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Foveal 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 log MAR. The contour interaction 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.

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, 1963). 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, Weymouth, & Kahneman, 1963; Hess & Jacobs, 1979; Simmers et al., 1999; Stuart & Burian, 1962); but see (Hess et al., 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, 1963; Masgoret et al., 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, Weymouth, & Kahneman, 1963; 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, Giaschi et al. (1993) found a difference between isolated letter and Snellen acuity in normal adults (i.e. their measure of crowding) for high but not for low contrast letters. Simmers et al. (1999) determined the percent correct recognition of Sloan letters as a function of flanking bar separation and reported an absence of contour interaction in both normal and amblyopic observers 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, and 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 and Abadi (1995) reported that flanking bars with a separation of one stroke width produced 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.

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Unlike results obtained at the fovea, several studies reported robust crowding effects using low contrast stimuli in the periphery (Pelli, Palomares, & Majaj, 2004; Strasburger, Harvey, & Rentschler, 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, Palomares, & Majaj, 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 male 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 × 768 pixels (refreshed at 100 Hz) 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, with appropriate refractive correction if needed, 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 viewing time was unlimited. 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 each observer (AC: 11.5 m; EO: 11 m; HB and JS: 10.7 m) 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 and 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, corresponding to a minimum of 50 letter presentations, per condition for each observer. Breaks were taken between conditions to minimize any fatigue effects.

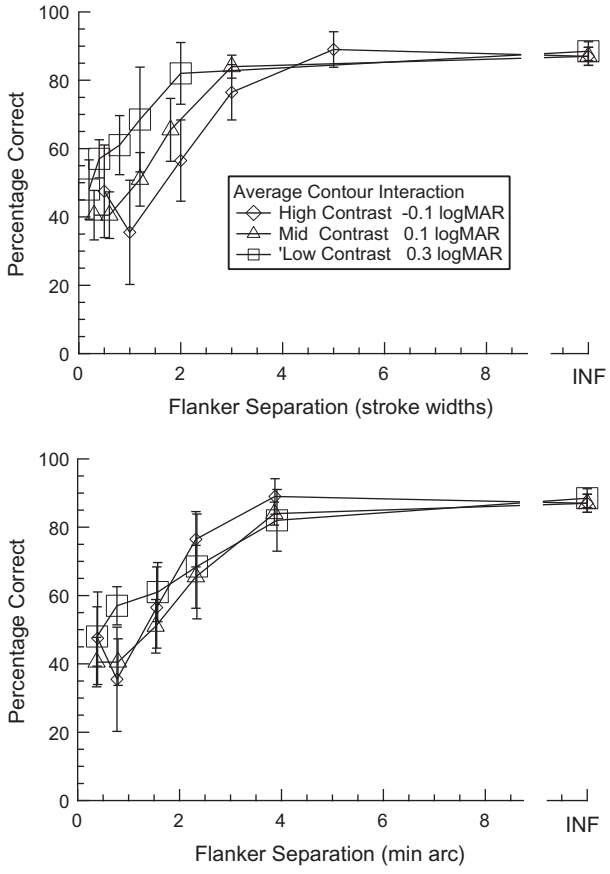

Fig. 1. Percentage correct responses averaged across observers and plotted as a function of flanker separation in stroke widths (top panel) and min arc (bottom panel) for the high (diamonds), middle (triangles) and low (squares) contrast conditions. The letter sizes specified in text box in the top panel represent the average logMAR values for the 4 observers. Similarly, the flanker separations plotted on the abscissa in the bottom panel are the average edge-to-edge separations for the 4 observers. Error bars represent ±1 SE. Data at 'INF' on the abscissa represent the unflanked condition.