A central role for the lateral prefrontal cortex in goal-directed and stimulus-driven attention

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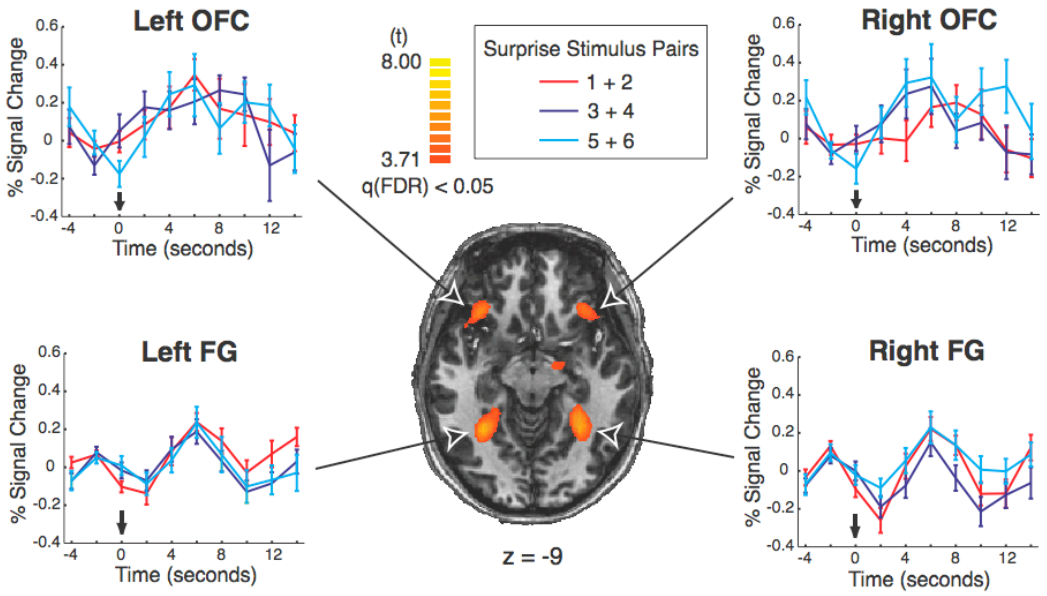
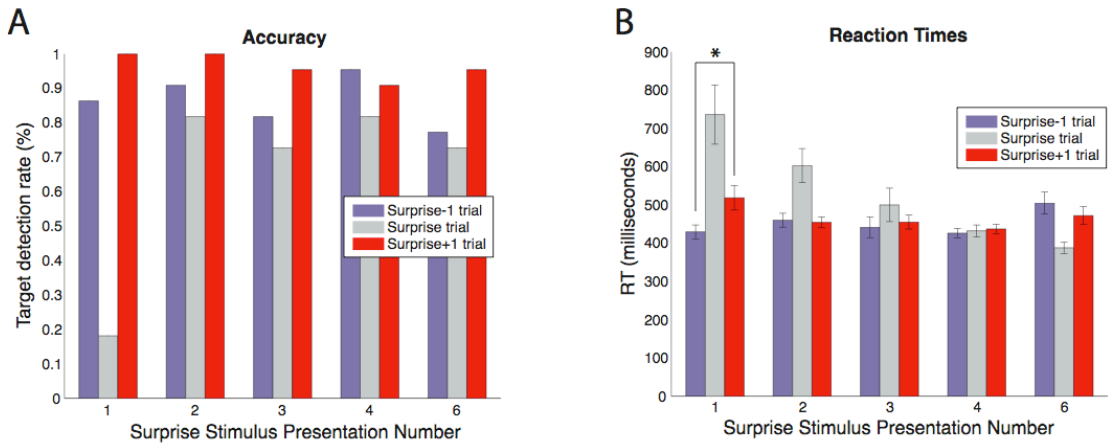
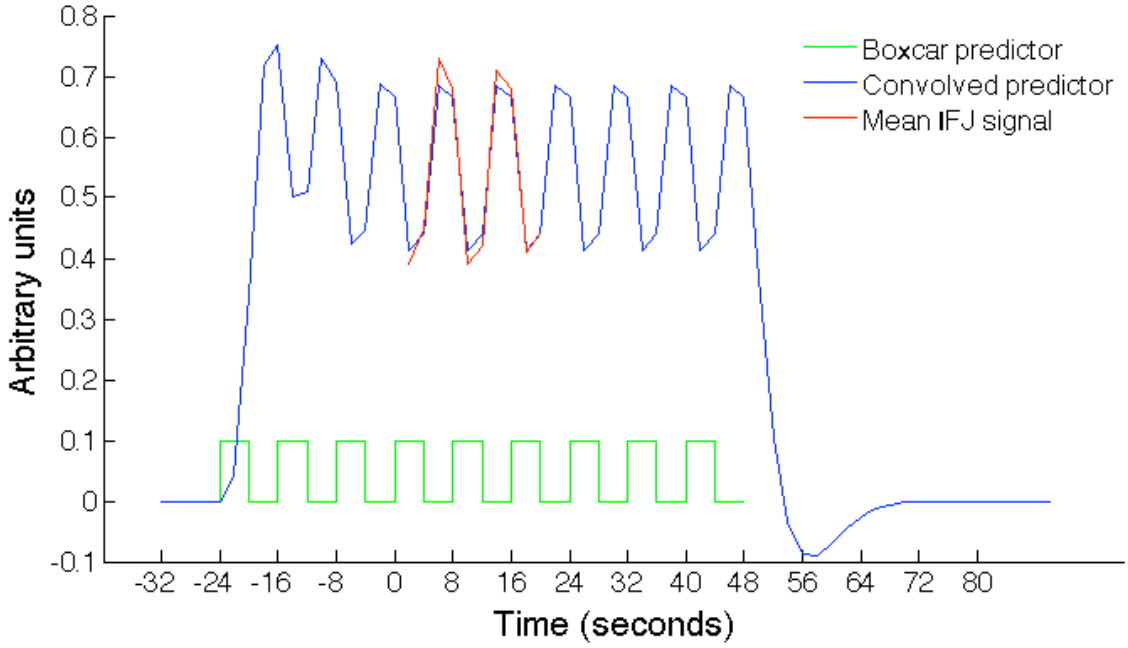
Supplementary Online Material – Supplementary Figures



Supplementary Figure 1. Brain regions showing no adaptation of Surprise stimulus-related activity in Experiment 1 (SiB experiment). The SPM highlights selected brain regions that responded to the six Surprise trials, and the time courses illustrate that these brain regions showed similar activity levels across the three pairs of Surprise trials. The Surprise stimulus appears at approximately time zero. Error bars represent standard errors of the mean. OFC = Orbitofrontal Cortex, FG = Fusiform Gyrus. The orbitofrontal cortex and inferior frontal gyrus (see Table 1) have been associated with the ventral attention network[1,2]. Their non-habituating response to the Surprise stimulus suggests that they represent different information that the information encoded in the more dorsally located IFJ (e.g. whether an event occurs with a low frequency, regardless of that precise frequency or the event's novelty).



Supplementary Figure 2. Performance on Supplementary SiB RT Experiment. A) Accuracy results. B) Reaction time results. The asterisk identifies the significant difference ($p < 0.05$) in RT between the Surprise+1 and Surprise-1 trial for the first Surprise stimulus presentation. Error bars represent standard deviations.



Supplementary Figure 3. Convolution model of Search trial activity in Experiment 1. The figure demonstrates that the Search trial hemodynamic activity pattern observed in

Experiment 1 (SiB experiment; see Fig. 3c) is predicted by linear convolution. To generate such a prediction, we first created a boxcar function (Boxcar predictor) representing the hypothesized neural activity associated with a sequence of Search trials. We next convolved the boxcar with a standard double gamma variate impulse function (as implemented in BrainVoyager QX). The resulting convolved predictor (Convolved predictor) matches well with the signal observed in the goal-directed attention regions (IFJ signal shown). This concordance should come as no surprise, as predictors similar to the convolved one shown in the figure were used to identify goal-directed attention regions.

Supplementary Online Material – Supplementary Tables

Supplementary Table 1. Average anatomical location for the individually-defined ROIs from Search trials of the Spatial SiB Experiment (open contrast SPM).

Region	Hemi	Tal co-ords (x, y, z) ± SD
IPS	Right	26 ± 5, -61 ± 6, 42 ± 6
IPS	Left	-26 ± 3, -60 ± 3, 43 ± 5
FEF	Right	30 ± 4, -8 ± 2, 51 ± 5
FEF	Left	-29 ± 4, -7 ± 2, 52 ± 4
TPJ	Right	47 ± 5, -55 ± 5, 28 ± 4
TPJ	Left	-50 ± 5, -53 ± 3, 24 ± 4
IFJ	Right	39 ± 3, 6 ± 1, 28 ± 2
IFJ	Left	-42 ± 6, 4 ± 2, 27 ± 3

Supplementary Table 2. Average anatomical location for the individually-defined ROIs from the Surprise trials in the Spatial SiB Experiment (Surprise trials – Search trials contrast). These ROI coordinates closely matched those isolated from Search trials (see Supplementary Table 1).

Region	Hemi	Tal co-ords (x, y, z) ± SD
IPS	Right	25 ± 7, -60 ± 6, 39 ± 4
IPS	Left	-26 ± 4, -61 ± 6, 43 ± 6
FEF	Right	30 ± 5, -6 ± 4, 46 ± 5
FEF	Left	-30 ± 3, -3 ± 1, 48 ± 4
TPJ	Right	49 ± 6, -50 ± 5, 23 ± 6
TPJ	Left	-49 ± 3, -52 ± 8, 20 ± 4
IFJ	Right	38 ± 7, 5 ± 5, 27 ± 3
IFJ	Left	-38 ± 7, 7 ± 3, 27 ± 4

Supplementary Online Material – Supplementary Data

Supplementary SiB RT Experiment

Because the FEF and IPS activations during Surprise trials in Experiment 1 occurred too late to account for SiB, we considered the possibility that these activations may instead reflect changes in attentional settings in anticipation of trials subsequent to the Surprise stimulus trials (Surprise+1 trials). It is possible, for instance, that subjects enhanced their attentional focus on the primary task in post-Surprise stimuli trials in order to prevent further potential Surprise stimulus presentations from interfering with the goal of target detection. Alternatively, the presentation of a Surprise stimulus (SS) may have caused subjects to divide attention between the primary target detection task

and the expectation of further SS presentations. These two accounts make opposite predictions on target detection performance, with the former suggesting an improvement and the latter an impairment. We found that target detection performance for the first two post-surprise stimuli trials in Experiment 1 were not different from those in their pre-SS counterparts (Sign test, $p = 1$), a result that does not distinguish between the two presented accounts. However, because the target detection task may have been too easy to detect subtle differences between pre-SS and post-SS trial performance (accuracy was at or near ceiling), we repeated the SiB experiment with a new group of subjects but using the sensitive measure of target response time to test for performance changes in Surprise+1 trials.

Methods

Twenty-four Vanderbilt University undergraduates (10 males) with normal or corrected-to-normal vision participated for course credit. Two subjects failed to follow task instructions, and their data were removed from the sample. Stimuli (letters and Surprise faces) were identical to those used in Experiment 1. Each trial contained an RSVP of 40 items, with each stimulus presented at fixation for 100 ms with a 17 ms inter-stimulus interval. Subjects' task was to respond to the presence of a target letter 'X' as quickly as possible with a key press. Of the 75 trials in the experiment block, 68 (91%) contained the target as one of the items between 15 and 30 inclusive. Six trials included a Surprise face, which was presented 350 ms before the target (5 trials) or in the absence of a target (always the fifth Surprise stimulus presentation). Six additional trials contained neither a target nor a face (target-absent trials). After 25 practice trials, during which no Surprise faces were presented, subjects completed the experiment trials. Surprise trials

and target-absent trials occurred randomly during these trials with the restriction that the trial preceding and the three trials following these key trials contained a target and no Surprise face.

Results and Discussion

The accuracy results show SiB, with target detection performance varying across successive Surprise stimulus presentations (Cochran's $Q(4) = 29.6$, $p < 0.0001$; see Supp. Fig. 2a). In the present experiment, target detection was worse for the first Surprise stimulus presentation (SS1) only (Sign tests, p's < 0.0034). As in Experiment 1, there was no target detection accuracy difference between these two groups of trials (Sign test, $p = 0.25$). However, the key comparison for this experiment is the RT difference between the trial immediately preceding (Surprise-1 trial) and the trial immediately following (Surprise+1 trial) the first Surprise trial. The Surprise+1 trial had a significantly longer mean RT than the Surprise-1 trial ($RT \pm SD$: 519 ± 32 versus 430 ± 18 ms; $t(18) = 2.19$, $p = 0.042$; 19 subjects were included in this comparison, as both the Surprise+1 and Surprise-1 trials had to be hits; see Supp. Fig. 2b). Crucially, this pattern was not observed for target-absent trials (423 ± 12 versus 421 ± 15 ms; $t(21) = 0.37$, $p = 0.72$) or Miss trials (455 ± 9 versus 451 ± 10 ms; $t(20) = 0.72$, $p = 0.48$), indicating that the increased RT in the Surprise+1 trial is due to the presentation of the Surprise stimulus in the preceding trial rather than the failure to detect the presence of the target in that trial.

This speeded SiB task showed that the first presentation of a Surprise stimulus slows target detection in the subsequent trial. This result is consistent with the hypothesis that presentation of a Surprise stimulus modifies attentional settings for the subsequent trial by dividing attentional resources between performance of the primary task and

vigilance for the potential presentation of another Surprise stimulus. Though speculative, this hypothesis may account for the late activation of the dorsal, goal-directed attention network following Surprise stimulus presentations that cause SiB.

Supplementary Online Material – References

1. Corbetta, M. & Shulman, G. L. Control of goal-directed and stimulus-driven attention in the brain. *Nature Reviews Neuroscience* **3,** 201-215 (2002).

2. Corbetta, M., Patel, G. & Shulman, G. L. The reorienting system of the human brain: from environment to theory of mind. *Neuron* **58,** 306-324 (2008).