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Title: Eye Position Signals in Human Visual Cortex in Darkness - Unexpected Effects of Motion Artifacts on Support Vector Machine Analysis of fMRI Data
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Abstract: Introduction: Perceptual constancy across saccadic eye movements requires the integration of eye position signals and visual information. Physiological studies have shown that visual information is encoded in a variety of coordinate frames across the visual cortex of nonhuman primates, with receptive fields being more explicitly space centered in the more parietal areas. Neurons in those parietal areas, however, typically have large receptive fields and it is unclear how they could form the basis for high acuity perceptual constancy. Furthermore, it remains a possibility that the world-centered representation in parietal areas, rather than being the result of an explicit coordinate transform of retina-centered information through oculomotor signals, is based on the combination of a distributed and implicit world-centered representation of space in earlier visual areas. Our goal is to determine whether such an implicit representation exists in human early visual cortex.

Methods: We used functional imaging in healthy human subjects to investigate eye position signals in human visual cortex. We first mapped subjects' visual areas using standard retinotopic mapping techniques. Then, we used auditory cues to instruct the subjects to direct their eyes to five distinct head centered directions - left, right, up, down and center. This eye-position experiment took place in complete darkness. Acquired volumes were motion corrected and individual voxels had head motion traces removed through linear regression. We then trained support vector machines to predict eye position from the time course of voxels within early visual areas.

Results: MR signals in and around the eyes were nearly perfectly predictive of the subject's eye position. This confirms both that subjects were accurately performing the difficult task of fixation in complete darkness, and that the multi-voxel analysis is capable of extracting eye position information. We then turned to visual cortex and found significant cross validation performance of support vector machines trained on voxels in retinotopically organized early visual cortex. Control voxels taken from the skull and analyzed identically did not lead to classification performance above chance level.

A finding of considerable methodological interest was that removal of motion signals from voxel time courses by linear regression led to artifactual results in the cross-validation performance support vector machines. As a particularly salient example; when applied to a simulated BOLD signal consisting entirely of Gaussian noise, the support vector machines consistently performed significantly below chance level on the classification task.

Conclusions: We conclude that eye position information is available early in the human

visual stream. This information provides a basis for a high-acuity, implicitly world-centered, representation of space.

We also conclude that classification analyses of fMRI data can suffer significantly in experimental setups where head motion correlates with the trial time course. While this correlation was especially pronounced in our experiments, many fMRI paradigms may produce small correlations. Small correlations may be quite harmless in a standard univariate analysis, but can lead to spurious results when analyzed with high-dimensional multi-voxel analysis techniques.