Crowding alters the spatial distribution of attention modulation in human primary visual cortex

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Crowding effect is the visibility reduction of a target when presented with neighboring distractors. It has been explained by either lateral inhibition at a pre-attentive level or coarse spatial resolution of attention. To test these theories, high-resolution fMRI was used to measure V1 response to the target in the presence or the absence of the distractors in both attended and unattended conditions. We found the cortical response to the target was not affected by the presence of distractors in the unattended condition. However, the spatial distribution of attention modulation in the target and its surrounding area depended on the crowding configuration. When distractors were placed in the same radial axis as the target, a configuration with a severe crowding effect, significant attention enhancements were observed not only in the target's and the distractors' locations, but also in regions next to the target where even no stimulus was presented. But this spread of attention enhancement did not occur when distractors were placed in the same circumference as the target, a configuration with a weak crowding effect. The pattern of interaction between attention and target-distractor configuration supports that crowding results from coarse spatial resolution of attention.

Keywords: attention, contrast, crowding, fMRI, vision, V1

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Introduction

(F 1A). (B 1970; , H , & , 1991) (C , B , & M , 2002; L & L , 1997). (L , K , & A , 1985; & E , 1986), (& , 1988), (, & M K , 1976), (, & E , 1997), (, & M , 2004), (L , B , & , 2007; M , M , & , 2005). O (B , L , & , 1979; L , K , & , 1987) (., 2004). (& , 1973; & C , 1983) (H , C , & I , 1996, 1997; I & C , 2001) (, 2005; ., 1991). C (B 1970; & B , 1962). H M I: (1) H ( )? (2) H ?

Methods

Participants

A (3 4 M I

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. A 23 34.

MRI data acquisition

MRI data processing and analysis

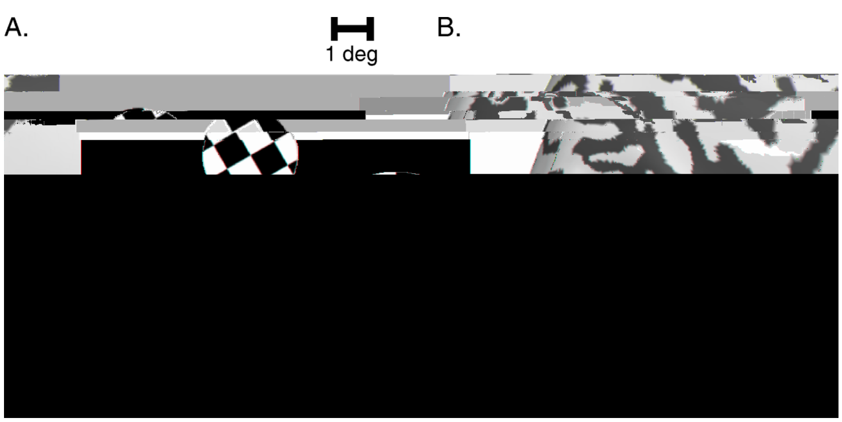

Figure 2. Regions of interest. (A) Five flickering round checkered patches with a full contrast were used to define the ROIs (central, upper, lower, left and right). They occupied the same spatial extents as the target and the distractors. (B) Cortical activations by the five patches are depicted in a representative inflated brain. The red, green, blue, yellow, and light blue areas correspond to the left, central, right, lower, and upper ROIs, respectively. V1 is defined by retinotopic mapping and its boundaries are indicated by the white dashed lines.

(., 1999) B 2000. H M I 1.5

AC- C 14 BOLD

A GLM ( ). OI OI 1 ($p < 10^{-4}$,) 1/ 2 E OI OI BOLD OI F M I M OI 20- OI 6- 20- A BOLD BOLD OI .

Eye movement recording

E. 60 H A L (A L , B , M) 3 ED (M I G H, G)

Results

(F 3A) ($t = 17.962$, $p < 0.001$),

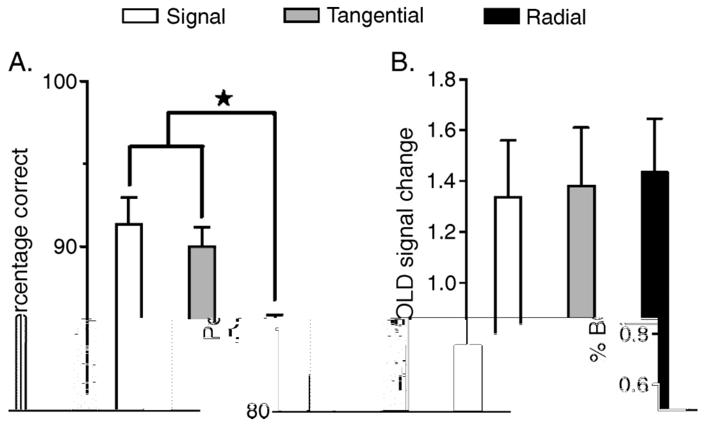

Figure 3. Behavioral and cortical responses to the target in the single, tangential and radial configurations. (A) Performance in the contrast discrimination task. (B) BOLD responses to the target with the luminance discrimination task at the fixation point. Error bars denote 1 *SEM* calculated across subjects.

. A (& L , 1992). F M I , BOLD (± *SEM*: 0.83 ± 0.03). (, ,) (F 3B).

F 4 BOLD OI A BOLD . A ($t > 3.738$ $p < 0.02$) (F 5A). H . I . F BOLD OI ($t = 4.347$, $p = 0.012$) OI ($t = 1.828$, $p = 0.142$). H , OI , OI.

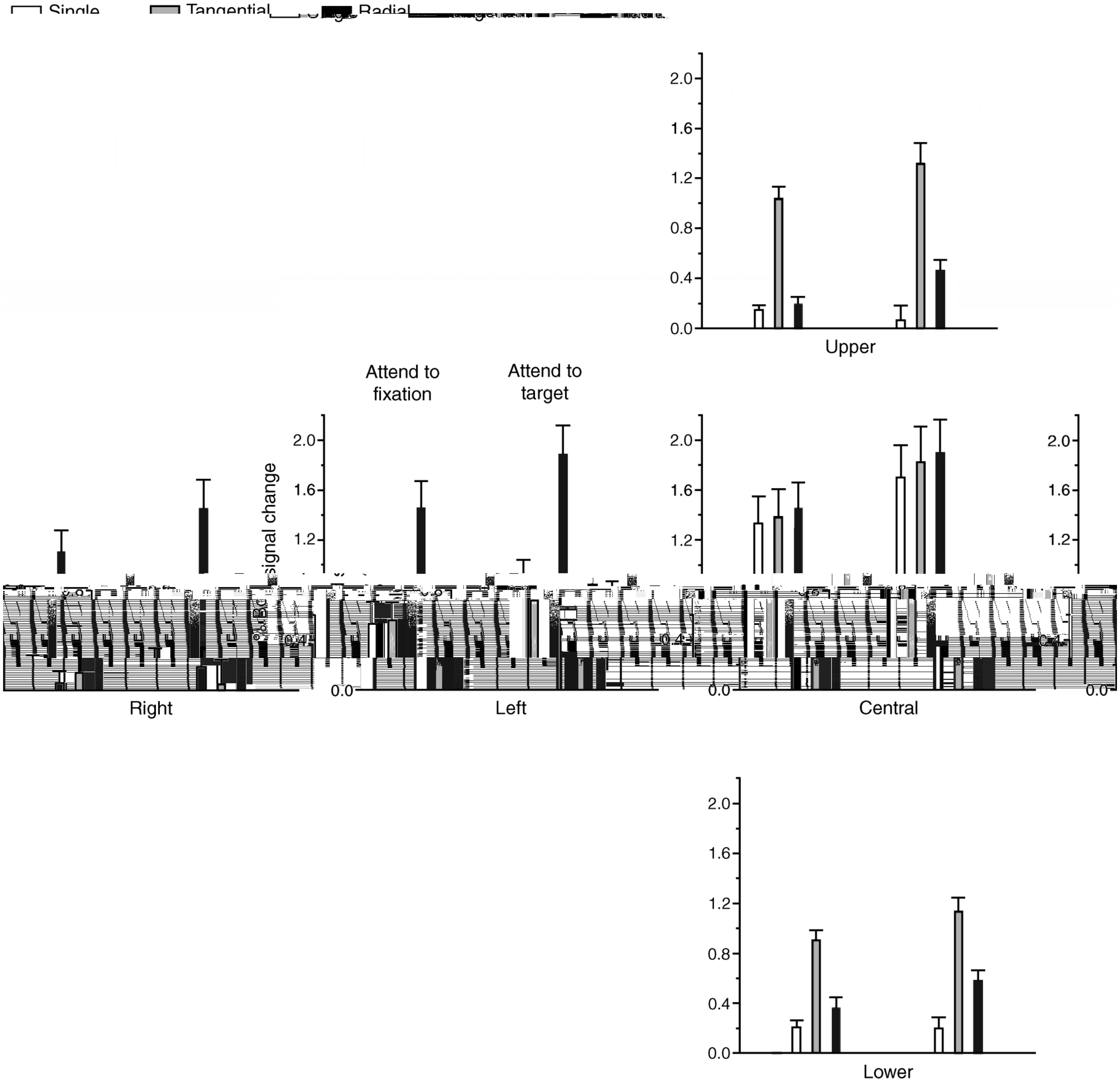

Figure 4. BOLD signals in the left, right, upper, lower, and central ROIs in the single, tangential, and radial configurations when subject attended to either the fixation (left part of a panel) or the target (right part of a panel). Error bars denote 1 *SEM* calculated across subjects.

(C & , 2002). I OI C (t = 3.118, p = 0.036) (t = 3.623, p = 0.022) OI, OI (F 5A,). O

(t = 3.64, p = 0.022) (t = 3.863, p = 0.018) OI (F 5A,). (F 4B). E. F 6 M I j

($t < 2$ $p > 0.12$).

Discussion

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BOLD

(-L & H , 2003).

H

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j M I (. ., -

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C , j (2006)

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