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Attention modulates psychophysical and electrophysiological response to visual texture segmentation in humans

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Abstract

To investigate whether processing underlying texture segmentation is limited when texture is not attended, we measured orientation discrimination accuracy and visual evoked potentials (VEPs) while a texture bar was cyclically alternated with a uniform texture, either attended or not. Orientation discrimination was maximum when the bar was explicitly attended, above threshold when implicitly attended, and fell to just chance when unattended, suggesting that orientation discrimination based on grouping of elements along texture boundary requires explicit attention. We analyzed tsVEPs (variations in VEP amplitude obtained by algebraic subtraction of uniform-texture from segmented-texture VEPs) elicited by the texture boundary orientation discrimination task. When texture was unattended, tsVEPs still reflected local texture segregation. We found larger amplitudes of early tsVEP components (N75, P100, N150, N200) when texture boundary was parallel to texture elements, indicating a saliency effect, perhaps at V1 level. This effect was modulated by attention, disappearing when the texture was not attended, a result indicating that attention facilitates grouping by collinearity in the direction of the texture boundary.

Keywords: Texture segmentation; Attention; VEPs; Psychophysics; Grouping

1. Introduction

It has been known for over 30 years that saliency of line-texture figures is higher when collinear elements in the figure group together (Field, Hayes, & Hess, 1993; Kapadia, Ito, Gilbert, & Westheimer, 1995; Nothdurft, 1992; Olson & Attneave, 1970) in a direction parallel to textural borders (Caputo & Casco, 1999). Grouping is not a property necessary to segment texture contours as such. Indeed, segmentation occurs by means of segregation based on orientation contrast, as well as grouping of texture elements (Field et al., 1993), and these two operations occur at a level of processing either concurrent or in close succession (Beck, 1982; Beck, Prazdny, & Rosenfeld, 1983; Julesz, 1981, 1986; Lamme, 1995; Nothdurft, 1992; Treisman, 1982; Treisman & Gormican, 1988). Grouping is a property that facilitates texture segmentation based on orientation contrast with consequent increase in saliency of segmented texture (Field et al., 1993; Nothdurft, 1992).

It is widely accepted that attention is allocated to the visual field after completion of grouping operations (Baylis & Driver, 1992; Beck, 1967, 1982; Moore & Egeth, 1997; Nothdurft, 1985, 2002; Sagi & Julesz, 1984; Treisman, 1982). This view is confirmed by studies that recorded cortical activity in human brain during texture segmentation (Bach & Meigen, 1992, 1997;

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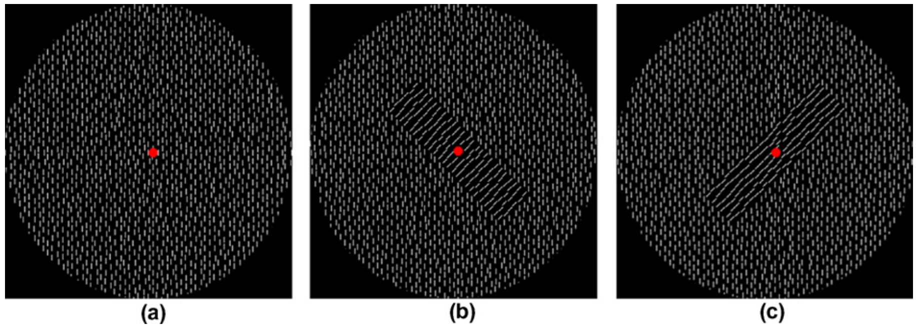

Fig. 1. Uniform texture stimuli (a) consisted of white vertical line elements 19′ long arranged on a diamond raster, with raster step of 30.5′ and jittered around their raster center by 0–2.7′. The segregation stimulus (b) consisted of a texture bar segregated from a uniform vertical texture displaying at the center the number 1 or 2. The texture bar comprised 6×24 line elements tilted either 45° or 135° at random. Note that at segregation edges, the local orientation contrast between the line elements of the bar and surrounding lines was kept constant (i.e., orientation difference always 45°). Two stimulus conditions were used. In the orthogonal condition (b), the bar short boundary had the same orientation as its line elements. In the parallel configuration (c) they were orthogonal with respect to bar orientation.

Fahle, Quenzer, Braun, & Spang, 2003). These showed a negative VEP component with latency around 200 ms, specifically elicited by textures pre-attentively segregated. However, Caputo and Casco (1999) showed that when attention is allocated on a texture bar during an orientation discrimination task, the VEPs associated with texture segmentation (tsVEPs, obtained by algebraic subtraction of uniform-texture from segmented-texture VEPs) present two peaks, with latency around 160 and 200 ms—20 ms faster with texture border parallel to texture elements vs. orthogonal. The new peak might be associated with attention involved in grouping, since the orientation discrimination task, used exclusively by Caputo and Casco (1999), involves attention and renders grouping necessary. The suggestion that grouping operations require attention also emerges from behavioral (Ben Av, Sagi, & Braun, 1992; Braun & Sagi, 1990, 1991; Yeshurun & Carrasco, 2000) and physiological data (Merigan, Nealey, & Maunsell, 1993; Motter, 1994).

To consider whether and how attention modulates texture segmentation, we evaluated both psychophysical and electrophysiological correlates of a texture-line figure segmentation, with attention: (i) not engaged on any task, (ii) engaged either (a) on spatial orientation of the texture boundary (texture figure attended), or (b) away from it on a central number that had to be identified (texture figure unattended).

The segmented texture figure was a bar oriented at 45° or 135°, presented on a uniform texture background (Fig. 1a). The boundary was either parallel (Fig. 1b) or orthogonal (Fig. 1c) to its elements.

In comparison with an orthogonal boundary, for a parallel boundary the texture elements are collinear and parallel to it. This geometrical arrangement can facilitate grouping of disconnected elements in the direction of the texture-figure boundary. In line with studies by other groups (Freeman, Sagi, & Driver, 2001; Gilbert, Ito, Kapadia, & Westheimer, 2000; Polat, Mizobe, Pettet, Kasamatsu, & Norcia, 1998), we asked whether this operation could be modulated by attention. We introduced this configural factor (boundary either parallel or orthogonal to texture elements) to assess whether attention modulates texture boundary segregation per se (based on orientation contrast), or else specific grouping operations that facilitate texture segmentation when the elements to be grouped are parallel to texture boundary. If attention generally modulates texture segregation, this would affect tsVEP amplitude (and/or latency) in the same way in the two configurations, since orientation contrast is constant. Alternatively, if attention modulates the facilitating of grouping by collinearity in the direction of the texture boundary, we would expect this specific effect, as reflected in tsVEPs, to be reduced when texture is unattended. Our results support this second hypothesis. When attention is engaged on the figure, we found that the higher saliency of parallel configurations was reflected in larger amplitude of tsVEPs, which occur early (N75, P100, N150, N200), perhaps at V1 level. With attention disengaged from the figure, the advantage in parallel-texture figure discrimination vanishes, as does the VEP correlate of this configural effect.

2. Experimental methods

2.1. Stimuli

In each trial, two kinds of stimuli were interleaved: uniform texture (Fig. 1a) and texture bar (Fig. 1b and c).

Stimuli were generated by a PC, displayed on a 15 in. color monitor (70 Hz vertical refresh) and viewed from a distance of 57 cm in a darkened room. Head movement was limited by a chin-rest. The monitor resolution was 640×350 with square pixel $2.7 \times 2.7'$. The monitor was viewed through a 16° diameter circular aperture.