Verifying visual fixation to improve fMRI with predictive eye estimation regression (PEER)

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INTRODUCTION Point-of-gaze is a common behavioral measure for cognitive studies and can complement fMRI data. Unfortunately, MR-compatible eye tracking systems are expensive and their performance can be limited. Once installed, setup and calibration for each scanning session also can be time-consuming. To overcome these issues, we recently proposed a statistical learning approach to estimate eye fixation directly from fMRI images [1]. The method, PEER (Predictive Eye Estimation Regression), uses a calibration run with sequence parameters matching those of the fMRI scans (slice prescription, TR, TE, flip angle, bandwidth, etc). Support vector regression (SVR) [2] is used to model each calibration image and its corresponding (known) fixation location. The SVR model can then be used to predict point-of-gaze for the session's fMRI runs. In the experiment reported, the fMRI task was designed to have "good" and "bad" blocks of fixation to illustrate the practicality and utility of tracking fixation with PEER. Specifically, we demonstrate that i) direction of gaze can be tracked during an fMRI-based retinotopic run, ii) improved retinotopic mapping is achieved when fixation information is available, and iii) the method gives comparable results to those by a commercial eye-tracking system.

METHODS Imaging: fMRI data were collected on a healthy 27-year-old male volunteer with a 3T Siemens TIM Trio, using 31 axial EPI slices (TR/TE = 2000/31 ms, voxel=3.4×3.4×5 mm^3). Visual stimuli were back-projected, providing an approximate visual field of 20˚ horizontally and 15˚ vertically. Point-of-gaze data were recorded using an infrared-based eye tracking system (Applied Science Laboratories, www.a-s-l.com). We performed three runs: 1) calibration, 2) retinotopic, and 3) calibration. The calibration runs both lasted 108 s (54 scans), during which the volunteer focused on a fixation symbol that progressed twice through nine calibration coordinates on the display, with position updates occurring every 6 s. The retinotopic run consisted of 20 s randomized blocks of a flashing wedge stimulus at 4 orientations (left/right/up/down) and 2 fixation symbol states (center/non-center) for a total of 8 conditions. The run lasted 13 min 20 s (400 scans), and had approximately 5 repetitions of each condition. The wedges were 30˚ in polar angle width and reversed black/white contrast at 4 Hz. For "non-center" conditions, the fixation symbol was at the outer radius of the wedge (e.g. for the right wedge, the symbol was at the extreme right). Analysis: BrainVoyager (Brain Innovation, the Netherlands) was used to segment, inflate and flatten anatomical data. Functional data were preprocessed using BrainVoyager's motion correction, scan time correction, linear drift removal, and normalization to Talairach space. General linear model results for the wedge orientations were thresholded at p=0.05 (corrected using false discovery rate) and a cluster size of 50 mm^2 on the flattened cortex. PEER was performed using both calibration runs to form a support vector regression model. All three runs were slice-time corrected and aligned to the first scan of the first run with AFNI [3]. The two calibration scans were concatenated and modeled using SVMlight [4,5], and fixation was estimated for the retinotopic run and compared with the eye tracking data.

RESULTS Fig. 1 shows A) corrupted activation on the flattened left hemisphere from all blocks in the retinotopic run; B) the improved pattern after discarding the "non-center" blocks detected by PEER; C) horizontal point-of-gaze data: eye tracking (blue), symbol position (black), and PEER (red) – blue and red correlations to black are 0.77 and 0.83, respectively. D) vertical data: (correlations 0.97 and 0.91).

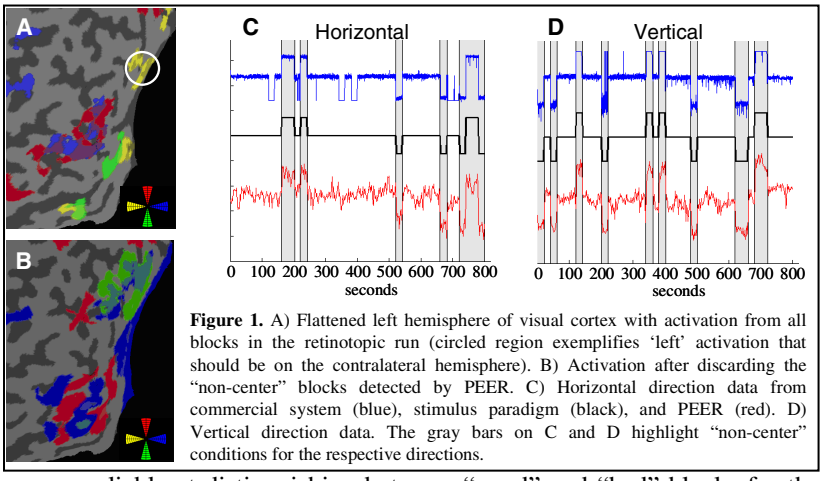

Figure 1. A) Flattened left hemisphere of visual cortex with activation from all blocks in the retinotopic run (circled region exemplifies 'left' activation that should be on the contralateral hemisphere). B) Activation after discarding the "non-center" blocks detected by PEER. C) Horizontal direction data from commercial system (blue), stimulus paradigm (black), and PEER (red). D) Vertical direction data. The gray bars on C and D highlight "non-center" conditions for the respective directions.

DISCUSSION AND CONCLUSION The acquisition of PEER calibration images required just over 3.5 min. - much less than our usual setup time for the eye tracking system, and it is possible to acquire calibration runs at any point in the scanning session. As a retrospective analysis tool, it can be applied at any fMRI site. For comparison, the eye tracking system has less variability during fixation than PEER, but PEER was more reliable at distinguishing between "good" and "bad" blocks for the horizontal data. Further, improved calibration approaches and model parameters may further enhance PEER's performance. This work demonstrates that PEER can be used for fMRI using different stimuli from the calibration runs. Indeed the TR-by-TR responsiveness shows that PEER uses image properties other than hemodynamics. Though rapid eye movements (e.g. saccades) would require much faster sampling than our current TR limitation, a great number of fMRI experiments would be enhanced with the addition of fixation data. We have demonstrated tremendous potential for this simple and cost-effective fMRI eye tracking technique and anticipate that further refinements will improve the temporal resolution and estimation precision.

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ACKNOWLEDGEMENT Thanks to Randall Stilla and Zhaohui Liu. Supported: Georgia Research Alliance, NIH grants RO1EB002009 and R21NS050183.