Spatial Vision, Vol. 19, No. 1, pp. 77–102 (2006)

Also available online - www.vsppub.com

Synergy of features enables detection of texture defined figures

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Received 11 April 2005; accepted 1 September 2005

Abstract—Traditional theories of early visual processing suggest that elementary visual features are handled in parallel by independent neural pathways. We studied the interaction of orientation and spatial frequency in the discrimination of Gabor random fields. Target textures differed from reference textures either in mean feature value, showing an edge-like transition between both textures (edge defined), or in the degree of feature homogeneity with smooth transitions (region defined). Irrespective of the kind of texture definition, we found strong cue summation for targets defined by both cues simultaneously, provided two conditions were fulfilled. First, they were barely discriminable when defined by one cue alone. Second, the target elements formed a closed 2D surface. Only marginal cue summation was observed when target elements were heterogeneously distributed in a predefined area, lacking a clear 2D shape. Our findings indicate that feature synergy enables figure-ground segregation when the information from independent feature-specific pathways is insufficient for solving this task.

Keywords: Feature synergy; independence; cue summation.

1. INTRODUCTION

Traditional theories claim that elementary visual features are handled in parallel by independent modules at the level of early vision (Treisman and Gelade, 1980; Treisman, 1988; Landy and Bergen, 1991). The question whether early feature specific pathways are independent or interact has raised much interest and provoked controversial discussion in the last two decades (Treisman and Sato, 1990; Wolfe *et al.*, 1989; Wolfe, 1994; Wilson and Wilkinson, 1997). Polat and Sagi have shown with electrophysiological (Polat *et al.*, 1998) and psychophysical methods (Polat and Sagi, 1993, 1994) that there are lateral interconnections between nearby but non-overlapping elementary feature detectors which modulate interactions across

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space and feature dimensions. These findings, which are in line with the observation that the responses evoked by local stimuli can be modulated by stimulation of a larger surround area beyond a cell's classic receptive field (Gilbert and Wiesel, 1990; Pettet and Gilbert, 1992; Knierim and van Essen, 1992; Kapadia *et al.*, 1999), led to the conclusion that different forms of interaction among early visual pathways exist, and that independence is just a particular case (Phillips and Singer, 1997; Gilbert *et al.*, 1996; Tononi *et al.*, 1992).

Measuring the performance improvement for targets that vary from the surround in more than one feature dimension is apt to reveal how feature dimensions interact. If more than one cue is available for solving a particular visual task, performance can be expected to increase since different cues can be integrated at least in an inclusive-or fashion. This mechanism, known as probability summation among independent pathways, has widely been studied in the context of multiple channel models (see Graham, 1989, for overview). However, if performance with more than one cue is better than expected from the assumption of independent processing of each individual cue, then this indicates that there is cooperation of feature specific modules in the task, which may be referred to as 'feature synergy' (Kubovy *et al.*, 1999; Kubovy and Cohen, 2001; see Methods).

While schemes of interaction across space appear to be well studied (Polat *et al.*, 1998; Polat and Sagi, 1993, 1994; Levi *et al.*, 1997; Saarinen *et al.*, 1997; Adini *et al.*, 1997; Wilson and Wilkinson, 1997), results are rather ambiguous for the interaction across feature dimensions. Some studies report improvement in detection, discrimination, localization or search performance when two or more features coincide at one location (Beck, 1967; Farell, 1984; Callaghan, 1984, 1989; Callaghan *et al.*, 1986; Caelli and Moraglia, 1985; Frome *et al.*, 1981; Nothdurft, 1993, 2000; Abele and Fahle, 1995; Kubovy *et al.*, 1999; Kubovy and Cohen, 2001; Rivest and Cavanagh, 1996; Bach *et al.*, 2000), but only in some studies was the performance advantage resulting from interaction in feature processing explicitly and successfully tested against the performance that is expected from independent neural pathways (Caelli and Moraglia, 1985; Kubovy *et al.*, 1999; Abele and Fahle, 1995). Further, there are also studies that report no or minor improvement with multiple coincident cues (Pashler, 1988; Gray and Regan, 1997; Phillips and Craven, 2000; Phillips, 2001). These rather inconsistent findings suggest that there must be side conditions for synergy and independence in feature processing which have not been revealed yet.

Some years ago Lamme and his colleagues (Lamme, 1995; Zipser *et al.*, 1996) have shown that object presence modulates processing of feature contrast at early levels. Responses of V1 cells to the same textured stimuli are enhanced when their receptive fields are within a region which perceptually appears as a texture figure relative to the surround, compared to a stimulus pattern in which the whole area of stimulation is covered by a homogeneous texture. Corresponding to these results, Zhou *et al.* (2000) found that responses of cells sensitive to luminance borders are modulated by the side of a figure to which the border belongs ('border