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Contrast sensitivity of form and motion discrimination during binocular rivalry

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Abstract

Binocular rivalry, which is induced by presenting the two eyes with incompatible stimuli, results in periods where one eye's stimulus is seen and the other stimulus is suppressed. We measured the depth of suppression in two ways, with very different results. First, two similar forms were briefly presented to one eye: the difference in shapes required to discriminate the forms was substantially greater during suppression than during dominance. Second, the two forms were made sufficiently different in shape to be easily distinguishable at high contrast, and contrast was lowered to find the threshold for discrimination of the forms. Contrast sensitivity did not differ between the suppression and dominance states. These results were replicated with a motion discrimination task: suppression markedly worsened the ability to distinguish increases from decreases in speed but did not elevate the minimum contrast required for the same task. We interpret the results in terms of steep contrast–response functions in visual cortex beyond the primary area.

Keywords: Binocular rivalry; Contrast; Form; Motion; Discrimination

1. Introduction

We are often unaware of a substantial fraction of our visual environment. As you read these words, for example, you have lost some awareness of the objects and events surrounding the written page. What is lost during unawareness, and what might be the mechanism underlying this loss? One approach to these questions is through binocular rivalry. When incompatible stimuli are presented to the two eyes, one monocular stimulus is seen for a few seconds and then the other stimulus is seen, in a never-ending cycle. When one stimulus is seen, and therefore termed dominant, the other stimulus is not seen. This loss of awareness is called binocular rivalry suppression. Binocular rivalry provides a convenient method for studying the loss of visual awareness because the perceptual changes are internally produced: they occur without any change in the stimulus.

Binocular rivalry suppression can be measured by delivering a brief test stimulus to one eye during its suppression phase, and varying some aspect of the test stimulus to find its threshold level. Early experiments, which required subjects to detect spots or gratings (Blake & Camisa, 1979; Makous & Sanders, 1978), showed that contrast sensitivity is reduced during suppression to about half of its value during dominance. We recently took a different approach to measuring suppression depth by requiring subjects to perform a form or motion discrimination during suppression (Nguyen, Freeman, & Alais, 2003). The depth of suppression, measured as the change in shape or speed needed to perform the task,

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grew with the complexity of the task. In particular, tasks that could be performed by examining small fragments of the test stimulus yielded shallow suppression and tasks requiring global computations over larger areas gave deeper suppression. This finding was interpreted to mean that rivalry is a process distributed along the visual pathway, and that suppression grows with distance along the pathway.

Contrast sensitivity for simple tasks such as grating detection is reduced during binocular rivalry suppression. Will it also be reduced for computationally more complex discrimination tasks? The answer to this question is neither obvious, nor available from previous work. Contrast–response functions become progressively steeper along the visual pathway (Sclar, Maunsell, & Lennie, 1990) with the result that changes in neuronal responses are minimised when contrast increases above its threshold level. Recent results from magnetic resonance imaging indicate responses that vary little with contrast in higher visual cortex, particularly for sophisticated form discrimination tasks such as face recognition (Avidan et al., 2002). It could be, therefore, that while form and motion sensitivity are strongly reduced during binocular rivalry, contrast sensitivity is not as affected.

We examine this suggestion here, by measuring the minimum contrasts required to perform form and motion discriminations during rivalry. A preliminary account of this work has been published in abstract form (Li & Freeman, 2004).

2. Methods

2.1. Subjects

Nine human subjects, aged 25 to 37, took part in these experiments. They had normal, or corrected-to-normal, visual acuity and good stereoacuity. All subjects provided written, informed consent for their participation.

2.2. Viewing arrangement

Experiments were run in a darkened room, and visual stimuli were presented on a computer monitor. Subjects viewed stimuli through a stereoscope, and used a chin-rest and forehead-rest to minimise head movements. Left-eye stimuli were presented on the left half of the monitor, and right-eye stimuli on the other half. A septum in front of the monitor, and front-surfaced mirrors adjacent to the stereoscope, ensured that each eye viewed only its own stimulus. Both arms of the stereoscope had three degrees of freedom, and subjects adjusted the arms to optimise fusion of the two monocular stimuli. A black fusion box, 2.7° on a side, was centred on each monocular stimulus to assist binocular fusion. Two types of stimuli were used, form and motion. For form stimuli, each monitor pixel subtended 1.1 min arc at the eye, the optical distance from monitor to eye was 1.14 m, and the frame rate of the monitor was 66.7 Hz. For motion stimuli, these stimulus variables were 2.4 min arc, 0.57 m, and 85 Hz.

2.3. Form stimuli

Visual stimulation consisted of a conditioning stimulus, which induced binocular rivalry, followed by a test stimulus to measure sensitivity during either the dominance or suppression phase of rivalry. The conditioning stimulus used for the form experiments, shown in Fig. 1(A), was a variation on the lobed circles described by Wilkinson, Wilson, and Habak (1998). Luminance along any radius of an unlobed circle, as shown on the right side of the conditioning stimulus in part A of the figure, equalled the fourth derivative of a Gaussian function of radial distance. The radius of the circle was 0.67°, and the annular width of the circle was set by the Gaussian's standard deviation, which was 7% of the radius. Background luminance was 45 $\mathrm{cd\,m^{-2}}$, and the peak contrast of the circle was 0.75. Lobes were generated by sinusoidally varying the radius of the circle with distance around the circumference. The left side of the conditioning stimulus in Fig. 1(A), for example, shows four lobes with an amplitude equal to 25% of the radius.

Brief test stimuli were delivered to the right-eye during rivalry, to measure visual sensitivity. The figurines at the bottom of Fig. 1(C) illustrate the test stimuli. Each test consisted of two adjacent, lobed, semicircles. One semicircle had two lobes and the other semicircle had fewer lobes. The two-lobed semicircle was placed in either the upper or lower location, and the subject's task was to decide where it appeared. Lobes were randomly rotated around the circumference of the circle between trials to prevent judgements based on small segments of the stimulus. Unless otherwise stated, the peak contrast of the test stimulus was 0.75. In some experiments, lobe amplitude was varied to find the subject's threshold. Large amplitudes produced contours near the centre of the right-eye's stimulus that were unmatched by any contours in the left-eye's stimulus. To avoid this difference, all stimuli (conditioning and test) were masked outside an annular area. The mask was a Gaussian function of radial distance. It produced no attenuation at the base radius, 0.67°; the attenuation elsewhere was determined by its standard deviation, which was 21% of base radius. The effect of this mask can be seen by close inspection of the left-eye stimulus in Fig. 1(A): there is a loss of contrast for the innermost and outmost projections of the lobed circle.