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Peripheral Colour Demo

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Abstract. A set of structured demonstrations of the vividness of peripheral colour vision is provided by arrays of multicoloured disks scaled with eccentricity. These demonstrations are designed to correct the widespread misconception that peripheral colour vision is weak or non-existent.

Keywords: Periphery Colour vision Eccentricity Cone distribution Fovea.

There is a widespread misconception even among vision scientists, and hence the population in general, that the high cone density in central vision implies that colour vision is restricted to the fovea, and conversely that the high density of rods in the periphery implies a lack of colour vision in the periphery. For example, the Wikipedia article on peripheral vision says "Peripheral vision is weak in humans, especially at distinguishing colour and shape. . . . rod cells are unable to distinguish colour and are predominant at the periphery, while cone cells are concentrated mostly in the centre of the retina, the fovea" (https://en.wikipedia.org/wiki/Peripheral_vision).

In fact, however, both historical (Oesterberg, 1935) and more recent (Curcio et al., 1987; Song et al., 2011) measurements of photoreceptor densities indicate otherwise. Despite the high concentration of cones in the fovea, even the central 5° of the retina contains only about 50,000 cones (1% of the total), while the remainder of the total population of about 5 million cones is distributed throughout the peripheral retina with an average density of about 5,000 cones/mm^2 (beyond about 10° eccentricity). Since the cone inner segments act as their light-catching apertures, and since their diameter is about 10 μm in peripheral retina (Jonas, Schneider & Naumann, 1992), this density implies that the light-catching area of the cones is about 0.3 mm^2 per mm^2 of peripheral retina, while the rod light-catching area accounts for most of the rest. Thus, about 1/3 of the peripheral retina should be considered to support colour vision (Williams, 1991).

The mapping from retina to cortex can be approximated as a linear scaling from the fovea to the periphery, particularly for the cortical mappings of V2 and V3 (Schira et al., 2009). To project from the retina to equal regions of early visual cortex, therefore, the stimuli should be scaled in proportion to eccentricity, and studies of peripheral colour processing should use such scaling in order to assess the cortical capabilities of colour processing. Indeed, with suitable areal scaling, colour discrimination can be equated at all eccentricities This is not the place for an extensive review, but it should be noted that many studies of peripheral processing have used constant stimulus size and report progressive declines in hue discrimination (Nagy & Wolf, 1993; McKeefry, Murray & Parry, 2007;

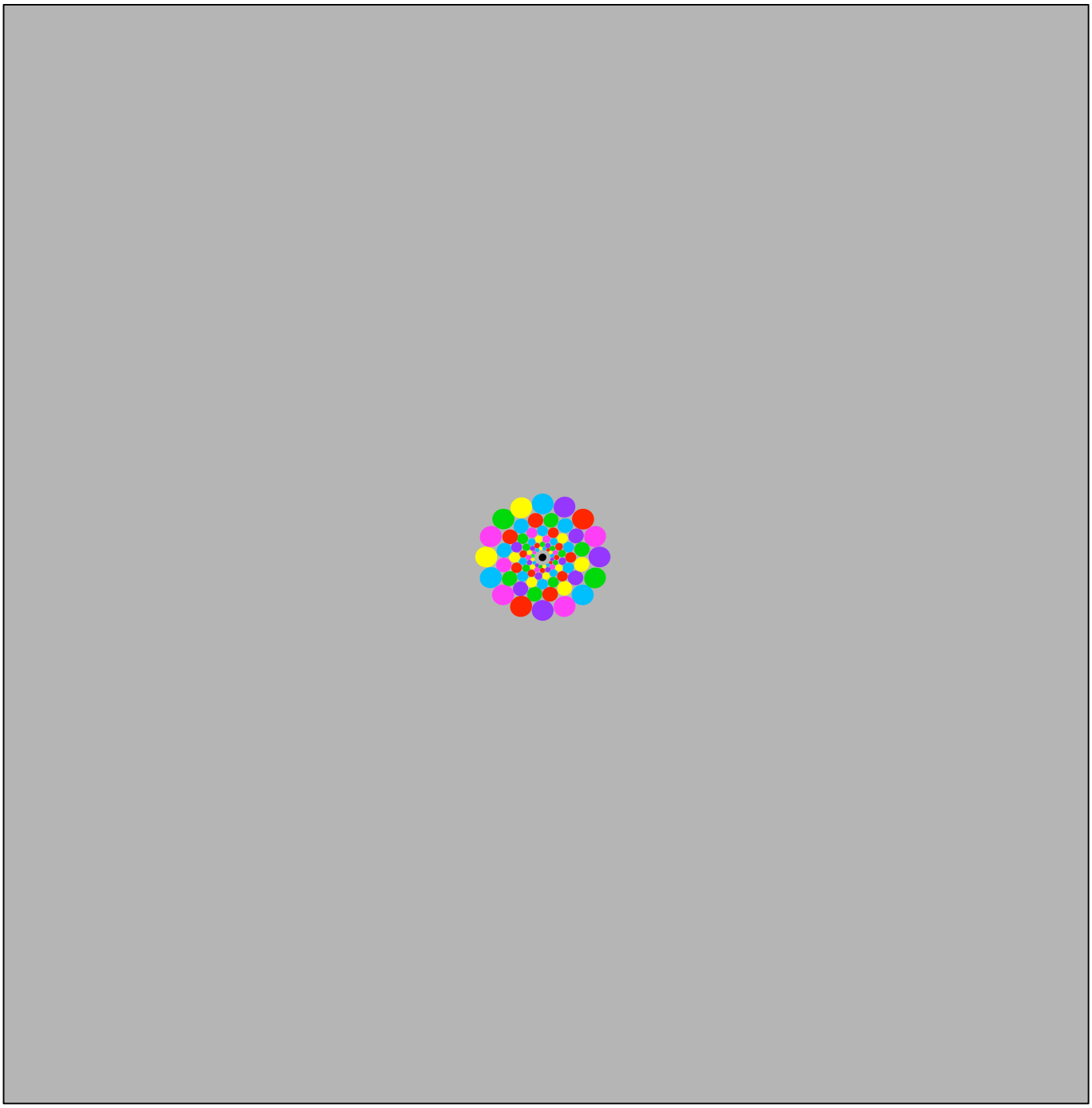

Fig. 1. Foveal colour vividness demo designed to be viewed at two viewing distances. At a viewing distance of 12x the circular array width it spans the 5° fovea, where the variegated colour disks show the vividness of foveal colour perception. At 60x the circular array width, it spans the 1° foveola, illustrating fine-resolution colour processing.

Mullen, 1991), chromatic saturation (Stabell & Stabell, 1982; Abramov, Gordon & Chan, 1992, McKeefry, Murray & Parry, 2007; Volbrecht & Nerger, 2012) and conspicuity (Gunther, 2014). Those studies using appropriate size scaling of the stimuli generally find approximate invariance of the processing properties as a function of eccentricity (Noorlander et al., 1983; Rovamo & Iivanainen, 1991; Abramov, Gordon & Chan, 1991, 1992; Sakurai & Mullen, 2006). Where significant effects are reported, one may question the precise choice of scaling factor. Tyler (1987a), for example, proposed that the appropriate scaling factor should be based on stimulating the same

number of cones at each eccentricity, whereas most scaling studies attempt tor equate the number of ganglion cells stimulated or the cortical magnification factor per se (although some such studies do not apply this logic to the central foveal stimuli).

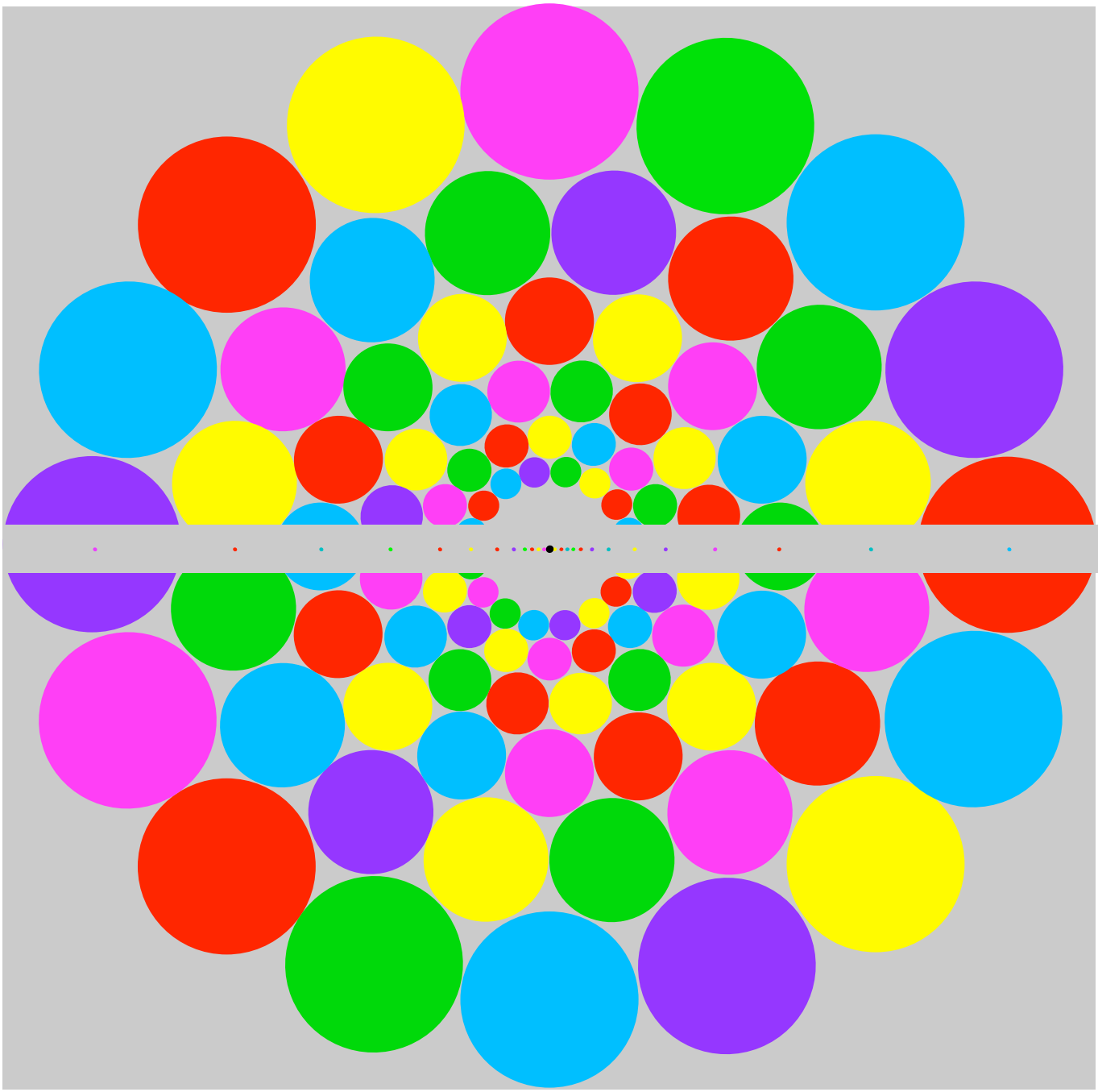

Fig. 2. Peripheral colour vividness demo designed for two viewing distances with central fixation. At 12x the central grey disk width it spans the periphery from 2.5-20°. At the close-up distance of 3x the central grey disk width, it spans from about 10-50° eccentricity, illustrating the vividness of peripheral colour processing. The central grey bar contains elements that are unscaled for eccentricity, to illustrate the perceptual fall-off in peripheral colour perception.

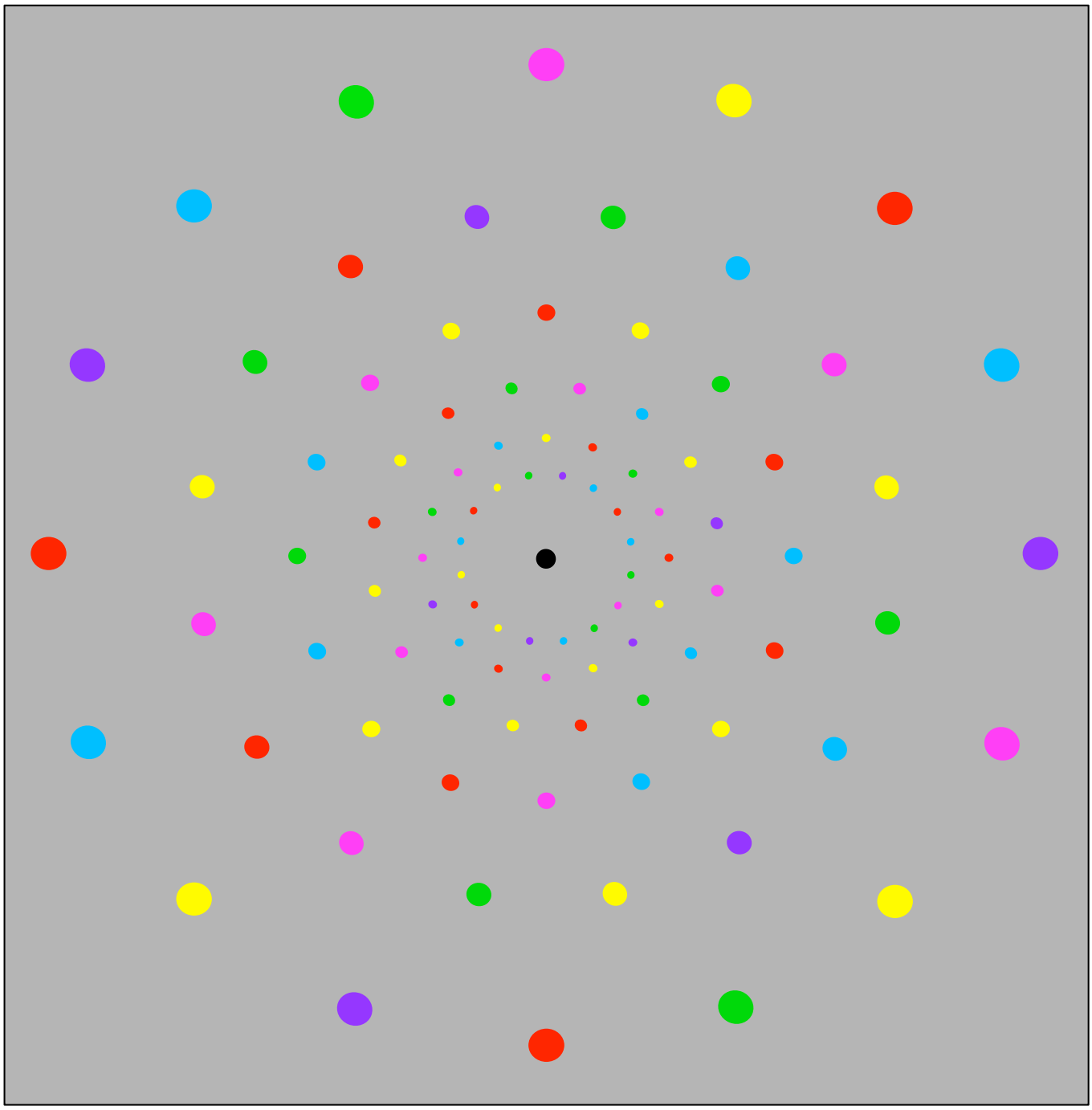

Fig. 3. Peripheral variegated colour disks at 5x reduced scale show that peripheral colour remains as vivid even close to the spatial summation limit.

These properties are indicated by the following demonstration images, which should be viewed at a distance so as to make the width of the central disk measure about 1/12th of the viewing distance (e.g., 1 inch diameter at a 12 inch viewing distance). This ratio corresponds to about the most liberal definition of the foveal region (5° diameter). Fig. 1 shows an array of multi-coloured 'balloons' within this foveal region scaled to stimulate about 1 cm^2 of visual cortex at each eccentricity. In Fig. 2, the same form of array is scaled up to project to the periphery beyond the foveal limit (2.5° eccentricity) into the periphery. If periphery colour vision had weaker colour vision, the colours when viewing Fig. 2 should appear desaturated relative to those in Fig. 1, but inspection verifies that they do not. (To reach the farther periphery, the viewing distance should be reduced to 5 inches with the 1 inch central disk region, when the outer rim will reach out to 45° eccentricity with central fixation.) Fig. 2 also includes

an overlay of a horizontal line of unscaled disks typical of unscaled studies of peripheral colour vision, to allow comparison of its degradation with eccentricity under these conditions.

Given that the natural units of cortical processing characterized by the concept of the 'hypercolumn' are of the order of 2 mm wide in human visual cortex, the disks in Figs. 1 and 2 should each stimulate about 25 such units. To check whether colour processing is similarly uniform at a grain of about 1 hypercolumn, the sizes of each disk are reduced by a factor of 5 for the peripheral version in Fig. 3. It can be seen that colour is again visible out to the edge of the image without noticeable desaturation under these reduced stimulation conditions, so integration across multiple hypercolumnar units is not required to support peripheral colour processing.

If anything, inspection of the figures shows the colour perception is more vivid in the periphery, as might be expected from the fact that the cone density decreases at a slower rate than linear reciprocity with eccentricity (Curcio et al., 1987). In fact, the cone density scales with approximately the -2/3 power of eccentricity out to 20° (Tyler, 1987b). Thus, the linear scaling of the disk sizes should result in the stimulation of about 5 times $[(10^{-2/3}/10^{-1})^2]$ more cones by 20° than 2° in areal terms, giving scope for cortical processing to account for the extra vividness that is perceptually observed.

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Dr. Tyler has over 40 years of experience of research in visual and cognitive neuroscience.