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Contour interaction for foveal acuity targets at different luminances

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ABSTRACT

Single-letter visual acuity is impaired by nearby flanking stimuli, a phenomenon known as contour interaction. We showed previously that when foveal acuity is degraded by a reduction of letter contrast, both the magnitude and angular spatial extent of foveal contour interaction remain unchanged. In this study, we asked whether contour interaction also remains unchanged when foveal visual acuity is degraded by a reduction of the target's background luminance.

Percent correct letter identification was measured for isolated, near-threshold black Sloan letters and for letters surrounded by 4 flanking bars in 10 normal observers, 5 at Anglia Ruskin University, UK (ARU) and 5 at Palacky University, Czech Republic (PU). A stepwise reduction in the background luminance over 3 log units resulted in an approximately threefold increase in the near-threshold letter size. At each background luminance, black flanking bars with a width equal to 1 letter stroke were presented at separations between approximately 0.45 and 4.5 min arc (ARU) or 0.32 and 3.2 min arc (PU).

The results indicate that the angular *extent* of contour interaction remains unchanged at approximately 4 min arc at all background luminances. On the other hand, the *magnitude* of contour interaction decreases systematically as luminance is reduced, from approximately a 50% reduction to a 30% reduction in percent correct. The constant angular extent and decreasing magnitude of contour interaction with a reduction of background luminance suggest foveal contour interaction is mediated by luminance-dependent lateral inhibition within a fixed angular region.

1. Introduction

Contour interaction is the reduction of performance on visual spatial tasks, such as letter acuity, that results from the presence of nearby flanking contours. Across observers, the lateral extent of contour interaction generally is scaled in proportion to the observer's visual acuity (Flom, Weymouth, & Kahneman, 1963; Hess & Jacobs, 1979; Simmers et al., 1999; Stuart & Burian, 1962; for exceptions see Hess et al., 2001). Within observers, the extent of contour interaction increases from the fovea to the peripheral retina, more rapidly than the worsening of non-foveal visual acuity (Bouma, 1970; Hess et al., 2000; Jacobs, 1979; Latham & Whitaker, 1996; Leat, Li, & Epp, 1999; Toet & Levi, 1992). However, recent studies demonstrate that the extent of contour interaction measured at a specific retinal location does *not* scale with the size of the target, but remains essentially fixed (Danilova & Bondarko, 2007; Pelli, Palomares, & Majaj, 2004; Siderov, Waugh, & Bedell, 2013; Tripathy & Cavanagh, 2002). For example, Siderov et al. demonstrated that the lateral extent of foveal contour interaction, expressed in units of min arc, remains the same for targets of high and low contrast, for which foveal acuity differs by up to 2.5 times (0.4 log units). This study showed also that the magnitude of foveal contour interaction, i.e., the maximum reduction in percent correct letter identification compared to the condition with no flanking targets, remains the same for high- and low-contrast acuity targets.

The purpose of the present study was to examine how the magnitude and extent of contour interaction depend on the luminance of a foveal acuity target. Although acuity is highly dependent on target luminance (e.g., Mandelbaum & Sloan, 1947; Shlaer, 1937), the influence of luminance on contour interaction has hardly been addressed. Takahashi (1968) measured foveal contour interaction using a two-line resolution task. Her results for one observer revealed a decrease in the magnitude of contour interaction but no change in its angular extent, as the luminance was reduced from 178 to 1.3 mL (567–4.1 cd/m^2). Matteucci, Maraini, and Peralta (1963) reported that the magnitude of 'separation difficulty' in amblyopic eyes, measured as the difference in visual acuity for lines of letters on a chart compared to isolated optotypes, is smal-

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ler for acuity charts presented at a mesopic (2 lux) compared to a photopic (120 lux) level of illuminance. Simunovic and Calver (2004) assessed contour interaction for scotopic Landolt C targets that were presented at an eccentricity of 10 deg. They found that contour interaction for different sized targets (range ≈ 1.2–1.9 deg) occurs within an approximately fixed spatial extent, on the order of 0.25 deg. Simunovic and Calver noted that this value is smaller than the extent of contour interaction that has been reported using peripheral photopic targets (e.g., Bouma, 1970; Jacobs, 1979; Tripathy & Cavanagh, 2002), but did not present comparison data for their subjects using other target luminances.

Our study examined the extent and magnitude of contour interaction produced by flanking bars on dark Sloan letters, presented at the fovea for a range of background luminances. Similar experiments were conducted concurrently at Anglia Ruskin University, Cambridge, UK (ARU) and at Palacky University, Olomouc, Czech Republic (PU). The results of both experiments indicate that the lateral extent of foveal contour interaction remains unchanged, but the magnitude of contour interaction decreases systematically as the background luminance of the acuity target is reduced.

2. Methods

A total of 10 observers participated in this study, 5 at ARU (3 female and two male, age range = 21–64 years old) and 5 at PU (5 women, age range = 22–24 years old). All of the observers had normal eye movement control, were free from ocular pathology, and had better than 6/6 corrected visual acuity in each eye. The research was conducted in accordance with the tenets of the Declaration of Helsinki. Appropriate institutional review board approval was obtained at each institution and written informed consent was obtained from each observer before participation. When required, the observers wore appropriate lens correction during testing.

The methods used in both labs were similar to those described previously by Siderov, Waugh, and Bedell (2013). Dark Sloan letters (C D H K N O R S V Z) with a Weber contrast of −89% were presented one at a time on a bright background, either in isolation or surrounded by 4 flanking bars with the same contrast, length, and stroke width as the surrounded letter. The stimuli were generated using Test Chart 2000Pro software (Thomson Software Solutions, Herts, UK) and displayed on a PC monitor. The display monitor at ARU measured 19 inches diagonally, with 1024 × 768 pixel resolution, a refresh rate of 100 Hz, and an unattenuated luminance of 108 cd/m^2. A 22-in. monitor was used at PU, with 1680 × 1050 pixel resolution, a frame rate of 60 Hz, and an unattenuated luminance of 195 cd/m^2. Ambient illumination in the experimental room at both experimental venues (produced primarily by luminance from the display monitor) remained dim. Testing was performed monocularly and each letter was presented until the observer made a verbal response.

Percent correct letter identification was determined in the absence of flanking bars and for 5 edge-to-edge separations between the letter and the surrounding flanking bars. The same 5 *angular* flanking separations were used for each observer for all background luminances, which spanned a range of 3 log units (see below). These letter-to-flanking-bar separations corresponded to 0.5, 1, 2, 3 and 5 stroke widths of the Sloan letters that were presented in the highest luminance condition, designated 0 ND. In the 0 ND condition, the letter size and viewing distance were selected for each observer to achieve approximately 80% correct when the letters were presented without flanking bars (range of angular letter sizes across observers = 3.2–4.75 min arc; range of viewing distances = 10–12 m). As the background luminance was reduced, the physical size of the targets on the display screen was increased to maintain approximately 80% correct identification in the no-flank condition. On average, a reduction of the background luminance by 3 log units (3 ND) required an increase in the angular letter size corresponding to 0.56 logMAR for the observers at ARU and 0.53 logMAR for the observers at PU (Table 1). Because of the increase in letter size as the background luminance was reduced, the edge-to-edge separations of the flanking bars at the lowest luminance, when expressed in multiples of the letter stroke width, were approximately 3.5 times smaller than the values listed above for the 0 ND condition (average values listed in Table 1).

For each observer, percent correct letter identification was determined from a total of 100–200 presentations per condition, presented in blocks of 25 for each combination of background luminance and flanking-bar separation. For all observers, the data for the 0 ND condition were collected first. The order of the other 3 background luminances varied pseudo-randomly among the observers tested at each site, with the trials for all 5 flanking-bar separations for one background luminance completed before the next luminance condition was begun. Observers were provided at least 10 min to adapt before the start of data collection at the two lowest luminance levels.

To vary the luminance of the acuity and background stimuli, the observers viewed through glass neutral density filters (Thorlabs; http://www.thorlabs.com/) with nominal values of 1, 2 and 3 ND, mounted in a pair of light-tight goggles that also included an opaque shield to occlude the non-viewing eye. The measured luminances of the background field without (0 ND) and with the neutral density filters (1, 2 and 3 ND) were 108, 12.1, 0.82 and 0.09 cd/m^2 at ARU and 195, 19.7, 1.46 and 0.21 cd/m^2 at PU. A difference between the testing conditions at the two institutions is that the observers at PU viewed the acuity targets through a 2.5 mm artificial pupil, whereas the observers at ARU viewed using their natural pupil. All observers were asked to centrally fixate the acuity targets at all luminance levels.

Because of the difference in the testing conditions, the percent correct letter-identification data obtained at ARU and PU were analyzed using separate repeated-measures ANOVAs. Where necessary, the levels of statistical significance reported in section 3, below, include a Huynh–Feldt correction for departures from sphericity.

3. Results

The two panels of Fig. 1 show the average values of percent correct letter identification for the observers at ARU (top) and PU (bottom) as a function of the edge-to-edge flanking-bar separation in min arc. Contour interaction is revealed by the reduced values of percent correct for flank separations less than approximately

Table 1
Average letter sizes and minimum and maximum flanker separations (gaps) for each of the luminance conditions for the two groups of observers.

	ARU				PU			
	0 ND	1 ND	2 ND	3 ND	0 ND	1 ND	2 ND	3 ND
Average letter size (min arc)	4.5	5.4	9.1	14.5	3.2	3.2	4.6	11.0
Min gap size (% letter size)	10	8	5	3	10	10	7	3
Max gap size (% letter size)	100	83	50	31	100	100	69	29