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Effects of pattern masks on the formation of perceptual grouping

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ABSTRACT

Mechanisms underlying perceptual grouping serve to bind stimulus components that are contained within grouped patterns. In order to examine the time course of grouping development, grids of spatially isolated dots were followed by pattern masks across a range of SOA. Subjects indicated the predominant perceived grouping of the dot patterns. Masks either spatially superimposed target elements (element mask), or superimposed elements as well as paths among elements (connection mask). Element masks thereby disrupted processing of target elements, while connection masks additionally disrupted representations in regions among elements. It was found that element masks disrupted grouping 12 ms after target offset, after which masks had no effect. Connection masks disrupted grouping up to 47 ms following target offset. Results suggest grouping mechanisms access the afferent signal for a brief period early in processing, after which binding formation proceeds for an addition 35 ms. Shortening connection mask duration to 12 ms enhanced performance during a brief temporal window within the interference period. For each set of conditions, target elements were visible during the time frame in which stimulus patterns could not be perceptually grouped. Full-field checkerboard masks degraded discrimination similarly as connection masks, although were more effective in disrupting discrimination with an SOA of 24 and 36 ms. Degrading stimulus organization progressively extended the time scale for each masking effect. For the grouping of low-level stimulus features tested here, results support a model in which afferent signals are accessed early, followed by progressive binding among grouped elements. Effect of shortening connection masks may reflect incomplete disruption of target processing, or possibly re-entry of stimulus representations by feedback from higher processing areas.

1. Introduction

Perceptual grouping serves to bind components of the visual scene. In the course of grouping, stimulus representations are processed within and across cortical areas to produce patterns of neural activity that correspond to unified forms. It is reported that effects of grouping occur early in processing (Kimchi, 2000; Kimchi, Hadad, Behrmann, & Palmer, 2005; Razpurker-Apfeld & Kimchi, 2007), and grouping develops progressively, in which the time scale varies with stimulus features, grouping cues, and task complexity (Beck & Palmer, 2002; Kimchi, 2000; Kurylo, 1997; Palmer, Brooks, & Nelson, 2003; Razpurker-Apfeld & Kimchi, 2007).

Visual processing initially progresses as a feedforward sweep through cortical areas. Feedback from higher areas, as well as local processing within regions, modify response properties and integrate activity (for reviews: Bullier, 2001; Hochstein & Ahissar, 2002; Lamme & Roelfsema, 2000; Lamme, Super, & Roelfsema, 1998). Neural mechanisms establishing grouping are theorized to progress in two phases (Roelfsema, 2006; Roelfsema & Houtkamp, 2011). An initial phase is based upon stimulus feature tuning of neurons, and is mediated as a cascade of feedforward connections through lower and higher visual areas. A second phase serves to integrate more complex relationships, and includes local processing mediated by horizontal connections, as well as feedback to earlier stages. The initial phase advances quickly through cortical areas, whereas recursive processing of the second phase requires longer durations.

Neural correlates of grouped patterns may include increased activity (Kapadia, Ito, Gilbert, & Westheimer, 1995), enhanced connection strength (Roelfsema & Houtkamp, 2011), or synchronous patterns of populations (Nikolaev, Gepshtein, Gong, & van Leeuwen, 2010; Yazdanbakhsh & Grossberg, 2004). Areas mediating grouping, and representations of grouped patterns, likely depend on the stimulus features and perceptual processes used to establish grouping.

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Grouping has been associated with processing in area V1 in terms of modulation of neural responses by contextual factors (Gilbert, Ito, Kapadia, & Westheimer, 2000). Local interactions among collinear Gabor patches are thought to occur in V1 through lateral connections (Polat & Sagi, 2006). Interactions among stimulus components begin soon after stimulus presentation. Specifically, backward pattern masks, thought to disrupt active processing of lateral interactions, masked interaction effects when separated from stimuli by as little as 50 ms (Sterkin, Yehezkel, Bonneh, Norica, & Polat, 2009).

Global processing of stimulus patterns have been associated with high-order visual areas. Higher levels of cortical processing, including intraparietal sulcus (Yokoi & Komatsu, 2009) and middle temporal cortex (Han, Jiang, Mao, Humphreys, & Gu, 2005), have been shown to play a role in grouping by similarity. It has been suggested that feed-forward and feedback signals between high-order and early visual areas contribute to binding stimulus elements into grouped patterns (Yokoi & Komatsu, 2009). Ishizu, Ayabe, and Kojima (2009) used random dot noise to mask stimulus patterns. Short SOA disrupted discrimination of the local, but not global features. Results suggested that global shapes are processed though feedforward connections to high-order visual areas, whereas masks interrupted feedback of target representations, which interfered with discrimination of stimulus details. fMRI analysis of grouping by proximity suggested an initial process in early visual areas that link local stimulus elements, followed by a later stage in more high-order areas that process the grouped shape (e.g., grouped rows and columns) (Han et al., 2005). The basic process of grouping by common luminance, as used here, may follow a similar scheme, such that lower levels identify stimulus regularity, followed by construction of grouped patterns in more high-order areas.

1.1. Masking effects on processing

The time scale of grouping formation may be explored by introducing pattern masks that disrupt components of grouping. Neural correlates of masking reflect suppression of stimulus responses, although details of masking effects are complex, and include interactions between targets and masks, as well as effects of transient on- and off-response to mask presentation (Breitmeyer & Ogmen, 2000). Using targets with a fixed duration of 20 and 40 ms, backward pattern masks inhibited neural off-response in area V1 (Macknik & Livingstone, 1998). For targets fixed at 34 ms and followed by a pattern mask, fMRI activity modulated with SOA, indicating masking effects in components of lateral occipital lobe, but not in areas V1 or V2. In addition, mask effects were found in other brain regions, including thalamus, which may be associated with masking effects on feedback to earlier levels of processing (Green, Glahn, Engel, et al., 2005). Masking effects are also evident in high-order visual areas using more complex stimuli. For the presentation of faces fixed at 16 or 20 ms, backward pattern masks reduced response duration, as well as information contained in the response pattern, of neurons in temporal lobe (Rolls & Tovee, 1994; Rolls, Tovee, & Panzeri, 1999). In each of these cases, the time scale of neural response to masks corresponded to decreased visibility of targets.

1.2. Processing cascade

Masking effects on grouping formation are described here in terms of a simple and intuitive framework. Fig. 1 depicts a cascade of processing, in which time is represented across columns (T), and levels of processing are represented across rows (L). For simplicity, pre-cortical processing and reciprocal interactions between LGN and cortex are not depicted. In addition, integration continues to more high-order areas not depicted here. Fig. 1 is not intended to suggest cortical areas in which grouping processing occurs, but instead describes a framework of information processing through cortical regions. Durations are not specified, but instead time frames represent sequential events.

Following stimulus onset, the stimulus representation is conveyed through primary afferent signals to an initial level of processing (T_1,L_1). Spatially isolated stimulus elements are represented in the cortex as independent sites of graded activation, separated by regions of less activity. For simplicity, the pattern of cortical activity depicted here parallels stimulus configurations, whereas actual activation patterns are distorted by cortical magnification, changes in receptive field size, and other topographic discontinuities. In the course of grouping, stimulus components become integrated by means of (1) feed-forward to higher areas (declining slanted arrows), (2) intrinsic processing within areas (horizontal arrows), and (3) feedback to lower areas (ascending slanted arrows). The level of integration is depicted as visibility of lines connecting stimulus components. Thickness of lines is not intended to represent enhanced cortical activity. Fig. 1 is a simplification of cortical processing, and serves as a framework to describe the flow of information across time and level of processing.

The neural representation of a mask progresses similarly through processing areas. Processing of the target is disrupted as the mask representation enters an area. By specifying stimulus onset asynchrony (SOA), masking interference may be introduced at selective times during grouping formation. In addition, the structure of the mask may be used to select which processing components are disrupted by masking either stimulus elements, or masking areas among elements.

To examine the time scale of grouping, a standard grouping task was used in which vertical/horizontal pattern discrimination was reported for a grid of stimulus elements. It was hypothesized that stimulus characteristics are utilized early in processing, followed by a more extended period during which grouping progressively develops. It was further hypothesized that reduced stimulus organization requires additional processing, and thereby extends the time scale of grouping.

2. Methods

2.1. Subjects

Four subjects participated in the study. All subjects were experienced with the procedures, and demonstrated best corrected 14″ visual acuity of 20/20 (Snellen). 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. Before participating in the study, participants signed an informed consent statement.

2.2. Stimuli

Stimuli consisted of targets (dot grid) and masks, which appeared on a computer monitor (Trinitron CPD 4401) set to 1280×1024 pixel resolution and 85 Hz refresh rate. Stimulus grids subtended a 19.3° square field, in which a 2.5° square centered in the array was devoid of pixels. The blank center of the array precluded foveal viewing of the array center, thereby producing greater uniformity in resolution across the stimulus array. Eliminating dots from the foveal viewing area precluded the possi-