A neurally plausible model of lightness illusions combining spatial filtering and local response normalization

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One of the properties that the human visual system extracts is the lightness of surfaces in the visual scene. It has been long known that the perceived lightness of a surface depends on the lightness of neighboring surfaces. Figure 1 shows several examples where identical gray patches appear lighter or darker depending on the immediate surround. There are many theories that attempt to explain one or more of these illusions, based on contrast enhancement, perceptual grouping, or parsing scenes into transparent layers. Blakeslee and McCourt (1999) have introduced a low-level computational model (ODOG) that accounts for many of these illusions by combining two simple mechanisms. First, multiscale oriented difference of Gaussian filters increase the relative contrast at higher frequencies and produce local blurring or assimilation at lower frequencies. Second, global response normalization equalizes the amount of energy at each orientation across the entire visual field. This model is a compelling starting point because it accounts for many different illusions, and uses low-level mechanisms that could easily be implemented by early visual areas such as V1.

In this work we extended the ODOG model by exploring whether more neurally-plausible normalization schemes will expand the range of illusions predicted by the model. The normalization step in the ODOG model is necessary to account for a family of illusions known as White's effect (Fig. 1a), which are characterized by a highly non-uniform distribution of energy at different orientations. We show that ODOG fails on a variation of White's effect that has equal energy at most orientations when integrated across the entire image (Fig. 1b), and also on several previously published variations of White's effect that have relatively uniform energy distributions (Fig. 1c-d). These illusions indicate that the global normalization step in ODOG cannot account for all variants of White's effect: instead, more localized normalization schemes may be

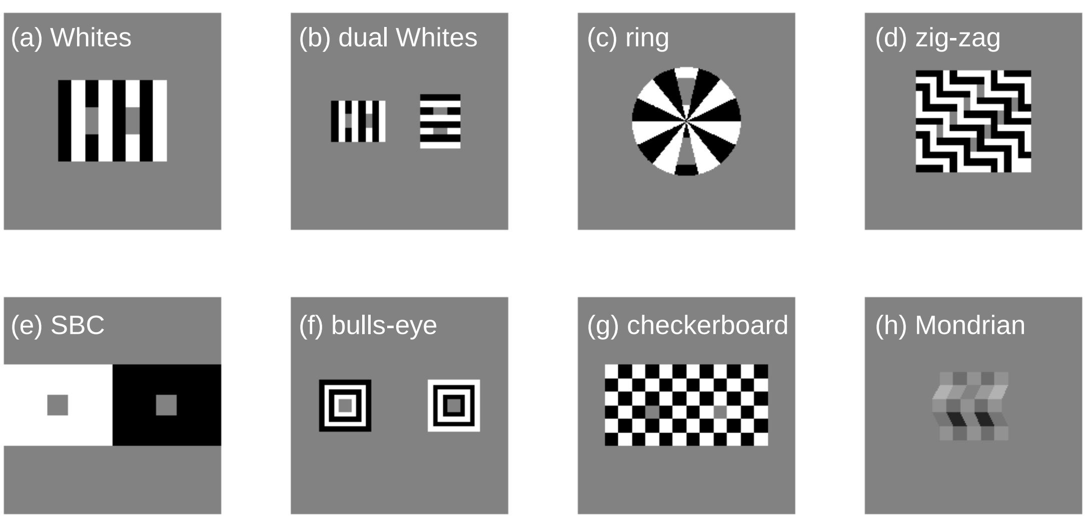


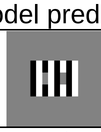
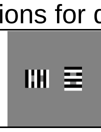
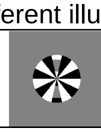
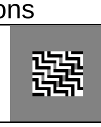
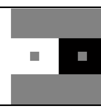
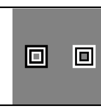
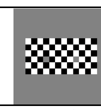
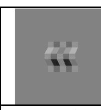
Figure 1. Lightness illusions – all gray patches are actually the same luminance.

necessary. A local model of contrast normalization also has the advantage of being more plausible for implementation in early visual areas such as V1, compared to the global normalization in the ODOG model.

We introduce 2 models that add local normalization to the original ODOG model. The first model is Locally normalized ODOG (LODOG): Instead of normalizing orientation energy across the entire scene, orientation energy is normalized within a moving window of ~4 degrees of visual angle. The second model is Frequency-specific Locally normalized ODOG (FLODOG): Instead of using a fixed window size, normalization is calculated separately for each frequency and orientation, and the window size depends on the spatial scale of the filter that is being normalized.

The LODOG and FLODOG extensions successfully account for many of the illusions shown in Figure 1, but no one model accounts for all illusions (Table 1). Our results suggest that no straightforward fix to the ODOG normalization scheme will allow it to account for a complete range of lightness illusions, and that it is unlikely that the ODOG model can be extended to correctly account for the full family of White’s illusions without much more radical departures from its original mechanisms.

Table 1. Model predictions for different illusions

model								
ODOG	✓				✓		✓	✓
LODOG	✓	✓			✓		✓	✓
FLODOG	✓	✓	✓	✓	✓	✓		

REFERENCES

Blakeslee, B. & McCourt, M. (1999). A multiscale spatial filtering account of the White effect, simultaneous brightness contrast and grating induction. *Vision Research*, 39, pp 4361-4377.