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Chromatic tuning of contour-shape mechanisms revealed through the shape-frequency and shape-amplitude after-effects

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Abstract

We investigated whether contour-shape processing mechanisms are selective for color direction using the shape-frequency and shape-amplitude after-effects, or SFAE and SAAE [Gheorghiu, E. & Kingdom, F. A. A. (2006). Luminance-contrast properties of contour-shape processing revealed through the shape-frequency after-effect. *Vision Research, 46*(21), 3603–3615. Gheorghiu, E. & Kingdom, F. A. A. (2007). The spatial feature underlying the shape-frequency and shape-amplitude after-effects. *Vision Research, 47*(6), 834–844]. All contours were defined along the 'red-green', 'blue-yellow' and 'luminance' axes of cardinal color space. Adapting and test contours were defined along the same or along opposite polarities within a cardinal axis, and along the same or along different cardinal axes. We found (i) little transfer of the after-effects across different within-axis polarities, for all cardinal axes and for both even-symmetric and odd-symmetric contours; (ii) little transfer between the red–green and blue–yellow cardinal axes; (iii) little transfer between the chromatic and luminance cardinal directions for the SAAE; (iv) large transfer between the chromatic and luminance cardinal directions for the SFAE. We conclude that contour-shape mechanisms are selective for within-cardinal axis polarity and for the chromatic axes within the isoluminant plane. However for certain types of contour-shape processing they are poorly selective along the chromatic versus luminance dimension. Overall our results suggest that contour-shape encoding mechanisms are selective for color direction and that color is important for contour-shape processing.

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1. Introduction

Natural contours, such as edges and lines, typically vary along multiple photometric dimensions such as contrast, luminance phase, blur and chromaticity. Models of early human vision concerned with contour processing invariably use operators that are selective to these dimensions; for example linear filters such as simple cells tuned to different scales and orientations. An important question is which characteristics of a contour's luminance and chromatic profile are preserved for higher visual functions such as shape processing. Gheorghiu and Kingdom (2006) have suggested that there are broadly speaking two classes of early vision model that deal with this issue. They differ in the way information from different scale filters and from the positive and negative parts of filter outputs are combined to produce a feature description of the image. One class of model, which we have termed 'feature-rich', explicitly represents characteristics such as phase, scale and polarity at higher stages. Examples are Marr's (1982) and Marr and Hildreth's (1980) model of the primal sketch, Watt's (1988) and Watt and Morgan's (1985) MIRAGE model, Hesse and Georgeson's (2005) model of feature localization. The other class of model, which we have termed 'feature-agnostic', does not represent such characteristics at higher stages. Moronne and Burr's (1988) local energy model would seem to be an example of this class of model as it delivers a phaseless map of the locations of local energy peaks to higher stages of processing.

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In this communication we consider whether contour-shape encoding mechanisms are selective for color direction, and hence whether feature-rich or feature-agnostic. By color direction we mean the angle of a vector in a three-dimensional color space that includes an isoluminant (chromatic-only) color plane and a luminance axis. We are not primarily concerned here with whether or not contour-shape mechanisms are sensitive to isoluminant stimuli, that is responsive or not to a stimulus defined solely by chromatic contrast, as considered by Mullen and Beaudot (2002). Our aim instead is to determine whether contour-shape encoding mechanisms are *selective to color direction*, that is tuned to particular colors or ranges of colors. We ask whether color direction can be added to luminance blur and luminance phase as photometric dimensions to which contour-shape mechanisms are selective (Gheorghiu & Kingdom, 2006). We are not aware of any previous studies that have investigated the chromatic selectivity of shape processing.

To explore the selectivity of contour-shape mechanisms to color direction, we have employed two recently discovered contour-shape after-effects: the shape-frequency and shape-amplitude after-effects, or SFAE and SAAE (Gheorghiu & Kingdom, 2006, 2007; Kingdom & Prins, 2005a, 2005b). The SFAE and SAAE are the perceived shifts in, respectively, the shape-frequency and shape-amplitude of a sinusoidal test contour following adaptation to a sinusoidal contour of slightly different shape-frequency/amplitude. As with other spatial after-effects such as the tilt and luminance-spatial-frequency after-effects, the perceived shifts in the SFAE and SAAE are always in a direction away from that of the adaptation stimulus. Readers can experience the SFAE and the SAAE in Fig. 1a and b by first moving their eyes back and forth along the horizontal markers on the left for about a minute, and then transferring their gaze to the central spot on the right. The two test contours, which are identical, should appear different in shape-frequency or shape-amplitude. An important property of both after-effects is that they survive shape-phase randomization during adaptation, as can be experienced in the non-static adaptor versions at http://www.mvr.mcgill.ca/Fred/research.htm#contourShapePerception.

Spatial after-effects are useful tools for exploring the color selectivity of spatial mechanisms. If an after-effect produced from adaptation and test stimuli of different color is smaller than that from adaptation and test stimuli of the same color, one can reasonably conclude that the mechanisms underlying the after-effect are selective for color direction.

What should we expect regarding the selectivity of the SFAE and SAAE to color direction? Gheorghiu and Kingdom (2006) found that both after-effects were selective for the polarity of luminance contrast, and on the basis of this finding one might expect the after-effects to be selective for color direction. Additional support for this prediction comes from studies showing that the tilt after-effect is selective to color (Broerse, Over, & Lovegrove, 1975; Elsner, 1978; Held & Shattuck, 1971; Kavadellas & Held, 1977; Lovegrove & Over, 1973; Lovegrove & Mapperson, 1981; Shattuck & Held, 1975; Smith & Over, 1976) (though perhaps surprisingly one study, that of Magnussen & Kurtenbach (1979) showed that the tilt after-effect was *not* selective to luminance polarity). Clifford, Spehar, Solomon, Martin, and Zaidi (2003) have recently shown that the related tilt illusion, in which the perceived orientation of a grating is altered by the presence of a differently oriented surround grating, is also color selective; they found that the illusion was reduced if test and surround differed in color direction. Interestingly however, Forte and Clifford (2005) found that if the color difference in the tilt illusion was along the chromatic–luminance dimension, the illusion was only reduced if monocular mechanisms were allowed to contribute, i.e., there was little-or-no reduction if binocular mechanisms contributed. This last result is important because it suggests that spatial mechanisms subserved by purely binocular neurons may not be color selective. Gheorghiu and Kingdom (2007) have shown that the SFAE and SAAE are very likely mediated by mechanisms sensitive to *local curvature*, rather than to either local orientation or global shape frequency/amplitude. Given that curvature-encoding neurons have been found predominantly in higher visual areas (Gallant, Braun, & van Essen, 1993; Gallant, Connor, Rakshit, Lewis, & van Essen, 1996; Pasupathy & Connor, 1999, 2001, 2002) where neurons are mostly binocular (Neri, 2005; Watanabe, Tanaka, Uka, & Fujita, 2002), we might therefore expect the SFAE/SAAE to be only weakly, if at all color selective along the chromatic–luminance dimension.

To test whether contour-shape encoding mechanisms are tuned to color direction, we have compared SFAEs/SAAEs for adaptor-test combinations defined along the same with along different color directions. The color directions have been defined within a modified version of the MacLeod–Boynton color space (MacLeod & Boynton, 1979). Stimuli defined along the three axes of the MacLeod–Boynton color space stimulate the ‘red-green’, ‘blue-yellow’ and ‘luminance’ post-receptoral mechanisms that have been isolated psychophysically (Cole, Hine, & McIlhagga, 1993; Krauskopf, Williams, & Heeley, 1982; Norlander & Koenderink, 1983; Sankeralli & Mullen, 1997; Stromeyer, Cole, & Kronauer, 1985). We chose to define the stimuli along the cardinal axes because these color directions are arguably the most likely to reveal selectivity in contour-shape encoding.

2. General methods

2.1. Observers

One of the two authors (EG) and one undergraduate volunteer (GI) participated in the study. Both subjects had normal or corrected-to-normal visual acuity.

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