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"Phase capture" in amblyopia: The influence function for sampled shape

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Abstract

This study was concerned with what stimulus information humans with amblyopia use to judge the shape of simple objects. We used a string of four Gabor patches to define a contour. A fifth, center patch served as the test pattern. The observers' task was to judge the location of the test pattern relative to the contour. The contour was either a straight line, or an arc with positive or negative curvature. We asked whether phase shifts in the inner or outer pairs of patches distributed along the contour influence the perceived shape. That is, we measured the phase shift influence function. Our results, consistent with previous studies, show that amblyopes are imprecise in shape discrimination, showing elevated thresholds for both lines and curves. We found that amblyopes often make much larger perceptual errors (biases) than do normal observers in the absence of phase shifts. These errors tend to be largest for curved shapes and at large separations. In normal observers, shifting the phase of *inner* patches of the string by 0.25 cycle results in almost complete phase capture (attraction) at the smallest separation (2λ), and the capture effect falls off rapidly with separation. A 0.25 cycle shift of the *outer* pair of patches has a much smaller effect, in the opposite direction (repulsion). While several amblyopic observers showed reduced capture by the phase of the inner patches, to our surprise, several of the amblyopes were sensitive to the phase of the outer patches. We used linear multiple regression to determine the weights of all cues to the task: the carrier phase of the inner patches, carrier phase of the outer patches and the envelope of the outer patches. Compared to normal observers, some amblyopes show a weaker influence of the phase of the inner patches, and a stronger influence of both the phase and envelope of the outer patches. We speculate that this may be a consequence of abnormal "crowding" of the inner patches by the outer ones.

Keywords: Amblyopia; Shape perception; Psychophysics; Influence function; Cue combination; Phase perception; Classification image; Crowding

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1. Introduction

Humans with normal vision have a highly acute ability to judge the shape of an object, and to identify and localize distortions in the shapes of smooth objects (e.g., Watt, Ward, & Casco, 1987; Whitaker & McGraw, 1998; Wilkinson, Wilson, & Habak, 1998; Zanker & Quenzer, 1999). Recent work suggests that when there is more than one cue to shape, each cue is given a weight based on its reliability (see Jacobs, 2002 for a recent review) and the cues are combined according to their weights. This approach explains how haptic and visual cues are combined (Ernst & Banks, 2002; Hillis, Ernst, Banks, & Landy, 2002). Other work suggests similar cue combination rules operate in other domains, e.g. stereopsis (Landy, Maloney, Johnston, & Young, 1995; Young, Landy, & Maloney, 1993), and in selective attention (Murray, Sekuler, & Bennett, 2003).

In a recent study (Levi, Li, & Klein, 2003) we used a string of four Gabor patches to define a contour. A fifth,

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center patch served as test pattern: we asked whether phase shifts in the inner or outer pairs of patches distributed along the contour, influence perceived shape. We found that shifting the *inner* patches of the string by 0.25 cycle results in almost complete phase capture (attraction) at the smallest separation (2λ), and the capture effect fell off rapidly with separation. A 0.25 cycle shift of the *outer* pair of patches had a smaller effect, in the opposite direction (repulsion). In these experiments, the contour was defined by two cues—the cue provided by the Gabor carrier (the 'carrier' cue) and that defined by the Gaussian envelope (the 'envelope' cue). Our phase shift influence function can be thought of as a cue combination task. An ideal observer would weight the cues by the inverse variance of the two cues. The variance in each of these cues predicted the main features of our results quite accurately.

Although the normal human visual system is highly sensitive to changes in phase, several studies suggest that strabismic amblyopes may be much less sensitive to spatial phase (Lawden, Hess, & Campbell, 1982; Pass & Levi, 1982). Of special relevance here is the finding that while normal observers see a strong illusion of tilt that is induced in a row of aligned Gabor patches, when a phase shift is added to successive patches (Popple & Levi, 2000a; Popple & Sagi, 2000), many amblyopes are blind or insensitive to this "phase illusion" (Popple & Levi, 2000b). Popple and Levi (2000b) favored an explanation based on an integration deficit for the failure of amblyopes to see the phase illusion (see also Simmers & Bex, 2004); however, an alternative hypothesis is that amblyopes fail to see the illusion because they are insensitive to phase shifts or because they do not apply the same weights to the phase cue as do normal observers (Popple & Levi, 2004). Insensitivity to phase shifts might provide an analog of a dichromat for spatial vision; i.e., a "phase blind" observer.

In the present study, we consider three aspects of amblyopes' shape perception: first, the precision with which amblyopes perform the task. A large number of previous studies have focused on the precision of position and shape judgments in amblyopia (e.g., Demanins & Hess, 1996; Hess, Wang, Demanins, Wilkinson, & Wilson, 1999; Levi, Klein, Sharma, & Nguyen, 2000 Pointer & Watt, 1987). Here we consider both the effects of separation and spatial scale. Second, we are interested in the perceptual errors (biases or shifts in the point of subjective alignment) that observers make, even in the absence of a phase shift of the neighboring patches (Levi et al., 2003). Large errors have been previously described in amblyopic position and shape judgments (Bedell & Flom, 1981; Demanins & Hess, 1996; Sireteanu, Lagreze, & Constantinescu, 1993). Third, we evaluate the effectiveness of phase-capture and determine the weights given to each of the cues (envelope and carrier) in the perception of shape. In particular, we are interested in whether amblyopes give different weights to these cues than do normal observers.

2. Methods

The methods are identical to those used by Levi et al. (2003), and will be only briefly described here.

2.1. Stimuli

The stimuli are illustrated in Levi et al. (2003, Figs. 1 and 2) and a subset are shown in the inset of Fig. 1. They consisted of strings of 5 circular Gabor patches. Each patch was constructed to have 0.66 carrier cycles per Gaussian envelope standard deviation (σ), corresponding to a spatial frequency bandwidth of 0.825 octaves. The carrier orientation was always aligned with the contour. The patches were briefly presented (≈200 ms) on a Sony Trinitron F520 21″ flat screen monitor at a contrast of 80%, on a mean luminance background (≈80 cd/m^2).

The contours were either a straight line, or a circular arc. We tested observers at one or more viewing distances. The viewing distance was selected to ensure that the stimuli were well within the observers' pass-band: at the closest distance the radius of curvature was 6° and the spatial frequency of the Gabor carrier was 3.33 c/°. At the intermediate distance the radius was 3° and the carrier spatial frequency was 6.67 c/°, and at the largest distance the radius was 2° and the spatial frequency was 10 c/°. At all distances the radius of the circle was 20 periods (lambda) of the Gabor carrier.

The observers' task was to judge whether the center 'test' patch was above or below the contour defined by the four outer patches (which provided samples of the contour). They were told that the contour was either a straight line or a circle. From trial to trial, the phase of the four outer patches was varied: either: (i) all four patches were phase aligned; (ii) patches 2 and 4 (the "inner patches"—see inset in Fig. 1) were shifted downwards by 90°; or (iii) patches 1 and 5 (the "outer patches"—see inset in Fig. 1) were shifted downwards by 90°. In all three cases, the patch centers were perfectly aligned along the contour. At the start of each trial, a reticule was presented to mark the location of the test patch. The reticule disappeared after 300 ms, and was followed immediately by the stimulus. Since we were interested in the perceived position of the central patch relative to the contour, no feedback was provided. In order to minimize bias, all 9 stimulus conditions (3 curvatures [positive, negative and zero, i.e., radius infinity] and 3 phases [all aligned; patches 2 and 4 shifted by 90°; patches 1 and 5 shifted by 90°]) were randomly interleaved in a single run of 450 trials (≈50 trials per condition). In order to avoid using edges or other