Function-based inter-subject alignment of cortical anatomy

Mert R Sabuncu[1], Benjamin D Singer[2], Ronald E Bryan[3], Peter J Ramadge[1], and James V Haxby[3]

[1]Department of Electrical Engineering, Princeton University, Princeton, NJ, USA
[2]Center for the Study of Brain, Mind, and Behavior, Princeton University, Princeton, NJ, USA
[3]Department of Psychology, Princeton University, Princeton, NJ, USA

Motivation

• Inter-subject cortical alignment is currently based on anatomy. However, the loci and orientation of neural activity is not always consistent relative to anatomical landmarks. Thus, adding a functional alignment step that refines anatomical alignment should improve functional correspondence across subjects and lead to improved group statistics.

Methods

• Much of what we know about the organization of functional regions in cortex tells us that they are intrinsically 2D (e.g., columnar and laminar organization in visual areas). It is therefore both informative and convenient to view functional regions on the convoluted manifold of the cerebral cortex. Here we work on a standard 2D representation of the cortex.

• Cortical meshes were extracted from structural volumes for seven subjects, then inflated to a sphere (represented by a triangulated mesh) and registered anatomically using FreeSurfer (Fischl et al, 1999). SUMA (Argall et al, 2005) was used to resample the mesh regularly so that same-indexed mesh nodes were in anatomical correspondence.

• Following Hasson et al (2004), fMRI data was collected from subjects while they viewed an action adventure movie, in this case Steven Spielberg's *Raiders of the Lost Ark*.

• As with Hasson, the movie data was highly correlated between subjects after anatomical alignment. This data was used to create a warp that further aligned subjects based on functional similarity. Similarity was measured using the *Pearson correlation* between corresponding time-series at each node. This is consistent with the standard GLM method used for fMRI time-series analysis.

• In our implementation, meshes are "warped" based on a 2D spherical warp field. The goal of the algorithm is to determine the warp field that maximizes the total node-pair correlations between the subjects' meshes. Every node is allowed to move independently to find its best match. To avoid over-fitting – so that the warp generalizes well to other experiments – we regularize the warp by (only) preventing "folds" in the warped mesh. This is a liberal regularization compared to most alignment algorithms (e.g., FreeSurfer or Talairach), since we expect major "metric distortion" (e.g., expansion or shrinkage of area) in some functional regions across subjects. So, the algorithm maximizes:

$$E = E_c - \lambda E_f,$$

where E_c is the correlation energy and E_f is the folding penalty, which is proportional to the difference between the current and original areas if the triangle is folded.

• We use iterative gradient-ascent for optimization, initialized by a warp-field obtained through an exhaustive search for optimal node matches within a 3 cm search radius.

Results

• The first half of the movie experiment was used to functionally align 6 subjects to a reference. The warp generalized (Figure 1); mean correlation improved in two test data sets (also shown is % increase in shared variance as a proportion of total variance):

Entire cortical surface
Movies 2nd half: .037 to .045 (37%)
Visual categories: .010 to .012 (16%)
VT only
Movies 2nd half: .054 to .072 (41%)
Visual categories: .027 to .035 (36%)

• Applying the warp to a group analysis (Figure 2) for a visual categories experiment (Haxby et al., 2001) improved *t* statistics (n=7):

Mean(+): 1.27 to 1.32
Mean(–): -1.14 to -1.22
Max: 10.85 to 11.24
Min: -10.53 to -12.60

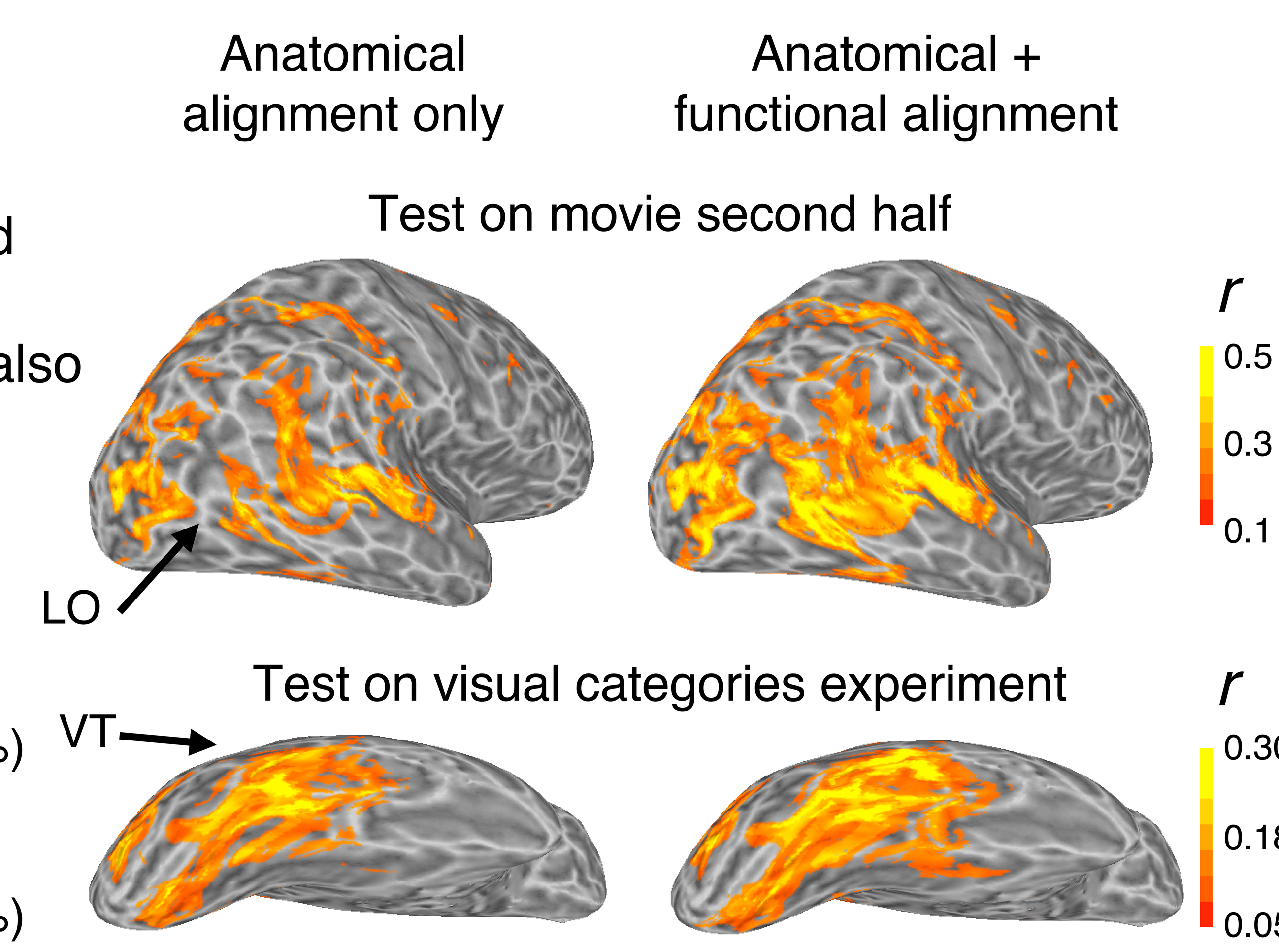

Figure 1*. Warp time-series generalization. In both the second half of the movie (top) and in a visual categories experiment (bottom), adding a functional warp (right) derived from the first half of the movie significantly improved alignment as measured by increase in mean correlation, especially in ventral temporal cortex (VT, shown in ventral view below).*

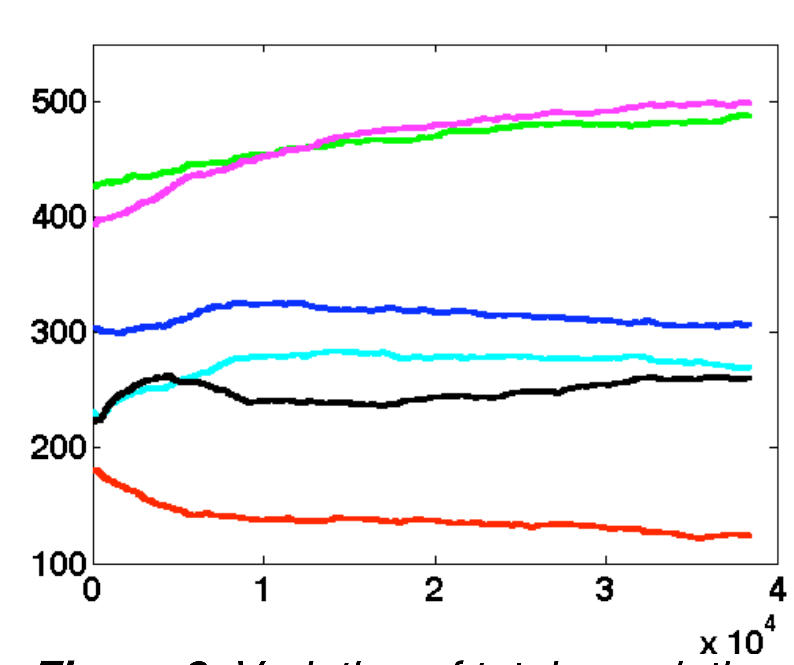

Figure 3*. Variation of total correlation (y) between 6 subject pairs for the visual category experiment wrt the number of optimal matches (x) used to set up functional correspondence based on the first half of the movie. Anatomical alignment only is at x=0.*

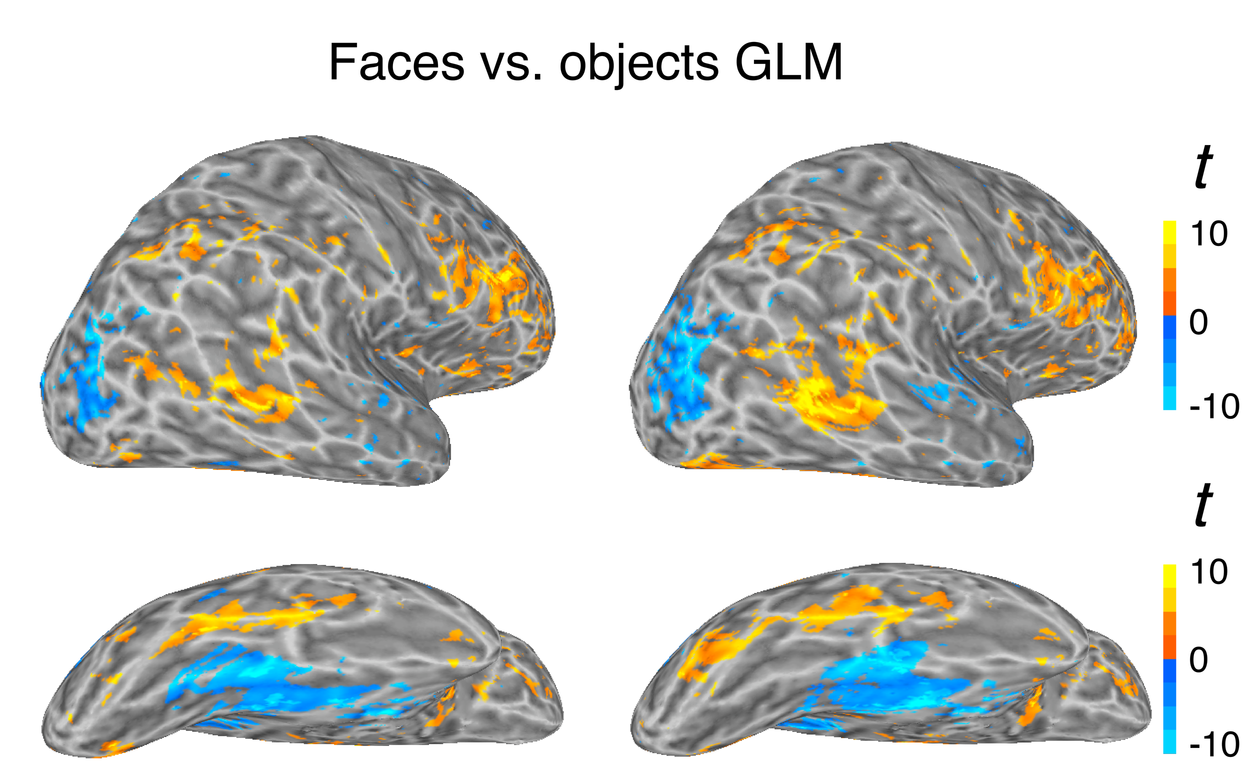

Figure 2*. Results of t-tests on GLM beta weights for a faces (yellow) vs. objects (blue) contrast in a visual categories experiment. Betas aligned via the movies warp (right) improved t-test statistics. Shown is |t| > 2.5 (p < 0.05).*

Conclusion

These results suggest that adding a functional alignment step to anatomical alignment improves inter-subject cortical alignment and group statistics.

Future work

• Improve multi-subject alignment by aligning to an average subject
• Integrate with multivariate learning algorithms (i.e., train on one subject and generalize to another).

References

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