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Defining the limits of flicker defined form: effect of stimulus size, eccentricity and number of random dots

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Abstract

We investigated the spatio-temporal limits of flicker defined form (FDF) phase contrast thresholds generated from the phantom contour illusion. Random dots (diameter 0.25°, tapered edge) were used throughout the test field. FDF was generated using circular stimuli (temporal frequency 30 Hz, mean background luminance 50 cdm^{-2}), the edges being defined by illusory borders generated from the out-of-phase dots within the display. Thresholds improved with increasing stimulus size and number of random dots at all eccentricities. For a constant threshold, fewer random dots were required with increasing eccentricity. Predictive mathematical relationships between contrast threshold, stimulus size and random dot number are discussed.

Keywords: Phantom contour illusion; Flicker; Contrast detection; Magnocellular pathway

1. Introduction

Livingstone and Hubel (1987) were the first to report on the contour perceived at the border of two adjacent chromatic regions with a luminance difference when flickered in counterphase at 15 Hz. They observed that when using equiluminant red and green sectors, this contour was no longer visible. They proposed that this stimulus, being a luminance dependent task, was preferentially stimulating the magnocellular pathway.

This idea was further developed by Rogers-Ramachandran and Ramachandran (1991) when they used a random dot stimulus design to generate the "phantom contour" illusion without the complications of spatial non-linearities at the temporally modulated border. Flanagan, Williams-Lyn, Trope, Hatch, and Harrison (1995) used a similar approach to create a phantom contour illusion letter test, in which logMAR Snellen optotypes were generated.

Rogers-Ramachandran and Ramachandran (1998) proposed that perception of this illusion was not due to the perception of the surface characteristics of the dots, as occlusion of the illusory border dramatically impaired detection of the phantom contour. Surface phase characteristics could only be discerned when using a temporal frequency of 7 Hz or less (i.e. above this temporal frequency, the temporally modulated dots either side of the phantom contour looked identical, and could not be used to judge the position of the contour). This transition from perception of the illusory contour to perception of the surface characteristics was suggested to represent the threshold between a "fast-contour extracting system" and a slower "surface system". Although the terms "magnocellular" and "parvocellular" pathways have been used as a sub-cortical correlate of these thresholds, it is more appropriate to discuss higher cortical areas in terms of dorsal and ventral pathways. It should also be noted that in most studies of the

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phantom contour illusion only supra-threshold stimuli have been studied (Rogers-Ramachandran & Ramachandran, 1991, 1998; Sperling, Lu, Manis, & Seidenberg, 2003).

The phantom contour illusion has also been called flicker defined contrast form (Barnard, Crewther, & Crewther, 1998). We have adopted the term flicker defined form (FDF), as it provides a more descriptive name and is consistent with conceptually similar stimuli (e.g. motion defined form, Giaschi, Regan, Kraft, & Hong, 1992; Kohly & Regan, 2002; Regan, Giaschi, Sharpe, & Hong, 1992; Regan & Hamstra, 1991).

The purpose of this paper was to define the perceptual limits of FDF phase contrast thresholds using a variety of stimulus parameters, including stimulus size, eccentricity and number of random dots used to generate the stimuli. This psychophysical mapping is essential if we are to understand how the various components of the stimulus interact to affect phase contrast thresholds. It is important to determine how much effect eccentricity has on the contrast threshold of the illusory contour given that it is believed to be processed preferentially via the dorsal pathway. It is also useful to establish whether this relationship changes depending on the random dot number and/or stimulus size used.

2. Methods

2.1. Subjects

The right eye of three clinically normal, trained observers (aged 22, 23 and 24) were examined using a variety of experimental paradigms. There were 280 stimulus permutations examined over 28 visits. The visit sessions and the order of tests within each session were randomised. All results shown are averaged from these 3 subjects unless otherwise indicated. The study complied with the tenets of the Declaration of Helsinki and was granted institutional human subject ethical approval. All subjects gave informed consent. The inclusion criteria were as follows: VA 6/6 or better; intraocular pressure of 20 mmHg or less; no abnormalities detected by fundus examination; no history of ocular disease or surgery; and visual fields within normal limits by automated perimetry.

2.2. Experimental procedure

All stimuli were achromatic and presented using a 20″ Sony Trinitron Multiscan CPD-G500 monitor (vertical refresh rate of 100 Hz, non-interlaced, Sony, Tokyo, Japan) with a pixel pitch of 0.25 mm and a resolution of 1024 × 768 pixels. The testing distance used was 0.48 m, resulting in a subtended visual angle of 45° horizontally and 35° vertically. Calibration was performed prior to each testing session, using a Minolta LS-110 photometer and a custom software utility that enabled testing over the full range of stimulus luminance. The maximum luminance was 100 cd m^{-2}, the minimum luminance was 1.33 cd m^{-2}, and at all times the mean luminance of the background and the mean luminance of a single cycle of the stimulus was 50 cd m^{-2}. All thresholds were expressed as a logarithm of the Michelson Contrast percentage (Log MC%).

In all experiments the illusory stimuli were circular and subjects were instructed to respond when they perceived a circular shape (i.e. the phase contrast detection threshold). All stimuli were defined from a random dot background within which all of the dots were flickering at 30 Hz (square wave), but the dots within the stimulus area were 180° out-of-phase to the random dots of the background (see Fig. 1). The random dots were 0.25° in diameter, and there was a linear taper applied to the outer 0.1°. Phase contrast thresholds were estimated for each stimulus location. The order of stimulus presentation was randomised.

Threshold was determined using a yes/no modified rapid estimation by binary search (MREBS). The thresholding procedure began at a supra-threshold level (the luminance was approximately 80 cd m^{-2} on the peak and 20 cd m^{-2} on the trough of the temporal cycle), and increased or decreased in luminance depending on the subjects response. The initial step-size was 0.4 log units relative to a maximum stimulus luminance of 100 cd m^{-2}, and was subsequently halved upon each reversal of the subject's response to a minimum of 0.1 log units, i.e. a 4–2–1 log unit pattern. The final threshold value was taken as the average of the final 6 reversals at the 0.1 log unit level.

All dots remained stationary in space (i.e. the dots were temporally modulated only). In order to avoid temporal transients, the dots within the stimulus area (i.e. the out-of-phase region) were ramped from their previous luminance, i.e. the end point of the previous stimulus presentation, to their desired luminance for 160 ms, presented for 400 ms, and then ramped for a further 160 ms in the direction of the luminance difference required by the subsequent stimulus, yielding a total presentation time of 720 ms. There was a response time of 2 s following the initial stimulus ramp of 160 ms which in turn was followed by an inter stimulus period of 2 s. In order to avoid temporal transients, the stimulus was also ramped in terms of the number of random dots that were "out of phase" with the random dots outside the stimulus area. Ten percent of the dots within the stimulus area became "out-of-phase" every 10 ms. Presentations were terminated if the subject responded during the presentation time, and the phase contrast difference was ramped to the inter stimulus interval level. This aided in avoiding rhythmic stimulus presentations. False positive (FP) and false negative (FN) catch trials were