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Microgenesis of surface completion in visual objects: Evidence for filling-out

Bruno G. Breitmeyer[a,b,*], Jane Jacob[a]

[a] Department of Psychology, University of Houston, Houston, TX 77204-5022, United States
[b] Center for Neuro-Engineering and Cognitive Science, University of Houston, Houston, TX 77204-5022, United States

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ABSTRACT

Using metacontrast masking we examined the temporal dynamics of surface completion in object vision. By varying the stimulus onset asynchrony between the target object and the flanking mask(s), we obtained estimates of the time required for the entire surface contrast to fill out within the area delimited by the contours/edges of the target. The estimated speed of the filling-out process was 36.0 deg/s. Using existing estimates of cortical magnification, the computed filling-out speed in terms of cortical distance is .385 m/s, a value that approximates the estimated cortical filling-in speed and the speed of horizontal propagation in monkey V1. We discuss our results in relation to (1) prior findings of filling-in and filling-out phenomena, using surface completion in cortical space as the unifying principle, and (2) extant computational models of object vision.

1. Introduction

Visually an object is spatially delimited by its contours which "confine" its surface properties. Contour and surface properties are processed interactively in complex ways that can be assessed by exploiting well-known surface completion phenomena. Troxler (1804) was the first to note that, with steady fixation, static stimuli can eventually fade from view as the surface characteristics of a background gradually fill in those of the stimulus. Relative to stimuli with sharp contours, stimuli with indistinct or blurred contours accelerate such surface filling-in (Friedman, Zhou, & Van der Heydt, 1999; Krauskopf, 1963). While filling-in of an object's surface properties such as luminance contrast or color is a well established phenomenon (Pinna, Brelstaff, & Spillmann, 2001; Pinna & Grossberg, 2005; Rossi & Paradiso, 2003; Spillmann & de Weerd, 2003), "filling-out" processes also have been reported (Hamburger et al., 2006; Kanai et al., 2006). Both of the filling-in and filling-out phenomena are typically observed under conditions which require observers to maintain very steady fixation. Since the complete filling-in or filling-out processes can require up to several tens of seconds (Kanai et al., 2006), we refer to this process of surface completion as "macrogenetic". According to the two-stage model of surface completion proposed by Spillmann and de Weerd (2003), under steady fixation the filling or spreading of surface features may actually be a relatively fast, microgenetic process, but starting only after the slowly, macrogenetically evolving degradation of contour, produced by adaptation processes occasioned during the steady fixation, has run its full course.

The temporal dynamics of a visual object's contour and surface attributes depends on spatial scale and on the type of attribute being processed. It is well known that the latency of perceptual and cortical processing of object features varies directly with their spatial frequency (Breitmeyer, 1975; Lupp, Hauske, & Wolf, 1976; Vassilev & Mitov, 1976; Vassilev & Strashimirov, 1979; Williamson, Kaufmann, & Brenner, 1978) and is slower for chromatic than for achromatic stimulus attributes (Satgunam & Fogt, 2005; Schwartz & Loop, 1983). Within this temporally dynamic context, masking procedures, which can assess perceptual contour and surface formation microgenetically, i.e., within the millisecond range (Bachmann, 2000; Breitmeyer et al., 2006; Breitmeyer & Öğmen, 2006; Pessoa & de Weerd, 2003), have been successfully employed to measure the time-course of surface completion – specifically filling-in – that proceeds from the outer contour of a stimulus to its interior (Caputo, 1998; Paradiso & Nakayama, 1991; Rossi & Paradiso, 2003). These studies reveal that the microgenesis of surface filling-in is not instantaneous but rather an incremental process that, depending on the spatial extent of the surface, requires anywhere from several tens to a hundred or more milliseconds.

However, at this microgenetic level, filling-out processes also are implied on theoretical and empirical grounds. In particular, Petry (1978) employed metacontrast masking to compare the masking of the inner, medial portions of the target stimulus relative to that of the outer, edge portions. For target-mask onset asynchronies (SOAs) greater than or equal to the value producing optimal masking, the results showed that the SOA at which the outer portions of a target's surface escape metacontrast masking

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* Corresponding author at: Department of Psychology, University of Houston, Houston, TX 77204-5022, United States. Fax: +1 713 743 8588.
E-mail address: brunob@uh.edu (B.G. Breitmeyer).

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is longer than the SOA at which the medial/inner portions of its surface escape metacontrast suppression. One way to interpret this finding theoretically is via the sustained-transient approach to masking proposed by Breitmeyer and Ganz (1976). Here the contrast of the surface progressively nearer to the edges of the target, containing progressively higher spatial frequency components, is perceptually processed more slowly than its inner surface contrast (see Breitmeyer & Ganz, 1976; Figs. 9 and 11), thus leading to a progressive filling-out of surface contrast. Although at first glance filling-in does not fit into this theoretical scheme, the well established coarse-to-fine spatial processing in the visual system can be implemented in extensions of computational models to reconcile the two phenomena in terms of a spatiotemporal process of filling-out by progressive filling-in.

2. Experiment: Metacontrast measures of filling-out

In the present experiment we adopt a metacontrast masking method similar to that used by Petry (1978) in that a rectangular target is followed at variable SOAs by two mask stimuli, one flanking each side of the target. Since the visibility of the target varies in a nonmonotonic, U-shaped manner with target-mask SOA (Breitmeyer & Öğmen, 2006) metacontrast SOAs are varied from an intermediate value, where metacontrast suppression of target visibility is strongest, to high values, where metacontrast no longer is effective. A preliminary study revealed that the SOA yielding optimal surface masking varied between 70 and 90 ms. Consequently, while the target's visibility was almost totally suppressed at an intermediate SOA of 80 ms, at progressively higher SOAs the target became progressively more visible. A facsimile of this systematic increase of visibility, starting with the appearance of a dark central blurred region at SOAs slightly above 80 ms and ending with the appearance of a totally filled out target with sharp edges at the highest SOA value of 240 ms, is depicted in Fig. 1. In the actual experiment, by requiring observers (Os) to indicate at each SOA whether or not the target was completely visible, we can track how complete visibility varies with SOA. Here we predict that, overall, complete target visibility increases as SOA increases. Since surface filling-out is expected to increase directly with target width, we also expected the psychophysical functions relating proportion of "complete" responses to SOA to shift towards progressively higher values along the SOA axis as target width increases.

2.1. Methods

2.1.1. Observers

A total of six observes participated in the experiment. One of them was the author BB; the other five were volunteers from the University of Houston undergraduate population ranging in age from 20 to 24 years. These five observers were naïve as to the purpose of the experiment but were well trained in making psychophysical judgments. All Os had normal or corrected-to-normal vision.

2.1.2. Stimuli and apparatus

All visual displays, generated by a Macintosh IIci microcomputer driving a Spectrum/8 graphics card, were presented at a 75-Hz frame rate on a 19-in. Trinitron high-resolution color monitor. The background luminance was 50 cd/m^2; the luminance of the target and mask stimuli was .5 cd/m^2, yielding a contrast of .98. Target and mask stimuli were each presented for 27 ms. Each of the two flanking mask rectangles (see Fig. 1) was .2° wide and .67° high. The height of all targets also was .67°, but their width could vary in .5° steps from .5° to 2.0°. Target and flanking masks were centered within a notional fixation cross as depicted in Fig. 1. As a result one half of the target fell to the left and the other half to the right of fixation. For that reason we describe the dimensions of the targets in terms of their half-widths. A target's half-width also corresponds to the retinal distance from the center of the fovea to the target's edges. The SOAs separating the onsets of the target and mask were: 80, 107, 133, 160, 187, 213, and 240 ms. The experiment was conducted in a dark room. All viewing was binocular at a distance of 114 cm. At that distance the display dimensions of the monitor were 14.5° × 11°. Although no chin- or headrest was used, observers were instructed to fixate the center of the notional fixation cross throughout each trial. Although eye movements might play a significant role in steady-fixation studies of surface completion, their role is minimized here since on any trial the entire target-mask sequence transpired in 267 ms or less.

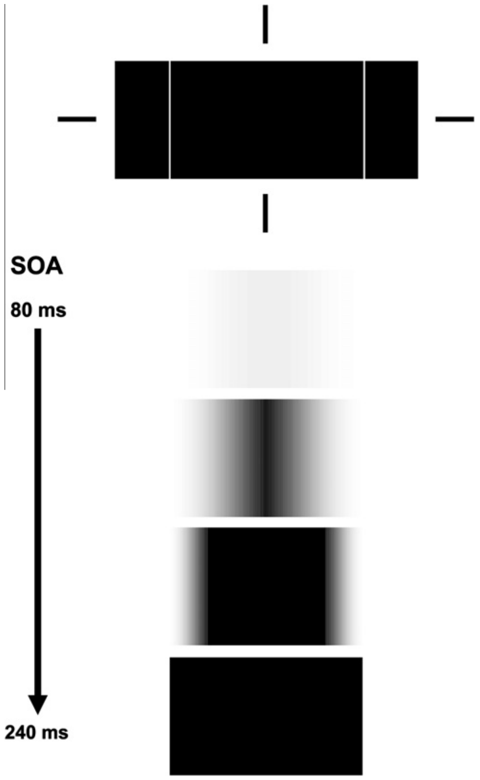

Fig. 1. Upper panel: Schematic representation of target rectangle and the two flanking metacontrast mask rectangles centered at the notional fixation cross depicted by the collinear vertically oriented and horizontally oriented bars. Lower panels: Depicted facsimiles of the phenomenal appearance of the target at target-mask onset asynchronies (SOAs) increasing from 80 to 240 ms.

2.1.3. Procedure

All Os served in two daily sessions, in each of which a separate block of 210 trials was devoted to each of the four target widths. The order of target-width blocks was counterbalanced across four naïve Os and randomized for one naïve O and BB. In each block, 30 trials were devoted to each of the seven SOAs. Subject to this constraint, SOAs were randomized across the 210 trials. Os were asked to fixate the center of the notional fixation cross. Target and mask were each presented for 27 ms. After each trial the O was asked to indicate, by pressing one of two keys, whether or not the (black) target was completely visible. The naïve Os were instructed that two criteria for complete visibility had to be met simultaneously: (1) the perception of clear and sharp left and right edges and (2) the perception of a uniform dark surface between these edges. Across the two sessions and for all target widths, each observer generated 60 responses for each of the seven SOAs.