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Spatial Facilitation Predicted with End-stopped Spatial Filters

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We examined the role of putative end-stopped spatial filters in determining spatial facilitation associated with a line target flanked by square inducers. Results obtained in normal and amblyopic observers were well predicted by end-stopping and other receptive field features of end-stopped spatial filters revealed in a modified Westheimer paradigm. The role of target–inducer collinearity, the effects of inducer polarity, and facilitation associated with non-orientational circular targets, were also studied. Our results suggest that spatial facilitation results from antagonism surrounding spatial filter centers, with end-stopping playing a prominent role. © 1997 Elsevier Science Ltd

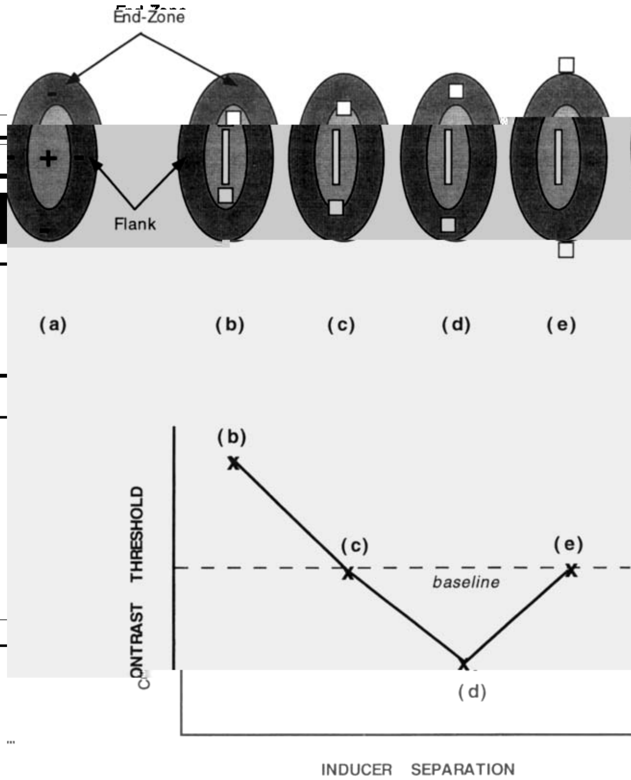
Spatial facilitation End-stopping Spatial filter Inducing paradigm Westheimer paradigm

INTRODUCTION

Several recent studies show that the contrast sensitivity to a target object can be increased by nearby spatially separated inducing objects (Dresp, 1993; Kapadia *et al.*, 1995; Morgan & Dresp, 1995; Polat & Sagi, 1993, 1994). Polat and Sagi (1993, 1994) reported that the contrast threshold for a foveal Gabor patch was first elevated (suppression), then reduced (facilitation), by two collinear inducing Gabor patches with increasing target– [redacted]

and 9′ at the largest λ (18′), the target and inducers at this separation were actually somewhat overlapped. Thus, it is uncertain that long-range interactions from spatially non-overlapped filters play an important role in spatial facilitation. Instead, spatial interactions within spatial filters may need to be considered.

Facilitation has also been obtained for a spot (Dresp, 1993) or line target (Kapadia *et al.*, 1995) placed near the end of an inducing line. Facilitation diminished when the [redacted]



suggesting central width summation and antagonistic flank inhibition. Length and width functions together revealed end-stopped perceptive fields or spatial filters

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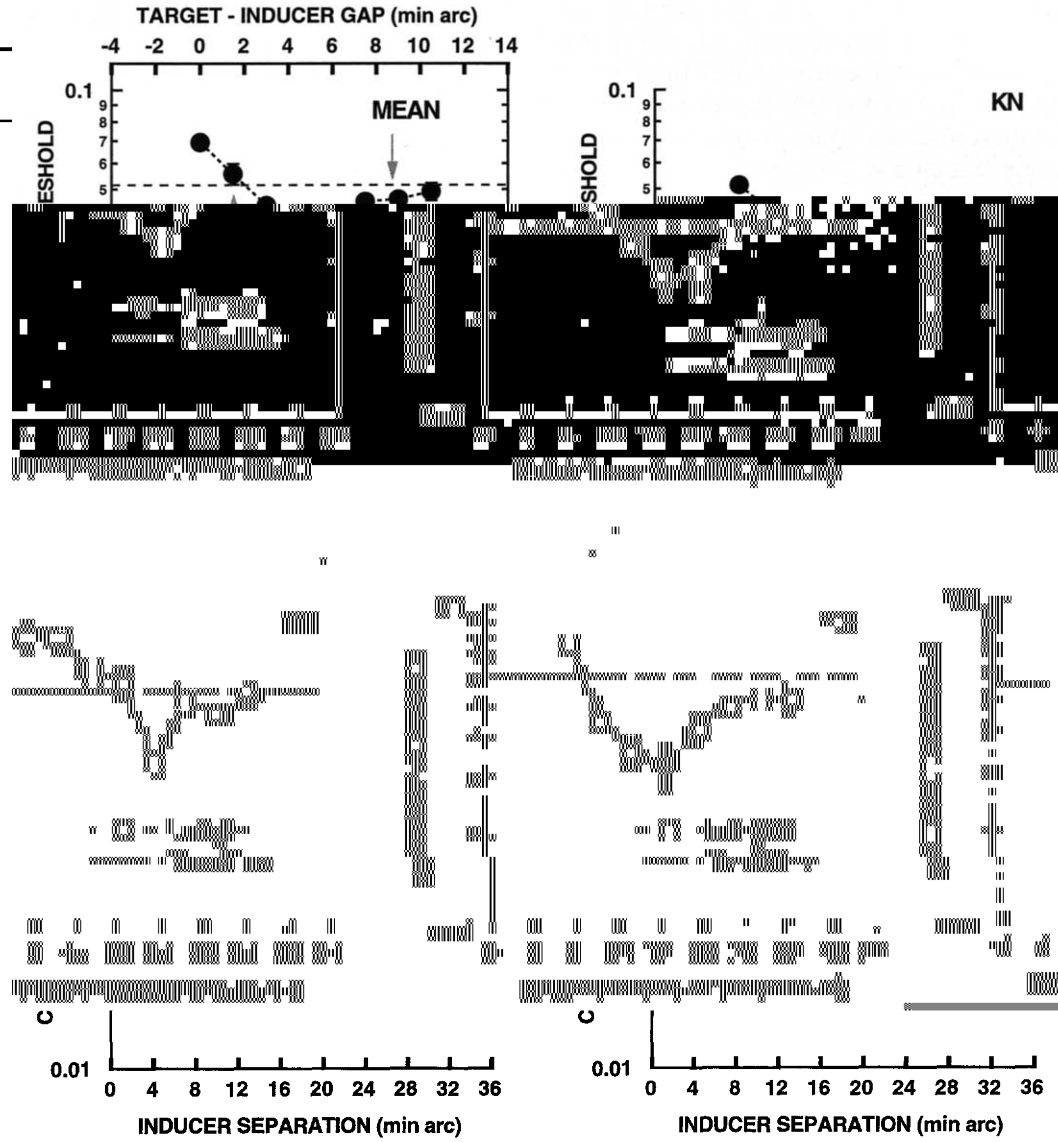
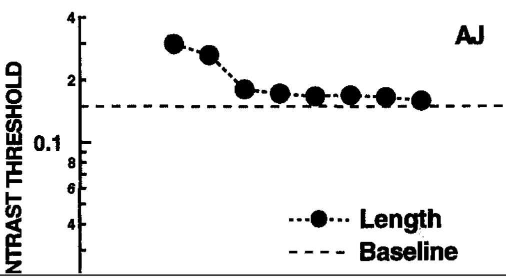


FIGURE 3. Contrast threshold for a $1' \times 5'$ line as a function of the center-to-center separation between two inducers placed end-to-end with the line target. The corresponding gap distance between target and inducer is also presented in the mean figure (top, x-axis). The arrows in the mean figure indicate predicted start and end of spatial facilitation.

EXPERIMENT 1: THE ROLE OF END-STOPPING IN SPATIAL FACILITATION

For a $1' \times 5'$ line, thresholds in the length Westheimer function reached a peak at a background length of $11'$, which then decreased until reaching a plateau at a background length of about $23'$ (Yu & Essock, 1996a). These data have been taken to suggest an $11'$ long

We conducted such an experiment on three normal observers to examine the above prediction. Contrast thresholds were measured for a $1' \times 5'$ line with two $3' \times 3'$ square inducers separated from $8'$ to $29'$ (center-to-center distance between two inducers, or $0'$ to $12'$ gap distance between the line end and the inner edge of the inducer). Results are shown in Fig. 3. Although individual in the macaque ranged from 6′ to 181′. In terms of the gap distance between the target end and inducer end, spatial facilitation starts to occur at a gap distance of 2.5′, and ends at a gap distance of 10.5′. The latter matches Dresp's (1993) report that facilitation disappeared at a gap distance of 10′–13′. Note too that it is well within the range of Polat and Sagi's facilitation effects observed with Gabor patches. Thus, it appears that end-stopping may be sufficient to account for spatial facilitation



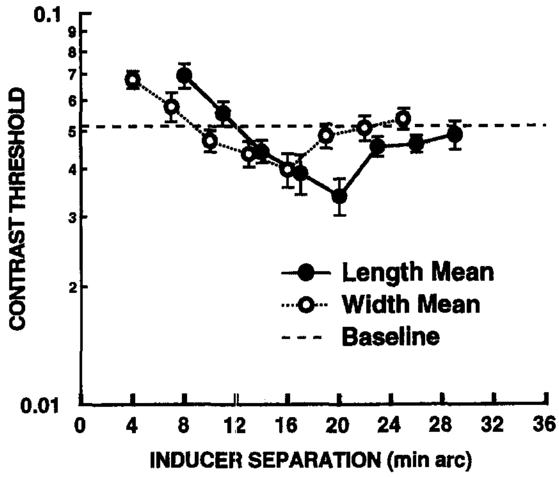
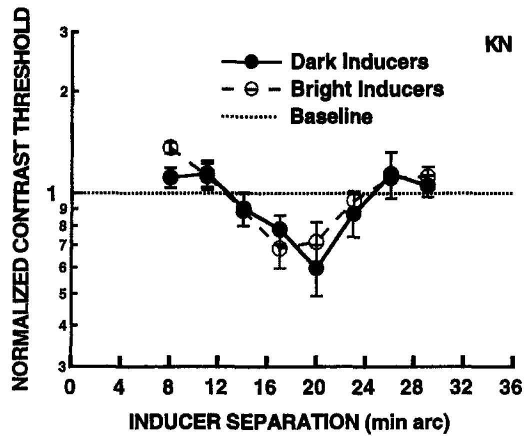
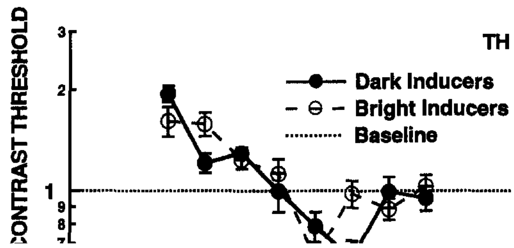


FIGURE 6. A comparison of spatial interaction effects between end-to-end inducing (collinear) and side-by-side inducing (non-collinear).





facilitation effect on the detection of a dot target, implying that spatial facilitation is specific to information from ON or OFF channels. This result provided evidence for the pedestal model, which is based on linear spatial

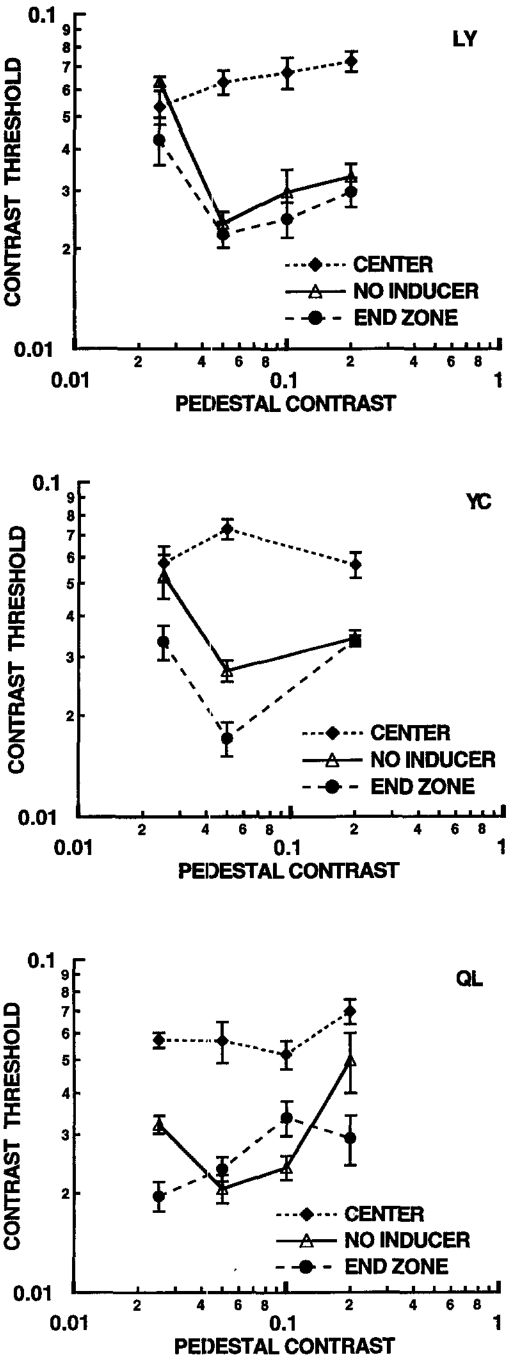


FIGURE 9. Inducing effects measured when the target was superimposed on a same-sized pedestal at near-threshold contrast (5%) and at supra-threshold contrast (20%). Inducers were placed either within [illegible]

contrasts, respectively. Slight facilitation at both pedestal contrasts is shown for LY. And no effect is found for YC at the 20% pedestal contrast (the 10% pedestal contrast was not measured). This large individual difference among three observers, as well as between our study and Morgan and Dresp's study, may be attributed to the complex nature of interactions between the supra-threshold inducer and supra-threshold pedestal, in a way similar to the interactions between supra-threshold center and surround patches studied by Cannon and Fullenkamp (1993), who found that the contrast induction of the surround patch to the center patch could be either suppressive or facilitatory for different observers. Therefore, if the apparent contrast of the supra-threshold pedestal in the current experiments is either reduced or enhanced for a particular observer, rather than a purely additive effect, it is unlikely that any simple lateral shift would superimpose the end-zone inducer function and the no-inducer function.

GENERAL DISCUSSION

The present results favor our hypothesis that spatial facilitation mainly results from surround antagonism in end-stopped spatial filters. The latter may increase the gain of the spatial filter through subtractive interactions with divisive suppression caused by pooled inputs from other filters. In most cases where inducers are collinear with the target, it is end-stopping which plays a central role. These results do not require the involvement of long-range interactions from spatially non-overlapped channels or filters, nor do they support a simple pedestal effect explanation of spatial facilitation.

The key assumption in this paper is that surround antagonism activated by inducers reduces suppression in the spatial filter through subtractive interactions with divisive signals. In other words, when the spatial filter surround is stimulated, it facilitates sensitivity by disinhibiting the suppressive effects on the spatial filter. Neurophysiologically, sensitivity facilitation by activating the receptive field surround has been reported when the receptive field center is concurrently activated (Jones, 1970; Maffei & Fiorentini, 1976; Nelson & Frost, 1985; Gilbert & Wiesel, 1990; Toth *et al.*, 1996). For example, Maffei and Fiorentini (1976) reported facilitation in simple and complex cells in area 17 of the cat cortex