

Rapid communication

Optimal size for perceiving motion decreases with contrast

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Received 2 July 2004; received in revised form 26 January 2005

Abstract

Visual patterns have widely varying contrasts and elicit local signals of varying reliability, ranging from noisy to relatively noise-free. One way to deal efficiently with the variable visual input is to employ flexible neural mechanisms that adapt to changing conditions. We investigated whether the spatial properties of motion mechanisms change with stimulus contrast and found that the optimal size for perceiving motion decreases with increasing contrast. These data were well-described by a model in which spatial summation increases with decreasing contrast.

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Keywords: Motion; Center-surround interactions; Surround inhibition; Spatial summation; Area MT

1. Introduction

The bulk of our psychophysical knowledge about the spatial properties of motion mechanisms comes from threshold experiments, usually contrast or motion coherence thresholds. Several groups have described the effects of increasing stimulus size on contrast and signal/noise thresholds, and have found that thresholds first improve rapidly with increasing size, and then level off or improve at a slower rate (Anderson & Burr, 1987, 1991; Fredericksen, Verstraten, & van de Grind, 1994; Gorea, 1985; van de Grind, Koenderink, & Doorn, 1986; Lappin & Bell, 1976; Watson & Turano, 1995). The initial rapid improvement is usually attributed to spatial summation within a single neural mechanism; and gradual improvement at larger sizes indicates probability summation over multiple mechanisms. These experiments assume that the spatial properties of the

underlying neural mechanisms are independent of stimulus contrast.

At the time, this contrast-invariance assumption agreed with the physiological conception of a receptive field as a fixed property of a neuron. Recent studies, however, have found that spatial properties of the receptive field are dynamic and depend on the stimulus and the visual context (Cavanaugh, Bair, & Movshon, 2002; Dragoi & Sur, 2000; Kapadia, Westheimer, & Gilbert, 1999; Levitt & Lund, 1997; Sceniak, Ringach, Hawken, & Shapley, 1999). Many of the observed changes in the receptive field physiology are believed to result from contrast-dependent interactions between excitatory and inhibitory processes. Specifically, spatial summation has been found to increase with decreasing contrast (Sceniak et al., 1999). Moreover, surround suppression often becomes more pronounced at high contrast (Cavanaugh et al., 2002). Such adaptive receptive fields make functional sense: At low contrast, sensitivity can be improved by increased spatial summation and reduced surround suppression. When visibility is well above threshold, however, spatial resolution can be improved by reducing spatial summation and taking

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advantage of center–surround antagonism to differentiate spatial patterns.

These recent neurophysiological findings suggest that psychophysically described motion mechanisms may also change with contrast. Indeed, Tadin, Lappin, Gilroy, and Blake (2003) found that the “sign” of spatial interactions changes with contrast: with spatial summation at low contrast and spatial suppression at medium and high contrasts. The counterintuitive finding was that direction discriminations at high and medium contrasts were improved by reducing the size of the motion pattern. This relation between size and discrimination thresholds of high-contrast patterns should be U-shaped, however: Further reductions in size below some optimal value should yield reduced discriminations. This minimum-threshold size may be taken to indicate the size at which spatial summation and suppression are optimally balanced.

A general aim of the present study was to identify an optimal size for perceiving motion. A more specific question was whether this optimal size varies with stimulus contrast. One possibility is that the spatial areas and the relative strengths of summation and suppression are independent of contrast, resulting in a fixed optimal size. (Note that an “optimal size” concept only applies to medium and high contrasts that show significant surround suppression.) Another possibility is that the optimal size changes with contrast—possibly decreasing as contrast increases. The results of Tadin et al. (2003) do not distinguish between these two alternatives because they focused on relatively large stimulus sizes (as limited by 1 cycle/° Gabor stimuli). We investigated this question by using dense random-pixel moving stimuli and measuring duration thresholds.¹

2. Methods

Stimulus patterns were created in MATLAB with the Psychophysics Toolbox (Brainard, 1997) and Video Toolbox (Pelli, 1997) and shown on a linearized monitor (1024 × 768 pixels resolution, 120 Hz). Viewing was binocular at 83 cm. The ambient illumination was 4.8 cd/m² and the background gray-level luminance was 60.5 cd/m². To allow presentation of brief motion stimuli, the contrast of a stimulus was ramped on and off with a

temporal Gaussian envelope (duration was defined as two standard deviations (2σ) of the temporal Gaussian). Thresholds (82%) were estimated by interleaved Quest staircases. For each condition, observers participated in four blocks, with two interleaved staircases in each block. The first block was discarded as practice, yielding six independent thresholds estimates for each observer in each condition. All experiments complied with institutionally reviewed procedures for human subjects. Four naïve and well-practiced observers participated in the study.

The stimuli were dense random-pixel motion patterns made up of light and dark pixels (each 3.1×3.1 arcmin) presented in a spatial Gaussian envelope. Size was defined as 2σ of the spatial Gaussian. Contrast was defined as the peak contrast of the spatial Gaussian. From frame to frame of the animation, half of the pixels shifted by 3.1 arcmin in one direction (6.2 °/s) while the remaining pixels were randomly regenerated (i.e., yielding 50% correlation)—conditions producing vivid motion perception at suprathreshold exposure durations.²

We measured the threshold exposure duration required for observers to accurately identify the motion direction. On each trial, a moving stimulus was presented foveally and the observer indicated the perceived direction (left or right) by a key press. Feedback was provided. In separate conditions, observers viewed foveally presented random-pixel motion stimuli of eight different sizes (0.25°–6°) and four contrasts (9–92%), yielding 32 conditions.

To gain insight into the properties of putative mechanisms that may account for our results we fitted three models to the data (see Appendix A). The models were chosen because they allowed for greater spatial summation at low contrast and/or stronger inhibition at high contrast, albeit in different ways. In the *CRF Model*, different contrast response functions are used for excitatory center and inhibitory surround responses, allowing relative strengthening of inhibition with increasing contrast. The *Size Model* allowed for size of the excitatory center region to vary (i.e., decrease) with contrast (cf., Sceniak et al., 1999), thus favoring greater summation at low contrasts. Finally, in the *Drive Model*, effective strength of the inhibitory surround influence was controlled by the activation (i.e., drive) of the excitatory center mechanism (cf., Somers et al., 1998). This model ensures that, regardless of contrast, all weak excitatory responses (i.e., applying to both high-contrast small stimuli and low-contrast large stimuli) are not

¹ Use of duration thresholds was based on the assumption that if the neural response to a stimulus is weak and/or noisy, then longer stimulus exposure will be required for correct perception. More specifically, deciding whether an object is moving in one of two possible directions can be conceptualized as a process involving accumulation of sensory evidence over time (Gold & Shadlen, 2000; Roitman & Shadlen, 2002). When neuronal responses are noisy or attenuated, as with a highly suppressed motion stimulus, sensory evidence accumulates more slowly and a correct decision thus may require longer exposure duration (Roitman & Shadlen, 2002).

² We used 50% correlation to avoid floor effects that were encountered in pilot work. One subject, however, had difficulty with 50% correlation (thresholds were high and very variable), thus she completed the experiment with 100% correlated motion. Her results at 100% correlation were qualitatively identical to those of other subjects at 50% correlation, but were not included in the average data.

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