Is the polarity of multifocal VEPs related to visual-cortex folding?

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Introduction

The idiosyncratic folding of retinotopic visual cortex is believed to dictate the dependence of multifocal visual evoked potential (mfVEP) amplitude and polarity on stimulus location in the visual field. We assessed that relationship in four subjects by comparing mfVEPs with measures of corresponding fMRI-derived regions of interest (ROIs) in V1 and V2, i.e., their curvature, orientation and distance from electrode.

Methods

- Dartboard-shaped, polarity-sensitive mfVEP activity maps were obtained as Pearson's correlations of the local signals with the polarity-corrected mean for the whole field.
- fMRI stimuli (wedges and rings) for retinotopic mapping matched mfVEP stimuli in size and texture.
- ROI surface orientation, location, and curvature were determined by Matlab scripts processing BrainVoyager vertex data. Heuristic checks verified the validity of these measures.

Results

As a first step, we associated particularly conspicuous visual field areas in the mfVEP with the respective fMRI ROIs (Fig. 1–3).

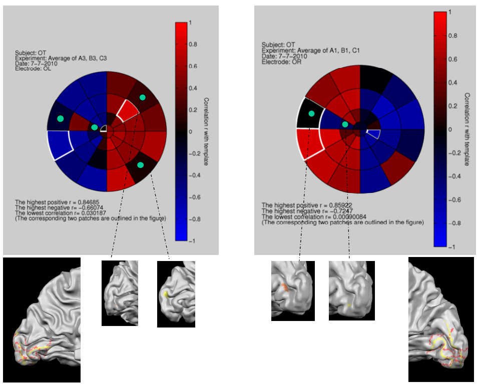


Figure 1. Mapping of conspicuous areas for subject OT

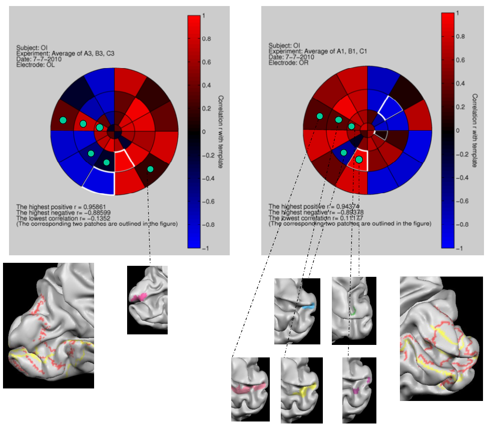


Figure 1. Mapping of conspicuous areas for subject OI

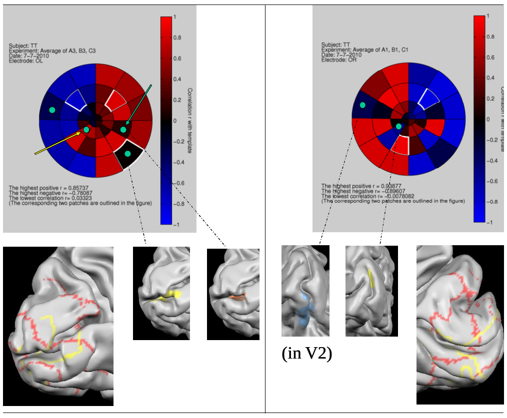


Figure 3. Mapping of peculiar areas for Subject TT. W12/R3 (arrow) further analysed.

To arrive at a dipole description of individual ROIs we determined the surface normal for each ROI vertex (red arrows), and their mean (blue arrow) as estimates of their local generators.

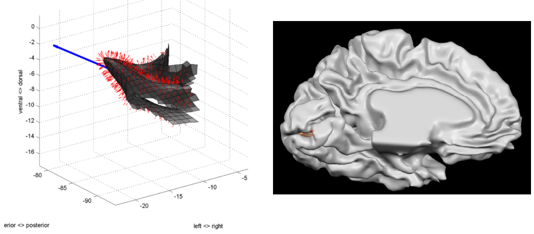


Figure 4. A ROI from the left calcarine sulcus of V1/ sj. TT that is strongly folded due to its location. The corresponding stimulus segment (W12/R3) is just below the right horizontal meridian and outside the fovea. The mfVEP activity map (Fig. 3, arrow) shows an isolated, local inversion of polarity there (both for electrode OL and OR). The large blue arrow indicates the average orientation (50 times enlarged for visibility). The right figure shows the location of the ROI (W12/R3) in color. The ROI is slightly shifted from what we'd expect (should be on the top surface of the calcarine sulcus).

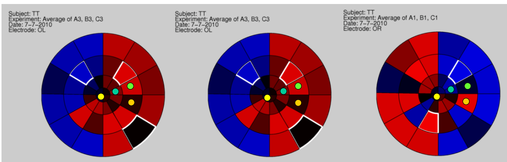


Figure 5. Same activity maps as in Fig. 3 (Subject TT). Segments p1–p4 from Fig. 6 highlighted by ● ● ● ●

The norm (length) of the mean normal vector quantifies the extent of folding of a region. Because if the normals are oriented similarly, the mean approaches one. In the activity map, there are regions of consistent polarity with respect to its local surroundings (W1/R2=p1 and W1/R3=p2), and of non-consistent polarity (W9/R1=p3 and W12/R3=p4). In the following distribution of norms, these are examples of high (p1, p2) and low (p3, p4) norm, or little vs. high folding.

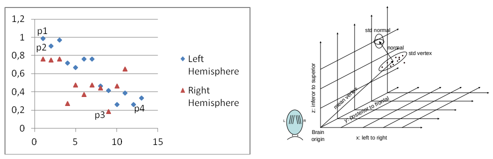


Figure 6. Distribution of the lengths of the mean normals for subject TT in V1.

The next figure shows another example of strong folding.

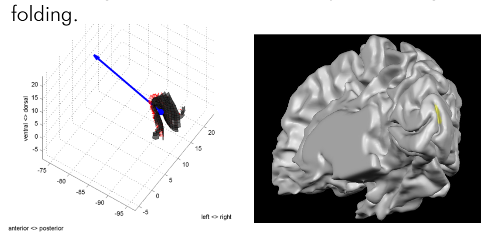
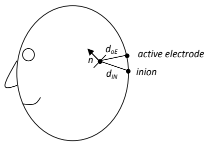


Figure 7. ROI and its location in the right hemisphere for stimulus segment W8/R2 (Sj. TT; see Fig. 3, yellow arrow ⟵).

For a systematic test of these relationships we drafted a simple model relating mfVEP activity and ROI location and orientation:



$$a_{aE} - a_{in} = \frac{\cos(n_a, d_{a,aE})}{d_{a,aE}^2} - \frac{\cos(n_a, d_{a,IN})}{d_{a,IN}^2}$$

Figure 8. Schematic representation of the geometric relationship between cortical generator (dipole) and electrode.

Unfortunately, none of the relevant parameters in the equation showed obvious resemblance to the activity maps.

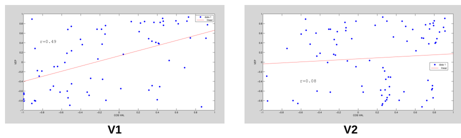


Figure 9. Scatter plot for correlations of mfVEP activity and cosine of the angle between dipole orientation and connecting line to the electrode (pooled over electrodes, subject TT). There is a substantial correlation in V1 (r=0.49), but not V2.

Based on these promising results we calculated similar correlations to all relevant parameters (mean normal: r=–0.05, distance ROI–electrode: r=–0.20, its inverse distance: r=0.14, square of inverse: r=0.10, and the same for V2 (cos: r=–0.08; normal: r=0.12; distance: r=–0.44; inverse distance: r=0.38, square inverse distance: r=0.34. Of significance were: Relative orientation and distance-to-electrode in V1, and distance in V2. Analysis for sj. OI: The same measures showed substantial correlations. We have no explanation for the lacking relationship with angle in V2. Overall, the explained variance was around 25% and that might be improved by multiple correlations.

Conclusion

MfVEP activity was correlated with ROI orientation and distance-from-electrode for V1, with up to 25% explained variance. Activity was further correlated with ROI distance in V2 but not with the ROI's orientation. Polarity reversals between upper and lower hemifield might reflect surface orientation in V2. In summary, mfVEP polarity reversals depend on V1 and V2 folding but further unknown factors also contribute.

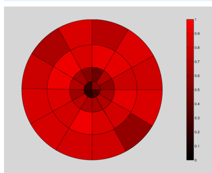


Figure 10. An improved mfVEP activity map for sj. TT: With segments scaled, polarity disregarded, maximum between electrodes chosen, improved similarity algorithm used.

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