Modelling the spatial tuning of the Hermann grid illusion

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Abstract—Purpose: Does a physiologically plausible model of the retinal ganglion cell (RGC) receptive field (RF) predict the spatial tuning properties of the Hermann Grid Illusion (HGI)?

Methods: The spatial tuning of a single intersection HGI was measured psychophysically in normal observers using a nulling technique at different vertical grid line luminances. We used a model based upon a standard RGC RF, balanced to produce zero response under uniform illumination, to predict the response of the model cell to the equivalent range of stimulus conditions when placed in either the ‘street’ or the ‘intersection’ of a single element of a Hermann grid. We determined the equivalent of the nulling luminance required to balance these responses and minimise the HGI.

Results: The model and the psychophysical data demonstrated broad spatial tuning with similarly shaped tuning profiles and similar strengths of illusion. The line width at the peak of the model tuning function was around twice the model RGC RF centre size. Modelling the psychophysical functions gave RF centre sizes smaller than expected from human anatomical evidence but similar to that suggested by primate physiological evidence. In the model and psychophysically the strength of the illusion varied with the luminance of the vertical grid line when HGI strength was expressed as a Michelson nulling contrast, but this effect was smaller when HGI strength was expressed as a nulling luminance.

Conclusions: The shape, width, height and position of the spatial tuning function of the HGI can be well modelled by a RGC RF based model. The broad tuning of these functions does not appear to require a broad range of different cell sizes either in the retina or later in the visual pathway.

Keywords: Retinal ganglion cell; Hermann grid illusion; spatial tuning; perceptive field; visual psychophysics.

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INTRODUCTION

The Hermann Grid Illusion (HGI) is a simultaneous contrast illusion that gives rise to the appearance of illusory spots at the intersections of orthogonal grid lines when they are presented against a contrasting background. It was presented by, and is named after, Hermann (Hermann, 1870) who described dark spots seen at the intersections of a grid of light lines when they were placed on a dark background. Whilst the origin of the illusion is somewhat contentious, the first and most lasting plausible explanation for the illusion was given by Baumgartner (Baumgartner, 1960), who attributed the spots to the antagonist and circular symmetric nature of the receptive fields of retinal ganglion cells (RGCs). On-centre RGCs centred at the intersections of the grid are subjected to greater inhibition from the four radiating ‘streets’ (or grid lines) than RGCs whose centres are remote from the intersections, when only two streets occupy the inhibitory surround of each cell’s receptive field. Consequently, the response from an on-centre RGC at the intersection is reduced with respect to the response remote to the intersection and the line appears darker at that point. A similar argument can be made for off-centre RGCs, or for grids with dark lines presented against a light background.

Although a variety of evidence, such as the effect of grid line orientation (de Lafuente and Ruiz, 2004), intersection position randomisation and the number of intersections (Wolfe, 1984) on the HGI, suggests that the above explanation is not capable of describing all the observations that can be made with the HGI (Schiller and Carvey, 2005), it remains unknown but likely that the structure of the inner retina and its physiological properties play a significant part in the perception of this illusion (Spillmann, 1994).

This association of the illusion with the inner retina gives us a potential tool that we can use to investigate the function of the inner retina in cases where its function is believed to be abnormal, such as in diabetic retinopathy (Davies and Morland, 2002) or primary open angle glaucoma (Kerrigan-Baumrind et al., 2000). In earlier work we have examined the possibility of measuring the strength of the HGI using a novel method with a view to investigating functional changes in primary open angle glaucoma (Ares-Gomez et al., 2005). This work found that the method could successfully measure HGI strength as a function of grid line width, effectively a spatial tuning function. This function has a peak, i.e. the grid line width at which the strength of the illusion is maximised, at around 17 arcmin for targets at 1.5 deg eccentricity to 30 arcmin for targets at 6.0 deg eccentricity. It also found that the illusion became stronger as the contrast between the vertical and horizontal line luminances increased.

Previous work has also found that the HGI is spatially tuned, with a maximal illusion strength being observed at an optimal grid line width and grid line length (Spillmann, 1971). This work estimated the diameter of a foveal RGC receptive field combined centre and surround at around 18 arcmin. The Westheimer paradigm, where the detectability of a very small spot is measured as a function of a concentric surround luminance over a range of surround diameters, has indicated