Background

The concurrent collection of fMRI and eye-tracking data is becoming increasingly common. Little attention has been paid to analytic strategies for incorporating eye gaze data into a model of brain activation. Most published studies have used average gaze fixation as a regressor on activation maps.

Here, we sought to incorporate gaze fixation data into models of brain activation to aversive images at multiple levels of analysis (for similar methods, see Sisgle et al., 2003). In addition to including mean fixation duration as a covariate of no interest in 2nd-level analyses, we used within-subject trial-by-trial variability in fixation duration to scale individual predictors in 1st-level analyses, and took resulting statistical coefficients to 2nd-level analyses.

We hypothesized that by accounting for variance otherwise included in the error term, both of these methods would enhance our power to detect effects of interest in a priori regions of interest (amygdala, anterior insula, and pregenual anterior cingulate cortex (ACC)).

Methods

Participants

- 18 healthy adult subjects (7 male, mean age = 23.0) with complete fMRI and eye-tracking data.

FMRI task

- Emotional anticipation task using pictures from the IAPS set (Lang et al., 1999).
- Cues preceded aversive pictures (X), neutral pictures (O), or either picture type (Y).
- 4 functional runs (~12:00 each); total of 48 aversive and 48 neutral picture presentations.

Eye-tracking data

- Gaze fixations measured using iView X system and processed offline in-house software.
- For each subject, calculated mean fixation duration for aversive and neutral pictures separately; also calculated trial-by-trial fixation duration.

FMRI processing and analysis

- Processing implemented in AFNI included slice time correction, 6-parameter rigid-body motion correction, field map correction, coregistration with high-resolution T1 images, and 12-parameter affine warp to MN152 brain.

MODEL 1 (Baseline model)

- Negative and neutral pictures separately convolved with a canonical HRF and resulting beta weights from GLM converted to % signal change.
- Conducted whole-brain, voxelwise t-tests (aversive-neutral pictures) to identify regions showing valence effect (p<0.005, corrected, 80mm³ extent).
- Extracted % signal change values from anatomically defined ROIs (amygdala, anterior insula, pregenual ACC) for aversive and neutral picture conditions.

MODEL 2 (Between-subjects eye-tracking covariate)

- Mean fixation duration values (averaged across picture valence) entered as covariates of no interest into voxelwise GLM (Model 1).
- After extracting percent signal change values for the contrast of aversive-neutral pictures from functionally and anatomically defined ROIs, regressed PSC values on mean fixation duration

MODEL 3 (Scaling individual predictors on trial-by-trial basis)

- For first-level analyses, replaced aversive-neutral picture predictors with predictors scaled by duration of fixation on each trial separately (Figure 2). Extracted (aversive-neutral picture) percent signal change values from anatomical ROIs, and conducted whole-brain voxelwise comparison with Model 2.

Results

1. Accounting for variability in mean fixation duration improves model fit (Model 2)

- Mean fixation duration did not differ by picture valence (aversive = 637±160 ms; neutral = 636±144 ms).
- Fixation duration correlated with aversive-neutral picture activity in amygdala and (at a trend level) anterior insula (Figure 2).

2. Modeling inter-trial fixation variability improves regional and whole-brain sensitivity (Model 3)

- Scaling predictors on a trial-by-trial basis (Model 3) led to striking increases in contrast estimates (Table 2) as well as in the anatomically defined amygdala (Figure 4, Table 2).
- Removal of mean fixation covariate led to broadly distributed, subtle improvements in voxelwise t statistics (not shown).

Discussion

The inclusion of mean gaze fixation time as a covariate of no interest reduced error variance and strengthened contrast estimates in a priori defined regions (amygdala and anterior insula) in several other regions activated by the viewing of aversive (relative to neutral) pictures.

Accounting for within-subject variability in fixation duration provided increased sensitivity over the covariate method, suggesting a critical relationship between gaze duration and brain activation on a given trial. This method of analysis may pay significant dividends for tasks with a high degree of between-trial variability in performance or task engagement, as assessed by eye-tracking, pupil dilation, reaction time, or peripheral physiology.

The specific nature of this paradigm (in particular, the relatively brief picture duration) dictates that caution be exercised in generalizing these findings to other tasks. Nevertheless, these findings suggest further research is warranted into the effects of individual differences in task engagement or attention on brain responses to visually presented stimuli. Among other applications, such strategies could provide insight into imaging research in various patient groups (e.g., Dalton et al., 2005).

References