Vision Research 50 (2010) 838–849

Contents lists available at ScienceDirect

Vision Research

journal homepage: www.elsevier.com/locate/visres

The horizontal effect in suppression: Anisotropic overlay and surround suppression at high and low speeds

Yeon Jin Kim, Andrew M. Haun [1], Edward A. Essock *

Department of Psychological and Brain Sciences, University of Louisville, Louisville, KY 40292, USA

ARTICLE INFO

Article history:
Received 16 June 2009
Received in revised form 25 January 2010

Keywords:
Surround suppression
Overlay suppression
Contrast gain control
Horizontal effect
Contrast normalization
Natural scenes
Oblique effect
Masking
Sustained and transient

ABSTRACT

When a pattern of broad spatial content is viewed by an observer, the multiple spatial components in the pattern stimulate detecting-mechanisms that suppress each other. This suppression is anisotropic, being relatively greater at horizontal, and least at obliques (the "horizontal effect"). Here, suppression of a grating by a naturalistic (1/*f*) broadband mask is shown to be larger when the broadband masks are temporally similar to the target's temporal properties, and generally anisotropic, with the anisotropy present across all spatio-temporal parings tested. We also show that both suppression from within the region of the test pattern (overlay suppression) and from outside of this region (surround suppression) show the horizontal-effect anisotropy. We conclude that these suppression effects stem from locally-tuned and anisotropically-weighted gain-control pools.

1. Introduction

Visual processing of images that contain a broad spectrum of content (e.g., 1/*f* or natural scenes) is anisotropic (Essock, DeFord, Hansen, & Sinai, 2003; Essock, Haun, & Kim, 2009; Hansen & Essock, 2004; Hansen & Essock, 2005; Hansen & Essock, 2006; Hansen, Essock, Zheng, & DeFord, 2003). When viewing broadband images, people find oblique content to be much more salient and horizontal content to be least so, with vertical content intermediate. Similarly, thresholds for oblique content in broadband images are lowest and thresholds are highest for horizontal content. There is strong evidence that this "horizontal effect" is due to anisotropic contrast gain control that provides less suppression at oblique orientations and most suppression at horizontal (e.g., Essock et al., 2009). When a grating pattern is viewed in isolation, without a broadband background to drive the anisotropic gain-control mechanism, oblique content is seen *least* well (the "oblique effect"). Although the contrast response function for a grating (i.e., from threshold vs. contrast (TvC) functions) is equivalent at all orientations once beyond the near-threshold region where the oblique effect is observed (Essock et al., 2009), when a broadband mask is present the effect of anisotropic gain-control suppression is observed in the TvC functions for different orientations (Haun & Essock, in preparation).

In the present study we again use 1/*f* random-phase noise to simulate the spatial context of viewing natural scenes. Here, we measure its masking effect at different orientations in specific spatio-temporal conditions in order to probe different detecting-mechanisms. We first consider the correspondence between the temporal characteristics of the target and (broadband) mask in the production of the anisotropy – specifically, whether a high-speed (temporally "transient") broadband pattern will anisotropically mask a low-speed (temporally "sustained") test grating, and vice versa. Snowden (2001); Hammett & Snowden, 1995) has shown the importance of the matching of temporal properties of test grating and a grating mask (i.e., narrowband mask), showing that masking is much stronger when a test grating with "sustained" temporal characteristics is masked by a sinewave mask also with "sustained" temporal properties (and likewise for "transient" tests and masks). Furthermore, Snowden (2001) has shown that in one case this masking is temporally sustained, occurring throughout the presentation of the mask, and in the other case the masking occurs at the temporal transients of mask onset and offset. In addition, studies employing a temporally-modulated narrowband mask have delineated temporal tuning of at least two mechanisms (Mandler & Makous, 1984; Fredericksen & Hess, 1998; Fredericksen & Hess, 1999; Anderson & Burr, 1985; Bex, Verstraten, & Mareschal, 1996; Boynton & Foley, 1999; Cass &

---

* Corresponding author.
E-mail address: essock@louisville.edu (E.A. Essock).

[1] Present address: Schepens Eye Research Institute Boston MA.

0042-6989/$ - see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.visres.2010.01.020

Alais, 2006) and their tuning suggests that masking should be greater when tests and masks are rather similar temporally than when they are very different (however, see Boynton & Foley, 1999). Assuming that broadband masking behaves like masking by a single grating, these prior results suggest that strongest broadband masking should also be seen when the spatial and temporal properties of a test and mask both strongly stimulate the same mechanism. If for test targets with very different spatio-temporal properties, masks with different temporal properties are differentially effective, multiple relatively-local gain-control pools would be indicated, raising the issue of whether all such pools are anisotropically weighted. In the first experiment, we assess whether detecting-mechanisms widely-separated on the spatial–temporal surface have distinct gain-control pools that show a horizontal-effect anisotropy.

A second issue addressed in this study was the nature of this anisotropy with respect to distinctly different types of suppression. Several authors have distinguished between suppression from a local region overlapping the test, termed "overlay" suppression, and "surround" suppression coming from within an annular region not covering the target location (Meese, Summers, Holmes, & Wallis, 2007; Petrov, Carandini, & McKee, 2005; Yu, Klein, & Levi, 2003). In our prior studies on the horizontal effect, we've considered a more general, "every-day", viewing situation where the spatial context is broadband, the pattern is centrally viewed, and the broadband mask covers a fairly large region (as when viewing a real-world object). That is, both the overlay and surround regions (of several spatially-distributed detectors) are covered by the broadband spatial context in the real-world and also by the 5–10° stimuli used previously in demonstrating the horizontal effect. In the second experiment, we consider whether this anisotropic masking comes from surround suppression, overlay suppression, or both, and whether either type of suppression mechanism occurs exclusively with either temporal transients or sustained presentations.

The goal of these experiments was to determine whether the horizontal effect could be localized to particular masking mechanisms. Our findings indicate that where significant broadband masking can be measured, by whatever presumed mechanism, a horizontal effect will also be observed. Thus, in general every-day viewing, the horizontal effect: is driven by contextual spatial structure similar to a particular filter's spatial and temporal tuning; is present for a range of spatial and temporal filters; and exists in both surround and overlay suppression.

2. Methods

2.1. General

A 1/*f* broadband noise spatial pattern was used to mask a grating target, and each mask and target was presented with either flickered (temporally-transient) or gradual (temporally sustained) temporal characteristics. The spatial frequency of the test grating was either 'low' (1 cpd at the fovea) or 'high' (8 cpd at the fovea). Masking was compared at horizontal, vertical and oblique orientations to evaluate the magnitude of the anisotropy ("horizontal effect") of suppression.

The configuration of the stimuli used in the experiments is shown in Fig. 1. Essentially, we tested with our "general-viewing" conditions in Experiment 1 (large broadband mask and test patch, foveal viewing) and evaluated temporal properties of the anisotropy; then in Experiment 2, stimulus sizes, configurations, and eccentricities were altered to evaluate the potential anisotropy of overlay suppression (Experiment 2.1) and surround suppression (Experiment 2.2) using conditions typical for evoking those two types of suppression (a smaller test patch and associated overlaid mask or contiguous annular mask).

2.2. Procedure and stimuli

2.2.1. Procedure

Each experiment used a 40-trial two-interval forced-choice (2IFC) QUEST procedure to estimate the 82%-correct contrast threshold for Gaussian-windowed sinewave grating targets (Gabors). Each trial consisted of two intervals, both containing an identical mask. One interval (randomly selected) also contained the target presented concurrently with the mask (see Fig. 1, right column). Both intervals contained either identical noise mask images or, in the baseline condition, an unpatterned mean-luminance background. (Thus except for the baseline condition, observers discriminated between the pattern in the middle column and the pattern in the column to the right in the same row, presented in the two intervals.) The subjects were asked to fixate a small circular centered spot present between trials and during the ISI (a 2-pixel-wide ring with an outer diameter of approximately 0.13°). In Experiment 1 targets were viewed foveally, whereas in Experiment 2 targets were either viewed foveally or at 2° to the left of fixation.

2.2.2. Temporal properties

The two intervals of each trial were separated by a 500 ms ISI, with trial duration depending on the temporal properties of each condition. Two temporal conditions were used: a "flickered" condition consisting of 16.7 Hz (12 frames per cycle) sinewave modulation windowed by a slow envelope, and a "gradual" condition consisting of a static pattern windowed with the same envelope. The envelope was either a slowly-ramped onset and offset (Experiment 1; see Fig. 2a) or a Gaussian envelope (Experiment 2; see Fig. 2b). The ramped waveform was 560 ms in duration (100 ms linear ramp from zero to nominal contrast, 360 ms plateau, and a 100 ms linear ramp to zero contrast). The Gaussian temporal envelope had a full width at half height of 400 ms ($\sigma = 170$ ms). Thus, the "flickered" and "gradual" stimuli had the same temporal envelope and the same peak contrast, but different time-averaged contrast (because the 'gradual' presentation was static rather than temporally counterphased).

2.2.3. Test stimuli

The grating target was presented at either 0°, 45°, 90°, or 135° clockwise from vertical. Target size (the width of the Gaussian window) was varied according to the demands of each condition: full width at half height of the target was 2° in Experiment 1, 1° in Experiment 2.1 and was $\lambda\sqrt{e}/\sqrt{2}°$ in Experiment 2.2 (where λ is the wavelength of the grating). Target spatial frequencies were 1 or 8 cpd at fixation, and .6 or 4.8 cpd at 2° eccentricity.

2.2.4. Mask stimuli

The masks consisted of oriented broadband noise with the band of orientations present centered at the same orientation as the test grating. The spatial-frequency band used was four octaves, including spatial frequencies from 1 to 16 cpd, and the orientation bandwidth was 15°. The 384×384-pixel mask images were created by inverse Fourier transform of 1/*f* amplitude spectra, with random phase coefficients generated on each trial (but the same on the two intervals of a single trial), and multiplied by a rectangular bandpass filter in orientation (see Essock et al., 2003 or Hansen & Essock, 2003 for more details). The spatial aspects of the mask differed depending upon experimental condition (see below). Contrast of the mask in all conditions was set so that the standard deviation of normalized pixel luminances (ranging from 0 to 1), or root-mean-square contrast, was 0.10.