

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The PDF file includes:

Figs. S1 to S6
Legends for movies S1 and S2

Other Supplementary Material for this manuscript includes the following:

(available at advances.sciencemag.org/cgi/content/full/6/44/eaaz8673/DC1)

Movies S1 and S2
Fig. S1. The development of retinotopic maps in the optimization process

The development of retinotopic maps simulated at two particular parameter settings is illustrated at 4 steps (iteration #0, #490, #690, and #840) in the optimization process. The maps illustrated at the upper and the lower panels of A and B correspond to type A and B retinotopy respectively (Fig. 2). See also Movies S7, S8 for the process as animations.

(A) The maps plotted in the visual space (as in Figure 1C). The inset illustrates the 500 red points \( (x_i \text{ in EQ. 1}) \) used to represent the geometry of the visual field. (B) The maps plotted in the cortical space (as in Figure 1D). Abbreviations: HM – horizontal meridian; M – medial; R – rostral; VM – vertical meridian.
Fig. S2. Further details about the maps developed under different initial conditions and parameters settings

Panels A and B illustrate the effect of random initialization of the map on the retinotopy developed. The panels suggest that region A in Figure 2I is a region where twisted maps are more likely to develop in a stochastic way. The variation is further characterized in Panel C and D based on 30 random initial conditions. Based on the bimodal distribution of the field sign homogeneity index $|\tilde{\lambda}|$ (Panel C), we used $|\tilde{\lambda}| < 0.7$ as the criterion for identifying twisted maps, and calculated the proportion of twisted maps. Panel D shows that the proportion dropped sharply with the smoothness parameter.

Panel E illustrates examples of maps formed under $(\beta_1, \beta_2)$ settings that were lower than the range explored in Panel A. The first two examples (the two parameters set to $10^{-4}$ and $10^{-5}$, respectively) show that the maps developed became more fragmented as the constraints became lower. When the smoothness constraint was turned off ($\beta_1=0$), the map was completely random. However, when the congruence constraint was turned off ($\beta_2=0$), a simple map was formed. Since the caudal border no longer represented the horizontal meridian because there was no constraint from V2.

(A) Two settings of model parameters, denoted by #1 and #2 in the $(\beta_1, \beta_2)$ parameter space are examined in panel B. (B) At the two parameter settings (rows), the maps developed under 8 different random initializations of the map are illustrated as polar angle maps. Note that the upper and the lower visual quadrants are symmetrical and can be flipped in the maps. (C) The distribution of the field sign homogeneity index $|\tilde{\lambda}|$, calculated across the parameter space and across 30 random initializations. (D) The proportion of twisted maps across 30 random initializations, as a function of the $\beta_1$ smoothness parameter. (E) Examples of map developed under parameter settings outside the range illustrated in panel A.
Case CJ134. (A1) The outlines of the receptive fields for each channel, measured with a flashing square stimulus. In each plot of the receptive fields, the estimated horizontal and vertical meridians are indicated by thin white lines. For some cases, the representations of the blindspot were visible in some of the receptive field maps. Representative receptive field
maps with “holes” (the blindspot) are shown on the right without spatial smoothing. The correspondence between those maps and the plots for the entire array is indicated by numbers in white. (B1, C1, D1) Maps of the eccentricity, polar angle, and diameter of the receptive fields without (top) and with (bottom) spatial smoothing. The color scales used to plot eccentricity and polar angles are the same those as used in Figure 3, B and C. (E1) The gradient vector fields used to estimate the field sign. The blue vectors represent the directions of the eccentricity gradient (\( \nabla r \)), and the red vectors represent the directions of the polar angle gradient (\( \nabla \theta \)). Field sign (\( \lambda \)) is the clockwise angle between the two vectors. (F1) The map of field signs, illustrated with the color scale shown in the right. (G1) The map of the reciprocals of the linear cortical magnification factor (unit: \(^\circ/mm\)). (H1) The assignments of the electrode array channels to one of four areas (V2d, DM+, DM-, and others).
Case CJ139LH. The information is presented in the same format as used for case CJ134.
Case CJ139RH. The information is presented in the same format as used for case CJ134.
Case CJ138. The information is presented in the same format as used for case CJ134.
Case CJ140. The information is presented in the same format as used for case CJ134.
Fig. S4. Comparing the characteristics of DM+ and DM-

Comparing the cortical magnification of DM+ and DM-, as well as the receptive field sizes and orientation selectivity of neurons in the two regions suggests that DM+ and DM- share striking similarities.

(A) The distributions of $1/M$ for DM+ and DM-, where M is the linear cortical magnification factor. The dashed regression line was calculated with data pooled from DM+ and DM-.

Inset: The cortical magnification factor of DM compared to the marmoset V1 (40) and V2 (41), in the eccentricity range of 5° to 20°. (B) The distributions of receptive field diameters estimated for DM+ and DM-, as functions of the eccentricity. The dashed regression lines were calculated separately for DM+ (red) and DM- (green). (C) The distributions of circular variance (a measure of orientation selectivity) for V2, DM+, and DM-. Most of neurons in DM+ and DM- are orientation tuned, in a distribution similar to that of V2.
We manipulated the weights of the smoothness and congruence constraints (the $\beta_1$ and $\beta_2$ parameters) for three modeling scenarios illustrated in panels A, F, and K.

The “V2”-scenario: For small values ($\beta_1 <= 0.08$, $\beta_2 <= 0.08$), the maps were similar to the idealized V2 map, with the rostral border representing the horizontal meridian (see panel D). For larger values (for example, $\beta_1, \beta_2 = 0.20$), some segments of the rostral border did not reach the horizontal meridian – a characteristics that had been investigated by others (25). It is an indication that $\beta_1, \beta_2$ were too high and overpowered the coverage term in EQ. 1. In the region where $\beta_2=0.03$ and $\beta_1>=0.2$, a different type of incomplete map was observed. In these conditions, the congruence term was too low such that the vertical meridian was not fully represented in the caudal boundary – a characteristics not observed in mapping experiments. Importantly, in all combinations of $\beta_1$ and $\beta_2$ explored, the field sign was homogenously non-mirror image, indicating that no twisting occurred.
formed under the 8x8 combinations of $\beta_1$ and $\beta_2$. A blue color scale was used to indicate that the averaged field sign was non-mirror image. (C) There was very little variation in $|\bar{\lambda}|$, which is why all pixels in panel B have similar colors. (D) The polar angle maps associated with a subset of the parameter space are plotted to show examples of the map developed. The maps are illustrated in $\frac{1}{4}$ aspect ratio (rather than the original $1/8$) to facilitate visualization. (E) The field sign maps associated with those in panel D. Abbreviations: V1d/v – the dorsal and the ventral part of the primary visual area; V2d/v – the dorsal and the ventral part of the secondary visual area; VM – vertical meridian; HM – horizontal meridian; C – caudal; R – rostral.
The “V3”-scenario: Panel I shows that for small values (β₁ and β₂ near 0.12), the maps were similar to the traditional view of V3 retinotopy, with the rostral border representing the vertical meridian. For larger values (for example, β₁, β₂ = 0.20), some segments of the rostral border did not reach the vertical meridian (analogous to the representation of the horizontal meridian in the “V2”-scenario). The field sign maps (panel J) were all homogeneous mirror image maps, except for the maps in the upper left corner of the parameter space (see Panel G). In this region, parts of the maps had non-mirror image field sign, indicating twisting. This type of twisting was associated with the low congruence constraints, rather than the low smoothness constraint associated with the twisted DM map (Fig. 2I). It’s a different kind of twisting that does not correspond to the known organization of the visual cortex.

(F-J) The information is displayed in the same format as in A-E. The geometry of the simulated area is indicated by the region shaded in purple in panel F. For panel G, a red color scale was used to indicate that the averaged field signs were mirror image.
The "displaced DM"-scenario: Panels K-O show that in this scenario, all combinations of $\beta_1$ and $\beta_2$ produced simple non-mirror image maps.

(K-O) The information is displayed in the same format as in A-E. The geometry of the simulated area is indicated by the region shaded in pink in panel K. For panel L, a blue color scale was used to indicate that the averaged field signs were non-mirror image.
Fig. S6. The locations of the implanted arrays

(A) The relative locations of the implanted arrays, inferred from histology. (B) The flat-mounted occipital lobe (stained for cytochrome oxidase) of case CJ138. The marks left by the individual electrodes confirmed that the array was implanted immediately rostral to area V2. Abbreviations: M – medial; R – rostral; L – lateral; C – caudal.
Movie S1. The development of a Type A (twisted) map in the optimization process. The number at the top indicate the number of iterations in the optimization process. The left panel shows the polar angle of the map in visual space, and the right panel shows it in cortical space. The format is the same as in Figure 1, C and D.

Movie S2. The development of a Type B (non-twisted) map in the optimization process. The number at the top indicate the number of iterations in the optimization process. The left panel shows the polar angle of the map in visual space, and the right panel shows it in cortical space. The format is the same as in Figure 1, C and D.