



# Attentional Modulation of Center and Surround Responses in Human Early Visual Cortex

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## Background

- Previous fMRI studies have shown that early visual cortical responses to an attended visual stimulus are larger than those to an ignored stimulus in the opposite hemifield (Gandhi et al., 1999).
- Human fMRI studies have further shown that sustained visual attention decreases blood oxygenation level-dependent (BOLD) signal in unattended regions surrounding the attended location (Smith et al., 2000; Silver et al., 2007).
- In macaque cortical area V1, presentation of a visual stimulus causes a positive BOLD response in portions of V1 that retinotopically represent the stimulus location and a negative BOLD response in surrounding cortex. This negative BOLD response is correlated with decreases in multiunit activity and local field potentials relative to baseline levels (Shmuel et al., 2006)

## Purpose:

To determine the effects of sustained visual attention on stimulus-evoked positive and negative BOLD responses in early visual cortex.

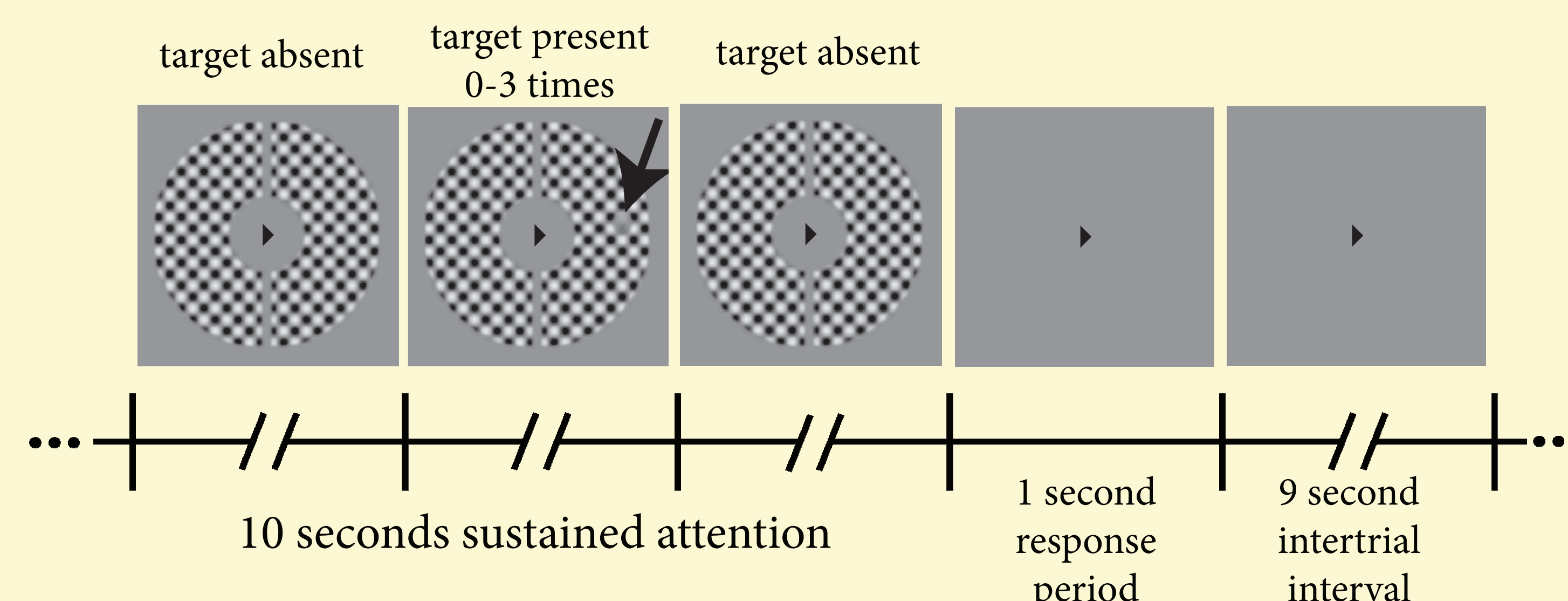
## Methods

### Subjects / Retinotopy

- Four healthy human volunteers participated in two fMRI sessions each
- The boundaries of V1, V2, and V3 were defined in independent fMRI sessions for each subject, using standard phase-encoded retinotopic mapping techniques

### Sustained Attention Task

- Subjects viewed 10 seconds of a contrast-reversing checkerboard annulus (with diameter subtending 3-9 degrees of visual angle) in block alternation with 10 seconds of a blank screen (uniform gray except for the fixation point):



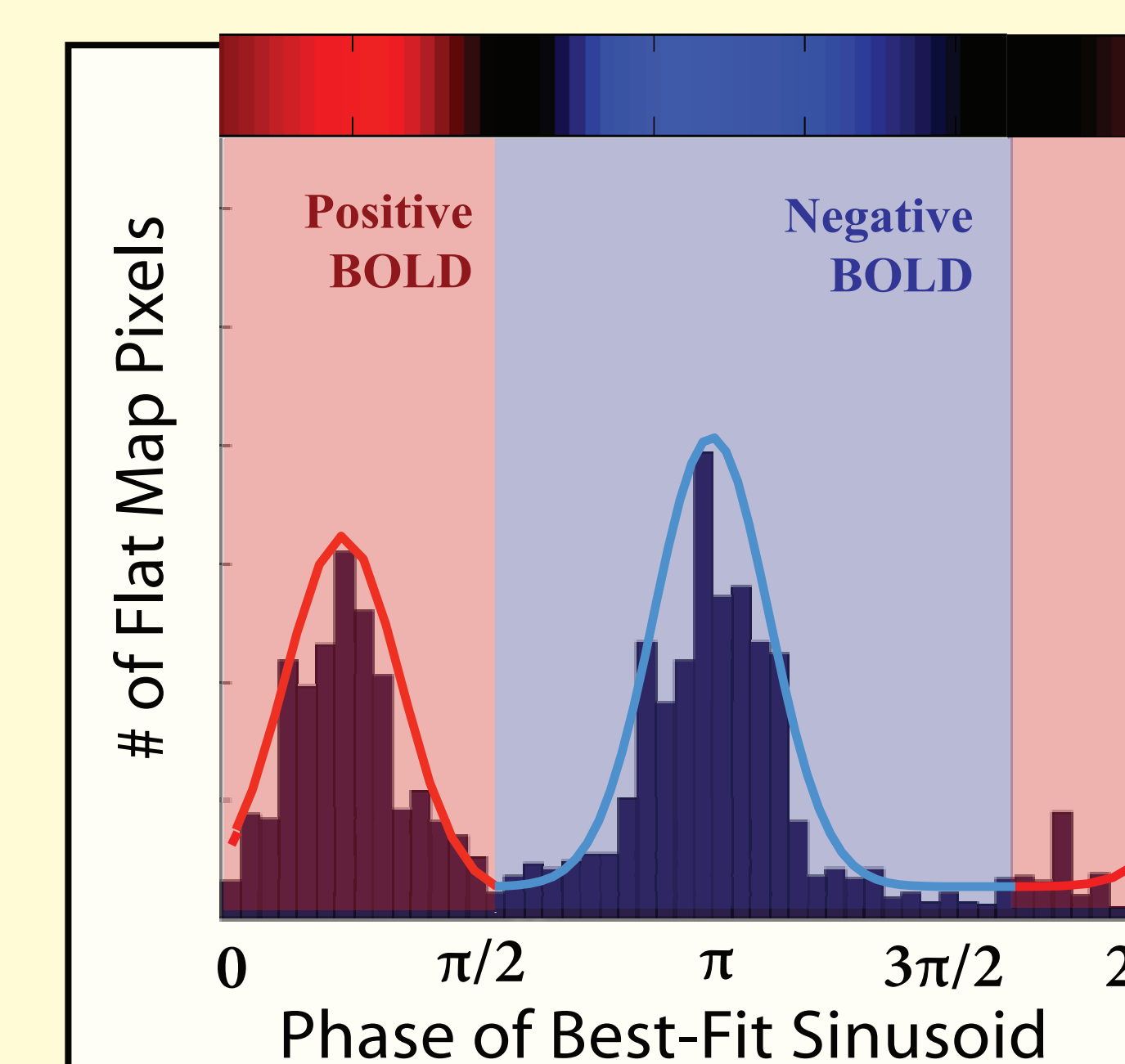
- Subjects were instructed to continuously maintain fixation and were cued at the start of each run to either passively view the stimulus annulus or to covertly attend to its left or right half while performing a target (contrast decrement) detection task.
- On sustained attention trials, targets occurred at random times and locations within the annulus, thereby requiring subjects to maintain attention over the entire cued hemiannulus for the full duration of each stimulus presentation.

## fMRI Analysis

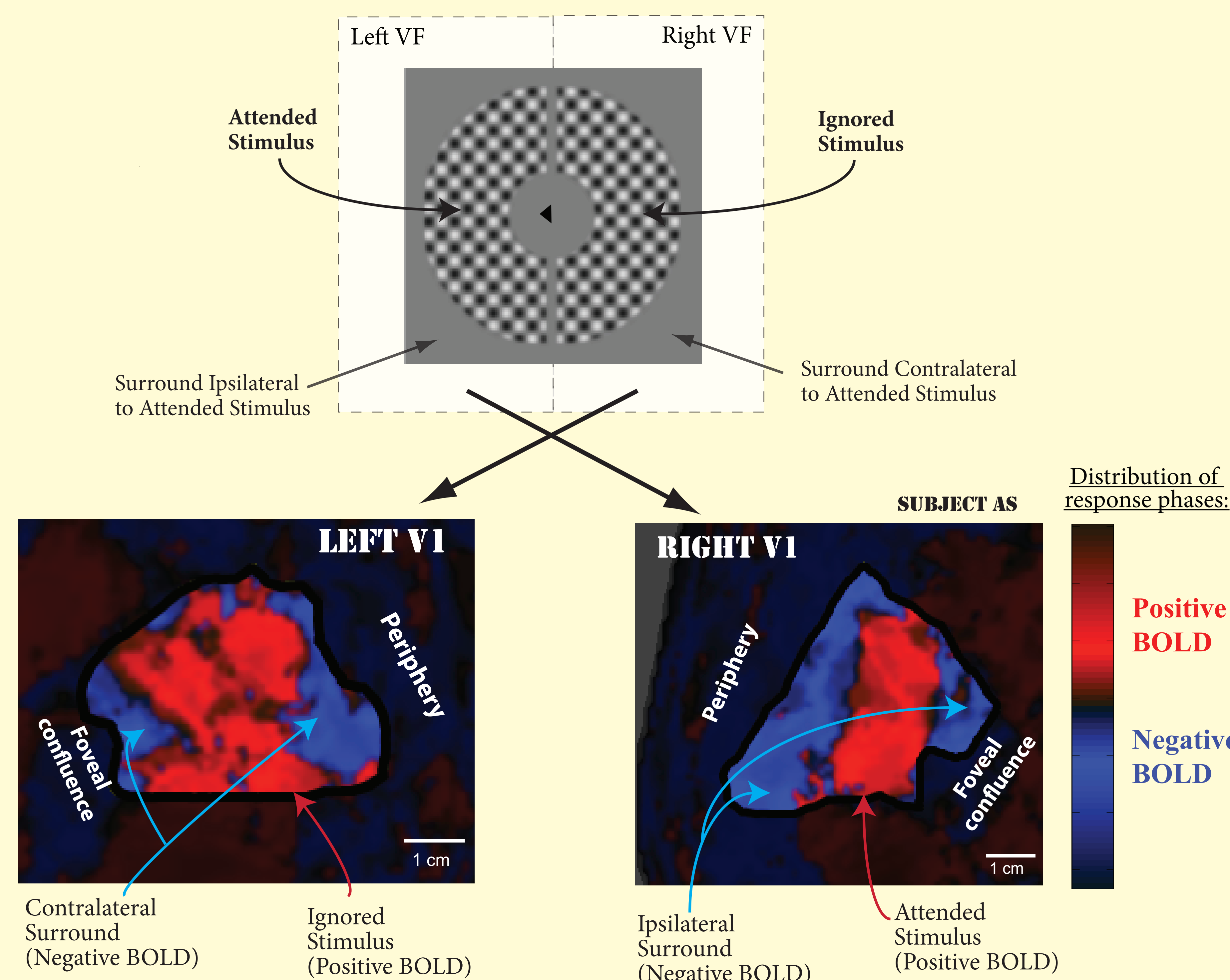
A 0.05 Hz sinusoid (same frequency as the stimulus block alternation) was fit to the fMRI time series for each flat map pixel within early visual cortex, and a phase was assigned to each pixel, corresponding to the temporal delay of the response relative to stimulus presentation.

The spatial distribution of response phases was displayed on flat maps of visual cortex. These response phases had a bimodal distribution, with one mode corresponding to positive BOLD responses to the stimulus and the other corresponding to negative BOLD responses.

The positive and negative BOLD phase windows were modeled independently for each run within each early visual area. Mean BOLD amplitude was calculated for the pixels within each phase window (example shown on right).



Pixels with positive BOLD responses were clustered within V1 with retinotopic boundaries corresponding to the inner and outer edges of the stimulus. This band of positive responses in V1 was flanked on either side by regions of negative BOLD (see below):



## References:

Gandhi SP, Heeger DJ, Boynton GM (1999). Spatial attention affects brain activity in human primary visual cortex. *Proc Natl Acad Sci* 96: 3314-19

Shmuel A, Augath M, Oeltermann A, Logothetis NK. (2006). Negative functional MRI response correlates with decreases in neuronal activity in monkey visual area V1. *Nat Neurosci* 9: 569-77.

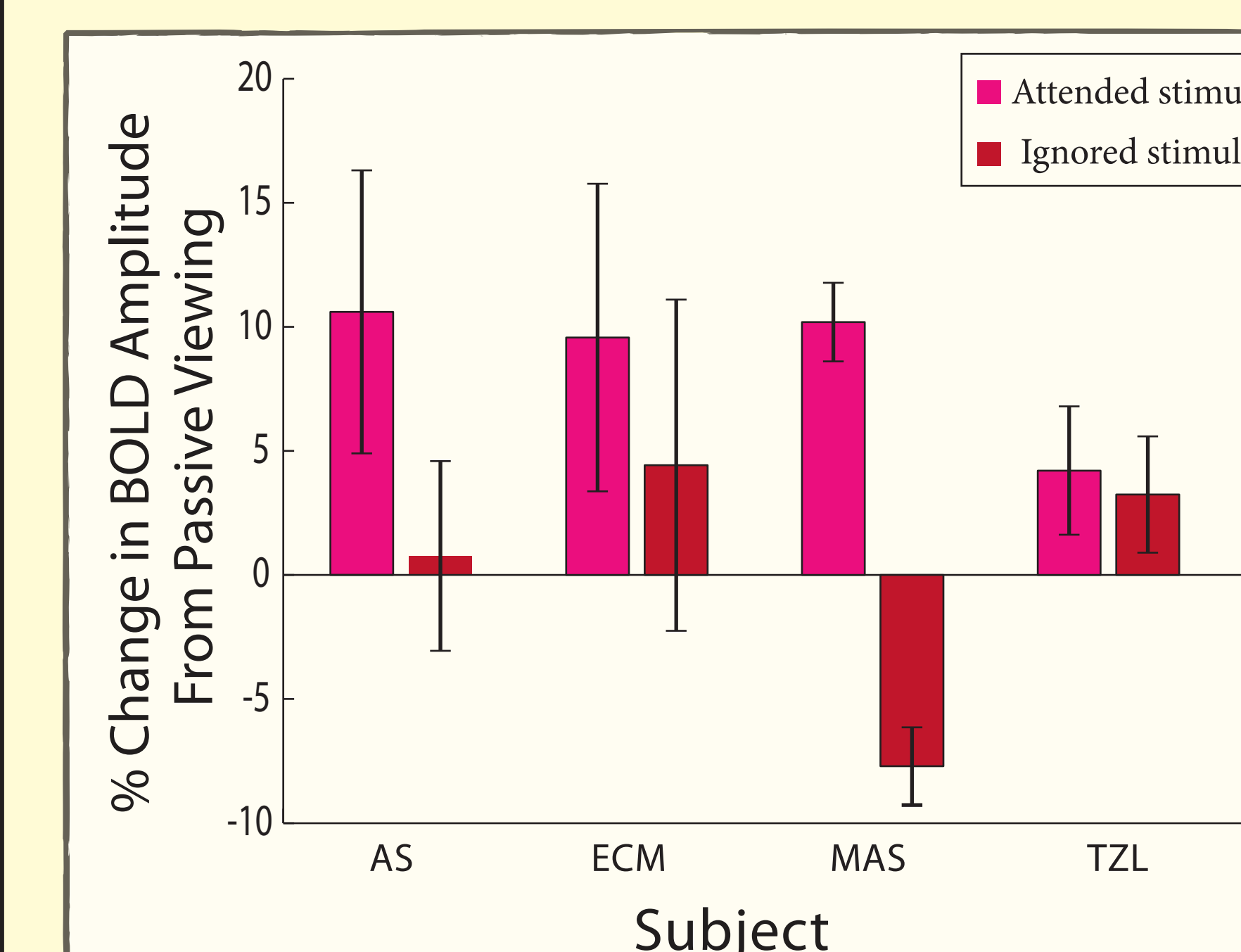
Silver MA, Ress D, Heeger DJ (2007). Neural correlates of sustained spatial attention in human early visual cortex. *J Neurophysiol* 97(1):229-37.

Smith AT, Singh KD, Greenlee MW (2000). Attentional suppression of activity in the human visual cortex. *Neuroreport* 11(2):271-7.

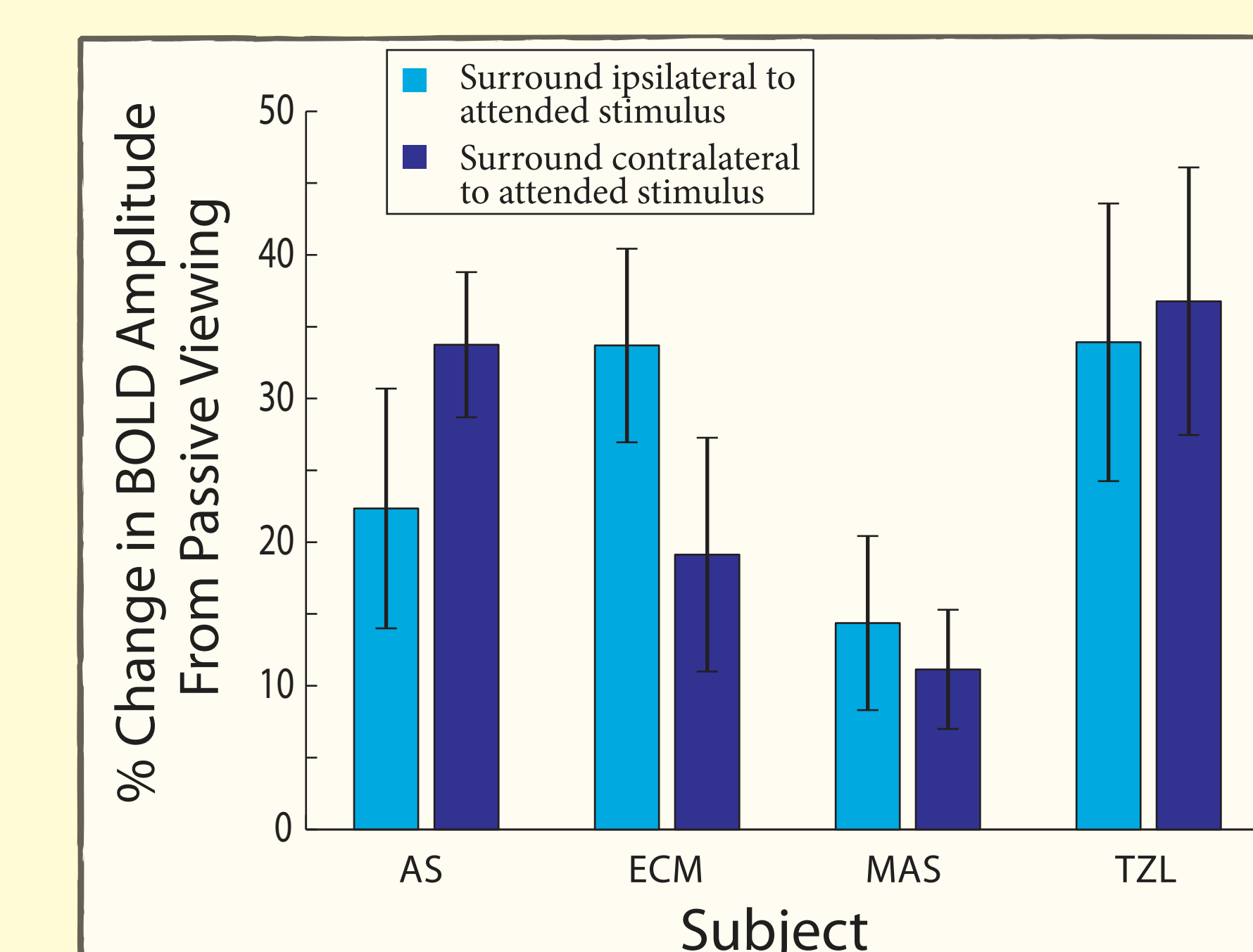
## Individual Results

### Cortical Area V1:

Attention Increased Amplitude of Positive BOLD Response

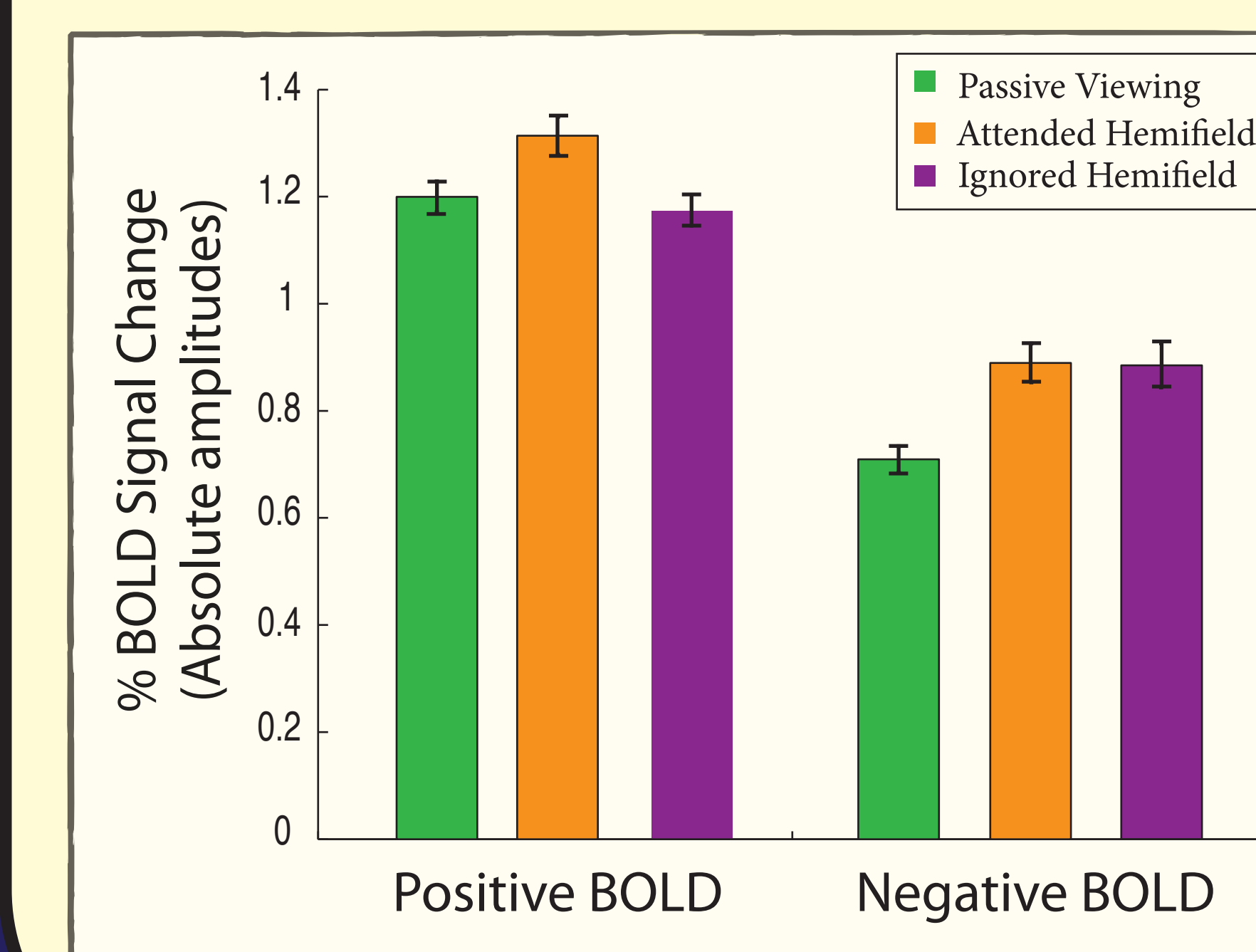


Attention Increased Amplitude of Negative BOLD Inhibitory Surround Response

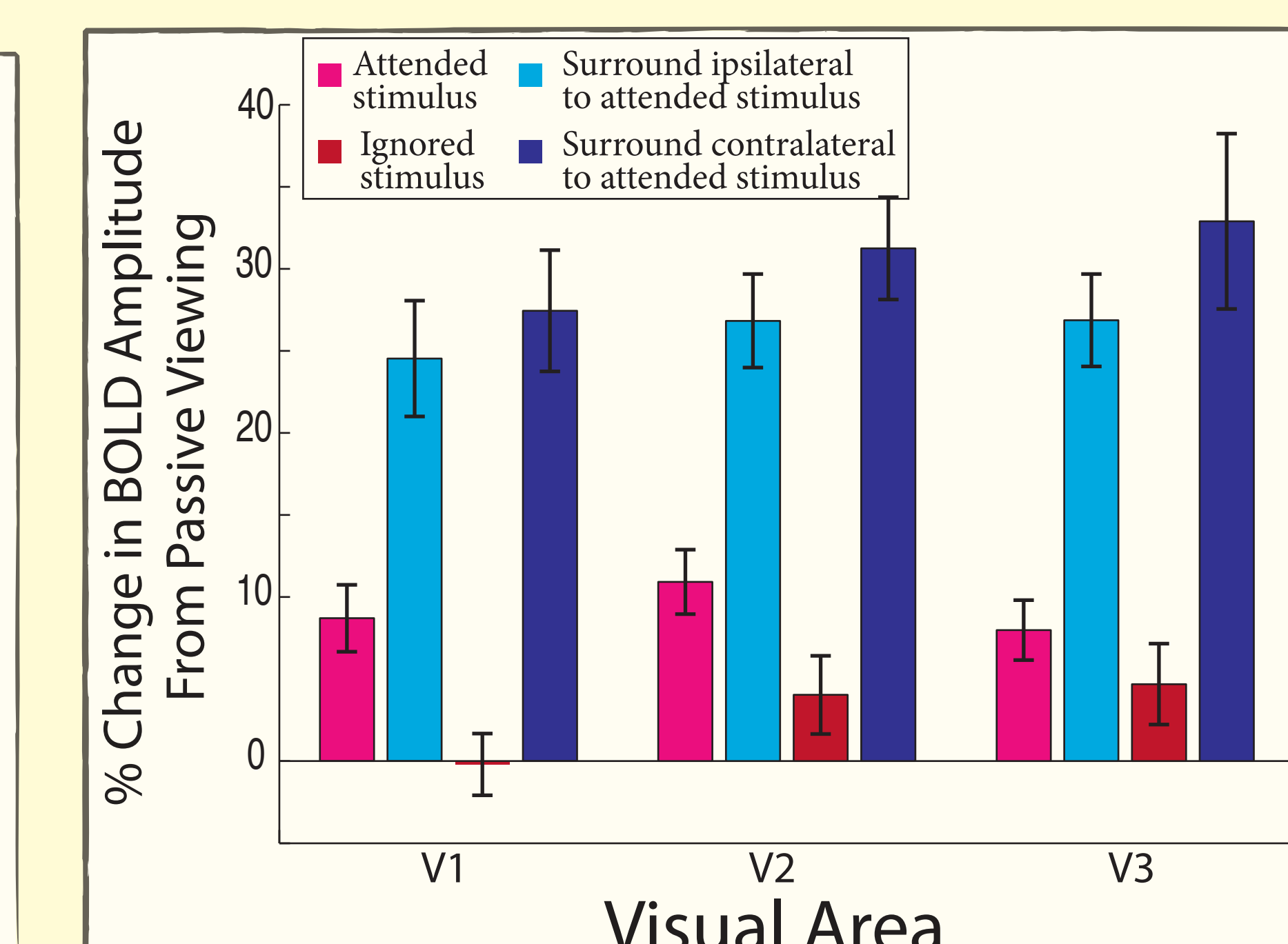


## Group Results

Relative to passive viewing, attention to a hemiannulus increased both V1 positive BOLD responses at the attended locations and negative BOLD responses in unstimulated visual field locations in both hemifields.



Attentional modulation of negative BOLD responses was substantially greater than attentional modulation of positive BOLD responses. This was true for all early visual areas.



## Conclusions:

1. Sustained attention increased the amplitudes of positive BOLD responses for attended stimuli and negative BOLD (inhibitory) responses for unattended regions surrounding the stimulus.
2. In all early visual areas, the **attention-related increase in negative BOLD amplitude for stimulus surround was substantially larger** than the increase in positive BOLD responses.
3. Together, these results demonstrate significant attentional modulation of fMRI signal in unstimulated visual cortex adjacent to an attended stimulus. **This suggests that one function of attention is to reduce activity at unattended locations, which may be related to suppression of distractors outside the locus of attention.**