**A reevaluation of area summation of contrast with compensation for retinal inhomogeneity**

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**Introduction**

- Contrast detection thresholds decrease as stimulus area increases. The rate of decline can reveal the properties of the mechanisms in the visual system that combine signals over space.
- Previous investigations suffered from the confounding effects of the inhomogeneity in contrast sensitivity over the visual field.
- Robson & Graham (1981) took account of this variation, positioning stimuli in an area with more homogeneous contrast sensitivity.
- However, summation may vary over the visual field. This is addressed here using a mapping of sensitivity across the visual field to create stimuli that are equally detectable at any point in space. This cancels out the effect of the inhomogeneity.
- This technique is applied to the summation of contrast over:
  2. Strips of grating presented in the fovea and periphery (after Robson & Graham, 1981; Mayer & Tyler, 1986; and Manahilov et al., 2001). Previous studies of summator along strips of grating in the periphery have found conflicting results (see inset figure).

**Witch’s hat attenuation surface**

- Baldwin, Meese & Baker (in press) measured the decline in log contrast sensitivity in the central visual field. It was found to be bilinear.
- The decline along each meridian was fit by the equations below. The resulting surface describes sensitivity at any point in the central visual field and has the shape of a witch’s hat.
- The attenuation surface was then used in two ways:
  1. Stimuli were multiplied by the inverse of the surface to amplify their contrast at the more eccentric locations.
  2. It was used in the model to simulate the inhomogeneity.

**Methods**

- **Viewing distance:** 1.19 metres. Mean luminance: 75 cd/m².
- **Detection thresholds measured with staircases using temporal 2FC presentation.**
- There were four observers (ASB, DHB, SAW & TSM).
- The stimulus duration was 100 ms for both experiments.

**Graging and Swiss cheese stimuli**

- 4 c/deg horizontal sine-wave gratings of eight diameters (1 - 32.7 cycles).
- Windowed by a 12 px, raised-cosine.
- Log area calculated from diameter at half-height: 20 log (d²).
- The Swiss cheese stimulus was those carrier gratings modulated by a raised plan (phase of 90° or 270°) with component frequencies of 0.7 c/deg, halving the total contrast over area. These were designed to investigate summation over a fixed stimulus extent (between gratings and Swiss cheese).
- Blocks of size and type, interleaved over compensated and non-compensated stimuli.
- Stimuli area indicated by a quad of dots. Observers fixated in the centre of the stimulus.

**Tiger tail stimuli**

- Formed from vertical Battenberg elements (Meese, 2010). Each element is a cycle of sine-wave grating at the target spatial frequency and orientation, multiplied by an orthogonal half-cycle of cosine grating at half the target spatial frequency.
- Stimuli of six widths (1 - 32 cycles), and three heights (1 - 4 cycles) were used.
- Log area is calculated as 20 log (w²) x (h²).
- Stimuli were presented both on fixation and at eccentric locations (12 & 42 cycles).
- Stimulus extent was indicated by a quad of dots. The fixation location was indicated either by a small circle or by a single dot. Both were blocked by size.
- Thresholds were obtained both with and without the witch’s hat compensation (interleaved).

**References**

- With witch’s hat compensation.
- Grating/Swiss cheese: template was the outer envelope of the target (not including holes).
- Tiger tail: the outer template was the envelope of the target.
- The pixel values were then summed to give the magnitude of the output.

**Modelling**

- **Stimulus attenuated by empirical witch’s hat’s.**
- **Cosine phase log-Gabor filtering.**
- **Square-law transduction at each pixel.**
- **Independent pixelwise additive Gaussian noise.**
- **Applying witch hat compensation to the stimuli equates the effects of the visual field inhomogeneity.**
- **Summation curves become straight revealing spatially extensive fourth-root summation of contrast.**

**Conclusions**

- **In general, applying the witch hat compensation to the stimulus equates the summation behaviour at each location.**
- It also flattens the summation curves (slope of approximately -4).
- **In general, applying the witch hat compensation to the stimuli equates the summation behaviour without the confounding effects of the inhomogeneity in sensitivity across the visual field.**
- Using this method in a study of the summation of circular gratings reveals an extensive summation of contrast (beyond 16 cycles from fixation).
- Applying the method to strips of grating at several locations in the visual field demonstrates the summation of contrast over area at these different locations to be remarkably similar, allowing these results to be understood under a single framework, and described using a single model.

**Table of results**

- **RMSe = 0.28 dB**
- **RMSe = 1.20 dB**
- **Swiss cheese results**
- **With witch’s hat compensation**
- **Grating/Swiss cheese: template was the outer envelope of the target (not including holes).**
- **Tiger tail: the outer template was the envelope of the target.**
- The pixel values were then summed to give the magnitude of the output.