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The orientation bandwidth of cyclopean channels

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Abstract

Orientation bandwidths of cyclopean channels were estimated using a notched noise technique. Observers were presented with random dot stereograms depicting a horizontal or vertical target sinusoidal depth modulation and a mask consisting of sinusoidal depth modulations whose orientations flanked that of the target. Masking reduced as the orientation difference between signal and mask increased. The orientation bandwidth of the masking effect was similar to that found for stimuli defined by luminance contrast, and showed no systematic difference for horizontal and vertical targets. These results suggest that the elongated summation found by Tyler, C. W., and Kontsevich, L. L. (2001). Stereoprocessing of cyclopean depth images: Horizontally elongated summation fields. *Vision Research*, *41*, 2235–2243, for horizontal stimuli occurs after a processing non-linearity.

Keywords: Orientation; Cyclopean; Bandwidth; Masking

1. Introduction

Spatial variation in binocular disparity provides the visual system with important information about the three-dimensional shape of surfaces such as their slant and curvature. Tyler (1975) proposed that this information is spatially pooled by cyclopean depth channels, which process depth information beyond the basic encoding of disparity. Such channels were proposed by direct analogy to channels for the processing of spatial contrast information (Campbell & Robson, 1968).

Similar to their analogues for spatial contrast, these channels are tuned for the spatial frequency and orientation of disparity variation. This has been demonstrated by the existence of tilt and size aftereffects in the cyclopean domain (Tyler, 1975). Prolonged inspection of a sinusoidal modulation of disparity of a particular orientation causes subsequently presented modulations of gratings of different orientations to appear shifted in orientation away from the adapting grating. Similarly, prolonged inspection of a sinusoidal depth modulation of a particular size will cause subsequently viewed modulations to appear shifted in size.

These experiments demonstrate that the processing of disparity information may be usefully described in terms of the action of a number of channels, differing in their tuning for the spatial scale and orientation of depth variation. The properties of these channels have been further quantified by measuring their spatial frequency bandwidths. Measures that have been obtained using a notched-noise paradigm to prevent off-frequency viewing have estimated the bandwidth to be around ±1.6 octaves (Cobo-Lewis & Yeh, 1994). The current study used a similar notched-noise paradigm to estimate the orientation tuning bandwidth of these channels.

There has been much recent interest in the nature of spatial pooling in visual processing, for both luminance contrast (Hess & Field, 1999; Polat & Tyler, 1999) and binocular disparity (Tyler & Kontsevich, 2001). This is of direct relevance to the issue of orientation and spatial frequency tuning. Broadly speaking, elongation of the receptive field of an orientation- and spatial frequency-tuned mechanism in a direction parallel to its preferred

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orientation will increase the orientation-specificity of the mechanism, while elongation in the orthogonal direction will increase its spatial frequency specificity. This is relevant to the current study since Tyler and Kontsevich (2001) showed that disparity is pooled across a horizontally elongated spatial region in the detection of horizontal cyclopean stimuli. In contrast, the detection of vertically oriented cyclopean stimuli relies on pooling in a relatively compact, isotropic region. This might be expected to lead to much narrower orientation-tuning for the detection of horizontal than for vertical stimuli. However, the effects of spatial pooling on orientation-specificity depend critically on the nature of the pooling.

Moulden (1994) proposed that spatial pooling might be performed by second-stage "collator units", summing the outputs of earlier, first-stage mechanisms. If the summation of the first stage mechanisms across their receptive fields, and the summation by the collator units were both linear, the response of an elongated collator unit would resemble that of a single, elongated receptive field. The response at this stage would therefore be expected to be narrowly-tuned for orientation.

Alternatively, there may be some non-linearity occurring prior to summation by the collator units. This has been proposed to account for conditions under which summation is not phase- or polarity sensitive (e.g. Chen & Tyler, 1999; Levi & Waugh, 1996). In this case, the response of the collator unit would not be equivalent to that of one single, elongated mechanism. Specifically, the orientation tuning of a collator unit performing non-linear summation would preserve the (relatively broad) tuning of the first-stage mechanisms. An elongated region of spatial summation, as observed for the detection of luminance or disparity defined stimuli (Polat & Tyler, 1999; Tyler & Kontsevich, 2001), is consistent with either linear or non-linear summation. The orientation tuning of cyclopean mechanisms, when considered in conjunction with the anisotropy found by Tyler and Kontsevich (2001), provides important constraints on the nature of spatial pooling. Orientation tuning for horizontal and vertical cyclopean mechanisms was therefore estimated on the basis of two notched-noise masking experiments.

2. Experiment one

2.1. Method

2.1.1. Apparatus

The stimuli were presented on a single 19" Sony Trinitron monitor. The resolution of the monitor was set to 800 × 600 pixels and the refresh rate was 100 Hz. Stimuli were viewed through four first-surface mirrors, arranged in a modified Wheatstone stereoscope configuration. The left and right images were presented side-by-side on the monitor, and the observer's field of view was carefully masked so that only the appropriate stimulus was visible to each eye. The viewing distance was 937 mm, at which each pixel subtended 1.28 arc min of visual angle. The orientations of the mirrors were carefully adjusted so that vergence was appropriate for the viewing distance. All experiments were carried out in a dark room.

2.1.2. Stimuli

Stimuli consisted of random dot stereograms. In all cases, these contained 800 dots, presented randomly in a circular region with a diameter of 5.4°. Each dot had a Gaussian luminance profile, with a standard deviation of 1.96 arc min. The maximum luminance of each dot was 103.7 cd m^{-2} and the background luminance was 0.3 cd m^{-2}. Dots were positioned with subpixel accuracy.

The sequence of events for each trial was as follows. Firstly, the observer was presented with a nonius fixation marker. When this was fixated, the trial was initiated by the observer pressing one of the two response keys. Two stereogram stimuli were then presented, in random order. Each was presented for 500 ms, with a 500 ms interval between the two stimuli. The nonius fixation was presented between and after the two stimuli. On each trial, one signal plus noise stimulus and one noise only stimulus were presented (these are described below). The observer's task was to indicate which of the two contained the signal. This was done be pressing one of two response keys, which initiated the next experimental trial.

2.1.3. Signal plus noise stimulus

The disparity of each point in the image was determined by a two-dimensional depth profile formed from the sum of a number of component sinusoidal depth modulations. These components consisted of the signal plus a number of noise components. The spatial frequency of the signal component was 0.73 cycles/degree, and its orientation was horizontal or vertical, depending on the block of trials.

The spatial frequency of all the noise components was also 0.73 cycles/degree. Their orientations fell into two regions, symmetrically arranged around the orientation of the target. For each block of trials, a notch region of orientations, symmetrically placed around the target, was defined. The orientation of the noise components did not fall into this region. Noise components filled a 10° range of orientations abutting the notch region on either side. Thus, for a horizontal target with a notch size of ±10°, the orientations of the noise components fell in the ranges 11° to 20° and −11° to −20°. Within each region, 10 noise components were summed, sampling the range in 1° intervals. The phases of both the signal and noise components were set at random for