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Research Note

The Effect of Nearby Luminance Contrast Polarity on Color Boundary Localization

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The study measured the shift in apparent position of a color-defined target boundary as a function of the distance, luminance polarity and amount of contrast of a nearby luminance-defined flanking boundary. In general, the position of the target boundary shifted towards the flank with the attraction being somewhat greater for negative than positive polarity flanks, and for high compared to low contrast flanks. High contrast, negative polarity flanks resulted in greater attraction at 3.69 min arc separation. For low contrast flanks, the apparent shift in position of the target boundary depended on the polarity and position of the flank relative to the target. For example, for small separations (< 3 min arc) flank polarity had little influence, while for larger separations (⩾ 3.69 min arc), negative polarity flanks exhibited attraction while positive polarity flanks began to show repulsion. The results support the notion that luminance and color processing may share a common representation for the localization of boundaries. Position judgments based on this representation appear to be influenced by the amount of luminance contrast in a nearby boundary.

Positional acuity Luminance Color Boundaries

INTRODUCTION

A fundamental goal of the visual system is to locate the contours in an image. Interestingly, the apparent position of a target contour can often appear shifted from its actual position if a flanking contour is presented prior to (Kohler & Wallach, 1944; Pollack, 1958; Ganz & Day, 1965) or simultaneously with it (Ganz, 1966; Rentschler, Hilz, & Grimm, 1975; Badcock & Westheimer, 1985a, b; Rivest & Cavanagh, 1992). Factors that influence perceived shift in position include the distance between the target and flank (e.g. Rentschler *et al.*, 1975), and the direction of contrast or luminance polarity of the flank (Badcock & Westheimer, 1985a). One explanation of the apparent shift has been based on the summation of post-retinal activity to locate centroids in the retinal light distribution (Westheimer & McKee, 1977). According to this view, location judgments are made based on the centroid of the flank and target. Badcock and Westheimer (1985a) propose the use of a weighted centroid involving center/surround zones. In the central zone (involving small flank-to-target separations), the weights are positive or negative depending on contrast polarity. As a result, a flank defined by positive contrast polarity shifts the centroid towards the flank. Subtracting luminance from the flank (i.e. negative contrast polarity) is equivalent to adding luminance to the target, thus shifting the centroid away from the flank. In the surround zone (involving large flank-to-target separations), the weights are always negative, so repulsion occurs irrespective of the luminance polarity of the flank.

The centroid hypothesis is based on luminance profiles (Westheimer & McKee, 1977; Badcock & Westheimer, 1985a, b; Watt, 1988). In the natural environment however, contours and boundaries are not defined solely by luminance profiles. This being the case, it is imperative to ask about the role of other boundary defining attributes (e.g. color, motion, texture) and their contribution in locating boundaries. The present study focused on the influence of luminance-defined flanking boundaries on the processing of the location of a color-defined boundary. Psychophysical evidence strongly suggests color and luminance information are comparable in being able to contribute to positional processing (Kooi, De Valois, & Switkes, 1991; Kingdom, Moulden, & Collyer, 1992). In addition, evidence from figural aftereffect (Day, 1959) and hyperacuity (Rivest & Cavanagh, 1992) studies also suggest that color-defined

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boundaries are subject to positional shifts similar to those observed with luminance-defined boundaries. One implication of these studies is that the visual system makes judgments of relative position from a central representation that treats color and luminance definitions in like manner (Rivest & Cavanagh, 1992). Position judgments by such a representation should be indifferent to luminance polarity.

In contrast to this interpretation, the attraction of a luminance-defined target (of positive contrast polarity) by a color-defined flank and vice versa at relatively small flank-to-target separations, in addition to the weak repulsion at large separations, may indicate that color-defined boundaries have a center/surround representation similar to that described by Badcock and Westheimer (1985a) for luminance-defined boundaries. If this is the case, then the polarity of a luminance-defined flank should effect the apparent position of a color-defined target boundary.

Greene and Brown (1994) have recently shown attraction of a color-defined target edge by just-noticeably-different (JND) luminance flanks irrespective of flank polarity using a dynamic random-dot noise display similar to Rivest and Cavanagh (1992). When the experiment was repeated using a static plain field display (i.e. no dynamic noise or dots), negative polarity flanks produced attraction. However, positive polarity flanks only produced attraction for small flank-to-target separations (up to 3 min arc), and weak repulsion for greater separations (maximum separation was 6.65 min arc). One possible explanation for the differing results between the dynamic and static display conditions may be that the dynamic display amplified apparent shifts in position towards the flank as though the edges were defined by motion [e.g. see Banton and Levi (1993) for discussion of motion-defined edges].

Another, more likely, possibility is that differences in the JND flank contrasts between the two experiments contributed to the quantitative differences. A comparison of the flank contrasts revealed a mean contrast of $17 \pm 2\%$ SE for positive polarity and $18 \pm 2\%$ SE for negative polarity flank in the dynamic display experiment, but only $6 \pm 1\%$ SE for the positive and $5 \pm 2\%$ SE for the negative polarity conditions in the static display experiment. Thus, a generally greater physical contrast was needed to produce a JND flank in the experiment using the dynamic noise display compared to the one using a static display. Past research suggests positional acuity for a target is sensitive to the physical contrast of the flank. Higher contrasts generally lead to greater shifts in the apparent position of the target (Pollack, 1958; Ganz & Day, 1965). Thus, flank contrast may account for the quantitative differences between Greene and Brown's (1994) dynamic and static display conditions. If this is the case, then high contrast flanks should produce attraction irrespective of flank polarity. Low contrast flanks should produce weak attraction for small flank-to-target separations, and weak repulsions for larger separations. The present study tested this idea.

METHODS

Subjects

Four observers (LS, JA, LE, and one author HG) participated. LS, JA, and HG had participated in Greene and Brown (1994). All had normal or corrected-to-normal acuity and normal color vision.

Stimuli and apparatus

Stimuli were created and presented on an NEC RGB monitor using a Data Translation frame grabber (DT2851) interfaced with an Everex computer. The monitor was viewed from a chin rest in a dark corridor at a viewing distance of 7.58 m. An example of a nonbaseline (flank) stimulus used in the experiment is presented with visual angle dimensions in Fig. 1. Total viewing area was 87 (w) × 62 (h) min arc. The right half of the display was green (41.5 cd/m^2) and the left half was gray. Each observer set his/her own isoluminant gray by minimizing the flicker in alternating gray and green fields with the same dimensions as the stimulus display. Flicker rate was 20 Hz. Isoluminance was defined as the average of three settings after three practice settings. In the flank conditions, the luminance flanks were positioned at 1.33, 2.66, 3.69, 5.32, and 6.65 min arc from the isoluminant gray/green (color-defined) boundary. There was also a no flank baseline condition.

Procedure

All observers set positive and negative polarity JND flanks using the dynamic and static displays of Greene and Brown (1994). The mean settings across observers were $17 \pm 4\%$ SE and $16 \pm 3\%$ SE for positive and negative polarity dynamic flanks respectively, and $5 \pm 1\%$ SE and $3 \pm 1\%$ SE positive and negative static flanks respectively. Thus, the values from dynamic JND settings defined the high contrast flanks and the static JND settings defined the low contrast flanks for each observer.

The low and high contrast flanks were then used in a 2 (flank polarity) × 2 (flank contrast level) × 6 (flank position) repeated measures design. Three observers (LS, JA, and HG) ran in the low contrast conditions first followed by high contrast conditions. LE ran in the high followed by the low contrast conditions. Flank polarity was counterbalanced across subjects. On each trial, a 21 min arc long × 16 sec arc wide gray comparison line abutted the display at a randomly chosen offset 4.35, 8.70, 13.06, or 17.4 min arc left or right of the gray/green edge. The task was to move the comparison line to a position collinear with the gray/green target boundary. Responses were recorded by the computer when the observers pressed the space bar on the keyboard.

RESULTS AND DISCUSSION

A 2 (flank contrast) × 2 (flank polarity) × 6 (flank position) within-subjects ANOVA revealed a significant main effect of flank contrast [$F(1,3) = 88.94$, $P < 0.05$]

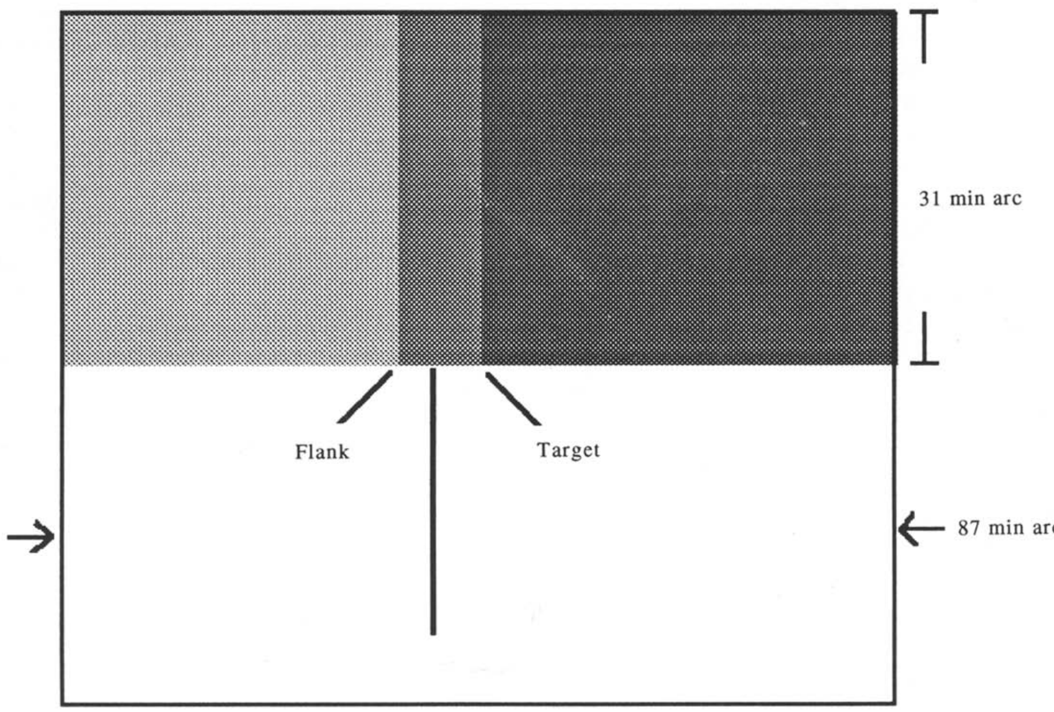

FIGURE 1. A non-baseline example of the stimulus. The task was to move the comparison line to a position collinear with the target edge. The position of the flank was varied in blocks of 24 trials.

indicating positional shifts induced by the flanks were greater for the high compared to the low contrast flank conditions. Similar to Greene and Brown's (1994) results, the main effect of flank position was significant [$F(5,15) = 9.96$, $P < 0.05$], while the main effect of flank polarity was not [$F(1,3) = 5.04$, $P > 0.05$]. The interaction of flank contrast and position was also significant [$F(5,15) = 2.94$, $P < 0.05$]. The pattern of performance is shown in Fig. 2. Trend analysis showed significant quadratic trends for the high contrast flank conditions [$t(1) = -2.92$, $P < 0.05$ for positive polarity; $t(1) = -4.23$, $P < 0.05$ for negative polarity], but not the low contrast flank conditions [$t(1) = -0.78$, $P > 0.05$ for positive polarity; $t(1) = -0.98$, $P > 0.05$ for negative polarity]. Thus, high contrast flanks elicited a significant increase followed by a decrease in attraction over the flank-to-target separations tested.

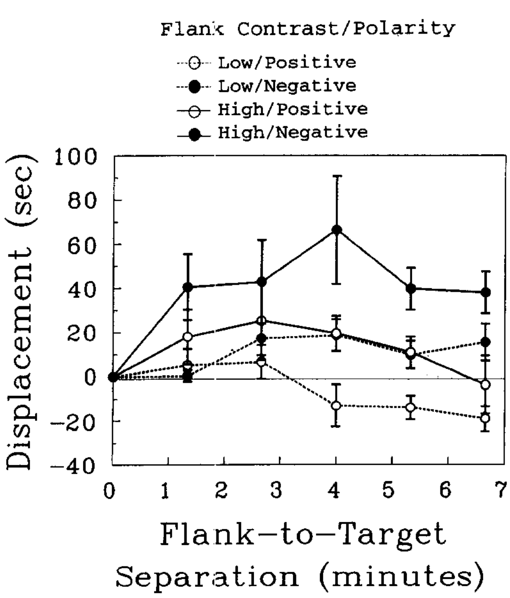

FIGURE 2. Relative mean positional errors for low and high contrast positive and negative polarity flanks.

The results with high contrast flanks and a static display are similar to the results of Greene and Brown (1994) with a dynamic display. The results with low contrast flanks replicate the results of the static display experiment of that study. The findings suggest that the discrepancy between the earlier reported results was due to the amount of physical contrast in the flanks and not the dynamic nature of one of the displays. The findings are consistent with earlier reports on the effect of contrast on positional acuity (e.g. Pollack, 1958; Ganz & Day, 1965). When the physical contrast of the adjacent luminance-defined flank was low, shifts in apparent position of the color-defined target were reduced.

The present experiment was concerned with how visual mechanisms that selectively process luminance and color information interact, and contribute to, boundary location processing. The results showed systematic influences on the location judgments for a color-defined target boundary as a function of a luminance-defined flanking boundary's distance and contrast polarity. Generally, attraction was stronger and the zone was wider for higher contrast flanks. Also, negative polarity flanks showed stronger and wider attraction than positive polarity flanks. The attraction zone for positive polarity flanks at $5 \pm 1\%$ SE contrast was about

3–3.5 min arc wide. At $17 \pm 4\%$ SE contrast, the zone extended to a width of about 6.5 min arc. The limits for negative polarity flanks were wider and were not investigated here. The interference of a nearby luminance-defined boundary on locating a color-defined boundary supports the view that color and luminance mechanisms interact in contributing to location processing (see also Rivest & Cavanagh, 1992), and that interactions between contours are dependent on their visibility and not how they are defined (Day, 1959).

The results also suggest positional acuity for boundaries is accomplished via a central representation that uses color and luminance information. Negative and positive luminance contrast polarity however appear to be weighted differently in this central representation. For the same amount of positive and negative contrast, the representation may attach more weight to negative contrast. The present interpretation is contrary to Badcock and Westheimer's (1985a) results with negative polarity flanks as well as the idea of a centroid that is oppositely sensitive to opposite polarity within a central zone. However, a number of factors may be contributing to the apparent discrepancy between their results and ours. In fact, once these factors are discussed below, the differences between their results and ours may not be too surprising.

One factor that could have contributed to the differences in results as a function of polarity is the difference in location judgment tasks. Badcock and Westheimer (1985a) used a jump detection task. A positive polarity vertical target line appeared for 500 msec. It was then immediately displaced to the left or right with either a positive or negative polarity luminance-defined flank appearing nearby at the same time. Thus, observers had to use the displacement of a luminance-defined line to judge its direction of motion. While a recent study suggests independent contributions of luminance sensitive and motion sensitive mechanisms to positional judgments (Banton & Levi, 1993), in Badcock and Westheimer's (1985a) study it was necessary to process the luminance information to be able to judge the target line's movement. The interdependence of luminance and motion processing was implicit in their jump detection task.

Another factor to consider is that in a jump detection task, the observer must compare the present target position to the previous position to decide the direction of displacement. This suggests the jump detection task may have also been influenced by figural aftereffects due to the offset target line that appeared before the jump (Kohler & Wallach, 1944). In the present study positional acuity was tested with the target, flank, and comparison line all present simultaneously.

Finally, the difference in results may be related to the difference in the displays, apart from the task. Badcock and Westheimer (1985a, b) used line flanks and targets, while the present study used boundaries. This distinction between contours or lines on the one hand, and boundaries/borders/edges on the other hand, may be an important distinction in terms of how the visual system treats the retinal discontinuity (e.g. see Badcock & Westheimer, 1985b). For example, for narrow thin line targets the centroid would occur at the center of the line, while for boundaries/borders/edges it would occur where the luminance change is most abrupt (Watt, 1988).

It should be noted that the present results are consistent with Grossberg's computational approach to modelling boundaries (Grossberg, 1987, 1992; Grossberg & Mingolla, 1987). The model (called FACADE) posits that boundaries are formed by a boundary contour system (BCS). This sytem works alongside a feature contour system (FCS) which fills in the space between the boundaries formed by the BCS. Featural filling-in is done by such visual cues as luminance and color. Boundaries formed by the BCS are invisible and visibilitiy occurs from operations in the FCS. Since the BCS does not form different types of boundaries for luminance and color featural filling, it makes sense that luminance-defined and color-defined boundaries could interact with each other. The present findings of an influence (i.e. attraction) of flank contrast but not contrast polarity would seem consistent with the FACADE model, where the BCS (beyond the level of the local contrast masks), is sensitive to the amount of contrast but not contrast polarity (see Grossberg, 1987, 1992).

In conclusion, the present study has shown that a luminance-defined boundary can attract a nearby color-defined boundary. This supports the notion that localization of boundaries is based on a central representation that may use color and luminance in a similar manner (Rivest & Cavanagh, 1992). The attraction effect appears to be sensitive to the amount of physical contrast in a nearby boundary in that attraction occurred over a wider range for higher contrast flanks. Also, negative polarity flanks showed stronger and a wider range of attraction than positive polarity flanks.

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