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Perceptual grouping across eccentricity

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ABSTRACT

Across the visual field, progressive differences exist in neural processing as well as perceptual abilities. Expansion of stimulus scale across eccentricity compensates for some basic visual capacities, but not for high-order functions. It was hypothesized that as with many higher-order functions, perceptual grouping ability should decline across eccentricity. To test this prediction, psychophysical measurements of grouping were made across eccentricity. Participants indicated the dominant grouping of dot grids in which grouping was based upon luminance, motion, orientation, or proximity. Across trials, the organization of stimuli was systematically decreased until perceived grouping became ambiguous. For all stimulus features, grouping ability remained relatively stable until 40°, beyond which thresholds significantly elevated. The pattern of change across eccentricity varied across stimulus feature, in which stimulus scale, dot size, or stimulus size interacted with eccentricity effects. These results demonstrate that perceptual grouping of such stimuli is not reliant upon foveal viewing, and suggest that selection of dominant grouping patterns from ambiguous displays operates similarly across much of the visual field.

1. Introduction

Across retinal eccentricity, progressive changes occur in neural processing, including factors such as sampling density and cortical magnification. Perceptual abilities also vary across eccentricity, depending upon specific stimulus feature as well as level of processing. Progressive decline in perceptual abilities accompanies increased retinal eccentricity for both basic and higher-order visual function. Eccentric viewing produces elevated thresholds for acuity (Riggs, 1965), stereopsis (Prince & Rogers, 1998), critical flicker fusion (Brown, 1965), movement detection (Graham, 1965), orientation discrimination (Sally & Gurnsey, 2003, 2004), lateral (flanker) stimulus facilitation (Giorgi et al., 2004; Shani & Sagi, 2005) and letter recognition (Melmoth & Rovamo, 2003; Williams, 1984). Moving patterns that are easily separated with foveal viewing are aggregated into a single pattern in the periphery (De Bruyn, 1997). Similarly, performance declines with increased eccentricity for higher-order functions, including word recognition (Lee, Legge, & Ortiz, 2003), biological motion identification (Ikeda, Blake, & Watanabe, 2005), facial recognition (Mäkelä et al., 2001), and object detection in natural scenes (Thorpe et al., 2001).

Perceptual differences across eccentricity are associated with differences in post-receptor mechanisms (Anderson, Mullen, & Hess, 1991) and cortical magnification of the central visual field. Consistent with these relationships, for some basic visual functions, performance with eccentric viewing is made equivalent to foveal viewing by increasing stimulus scale. Adjusting scale in accordance with cortical magnification factors improves performance for measures of acuity (Virsu, Näsänen, & Osmoviita, 1987), motion coherence (van de Grind, van Doorn, & Koenderink, 1983), and letter recognition (Higgins, Arditi, & Knoblauch, 1996). However, increased stimulus scale does not equate foveal and eccentric viewing for stereopsis (Prince & Rogers, 1998), word recognition (Lee, Legge, & Ortiz, 2003), contour integration (Hess & Dakin, 1997), biological motion (Ikeda, Blake, & Watanabe, 2005), or facial recognition (Mäkelä et al., 2001). In this regard, processing such stimuli require foveal viewing for optimal performance, regardless of scale adjustments.

Less is known about the effect of eccentricity on perceptual grouping. Perceptual grouping enables observers to resolve elements of a complex scene into a series of unified forms (for a recent review: Wagemans et al., 2012). Perceptual grouping occurs at an intermediate level of visual processing, preceded by the reception and encoding of basic stimulus features, and followed by more high-order processing. Perceptual grouping is a robust and dynamic process mediated by multiple interacting processes. In

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this regard, perceptual grouping is guided by both stimulus metrics as well as top-down factors (Beck & Palmer, 2002; Kimchi et al., 2002; Palmer, Brooks, & Nelson, 2003).

Contour integration is reported to progressively decline with eccentricity (Hess & Dakin, 1997, 1999; Nugent et al., 2003). Detection of adjacent Gabor patches oriented along a path and positioned in a field of randomly oriented elements was reduced for stimuli presented peripherally. Hess and Dakin (1997, 1999) further reported that for paths composed of alternating phase elements, path detection dropped to chance level at 20° eccentricity, although these results were not replicated by Nugent et al. (2003). In contrast, shape discrimination based upon Gabor patches that formed completed figures (e.g., full circles) remained relatively unchanged up to an eccentricity of 35° (Kuai & Yu, 2006).

Properties of grouping across eccentricity have been examined with apparent motion (Alais & Lorenceau, 2002). Measurements were made with Ternus displays, in which Gabor patches or Gaussian blobs were perceived as either moving together, or as jumping across outer positions. For these stimuli, perceived group motion decreased with eccentricity, tested to 12°. In contrast to orientation-dependent grouping and apparent motion, Bleumers et al. (2008) found that grouping by proximity either remained the same, or became stronger with increased eccentricity. For each of these stimulus domains, eccentricity effects on grouping have generally been modeled in terms of differences in lateral integration across eccentricity, for which resolution declines with peripheral viewing.

In order to explore whether grouping processes for eccentric viewing operate similarly across basic stimulus feature domains, effects were examined here for grouping based upon similarity in luminance, motion, and orientation, as well as spatial proximity. It was hypothesized that because processing density for basic stimulus components is reduced across eccentricity, perceptual grouping should decline similarly. In addition, because grouping occurs at a level of processing more advanced than initial representations of basic stimulus features, it was hypothesized that scalar increases will not significantly improve performance across eccentricity. In order to test these predictions, psychophysical measurements were made of perceived grouping of dot patterns across eccentricity. In order to investigate stimulus metrics associated with changes in performance across eccentricity, grouping thresholds were compared across stimulus scale, size of individual stimulus elements, and total size of stimulus arrays.

Subjects reported the perceived grouping of an array of spatially isolated stimulus elements. In three of the conditions, local element density was equivalent along the vertical and horizontal orientation and grouping was based upon similarity in either luminance, motion direction, or Gabor patch orientation. In a fourth condition, grouping was based upon relative proximity. High levels of similarity, or greater relative proximity, provide robust cues for grouping, and perceived grouping reliably occurs among the common, or more proximal, elements. Across trials, element type was progressively interchanged, or the relative proximity reduced, thereby reducing the strength of the grouping cue. With reduced cue strength, perceived grouping became less stable, and the alternate grouping pattern competed with that possessing the stronger cue. The level at which the prevailing stimulus organization no longer reliably produced grouping served as an index of grouping capacity. Elevation of this index thereby reflects a decreased capacity to identify global regularities in disordered patterns. This index is found to be elevated in certain subject populations, including aged individuals (Kurylo, 2006), or those diagnosed with Alzheimer's disease (Kurylo, 2004; Kurylo et al., 2003), acquired brain injury (Kurylo, Waxman, & Kesin, 2006), or schizophrenia (Kurylo et al., 2007). As such, these subject populations require a greater level of stimulus organization in order to reliably perceive grouping of the pattern containing the greater cue strength.

The index of grouping used here reflects the predominant organization of a patch of elements. These stimuli represent a type of competitive grouping array, in which specific elements may belong to one of multiple grouping patterns. The perceived grouping pattern is based upon the cumulative associations among elements, representing the global organization across the array. Such multistable arrays produce a globally coherent organization (Claessens & Wagemans, 2005). With similar stimuli as those used here, measures of relative attractive force among elements have been derived from probabilities of perceived grouping, including grouping produced by proximity ((Kubovy, Holcombe, & Wagemans, 1998; Kubovy & Wagemans, 1995), as well as by the concurrent presentation of proximity and Gabor patch alignment (Claessens & Wagemans, 2005), or proximity and similarity (Kubovy & van den Berg, 2008), which act as either competitive or cooperative cues for grouping. The current study does not serve to investigate characteristics of grouping per se, or to investigate principles of contour integration or texture segmentation, but instead serves to examine change that may occur in grouping capacities across eccentricity. As such, an elevation in the grouping index used here would indicate decreased capacity to perceive grouped patterns within the stimulus array.

2. Methods

2.1. Subjects

Four subjects, experienced with the procedures, participated in the study. Subjects demonstrated a 14" visual acuity of 20/20 (Snellen), either uncorrected or corrected with contact lenses.

This research was conducted in accordance with APA standards for ethical treatment of subjects and with the approval of the Institutional Review Board for Human Research of Brooklyn College. This research is in accordance with the Code of Ethics of the World Medical Association (Declaration of Helsinki) for experiments involving humans.

2.2. Stimuli

Stimuli were presented on a computer monitor (Trinitron CPD 4401) set to 1024×768 pixel resolution at a refresh rate of 85 Hz. Luminance was linearized with software adjustment. Stimuli were generated by customized computer software (Bukhari & Kurylo, 2008). Four sets of stimuli were presented in which perceptual grouping was based upon similarity in luminance, motion, and orientation, and on proximity.

2.2.1. Similarity in luminance

For the luminance condition, stimuli consisted of a 20×20 array of square elements. Stimulus elements were presented at two luminance levels (3.9 and 29.5 cd/m^2, Michelson contrast = 0.77) on a gray background (16.5 cd/m^2). As such, similarity in luminance could correspond to a similarity in contrast. Stimulus organization was established by similarity in luminance along either columns or rows (Fig. 1A).

2.2.2. Similarity in motion

For the motion condition, stimuli consisted of a 20×20 array of square elements. The luminance of stimulus elements was 29.5 cd/m^2, presented on a gray background of 16.5 cd/m^2. Stimuli consisted of five consecutive frames, producing motion for 235 ms, at a rate of 4 deg/s. The direction of displacement was selected from four possibilities (each a 45° path, either ↖, ↗, ↙, or ↘). Each