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Spatial and temporal influences on the contrast gauge

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ABSTRACT

A contrast gauge consists of a narrow bar shaded from dark on bottom to light on top [Shapiro, A. G., Charles, J. P., & Shear-Heyman, M. (2005). Visual illusions based on single-field contrast asynchronies. *Journal of Vision, 5*(10), 764–782]. The perceptual division between dark and light on the bar depends on the luminance level of the surround: when the surround has a high luminance level, the perceptual divider moves up the bar; when the surround has a low luminance level, the perceptual divider moves down the bar. This paper examines the extent to which the perceptual division between light and dark can be used as an indicator to mark the zero contrast level between the bar and the surround. In the experiments, the bar was surrounded by a field whose luminance modulated in time. Three observers marked the maximum and minimum levels of the perceptual divider as a function of modulation amplitude, chromaticity (R, G, B, W), temporal frequency, and width of the surround. Linear changes in the modulation amplitude of the surround produced linear changes in the observers' settings of the indicator. Observer settings matched zero luminance contrast when the surround was wide (12.5 deg), was modulating at less than or equal to 1 Hz, and had W or G chromaticity, but not when the surround was narrow, or was modulating faster than 1 Hz, or had R or B chromaticity. The effects of surround size suggest that the perceived minimum contrast results from processes that operate over multiple spatial scales. To test this hypothesis, the paper presents a new configuration in which near and far contrast information create different perceptual signatures. Under normal viewing conditions, the motion of the indicator follows the contrast information from the nearest edge, but when high spatial frequency information is removed (through image blur), the motion follows the contrast from the far spatial edge. It is therefore likely that the setting for the indicator for the contrast gauge depends on multiple processes and is not a simple indicator of luminance contrast. The perceptual response to low spatial frequency contrast appears to be given less perceptual weight when high spatial frequencies are present in the image.

1. Introduction

A longstanding goal of visual psychophysics is to specify the relationship between physical attributes (e.g., radiance, spectral composition, spatial and temporal frequency) and perceptual response (e.g., hue, saturation, brightness, lightness). One of the earliest attempts at standardizing such a relationship is the C.I.E.'s 1931 definition of luminance,

$$L = k_m \int L_{e,\lambda} V_\lambda \, \mathrm{d}\lambda$$

where L is luminance, k_m is a constant, $L_{e,\lambda}$ is the integrated radiant energy, and V_λ is the spectral luminance efficiency function. This standardization grew out of an early 20th-century technological desire to replace visual photometry with physical photometric measures (Johnston, 2001), and has been exceptionally successful even though it has some notable shortcomings (Lennie, Pokorny, & Smith, 1993). Currently, many experimental and clinical testing situations require efficient methods for estimating the relative efficacy of lights for individual observers. For instance, in fMRI experiments, an observer views images from a single multipurpose projection monitor that may have limited temporal resolution; the observer may be asked to equate the relative efficiency of lights that have a task-specific spatial configuration. A standard way to equate lights would be to use a flicker photometric procedure (or minimally distinct border task); however, given experimental constraints, there may be more practical methods for equating the relative luminance (or brightness) of the lights for individual observers.

Recently, Shapiro et al. developed a class of stimulus (referred to as contrast asynchronies) that translates minimum contrast levels into spatial displacements (Shapiro, 2008; Shapiro, Charles, & Shear-Heyman, 2005; Shapiro et al., (2004a), Shapiro, D'Antona, Smith, Belano, & Charles (2004b))—a characteristic that makes contrast asynchronies an efficient stimulus for investigating theo-

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retical questions related to the perceptual representation of contrast. Contrast asynchronies consist of fields that have identical phases of luminance or chromatic modulation, but have different phases of contrast modulation relative to the surrounding fields. A typical example of this stimulus class consists of a rectangular field whose luminance is modulated in time, so that the field changes from light to dark; this rectangle surrounds, or is surrounded by, a gradient field, shaded from light to dark. When the rectangle is in the white phase of modulation, the contrast between the rectangle and the light part of the surrounded/surrounding gradient is low, and the contrast between the rectangle and the dark part of the gradient is high. When the rectangle is in the dark phase of modulation, the contrast relationships are reversed. Shapiro et al. (2005) showed that the alternation of contrast across different spatial locations creates apparent motion that shifts back and forth across the modulating rectangle.

The motion produced by asynchronous contrast modulation tracks the minimum contrast between the modulating field and the gradient field; this type of motion can be described by a second-order (i.e., contrast-defined) process (Lu & Sperling, 2001). To understand why this is so, consider the motion in Supplementary movies 1a and b, in which the luminance levels of five identical disks modulate at 1 Hz (summarized in Fig. 1A). When the disks have a uniform gray surround (movie 1a), no motion is perceived; when the disks have a gradient surround, motion drifts back and forth from one disk to the other (see movie 1b, and also Shapiro & Hamburger, 2007). Fig. 1B shows an *X,t* plot of the disks with a gradient surround. The vertical strips represent the change in luminance over time (note: the strips are physically identical to each other even though the contrast from the surround creates a perception of compression in the sinusoidal gratings). Fig. 1C shows an *X,t* plot of the five disks viewed through an array of contrast filters; i.e., each horizontal line of the *X,t* plot in Fig. 1B was convolved with a one-dimensional difference of Gaussian filter, and the convolution output was then squared. The output from the contrast filters shows lines of minimum response that move back and forth in time in the same direction as the perceived motion. A similar process can account for the perceived motion in a wide variety of contrast asynchrony configurations (Shapiro et al., 2005).

This paper examines a particular form of contrast asynchrony, referred to as the contrast gauge asynchrony (see Supplementary movie 2 and Fig. 2). A center gradient rectangle shades from light to dark. In panel A, the rectangle is surrounded by a white field. The arrow indicates the point of zero contrast: above the arrow the ramp looks light, and below the arrow the ramp looks dark. In panel B, the rectangle is surrounded by a gray field, and the perceptual divide between light and dark moves to the middle of the ramp. In panel C, the rectangle is surrounded by a black field, and the perceptual divide between light and dark moves down the ramp. If the luminance of the surround modulates in time, the perceptual divide slides up and down the ramp in synchrony with the modulation. In the configuration in Fig. 2, then, the rectangular field can be treated as a "gauge" of varying luminance levels, and the induced perceptual divider can be considered an "indicator" that marks the level of the surround that produces zero contrast. In order to assess the light level of the surround, the observer has to "read" where the indicator marks the point of zero contrast on the gauge.

The experiments presented in this paper measure observers' settings of minimum contrast in response to parametric changes in chromatic, spatial, and temporal characteristics of the surround. The gauge procedure shows systematic changes in the level of the indicator in response to luminance modulation, suggesting that the techniques may be useful for equating the luminance (or brightness) of lights for individual observers. At a more fundamental level, the finding that observer settings are greatly affected by the spatial extent of the modulating surround suggests that the perceived minimum contrast results from processes that operate over multiple spatial scales. To test this hypothesis, we present a novel display that creates different perceptual signatures for visual responses to fine and coarse spatial contrast. In this display, the direction of perceived motion is determined by contrast edges under normal viewing conditions, and is determined by the response to low spatial frequency information when high spatial frequency information is removed. The demonstration indicates that minimum contrast settings involve multiple processes that operate over different spatial scales.

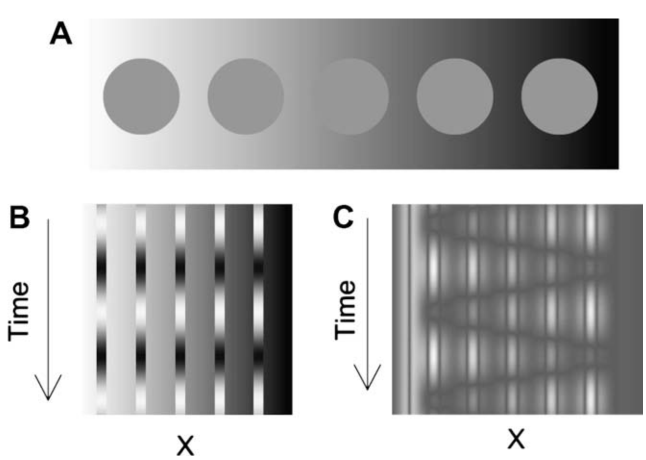

Fig. 1. (see Supplementary movies 1a and b). An example of a contrast asynchrony. (A) Five disks whose luminance levels modulate identically in time. When the disks are placed against a gradient surround, the temporal phase of contrast modulation is shifted for each disk. The alternation of contrast produces the perception of motion. (B) An *X,t* plot of the disks modulating in time. (C) A contrast versus *t* plot. The zigzag line indicates minimum contrast values. The minimum contrast follows the direction of perceived motion.

2. Experiment 1: Does the divider track the point of zero luminance contrast?

For achromatic lights, the luminance modulation of the surround affects the range of the perceptual divider, but the effect has never been measured for chromatic modulation. This experiment measures observers' settings as a function of the modulation amplitude of each of the phosphor channels (R alone, G alone, B alone, and W, all three channels together), at two different temporal frequencies (.5 and 2 Hz). If the perceptual divider follows the location of zero luminance contrast, then the observer settings of the indicator should increase linearly with surround modulation amplitude. The width of the surround is fixed in this experiment; the width of the surround becomes a factor in experiment 2.

2.1. Methods

2.1.1. Apparatus

The stimuli were presented on a 21″ Sony Multiscan G520 monitor using a Cambridge Research VSG 2/4 graphics board. Gamma correction was conducted using a Cambridge Research OptiCal photometer and linearization software. Calibration and gamma correction were checked with a Spectroscan 650 spectroradiometer. The viewing distance was 90 cm.

2.1.2. Observers

There were three observers, between the ages of 18 and 22. The observers had normal or corrected visual acuity, and were color normal as assessed by an Ishihara plate test. All observers' error scores on the FM-100 hue test were within normal limits.