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Psychophysical and electrophysiological evidence of independent facilitation by collinearity and similarity in texture grouping and segmentation

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ABSTRACT

Gestalt factors of collinearity and similarity facilitate two fundamental perceptual tasks: grouping elements into figures and segmentation of figures from the ground.

We have used a global–local paradigm to examine the psychophysical and neural correlates of these processes in humans: observers discriminated between orientations of either a three-Gabor group (grouping), or of a central Gabor within the group (segmentation). Groups were centered on a background of differently oriented Gabors. In both tasks, accuracy was increased by the collinearity (Experiment 1) and similarity (Experiment 2) of elements within the three-Gabor group. ERP correlates of facilitation differed across tasks. For segmentation, they were indexed by increased amplitude of negative ERP components, specific for processing textures, peaking at 75–250 and 150–250 ms, respectively. For grouping, collinearity and similarity had different effects. Collinearity produced a positive polarity deflection between 40 and 179 ms (i.e. the opposite to segmentation). This task-dependent switch in sign of polarity change, without corresponding changes in the stimulus or perception, reflects distinct neural mechanisms for collinear facilitation in grouping and segmentation. In contrast, similarity reduced positivity at 275 ms. Results show similar modulation of segmentation components via the distinct mechanism underlying collinearity and similarity, but distinct modulation of grouping components via collinearity and similarity.

1. Introduction

Two visual tasks are important for survival: deciding which fragmented contours forming the retinal image belong to one same object, and segmenting the contour of a given object from the surround. For these visual operations, grouping and segmentation of contour elements the geometrical relationships between contour segments are extremely important. Gestalt psychologists (Wertheimer, 1923) provided phenomenological demonstrations of the laws of perceptual grouping and figure-ground segmentation and their work has been an important source of inspiration for later psychological and neurophysiological experiments that unveiled the mechanisms underlying grouping and segmentation. Using multistable dot patterns that can be perceptually organized into alternative collections of parallel strips of dots, the law of grouping by proximity has been extensively studied both in isolation (Kubovy, Holcombe, & Wagemans, 1998; Kubovy & Wagemans, 1995) and in its interactions with other grouping factors: similarity and alignment (Claessens & Wagemans, 2005; Kubovy & van den Berg, 2008).

In the present study we focused on similarity and alignment. With stimuli made up of line segments or oriented Gabors, similarity and alignment can be respectively manipulated by varying orientation and collinearity (alignment of elements along the orientation axes). Psychophysical studies showed that collinearity and similarity determine contrast detection enhancement (Polat, 1999; Polat & Sagi, 1994) and modulate both grouping of elements into contour (Field, Hayes, & Hess, 1993) and texture segmentation (Giora & Casco, 2007; Nothdurft, 1992; Polat & Bonneh, 2000).

These configurational effects based on orientation similarity and collinearity may result from modulation of the response in V1 to stimuli presented within the receptive field (RF) by stimuli outside the RF (Kapadia, Ito, Gilbert, & Westheimer, 1995; Polat, Mizobe, Pettet, Kasamatsu, & Norcia, 1998). This modulation can be facilitatory, based on short- and long-range horizontal connections, or suppressive, based on short-range interactions (Adini, Sagi, & Tsodyks, 1997; Lamme, 2003; Mizobe, Polat, Pettet, & Kasamatsu, 2001; Polat & Bonneh, 2000).

With a high contrast target and extended background, these "contextual influences" are facilitatory when the elements outside the RF are collinear to and iso-oriented with those inside (Kapadia et al., 1995), and this could account for facilitation by collinearity and similarity in perceptual grouping with consequent increased

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saliency of the group (Field et al., 1993; Hess & Field, 1999; Li, Piech, & Gilbert, 2006). With iso-oriented but non-collinear flanks, an inhibition of the target is observed (Kastner, Nothdurft, & Pigarev, 1997; Knierim & van Essen, 1992), and reduction of this background-to-target surround suppression due to orientation contrast may be the neural correlate of local texture segmentation.

In the present study we asked whether collinearity and similarity between target elements modulate not only the efficiency with which they group together but also the efficiency with which they segment from a background of differently oriented elements (45° orientation contrast). In order to answer this question, performance in grouping and segmentation was compared within each experiment to find out whether these two tasks were differently affected (facilitated or interfered) by the congruency of either global and local orientation (Experiment 1) or of local orientations of target elements (Experiment 2). The prediction was that collinearity and similarity may improve the efficiency of these two tasks through involvement of different mechanisms: they may facilitate grouping operations (Field & Hayes, 2003; Field et al., 1993; Hess & Field, 1999), and this can increase group saliency per se, but they can also increase the efficiency of a second operation, the reduction of surround suppression leading to segmentation (see Polat & Bonneh, 2000 for a similar question in contrast detection), and this also results in increased saliency. In other words, we predicted that not only grouping based on facilitatory interactions but also segmentation of target elements from the background – which is based on surround suppression reduction – may be facilitated by target element collinearity and similarity. Although the facilitation may be similar the neural correlates in humans may be different. To test this hypothesis we combined the psychophysical and ERP measurements while observers viewed a texture of Gabors all iso-oriented except for a three-Gabor group and were asked to perform a segmentation either of the central Gabor in the group (local segmentation task) or of the whole group (grouping task), this second task involving both segmentation from background and grouping within the target.

Facilitatory and inhibitory contextual influences may occur in the target and, to a lesser extent, in the uniform texture background. Use of a uniform texture allowed us to determine how target grouping and segmentation resulted from a modulation of facilitatory and inhibitory contextual influences in the target with respect to the background region.

2. Materials and methods

2.1. Stimuli

Stimuli were generated using a Pentium IV computer and displayed on a 17-in. Sonic P70 monitor driven by a NVIDIA GeForce4 MX graphics card, with a resolution of 1024 × 768 pixels, refreshed at 100 Hz. Stimuli were presented in a darkened room at 57 cm viewing distance.

The texture stimuli consisted of 9 × 9 matrices of circular cosine-phase Gabor-elements (the product of a sinusoidal grating and a Gaussian blob all oriented at 45° (in half of the trials) or 135° (in the other half) except for the three-Gabors displayed foveally at the center of the matrix to form a three-Gabor group (either horizontal or vertical). They had an orientation of either 90° or 180°, to form the configuration most suitable to investigate facilitatory and inhibitory lateral interactions (Khoe, Freeman, Woldorff, & Mangun, 2004; Polat & Sagi, 1993; Polat & Sagi, 1994). The three-Gabor target was iso-oriented, either collinear (iso/collinear) or non-collinear (iso/non-collinear) in Experiment 1 – as well as non-collinear, either iso-oriented (iso/non-collinear) or ortho-oriented (ortho/non-collinear) in Experiment 2 (see Fig. 1). The uniform stimulus was always oblique, made up of either 45° (half the trials) or 135° (half the trials) oriented Gabors.

Each Gabor had spatial frequency equal to 3.2 cycles/deg, corresponding to a wavelength (λ) of .31 °, multiplied by a Gaussian envelope, with standard deviation (σ) of .19 °. Center-to-center element separation was 3.66 λ. Mean luminance of a Gabor element was equal to the luminance of background (50 cd/m^2). Orientation of the Gabor matrices of the texture mask was varied randomly from trial to trial.

2.2. Procedure

We used an experimental design in which the task was varied within-experiment but in independent blocks: in both experiments observers had to discriminate the orientation of either the three-Gabor group or the central Gabor. Each block consisted of 234 trials, comprising 78 repetitions of three conditions randomly intermixed: uniform, iso/collinear and iso/non-collinear textures, in Experiment 1, and uniform, iso/non-collinear and ortho/non-collinear textures, in Experiment 2. The two experimental blocks were preceded by 12 practice trials.

Each trial (see Fig. 2) started with a central fixation point, presented for 1000 ms on a gray background. The stimulus texture was then presented for 160 ms and replaced immediately (no interval) by the mask texture made up of randomly oriented Gabors, presented for 200 ms. Finally, the screen was turned black and the subject's response (horizontal or vertical) recorded. Following the standard psychophysical method of forced-choice, observers were asked to respond horizontal or vertical to the uniform texture without targets that produced chance response. Time limit for each response was set to 2500 ms.

2.3. Subjects

Fifteen (six males) and eight right-handed subjects (three males), aged 20–35 years, with normal or corrected-to-normal visual acuity participated in Experiments 1 and 2, respectively. All subjects were volunteers and naïve to the purposes of the experiments. Half of the subjects executed the segmentation task first; the other half performed the grouping task first.

2.4. ERP recordings

Electroencephalographic activity (EEG) was recorded continuously from 12 scalp electrodes (O1, O2, Oz, P3, P4, Pz, C3, C4, Cz, F3, F4, Fz) using sintered Ag/AgCl ring scalp electrodes and BrainCap, labeled according to the 10–20 international system. All scalp channels were referenced to the average reference. Recording was carried out at 12 electrodes because with the QuickAmp72 the unipolar electrophysiological inputs are configured as a reference amplifier. The ground electrode was positioned in front of Fz. The EEG was amplified, band-passed (0.1–40 Hz), and digitized at a sampling rate of 1000 Hz (Recorder software, QuickAmp amplifier). Scalp electrode impedance was maintained below 5 kΩ. Scalp electrooculogram (EOG) was also recorded bipolarly through four additional electrodes placed left and right of external canthi for horizontal eye movements, and above and below the right eye for blinks and vertical eye movements. All trials in which the subject made an eye movement larger than 1° were rejected.

2.5. Data analysis

Accuracy data were analyzed with repeated-measures ANOVAs both separately for each experiment, with Task and Configuration as factors, and in a general analysis, with Experiment, Task and Configurations as factors.