Decoding Subjective "Yes/No" Thoughts using fMRI

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Introduction:

Multi-variate pattern analysis (MVPA) applied to BOLD fMRI data has proven successful at decoding different aspects of cognitive function (e.g., observed stimuli[1], presence or absence of memories[2]). In this work we focus on examining whether subjective "Yes/No" thoughts in response to binary "Yes/No" questions can be decoded from BOLD-fMRI signals using MVPA and whether they can be decoded regardless of instructed intentions.

Methods:

Two fMRI experiments were conducted. In Exp. 1, we used a temporal dynamic MVPA searchlight approach[3] to investigate whether, and where and when in the brain, subjective "Yes/No" answers can be decoded. Ten subjects participated in the experiment. Each trial of the paradigm starts with a visual cue (2s) instructing subjects to respond the subsequent question either honestly or dishonestly, followed by a common-knowledge question (4s), a random delay period (2–6s), and a final prompt asking for a motor response. Hemodynamic response associated with subjectively "Yes" and "No" thoughts were estimated[4] for each of 10 runs. The spatial patterns were input to Gaussian Naïve Bayesian classifiers in a searchlight manner. All time points in a range of 12s starting at the onset of the intention cue were searched.
In Exp. 2, we applied the regions identified above to six subjects scanned on a 7T device, aiming to validate that these regions carry information to accurately decode "Yes/No" thoughts at the individual level; and further examine if accuracy of "Yes/No" decoding is independent from the subject's intentions. The paradigm was similar to Exp. 1 except the delay between offset of question and motor response cue was extended to 8s, and the correspondence between the buttons and "Yes/No" answers was randomized across trials. We trained classifiers using averaged spatial patterns from increasing numbers of randomly selected trials (Navg), ranged from 2 to 18. In each cross-validation iteration for a given ROI and Navg level, we trained classifiers using the data 2s, 4s and 6s from question onset to separately predict the labels of the time points in test trials, which voted for the final "Yes/No" label for the test trial. In the same way, we conducted a cross-intention decoding, where the classifiers trained only using spatial patterns from the "honest" trials were used to predict the labels for the "dishonest" trials.

Results:

We observed nine regions (ROIs) with decoding accuracy significantly above chance level in Exp. 1 at time points 2s, 4s, and 6s after question onset (Fig 1). Changes in decoding accuracy with number of averaged trials (Navg) for each ROI are shown in Fig. 2. Notably, the left middle frontal gyrus ROI found in both 4s and 6s after question onset (in Exp. 1) showed consistent increases in decoding accuracy with Navg in all six subjects; reaching accuracy>85% for Navg=18 in most subjects. As a control, we also include results for the primary visual cortex (a region that did not show decoding accuracy above change level in Exp.1). Additionally, we also conducted a permutation test for each ROI by randomizing labels in classifier training. Results from the permutations are shown in grey color for each ROI. In all control cases, the decoding accuracy did not increase with Navg. The cross-intention decoding results are shown in Fig. 3. The left middle

frontal gyrus ROIs still showed consistently increasing decoding accuracy with Navg across all subjects except Subject 2.

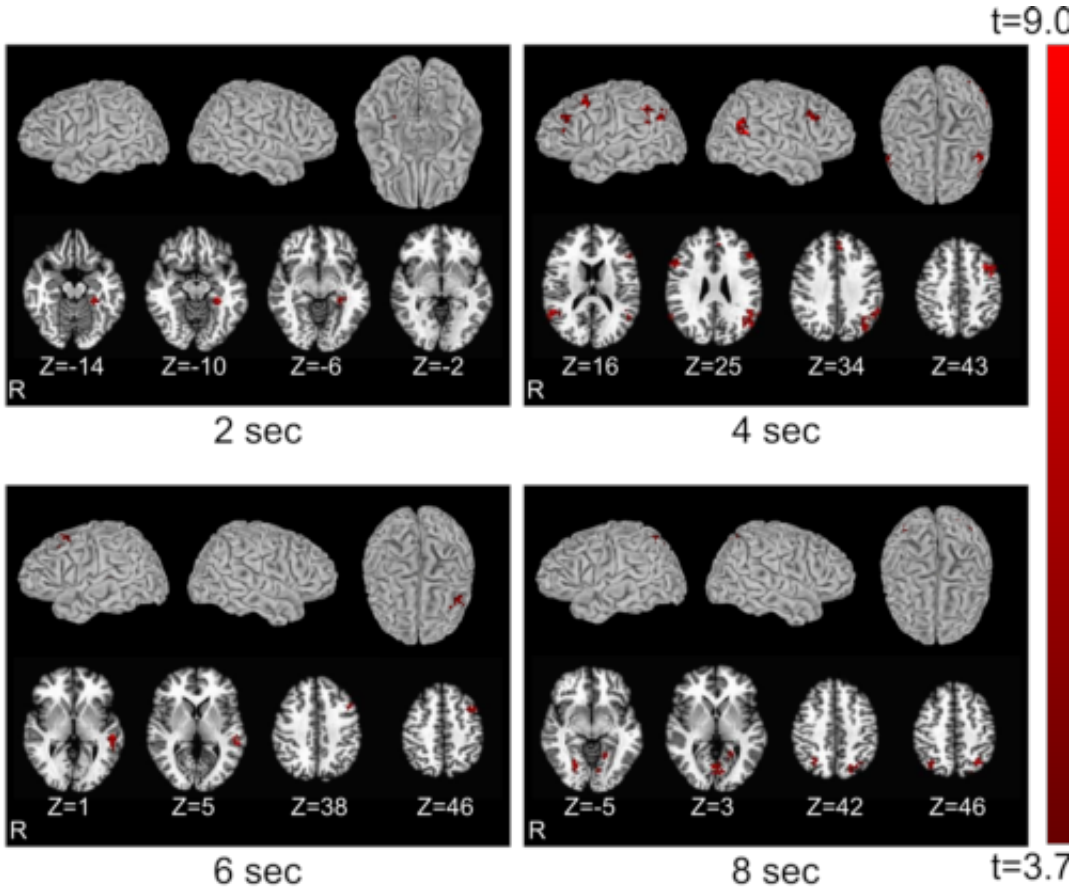

Figure 1. Group-level maps showing brain regions with above-chance classification accuracy in decoding subjective "Yes/No" answers. The times are relative to the onset of the question. The activated regions from 2-6 sec are: left parahippocampal gyrus (2s after question onset), left supra-marginal gyrus (4s), left middle frontal gyrus (4s), right superior temporal gyrus (4s), left and right inferior frontal gyrus (4s), left medial frontal gyrus (4s), left superior temporal gyrus (6s), and left middle frontal gyrus (6s). The 8-sec point exhibits motor and visual areas, reflecting the potential confounding from motor responses. We therefore only investigated the 9 regions identified from 2-6 sec in further analyses.

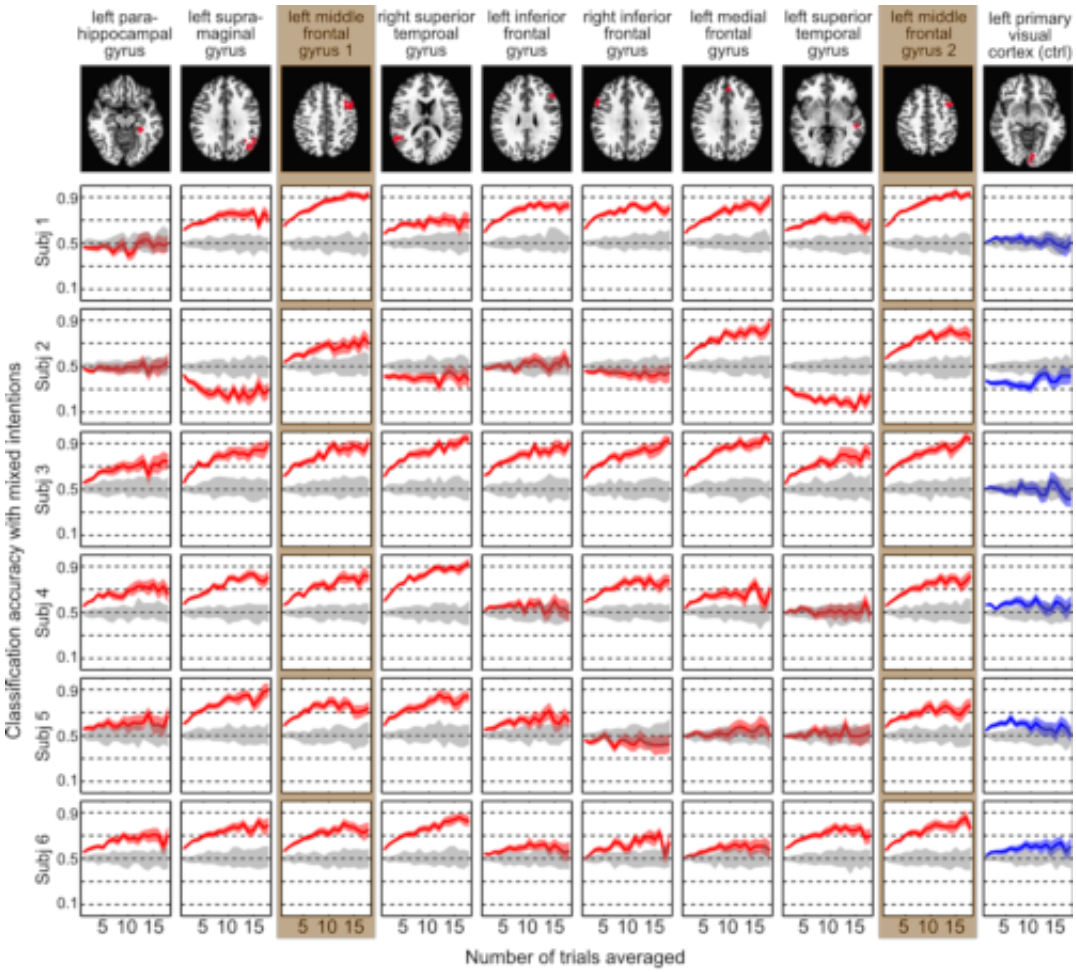

Figure 2. Classification accuracy changes with increasing numbers of trials averaged (Navg). All the trials were separated into "Yes" or "No" trials regardless of the intentions with them. The semi-transparent bands that accompany each line indicate 95% confidence levels of the accuracy estimation. The grey bands present the 95% range of the accuracy distribution in the permutation tests. The left middle frontal gyrus ROI found in both 4s and 6s after question onset in Exp. 1 (highlighted with orange color) showed consistent increasing trend in all the six subjects.

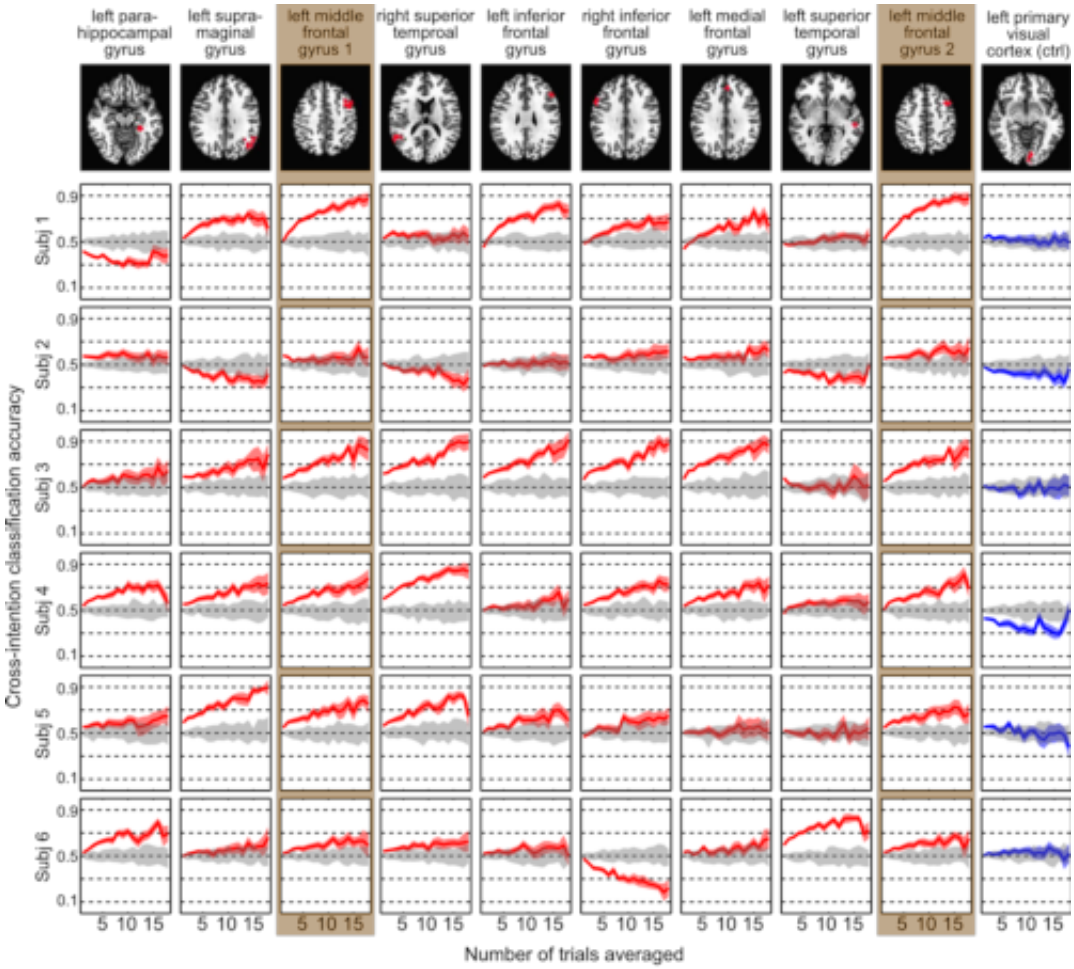

Figure 3. Classification accuracy changes with increasing numbers of trials averaged (Navg). All the trials were separated into "honest-Yes", "honest-No", "dishonest-Yes", and "dishonest-No" trials. The classifers were trained to predict "Yes" vs. "No" only using either "honest" or "dishonest" trials, and were tested with trials with the opposite intentions. The semi-transparent bands that accompany each line indicate 95% confidence levels of the accuracy estimation. The grey bands present the 95% range of the accuracy distribution in the permutation tests. The left middle frontal gyrus ROI found in both 4s and 6s after question onset in Exp. 1 (highlighted with orange color) showed consistent increasing trend in all the six subjects.

Conclusions:

We first identified a set of brain regions showing group-level above-chance accuracy in decoding the subjective "Yes/No" answers to binary questions. Results from 7T scans further verified that at least the left middle frontal gyrus can robustly decode subjective "Yes/No" answers - independent of intention - with high accuracy, given sufficiently high TSNR. These findings suggest that subjectively correct answers can be accurately decoded with fMRI in the spatial-temporal patterns of prefrontal cortex.

Higher Cognitive Functions:

Reasoning and Problem Solving

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