



## Contour interaction in amblyopia: scale selection

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### Abstract

It has been known for some time that visual acuity in amblyopia is higher for single letters than for letters in a row (termed crowding). Early work showed that this could not be accounted for on the basis of the destructive interaction of adjacent contours (termed contour interaction), which was shown to be, in resolution units, normal in amblyopia. We have re-examined this issue using a letter stimulus that is modulated about a mean light level. This allows an examination of the effects of contrast polarity and spatial filtering within the contour interaction paradigm. We show that the majority of strabismic amblyopes that we investigated exhibit an anomalous contour interaction that, in some cases, was dependent on the contrast polarity of the flanking stimuli. Furthermore, we show that while amblyopes do select the optimum scale of analysis for unflanked stimuli, they do not select the optimum scale of analysis for flanked stimuli. For reasons that may have to do with their poorer shape discrimination, they select a non-optimal scale to process flanked stimuli. © 2001 Elsevier Science Ltd. All rights reserved.

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### 1. Introduction

Humans with amblyopia not only have reduced acuity, but also single letter acuity is usually better than linear acuity (letters in a line). In the clinic, both measures of acuity are recorded and individually monitored with treatment. This difference between the acuity for letters presented singly as opposed to within a row of other letters is termed ‘crowding’ and is characteristic of amblyopia (Stuart & Burian, 1962).

To a lesser extent this is also the case for normal observers, with best acuity being obtained with single letters (Muller, 1951; Flom, Weymouth, & Kahneman, 1963a; Loomis, 1978; Strasburger, Harvey, & Rentschler, 1991). The detrimental effect of the proximity of nearby letters or contours (Bouma, 1970; Loomis, 1978; Toet & Levi, 1992) is referred to as contour interaction in the visual literature and has been studied by examining the effect of the proximity of nearby contours on the detectability of a single letter (Flom et al., 1963a; Flom, Heath, & Takahashi, 1963b; Flom,

1991). These studies clearly show that there exists a region within about two gap widths of the test letter, where adjacent contours produce measurable interference. Similar studies in amblyopia have provided evidence for the same form of interference relative to the amblyopes’ poorer acuity (Flom et al., 1963a; Hess & Jacobs, 1979; Simmers, Gray, McGraw, & Winn, 1999). This suggests that lateral interactions in amblyopia may be normal and that previous clinical reports of enhanced crowding effects in amblyopia may be simply due to the poorer acuity of amblyopes combined with the lack of proportional spacing for letters of different size in conventional clinical acuity charts, or to poor control of fixation (Kothe & Regan, 1990; Regan, Giaschi, Kraft, & Kothe, 1992), or divided attention (Flom, 1991). If contour interaction is indeed normal in amblyopia, then this questions the relevance of the recently reported anomalous lateral interactions in amblyopia (Polat, Sagi, & Norcia, 1997).

Recently, we have been able to gain some insights into the mechanisms underlying contour interaction by modulating letter stimuli about a mean light level. Such a stimulus affords one the opportunity to examine the influence of adjacent contours of opposite polarity, as

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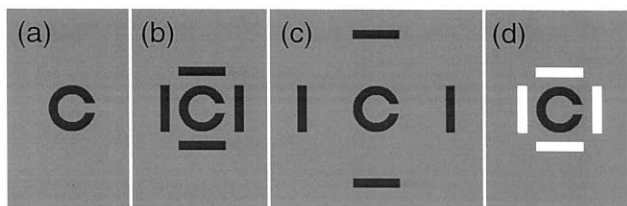


Fig. 1. A subset of the stimuli used in the contour interaction task.

well as the ability to use spatial filtering to examine what spatial scale the visual system uses for analysis (Hess, Dakin, & Kapoor, 2000a; Hess, Dakin, Kapoor, & Tewfik, 2000b). These studies have shown that there are important changes in the spatial scale of analysis associated with the introduction of adjacent contours (i.e. contour interaction) in foveal and peripheral vision. For foveal vision, these are small ( $\approx 0.5$  octaves) and may be accounted for by the physics of the stimulus (though not in the dichoptic case, see Flom et al., 1963b). In peripheral vision, contour interaction has a neural basis and involves a much larger change in the spatial scale of analysis ( $\approx 1$  octave).

In the present study, we wanted to address three questions that are relevant to the mechanisms underlying contour interaction in amblyopia. (1) Is the extent of contour interaction, in resolution units, abnormal in amblyopia? (2) Are these interactions in amblyopia due to the physics of the stimulus or to neural interactions? (3) Are there associated changes in the spatial scale of analysis when adjacent contours are introduced and are these what one would predict for the eccentric region used for fixation? In brief, the results suggest that amblyopes exhibit anomalous contour interaction, even when measured in resolution units. Furthermore, the form of this abnormality varies greatly within the population of strabismic amblyopes that we tested. All of these effects are neural and are associated with relatively large changes in the spatial scale of analysis, well beyond that expected from the eccentric region of retina used for fixation.

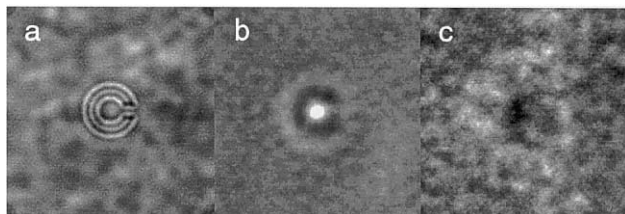


Fig. 2. Examples of an unflanked C spatially filtered (see Section 2) at three different scales ( $\sigma$  of 18, 8.9 and 2.39 pixels, corresponding to 0.7, 1.6 and 5.6 cycles per letter).

## 2. Methods

### 2.1. Apparatus

An Apple Macintosh computer controlled stimulus presentation and recorded subjects' responses. Programs for running the experiment were written in the Matlab programming environment (Mathworks Ltd.) using Psychtoolbox code (Brainard, 1997). Stimuli were displayed on a 21" Nanao FlexScan monochrome monitor, with a frame refresh rate of 75 Hz. Pseudo 12-bit contrast accuracy was achieved by electronically combining the RGB outputs from the computer using a video attenuator (Pelli & Zhang, 1991).

### 2.2. Stimuli

Landolt C stimuli were based on an annulus with a stroke width of 11 pixels and a total diameter of 55 pixels. An 11 pixel-wide gap was inserted into the annulus at either the top, bottom, left or right position on the annulus. Outline edges of the figure were not anti-aliased. In the flanked conditions, two horizontal ( $55 \times 11$  pixel) bars were positioned above and below the C and two vertical bars positioned to its left and right. Flank distance was defined as the distance from the edge of the bar closest to the C, to the outer edge of the annulus defining the C. The standard stimulus appeared on a mid-grey ( $45 \text{ cd/m}^2$ ) background. Flanks either appeared black (same contrast polarity condition) or white ( $90 \text{ cd/m}^2$ ; opposite contrast polarity condition). Fig. 1 shows a subset of the stimuli used.

We used an isotropic Laplacian-of-Gaussian filter ( $\sigma$  ranged 4.78 to 18 pixels in steps of  $\sqrt{2}$ ) to define a region of the broadband image (Landolt C as well as adjacent bars) where the phases were to be 'filtered'.

The above filter defined a spatial frequency region where local phase components were allowed to pass unaltered. Outside this specified passband, phase components were scrambled (hence stochastic in nature). 'Scrambling' was achieved by randomizing the phase component (by replacing that value with a random value between 0 and  $360^\circ$ ) of the image (while maintaining local power) at certain spatial frequencies. The resulting image has the same global amplitude spectrum as the original; only the phase structure has been altered. An example of such filtering is seen in Fig. 2 for an unflanked Landolt C.

### 2.3. Procedure

The task that was performed was a single-interval four-alternative forced task. Amblyopes were presented with a Landolt C stimulus for 500 ms and required to judge whether the gap was in the top, bottom, left or right position. We first measured the amblyopes' ability

Table 1  
Clinical details of amblyopic subjects

Subject	Age/sex	Eye	Refraction	Letter acuity	Fixation	Ocular alignment
A	18/M	RE	−4.50/−5.00 × 030	6/24	3° nasal	5° RET
Trab		LE	−1.75/−1.75 × 150	6/6	Centered	
Aniso						
T	40/F	RE	Plano	6/6	Centered	5° LET
Trab		LE	+3.25/−3.25 × 180	6/60	3° nasal	
Aniso						
B	52/M	RE	+0.50/−0.50 × 160	6/5	Centered	5° LET
Trab		LE	+1.25/−0.25 × 180	6/180	4° nasal	
W	50/M	RE	+3.50 DS	6/90	0.5–1° nasal	2° RET
Trab		LE	−3.50/−1.00 × 120	6/5	Centered	
Aniso						
G	17/F	RE	+1.75 DS	6/30	2° nasal	10° RET
Trab		LE	+1.50 DS	6/6	Centered	
L	48/F	RE	+0.75 DS	6/4.5	Centered	3° LHT
Trab		LE	+0.75/−0.25 × 140	6/30	2.5° nasal	
P	40/F	RE	−5.25/−2.25 × 180	6/18	1.5° temporal	5° RXT
Trab		LE	−3.00/−1.75 × 170	6/6	Centered	Intermittent
Aniso						
E	65/M	RE	+2.00 DS	6/5	Centered	9° LXT
Trab		LE	+2.50 DS	6/24	Centered	

to perform this task with unflanked Cs at a variety of viewing distances, in order to determine the minimum angle of resolution (MAR) of the gap for each subject for this task. The viewing distance that produced 85–95% correct gap-position discrimination was then used in all subsequent conditions (this performance range was selected to avoid ceiling and floor effects).

Runs consisted of 100 trials, but breaks were taken within runs to alleviate the effects of fatigue. Graphs show percent correct performance (from single runs of 100 presentations). We collected responses for the correct identification of the position of the gap (up, down, right, left) as well as for the correct orientation (horizontal, vertical). A comparison of these two allows one to estimate the importance of positional uncertainty in the task.

#### 2.4. Modeling

The procedure for predicting the spatial frequency is based on the idea that performing the position discrimination task involves two sub-tasks. First, one determines the orientation of the gap (either horizontal or vertical) and then one determines its position (either left/right or above/below). The first stage is assumed to be the point at which spatial frequency selection takes place. If that is true, Bondarko and Danilova (1997) reason that the most sensible spatial frequency for subjects to use when performing the position discrimination task is one that maximizes the difference in

Fourier power at horizontal and vertical orientations. This can be determined by simply computing the discrete Fourier power spectrum of a stimulus, plotting the absolute difference between the horizontal and the vertical components (as a function of spatial frequency) and selecting the frequency that maximizes this function.

#### 2.5. Clinical data

Eight strabismic amblyopes were tested, all had been refracted and wore their optimal corrections. Their clinical information is provided in Table 1 below.

### 3. Results

Typical foveal and parafoveal, contour interaction effects for this Landolt C stimulus for normal observers have been reported elsewhere (Hess et al., 2000a,b). In normal vision for foveal and parafoveal (out to 4°) stimulation, contour interaction for our stimulus is only seen when the adjacent contours are of the same polarity as the test stimulus and only when the flanks are at or within 2 bar widths separation. These effects can be adequately explained by the physics of the stimulus and, at least for non-dichoptic presentations (Flom et al., 1963b), one need not invoke neural explanations (Hess et al., 2000a).

Compare this situation for normal vision to similar measurements on strabismic amblyopes, presented in Fig. 3. There are two important differences between the

normal observer and amblyopes — the extent of contour interaction and its dependence on contrast polarity. For some amblyopes (BB, MG, JL, CP and CT),

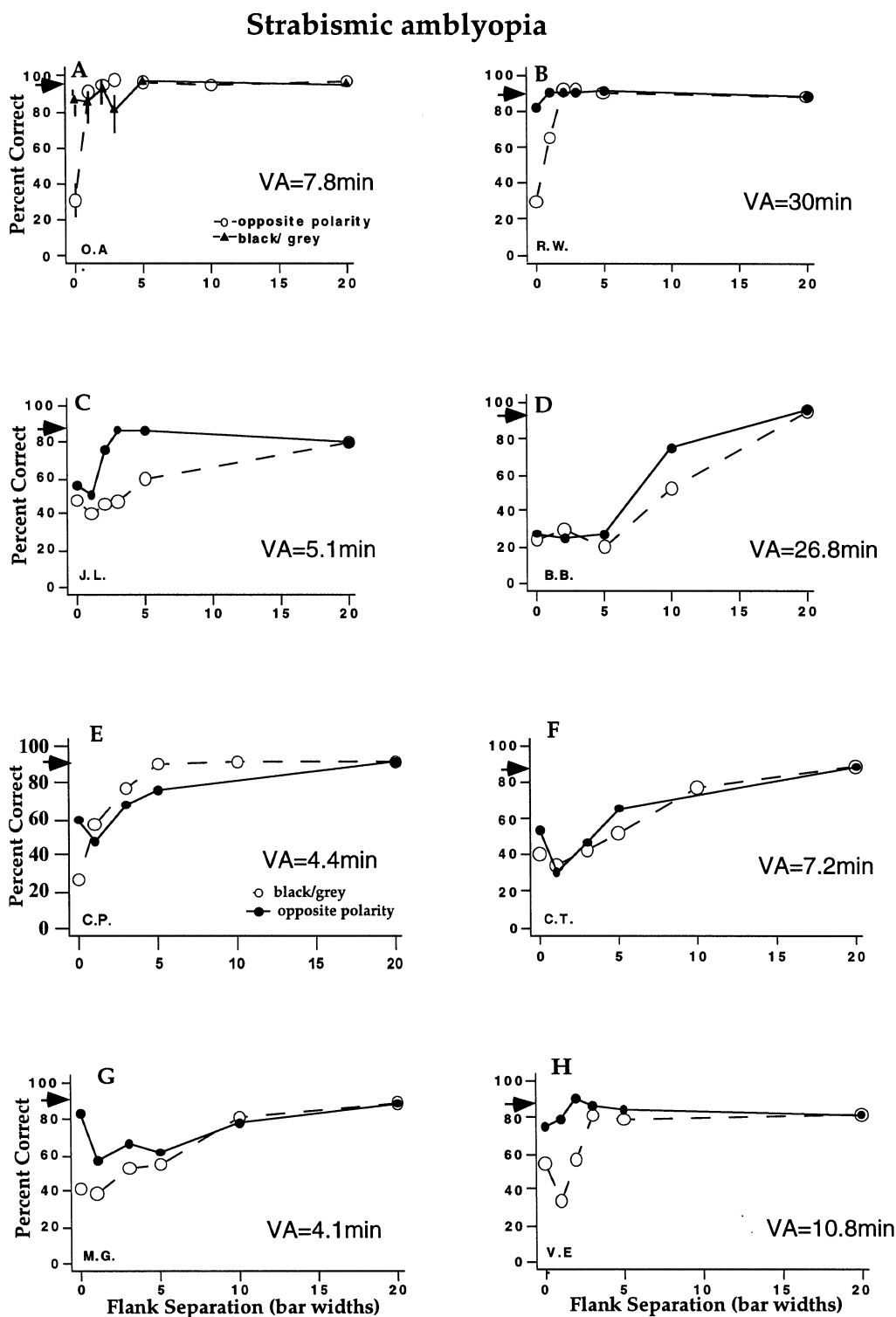


Fig. 3. Percent correct for the identification of the position (up, down, left, right) of a gap in a Landolt C is plotted as a function of the distance of lateral contours (see Fig. 1). Results are displayed for eight strabismic amblyopes for the same (unfilled symbols) and reverse contrast polarity flanking contours (filled symbols). The unflanked acuity is inset in each figure (normal value = 1.02 min). Where they are greater than the symbol size, 95% confidence limits are displayed in panel A.

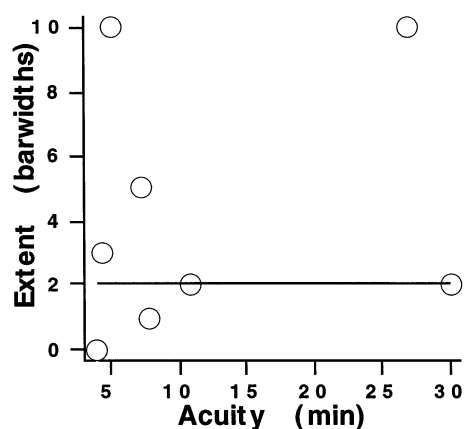


Fig. 4. Scatter plot of the extent of the contour interaction zone (in bar widths) for the flanked Landolt C against the absolute acuity (minutes of arc) for the unflanked Landolt C. The horizontal line represents the conclusions of a number of previous studies (see text). The correlation between these two measures is weak ( $r = 0.21$ ). The two amblyopes who contributed most to decorrelating these two measures were RW (bottom right most data point) who had poor acuity and normal contour interaction and JL (top leftmost data point) who had relatively good acuity, but anomalous contour interaction.

adjacent contours produced interference over much larger distances (unfilled symbols in Fig. 3; note that these are already plotted in units relative to the amblyopes unflanked acuity, which is inset in this figure). In some cases, this interference extends out to 10 bar widths (CT, JL, BB). For other amblyopes (OA, RW and VE), the zone where adjacent contours produced interference was similar to that previously found for normal observers (Flom et al., 1963a; Hess et al., 2000a,b). In some cases, only contours of the same polarity produced interference (OA, RW and VE), whereas for the majority of subjects, contour interaction, though differing in extent, occurred regardless of the contrast polarity of the adjacent contour (JL, BB, CP, CT and MG).

There is no doubt that contour interaction is abnormal in amblyopia even when their acuity loss is taken into account and that the form of the abnormality varies in different amblyopes. To ascertain whether the degree of contour interaction bears a direct relationship with the depth of amblyopia, we plotted the extent of the lateral interference region in bar widths against the unflanked acuity in minutes of arc (Fig. 4). The horizontal line represents the conclusions from previous studies (Flom et al., 1963a; Hess & Jacobs, 1979; Simmers et al., 1999), where the extent of the interaction region in amblyopia was of a fixed relative size. The correlation between the extent of the interaction zone and the acuity deficit in amblyopia is weak ( $r = 0.21$ ).

In order to assess the spatial scale of analysis used by the amblyopic visual system and to determine whether

it is different to that of a normal eye in either unflanked or flanked conditions, we measured performance for spatially filtered versions of our the stimuli (see Section 2 and Fig. 2, for an example). In the following figures we plot the percent correct performance for flanked and unflanked Landolt C stimuli that have been bandpass filtered. In each of these figures, the horizontal dashed line represents performance in the unfiltered case and the vertical dashed line represents the physical prediction, namely where the peak is in the Fourier difference spectrum (Bondarko & Danilova, 1997; Hess et al., 2000a). This is located at  $\approx 1.2$  cycles per letter. For normal observers, the spatial frequency band that is carrying the most relevant information and for which performance is best coincides with the physical prediction at  $\approx 1.2$  cycles per letter. This is true for the fovea (Hess et al., 2000a) and for para-foveal eccentricities relevant to the eccentric fixation range exhibited by these amblyopes (Hess et al., 2000b). In normal observers, adjacent bars within 2 bar widths of the Landolt C result in a shift of the most relevant spatial frequency band to spatial frequencies a half octave higher, in accordance with the physical prediction. Adjacent bars of opposite contrast polarity produce no interference and performance is again best at a spatial frequency band centered on 1.2 cycles per letter, again in accordance with the physical prediction.

A comparison of these results for strabismic amblyopes with previous results for normal observers (Hess et al., 2000b) reveals a number of similarities and a number of differences. These results (Figs. 5–8) for amblyopes are summarized in Fig. 9 where the octave difference in the masking functions are plotted relative to those previously found for normal observers for the unflanked, close flanked (chosen for each amblyope to represent the case of significant contour interaction, but where performance is sufficiently above chance to make meaningful measurements of its scale dependence) and the opposite polarity conditions. All amblyopes exhibited a similar pattern of masking in the unflanked condition compared to normal observers. The peak was located at  $\approx 1.2$  cycles per letter (indicated by the vertical dashed line) and its height was similar to that found in the unfiltered, unflanked case. This suggests that the most relevant spatial frequencies for detection of the unflanked Landolt C are  $\approx 1.2$  cycles per letter, as suggested by Bondarko and Danilova (1997) (but also see Alexander, 1994; Soloman & Pelli 1994). All amblyopes exhibited similar masking functions in the unflanked and opposite-polarity flanked conditions, indicating that the spatial scale of analysis was identical in these two conditions. This appeared to be unconnected with whether there was a performance decrement in the latter condition. An important difference between normal and amblyopic performance comes about in the same polarity, close flanked condition. In

the majority of cases (OA, VE, CT, MG, BB, RW), the peak of the masking function moves to higher spatial frequencies by as much as an octave, suggesting a shift in the scale of analysis to much higher spatial frequencies. In one case (JL), the position of the masking function was unaltered by adjacent contours and in another case (CP), the spatial scale of analysis shifted to lower spatial frequencies in the presence of flanking contours. Thus, in all but one case (JL), contour interaction in amblyopia, whether it is abnormal in extent or not, is associated with anomalous shifts in the spatial scale of analysis.

In the above analysis, we have not considered the influence of positional uncertainty which is known to be an important feature of amblyopic vision (Bedell & Flom, 1981, 1983; Levi & Klein, 1982, 1983, 1985; Lagreze & Sireteanu, 1991, 1992; Hess & Holliday, 1992; Demanins & Hess, 1996). The present task contains not only an orientational component (horizontal versus vertical) but also a positional component (up/down versus right/left). To assess the possible influence of positional uncertainty on our task, we recorded not only when subjects correctly identified the position (4afc: up, down, right, left) of the gap

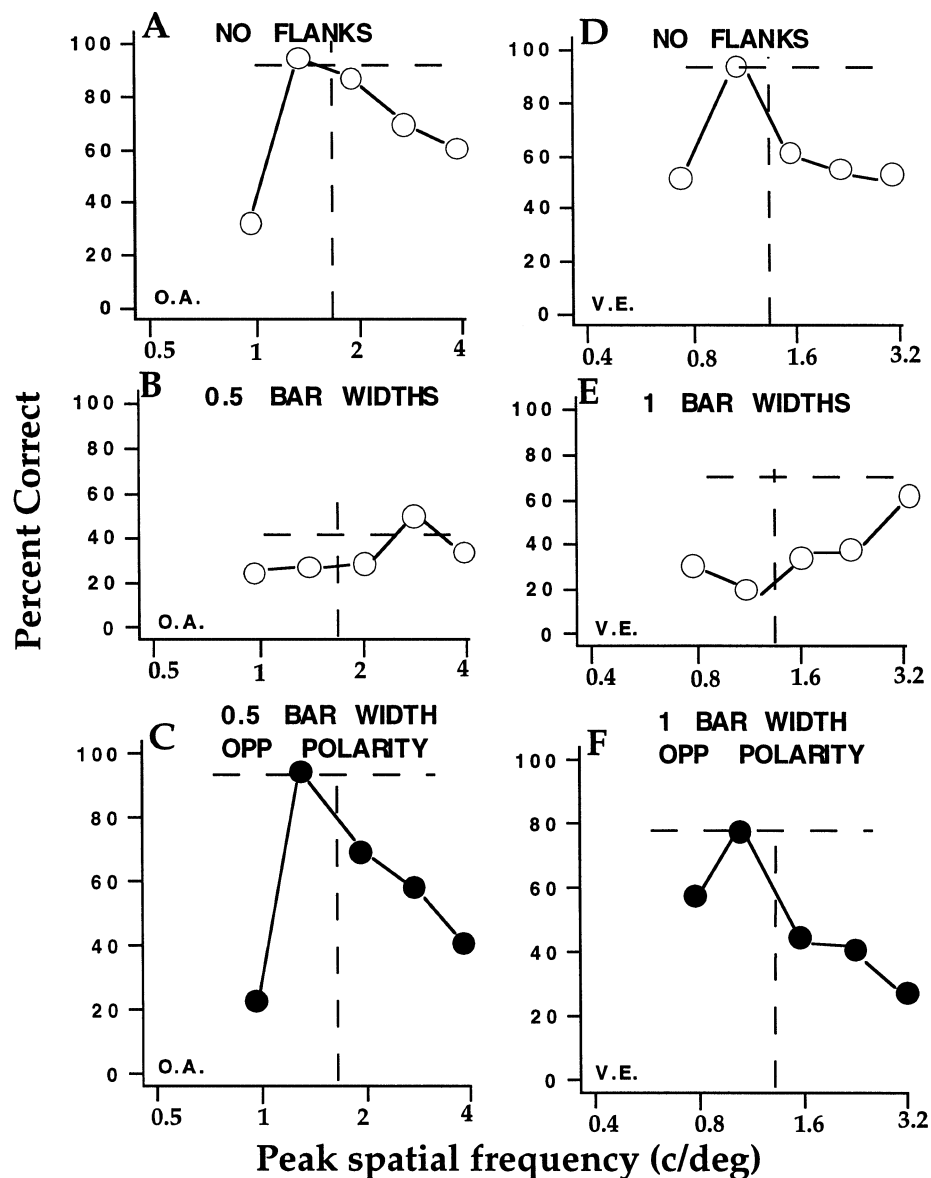


Fig. 5. Foveal bandpass-filter masking functions for Landolt C identification for two strabismic amblyopes OA and VE (unfilled circles for unflanked (a,d); same polarity flanks at bar width separation indicated (b,e); and opposite polarity (c,f) flanks). Percent correct is plotted against the peak spatial frequency of the passband in cycles per degree. The horizontal dashed line gives the unfiltered performance, whereas the vertical dashed lines give the predictions for the peak masking location based solely on the difference spectra (see text). The predictions when converted from c/letter to c/deg differ slightly for each subject because their absolute acuity is not the same (see Hess et al., 2000a).

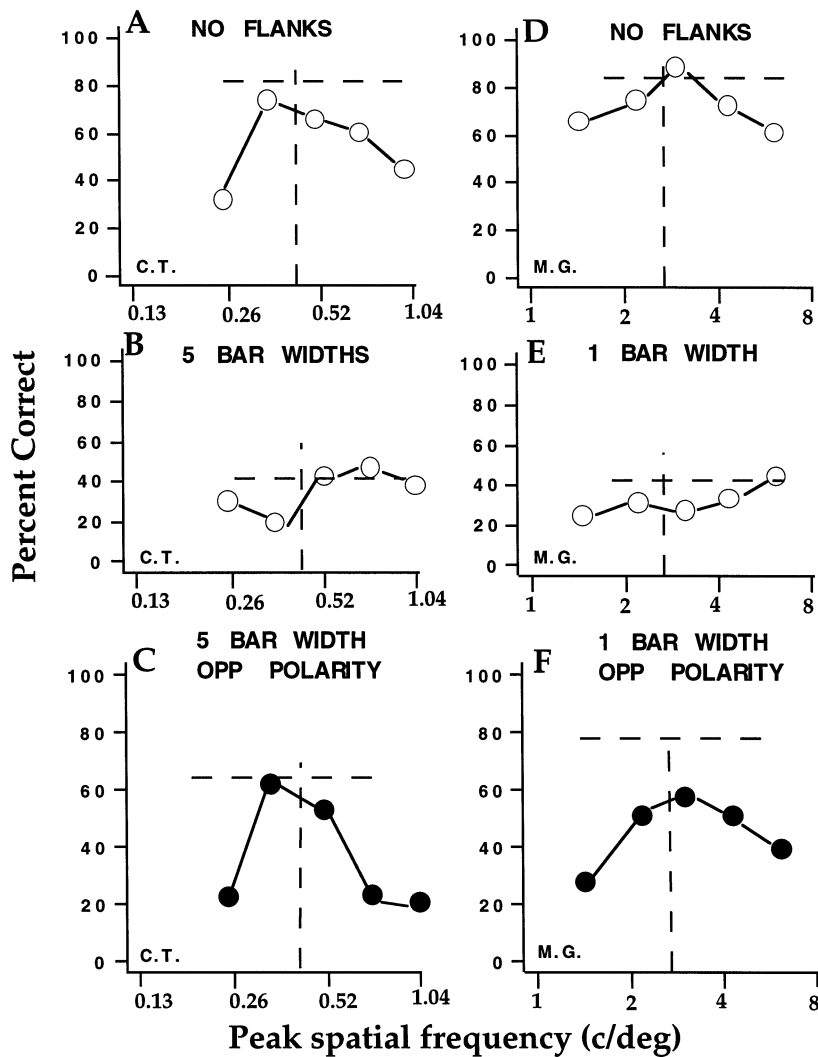


Fig. 6. Foveal bandpass-filter masking functions for Landolt C identification for two strabismic amblyopes CT and MG as per Fig. 5 (unfilled circles for unflanked (a,d); same polarity flanks at bar width separation indicated (b,e); and opposite polarity (c,f) flanks).

in the C target, but also when they correctly identified only its orientation (2afc: horizontal, vertical). When scaled for the different chance levels associated with these two tasks, the difference between these two responses gives a measure of the influence of positional uncertainty. In Fig. 10, we plot the flank separation at which performance fell to two-thirds of its maximum, asymptotic level for the positional judgement (termed position threshold; units bar widths) against the identical measure for the orientation judgement (termed orientation threshold; units bar widths). The results show that the extent of the contour interaction region was comparable (the solid line represents perfect correspondence), regardless of whether criterion responses were based on position or orientation. This suggests that the raised level of positional uncertainty that is a feature of amblyopia, does not strongly influence performance for this particular task.

#### 4. Discussion

A number of studies have suggested that contour interaction is essentially normal in amblyopia when considered in units relative to the amblyope's reduced acuity (Flom et al., 1963a; Hess & Jacobs, 1979; Simmers et al., 1999). The present results show anomalies, not only in the extent of the contour integration region in amblyopia, but also to the extent to which the spatial scale of analysis changes in contour interaction.

The finding that the extent of the region over which contour interaction occurs is larger in amblyopia is perhaps not altogether new. Flom et al., (1963a) and later Flom (1991) and Simmers et al. (1999) show results for one subject who had such an anomaly. In the present study, we are really just changing the emphasis because the majority of our amblyopes exhibited such anomalies (though some did not e.g. OA, VE and RW) The extent of the interaction can range from  $\approx 2$  bar

widths separation, which is what it is in normal observers for foveal and para-foveal (up to  $4.7^\circ$  of eccentric fixation) viewing, up to the limit of our measurement which was 10 bar separations. The extent of this region is affected by the contrast polarity of the adjacent contours, at least in some amblyopes. In these amblyopes, contour interaction is abolished by reversing the contrast polarity of the interfering contour (OA, RW and VE). In some it is only reduced (JL and MG), while in others it has no influence (CT, CP and BB).

What is novel about this study is that we have assessed what spatial scale is used for analysis by the amblyopic visual system and how this changes when adjacent contours are introduced within the region associated with contour interaction. For the detection

of an unflanked Landolt C, normal and severely amblyopic eyes use approximately the same scale of analysis relative to their respective acuities. This corresponds to  $\approx 1.2$  cycles per letter, as Bondarko and Danilova (1997) predicted. Regardless of whether opposite contrast polarity contours produce interaction or not, the same spatial scale of analysis is used for normal and amblyopic eyes when the flanking contours are of opposite polarity. In normal observers, under conditions where contour interaction occurs, the spatial scale of analysis changes to higher spatial frequencies by only half an octave (Hess et al., 2000a). The majority of amblyopes shift their scale of analysis by up to an octave and we have evidence that the scales shift progressively with the lateral separation of the interfering

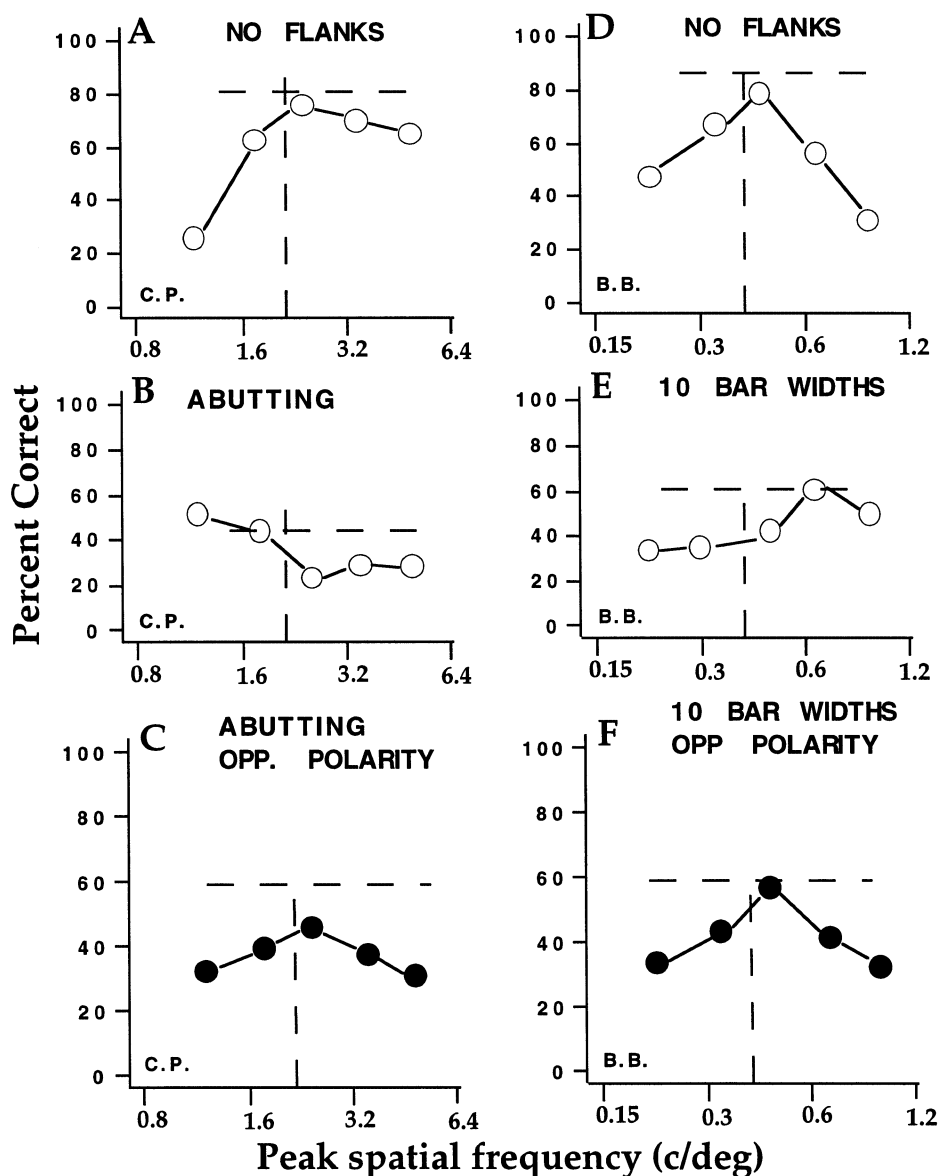


Fig. 7. Foveal bandpass-filter masking functions for Landolt C identification for two strabismic amblyopes CP and BB as per Fig. 5 (unfilled circles for unflanked (a,d); same polarity flanks at bar width separation indicated (b,e); and opposite polarity (c,f) flanks).



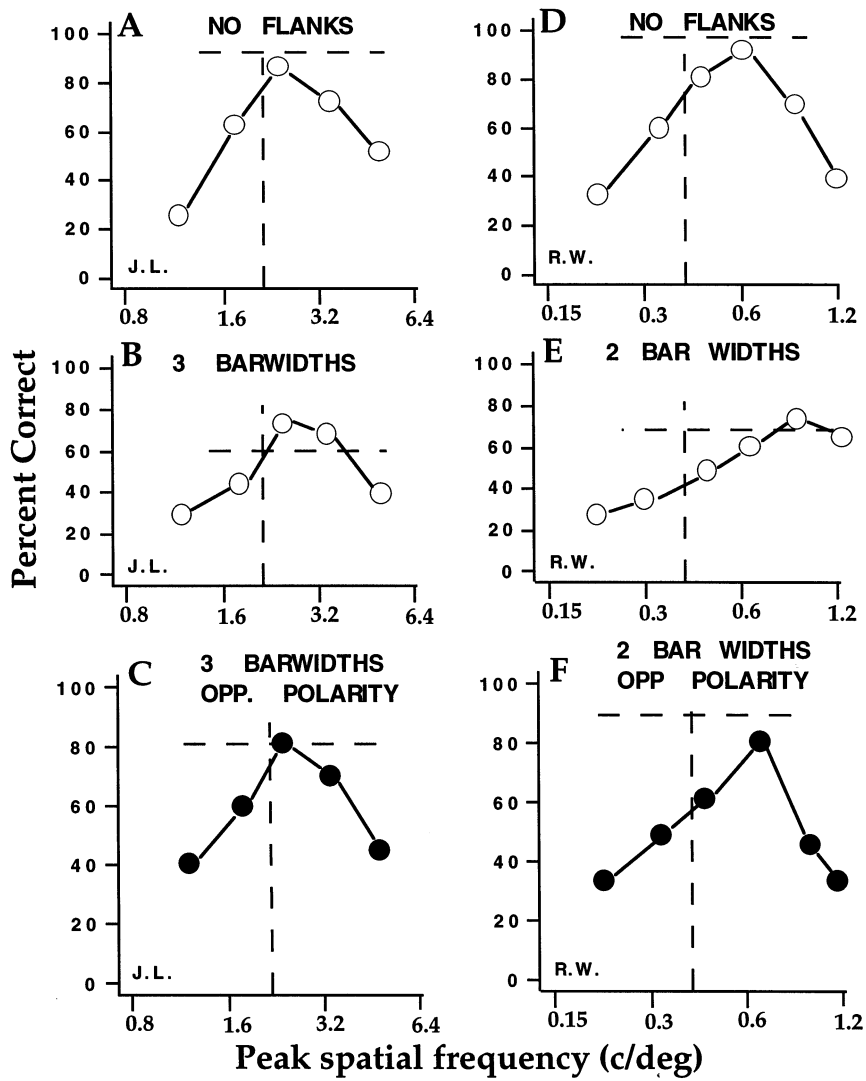


Fig. 8. Foveal bandpass-filter masking functions for Landolt C identification for two strabismic amblyopes, JL and RW as per Fig. 5 (unfilled circles for unflanked (a,d); same polarity flanks at bar width separation indicated (b,e); and opposite polarity (c,f) flanks).

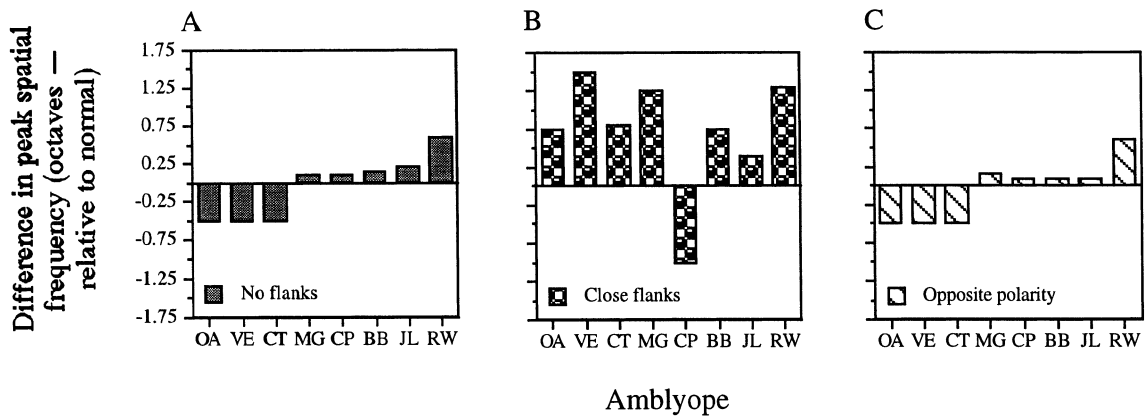


Fig. 9. Summary results from Figs. 5–8 for how the peak position of the filtering functions varied in amblyopia relative to that previously found for normal observers. The results from normal observers are from Hess et al. (2000a). Three conditions are compared: unflanked, close flanks and opposite polarity.

contour (data not displayed). Two of our subjects did not fit this pattern; for one (CP), the shift was to lower spatial frequencies and for the other (JL), the function did not shift at all (summarized in Fig. 9).

Why does the spatial scale of analysis shift when adjacent bars are brought close to the test letter in normal observers? And why should this be exaggerated in the majority of amblyopes? In normal observers, the simplest explanation for this change in the spatial scale of analysis is that this is where the most relevant information is contained in the stimulus. Hess et al. (2000a) showed that when adjacent bars of the same contrast polarity are within 2 bar widths of the test target, the peak in the difference spectrum (difference in the Fourier spectrum for horizontal and vertical components) shifts to higher spatial frequencies by half an octave. In the case of amblyopia, such a physical explanation cannot be sufficient because the shift in the spatial scale of analysis is much larger. Bondarko and Danilova (1997) first showed that the most relevant frequency band for detecting an unflanked Landolt C should be  $\approx 1.2$  cycles per letter, this was experimentally verified later by Hess et al. (2000a). For normal vision, this must mean that rather than the gap being detected by processing spatial frequencies relevant to its dimension (i.e. 2.5 cycles per letter), performance is

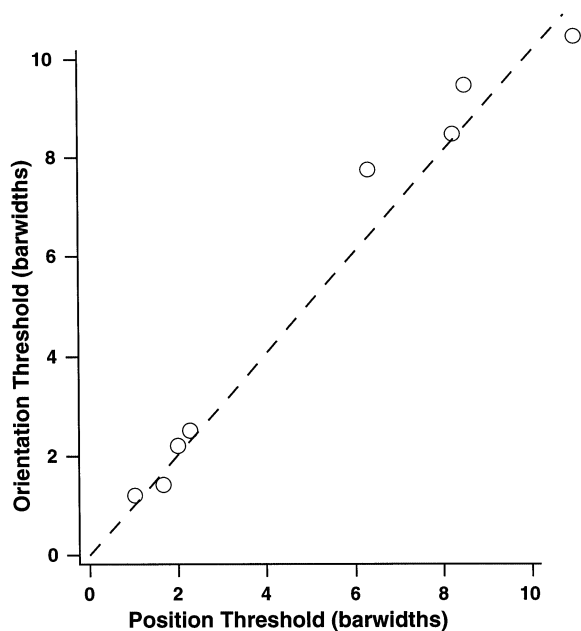


Fig. 10. The relationship between the measured extent of the contour interaction zone (separation of flanks for which performance falls to two-thirds of asymptotic level) for detecting the position, as opposed to the orientation of the gap in the C. The two measures have been corrected for their different ranges (the position task was a 4afc task with a 25% chance level, whereas the orientation task was a 2afc task with a 50% guess level). There is good agreement between the two measures indicating that any elevated positional uncertainty in amblyopia did not play a role in this particular task.

governed by spatial frequencies relevant to the dimensions of the C itself (i.e. 1 cycle per letter). In other words, at the limit of performance, overall subtle shape changes in the C indicate the position of the gap. This corresponds to the fact that observers report that a subtle flattening, either up, down, left or right can be perceived at the acuity limit. For some reason, the majority of amblyopes cannot use this lower spatial frequency, shape-based information when flanking bars are present. Under these conditions they are forced to use the spatial frequencies that relate to the dimensions of the gap itself. The reason cannot simply be due to optimizing sensitivity because for normal observers and amblyopes, the lower the spatial frequency, the higher the sensitivity, especially in this relatively high frequency range. One possibility is that the sensitivity of amblyopic observers for detecting changes in shape may be poor, for which there is some evidence (Hess, Wang, Demanins, Wilkinson, & Wilson, 1999) and that in the presence of the flanking bars, this information cannot support optimum performance.

#### 4.1. Scale selection in amblyopia

The scale of analysis used by the amblyopic eye for the detection of broadband images is an important topic that has received little attention. We know that amblyopes have a reduced passband from contrast sensitivity measurements for narrowband stimuli (gratings), but can amblyopes select the appropriate scale of analysis for processing broadband stimuli? This cannot be answered by using only one task, however in the present task, the majority of amblyopes did select the most relevant spatial scale in the unflanked case, one that optimized the information content of the stimulus for the task at hand. For an as yet unknown reason, this was not the case when flanking stimuli were present.

#### 4.2. Basis of crowding

In principle, increased crowding in amblyopia could be due to a number of explanations. The one favored by Flom et al. (1963a) is that the underlying mechanism's receptive field is larger. This is a low level explanation. A higher level one along the same lines would be that the mechanism that segregates information (e.g. the C from the flanking bars) is anomalous in amblyopia and as a consequence, a larger scale of analysis is used than is appropriate (encompassing both the C and the flanking bars). Both these explanations would predict either that the spatial scale of analysis would be larger than normal in the unflanked case and stay that way or that it would get even larger (i.e. move to LOWER spatial frequencies) when the flanks are present. The first did not happen and the second only

happened in one of our amblyopes and does not appear to be typical. Another possibility is that the increased contour interaction may have been due to a pure sensitivity change without any associated change in the scale of analysis. This also can be ruled out by the present data that show quite large changes in the scale of analysis when flanking stimuli are introduced. It is possible that a finer scale of analysis than is optimal (for detecting the unflanked Landolt C) was utilized in amblyopia to help in the segregation of C from its flanking contours. The generally beneficial effects of opposite contrast polarity flanks may be because this also aids segregation. This suggests that a defect may exist in the mechanisms that underlie object segregation in amblyopia.

#### 4.3. Relationship to peripheral processing

Visual function in strabismic amblyopia has often been likened to that of the normal periphery (Levi, Klein, & Yap, 1987). While the shifts in spatial scale are much greater than we had previously found in the parafovea corresponding to the eccentric fixation of our strabismic amblyopes, they do approximate those found in the normal periphery beyond 10° (Hess et al., 2000b). In the region beyond 10° in the normal visual field, flanking contours produce scale shifts in the same direction and of the same magnitude to that observed in the parafovea of our amblyopes, suggesting the possibility of a common explanation.

#### 4.4. Letter identification in general

The present results have involved the detection of a gap in a Landolt C. The discussion of the results has concentrated on this specific task neglecting the extensive literature on letter detection and identification. We have done this because we believe that this task, which has contributed a lot to our initial understanding of contour interaction, may not be representative of similar interactions for letters in general. At the gap detection threshold, subjects do not perceive the gap per se but a fluttering caused by it. It is the overall shape of the C that is being detected secondary to the gap position. This is why optimum performance occurs at lower letter frequencies for the Landolt C (1.2 cycles per letter) compared with other letters (2.5 cycles per letter).

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