Contour interaction for low contrast acuity targets

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Abstract

Previous investigators reported the impairment of foveal visual acuity by nearby flanking targets (contour interaction) is reduced or eliminated when acuity is measured using low contrast targets. Unlike earlier studies, we compared contour interaction for high and low contrast acuity targets using flankers at fixed *angular* separations, rather than at specific multiples of the acuity target's stroke width. Percent correct letter identification was determined in 4 adult observers for computer generated, high and low contrast dark Sloan letters surrounded by 4 equal contrast flanking bars. Two low contrast targets were selected to reduce each observer's visual acuity by 0.2 and 0.4 logMAR. The crowding functions measured for high and low contrast letters are very similar when percent correct letter identification is plotted against the flanker separation in min arc. These results indicate that contour interaction of foveal acuity targets occurs within a fixed angular zone of a few min arc, regardless of the size or contrast of the acuity target.

Key words: contour interaction; crowding; contrast; acuity; Sloan letter

Highlights

- Previous work found that crowding at the fovea is reduced or absent with low contrast targets
- We investigated foveal contour interaction at three contrast levels for letters and flankers at fixed angular separations
- Similar amounts of contour interaction occur at the fovea for all target contrasts within a fixed angular zone

1. Introduction

Contour interaction is the degradation of single letter visual acuity by the presence of surrounding stimuli, such as flanking bars, and is thought to contribute, together with unstable and inaccurate fixational eye movements and attention, to the more general crowding effect seen in full chart letter acuity measurements (Flom, 1991, Flom, Weymouth & Kahneman, 1963b). Here, we will use the term “contour interaction” when the acuity stimulus consists of a single target (including flanking bars) and the term “ crowding” when more than a single target, such as a line of letters, is used. The spatial extent of contour interaction has been quantified for high contrast foveal acuity targets and found generally to be proportional to the minimum angle of resolution for both normal and amblyopic observers (Flom et al., 1963b, Hess & Jacobs, 1979, Simmers, Gray, McGraw & Winn, 1999, Stuart & Burian, 1962); but see Hess, Dakin, Tewfik & Brown, (2001) for exceptions. On the basis of this relationship, contour interaction is evaluated traditionally by plotting a measure of psychophysical performance, such as percent correct letter identification, against the flanker to target separation in optotype units, e.g., multiples of the letter stroke width. Contour interaction also has been shown to occur when the target and surrounding contours are presented to each eye separately, implicating a post retinal mechanism (Flom, Heath & Takahashi, 1963a, Masgoret, Asper, Alexander & Suttle, 2011, Taylor & Brown, 1972). For high contrast stimuli at the fovea, contour interaction in normal observers extends over short distances (Ehrt & Hess, 2005), on the order of about one letter size, or 4 - 6 min arc (Danilova & Bondarko, 2007 , Flom et al., 1963b, Jacobs, 1979, Takahashi, 1968, Wolford & Chambers, 1984).

A different result has been reported by most studies that assessed foveal acuity using low contrast targets. Specifically, Kothe and Regan (1990) found that the difference between isolated letter and Snellen acuity in children (i.e. their measure of crowding) was substantially less for low than for high contrast letters. Simmers and colleagues (1999) measured the percent correct recognition of Sloan letters as a function of flanking bar separation and reported an absence of contour interaction for low contrast foveal stimuli. Based on their results, Simmers et al concluded that contour interaction only occurs for high contrast acuity stimuli. Strasburger, Harvey & Rentschler, (1991) measured the contrast required to identify foveally presented numerals and reported little or no difference for isolated and crowded targets, the latter being the center element of a three number string. These authors also concluded that no crowding effect exists at the fovea. On the other hand, Pascal & Abadi, (1995) reported significant contour interaction in normal observers and patients with nystagmus for Landolt C stimuli with 94%, 34% and 12% contrast. Although Pascal and Abadi found contour interaction at all three contrast levels of their Landolt C stimuli, the magnitude of the effect was reduced for low contrast targets.

Unlike results obtained at the fovea, several studies reported robust crowding effects using low contrast stimuli in the periphery (Pelli, Palomares & Majaj, 2004, Strasburger et al., 1991, Tripathy & Cavanagh, 2002). An explanation for this discrepancy could lie in the relatively short distances over which contour interaction operates in the fovea (Toet & Levi, 1992, Tripathy & Cavanagh, 2002).There is evidence that, for an individual observer, the critical separation for contour interaction does not scale with the size of the acuity target, either in foveal or peripheral viewing (Chung, Levi & Legge, 2001, Danilova & Bondarko, 2007, Hariharan, Levi & Klein, 2005, Pelli et al., 2004, Tripathy & Cavanagh, 2002). Because acuity worsens as contrast is reduced, a low contrast target that is at or near the acuity threshold will be larger than a high contrast target. If the spatial extent of crowding does *not* increase with the letter size, then an appropriate comparison of contour interaction for high and low contrast acuity targets requires that flankers be presented at fixed *angular* separations, rather than at specific multiples of the acuity target’s stroke width. This was the strategy adopted in the experiment reported below.

2. Methods

2.1 Subjects

Four adult observers with normal or corrected to normal visual acuity (of at least 6/6), normal binocular vision and who were free from ocular disease participated in the experiment. Two of the observers were authors; the other two were unpaid well practiced volunteers. The research followed the tenets of the Declaration of Helsinki and approval of the experimental protocol was obtained from Anglia Ruskin University Human Research Ethics Committee. Informed consent was obtained before the experiments were conducted and after the nature and consequences of the study were explained.

2.2 Stimuli

Stimuli were generated by a commercially available visual acuity test program (Test Chart 2000Pro; Thomson Software Solutions, Herts, UK) using a standard PC platform and presented on a 19” PC monitor (Dell systems) under normal room illumination. The stimuli were high or low contrast dark Sloan letter optotypes displayed either in isolation or surrounded by 4 flanking bars of equal contrast, length and stroke width. When present, the flanking bars were 0.5, 1, 2, 3, or 5 edge to edge stroke widths from the high contrast optotype. The screen resolution was 1024 X 768 pixels (refreshed at 100Hz) with a background luminance of 100 cd/m^2. Optotype Weber contrast varied in the 3 experimental conditions from high (-89%) to low (range: -2.5% to -7.9% contrast across observers). The two lower contrast values were obtained based on the reduction of each observer’s visual acuity by 0.2 and 0.4 logMAR, respectively. On average, the lowest contrast was -3.8% and the middle contrast was -6.1%.

2.3 Procedures

Observers viewed the monitor monocularly after reflection from two optical quality front surface mirrors. Single Sloan letters were presented in the middle of the monitor and observers were required to identify each letter. The proportion of correctly identified letters (percent correct) was determined for each run of 25 trials. For each observer, initial trials using high contrast unflanked letters were employed to find the distance from the monitor where performance was consistently within the range of 80-94% correct. Once this distance was established it was fixed for that observer for all subsequent runs and conditions.

Subsequently, letter size was increased by 0.2 logMAR and 0.4 logMAR for the 2 lower contrast letter conditions, respectively. The contrast values for the lower contrast letter conditions were determined, separately for each observer, by finding the letter contrast that again produced unflanked performance between 80 and 94% correct. For the 2 lower contrast conditions, the five flanking bar separations were the same *angular* separations used for the high contrast condition. These edge to edge flanking bar separations ranged between 0.3 to 4.1 min arc for the different observers, which corresponded to a range between 0.15 and 3.2 stroke widths. In all conditions, the Sloan letters and flanking bars had the same contrast. For any one run, letters were presented at random and only a single flanking separation was used. The flanking separation was randomized between runs. Each datum reflects at least 2 runs per condition for each observer. Breaks were taken between conditions to minimize any fatigue effects.

3. Results

Percentage correct response for each contrast condition, averaged across the 4 observers, is plotted as a function of the edge to edge flanker separation in Figure 1. The error bars in the figure represent ±1 SE. In the top panel, flanker separation is represented as a multiple of the letter stroke width, whereas in the bottom panel flanker separation is given in min arc. The abscissa values in the lower panel represent the average of the angular separations for the four observers, whose unflanked high contrast acuity ranged from 6/3.6 to 6/4.9. As contrast was reduced, the angular size of the letters increased. Because the same flanker separations in min arc were used for all 3 contrast conditions, the flanker separations shown in the top panel of Fig. 1 decrease systematically when expressed as multiples of the stroke width.

Insert Figure 1 about here

Both panels of Fig. 1 show that the magnitude of the contour interaction effect, *i.e.*, the reduction in percentage correct performance, decreases similarly in the presence of flanking bars for the three contrast conditions. The top panel of Fig. 1 shows a systematic decrease in the extent of contour interaction as contrast is decreased. Consistent with previous reports, the high contrast letters exhibit contour interaction that extends to a flanker separation of at least 3 stroke widths (Danilova & Bondarko, 2007, Ehrt & Hess, 2005, Flom et al., 1963b, Jacobs, 1979). On the other hand, the extent of contour interaction for the lowest contrast condition is reduced to less than 2 stroke widths. However, the bottom panel of Fig. 1 illustrates that the extent of contour interaction, when plotted in min arc, is approximately equal under all contrast conditions.

4. Discussion

Our results indicate that both the magnitude and the angular extent of foveal contour interaction are approximately the same for high and low contrast foveal acuity targets. Even so, our data are consistent with previous studies that reported foveal crowding to be reduced or absent for low contrast stimuli (Kothe & Regan, 1990, Pascal & Abadi, 1995, Simmers et al., 1999, Strasburger et al., 1991). This is because previous authors generally presented both high and low contrast stimuli with the same proportional spacing between the acuity target and flankers. For observers to achieve similar performance for high and low contrast targets in the unflanked condition, the letter size must be increased when the contrast is reduced. If the letter to flanker spacing remains proportional, then the low contrast acuity targets used in previous studies were necessarily located further rightward on the abscissa in the lower panel of Figure 1, where the magnitude of crowding is reduced.

As indicated in section 2.2, above, we followed the convention established by Flom et al (Flom et al., 1963a, Flom et al., 1963b) and expressed letter to flanking bar distances in terms of the edge to edge separation. Several more recent studies have instead quantified the target to flanker separation in terms of the center to center distance (Chung et al., 2001, Levi, Klein & Hariharan, 2002, Strasburger et al., 1991). Our use of edge to edge separation is based in part on the studies of Takahashi, (1968), who investigated the influence of flanking bars on two line resolution. Takahashi determined that the threshold elevating effect of flanking bars on a narrow two line resolution target is maximal when the edge to edge separation is approximately 2.5 - 3 min arc and declines to essentially zero when the separation is 4 - 5 min arc. Importantly, the edge to edge separations that produced (1) the maximum threshold elevation and (2) beyond which contour interaction disappears were the same for flanking bars that were 1.4 and 4.3 min arc wide, and even when each flanking bar extended to the outer margin of the stimulus display (approximately 1 deg). A second justification for using edge to edge separation is evident if the data in the lower panel of Fig. 1 are replotted in terms of the center to center target to flanker separation. Because center to center separation increases with the size of the acuity target, a plot of our data using center to center separation on the abscissa yields functions for the different contrast conditions that are similar to those in the top panel and no longer superimposed. Although we present our results in terms of edge to edge separation, it is possible that center to center separation is a more appropriate metric when the flanking targets do not have well defined edges, i.e., when blurred or spatially filtered targets are used.

The results reported here provide added support for the contention that foveal contour interaction can not be explained on the basis of lateral masking (Chung et al., 2001, Danilova & Bondarko, 2007, Ehrt & Hess, 2005, Nandy & Tjan, 2007). An explanation that is based on masking would predict that the contour interaction function should scale with the size of the acuity target. Contrary to this prediction, our data indicate clearly that contour interaction occurs over approximately the same angular extent for high and low contrast letters that differ in size by 0.4 log units (2.5 times).

Finally, the demonstration that substantial contour interaction occurs for low contrast foveal targets eliminates a potential distinction between the mechanisms that generate foveal and peripheral contour interaction. Although it is clear that the magnitude and extent of contour interaction are greater in the retinal periphery than in the fovea (Bouma, 1970, Jacobs, 1979, Leat, Li & Epp, 1999, Takahashi, 1968, Toet & Levi, 1992, Wolford & Chambers, 1984) an implication of the results reported here is that the differences between peripheral and foveal contour interaction may be more quantitative than qualitative.

Conclusion

Similar amounts of contour interaction occur at the fovea for all target contrasts within a fixed angular zone.

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Figure Caption

Figure 1: Percentage correct responses averaged across observers and plotted as a function of flanker separation in stroke widths (top panel) and min arc (bottom panel) for the high (diamonds), middle (triangles) and low (squares) contrast conditions. Error bars represent ±1 SE. Data at ‘INF’ on the abscissa represent the unflanked condition.