Simultaneous Contrast and Intraocular Glare: Opposing Image Dependent Mechanisms in Appearance

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ABSTRACT

We all use examples of simultaneous contrast to illustrate that human color appearances are dependent on the content of the image. Observers report that identical colored papers appear darker on a white surround, and lighter on a black surround (Figure 1, left). Although there have been innumerable studies of the properties of simultaneous contrast, there is very little discussion of the theory to explain its purpose. What is the advantage for humans to have this simultaneous contrast visual process?

There is another significant visual phenomenon that is image dependent. It is the optical modification of the image on the retina by intraocular scattered light. The human optical system has macromolecules that exhibit Tyndall scattering. When a gray patch is surrounded by a large white area, the luminance falling on the retina is significantly higher because of scatter. The amount of scattered light at a pixel depends on the luminance of all the other pixels in the scene, and their separation from the pixel of interest (T. van den Berg, 2007). Optical scatter increases the retinal luminance, but simultaneous contrast makes these higher luminance areas look darker. This pair of image-dependent processes work against each other. In a black surround, such as stars in the night sky, there is little scatter and little simultaneous contrast. Any area in a white surround there is considerable scatter. Simultaneous contrast not only counteracts scatter, but makes the higher luminance paper appear darker.

This paper describes the interactions of simultaneous contrast and intraocular scatter. The paper reports recent experiments using High-Dynamic Range (HDR) test targets. These experiments show that the dynamic range of appearance is image dependent, and does not correlate with the range of luminances. While intraocular scatter decreases the range of luminance on the retina, simultaneous contrast makes areas with increased scattered light appear darker.

1. INTRAOCULAR SCATTER AND LIGHTNESS

Studies on visual perception pointed out the difference between the physical measure of the stimulus and its perception according to the spatial configuration of the scene to which it belongs. Stiehl et al. (1983) studied transparency images that contained equally spaced steps in the lightness appearance. Stiehl asked observers to selected a middle-gray that bisected the appearance between white and opaque black in a maximum luminance surround. Additional bisections made a scale of grays that were equal steps in appearance. Stiehl measured the luminance of these steps and found a cube root relationship with luminance of the display and appearance. This is the same function used in CIE Lab and Luv.

Stiehl used Voss and Walraven’s point spread function to calculate the luminance on the retina after intraocular scatter. They found a different relationship between retinal luminance and appearance. Log retinal luminance is proportional to lightness appearance. Cube-root function in CIE Lab and Luv correlates with log retinal luminance after scatter.
2. HUMAN DYNAMIC RANGE, CONTRAST, AND GLARE

When experimenters probe human response with single spots of light they find a dynamic range of more than 10 log units for the combined responses of rods and cones. For most ordinary scenes, the dynamic range of the retinal image depends on the distribution of luminances in the scene. It is not the average luminance that matters, rather the sum of glare at each point, from all other individual pixels in the scene. For most scenes, human visual dynamic range is between 2.0 to 3.0 log units, much less than the rod / cone responses of light (McCann, 2007).

The following experiments measure the range of human responses by controlling both simultaneous contrast and scattered light. The key to this experiment is the fact that contrast and glare are dependent on the spatial configuration of the scene. An experiment that measures the dynamic range of appearance needs to have constant spatial properties while altering the dynamic range of the scene.

In our experiments, we asked observers to use magnitude estimates between the appearance White (100) and Black (1). The surround area was 50% maximum transmission and 50% minimum transmission (Figure 1, right: Figure 2 left). Five observers made 5 estimates of 40 gray squares in a transparent target on a lightbox. The dynamic range of the transparency was 500:1, or 2.7 log units.

The next experiment added a second, identical transparency in superposition to the first. This doubled the optical densities of the target. The display dynamic range changed from 2.7 log units to 5.4 O.D. The contrast of the image remained the same: 50% of the area was maximum transmission and 50% was minimum transmission. The luminance of the white area decreased slightly because the film did not transmit 100% of the light. The black density doubled. However the 50% white surround is by far the major contributor to scattered light. The double density of each area in the target had minimal effect on the image’s scattered light.

If the dynamic range of the retinal image luminances is controlled by scatter, and if the two targets have very similar scattered light patterns, then these targets must have similar appearance dynamic ranges. Observer magnitude estimate data fits this analysis. When simultaneous contrast and scatter are held constant, apparent dynamic range is nearly constant, despite a 2.7 log unit increase in display dynamic range. Figure 2 (right) shows average observer magnitude estimates for single and double density targets. Both plots show that humans can see a range of 2.3 log units of luminance. Increasing the dynamic range of the target had little effect on the range of appearance.

Figure 1. (left) Illustration of simultaneous contrast in which contrast offsets glare. (right) Magnified image of areas A and B in 50% white area surround target.
Further experiments changed the surround, using 100% white and 0% white backgrounds. The results show the substantial effects of intraocular scatter. In the 100% white surround the range of luminances between white and black decreased to 2.0 log units for both single and double density targets. With 0% white surround the range increased to 5 log units. These experiments show that the amount of white in the surround controls the usefulness of HDR displays. The luminance on the retina plays a major role controlling appearance. The combination of intraocular glare and simultaneous contrast results in changes in the relationship between stimulus luminance and appearance (Figure 3, left).

To investigate the role of the glare vs. that of simultaneous contrast we calculated the retinal luminance for each gray square (Rizzi, 2008). Figure 3 (right) plots of appearance vs. log retinal luminance. It shows three different surround-dependent, linear functions. Figure 3 also plots the Stiehl et al. calculated retinal luminance. Stiehl’s target and 100% white target share the same function of relating Lightness to retinal luminance. Increasing the amount of white in the background decreases the dynamic range of the retinal image because of glare. Increasing the amount of white in the background increases the apparent contrast of the image. Glare and physiological spatial contrast act in opposition to each other. They tend to
cancel each other. Both simultaneous contrast and intraocular scatter are different image-dependent mechanisms. Although contrast tends to cancel scatter, each spatial mechanism is different. Thus, the cancellation is imperfect.

3. CONCLUSIONS

Simultaneous contrast is a spatial mechanism that generates appearances by comparing different parts of the image. If appearance depended on the luminance of individual pixels, then identical grays in different surrounds would be identical. Our experiments measured the appearance of single- and double-density displays with the same spatial patterns. The dynamic range of appearance is image dependent. It depends on both the intraocular scatter and simultaneous contrast.

Then, we have investigated the reciprocal roles of glare and simultaneous contrast, presenting data of appearance against retinal stimulus. The retinal stimulus has been computed according to CIE standards (Vos, 1999). Results show a simple relationship between appearance and log retinal luminance. The rate of change of that relationship is a function of the amount of white in the surround. While intraocular scatter decreases the range of luminance on the retina, simultaneous contrast makes areas with increased scattered light appear darker. Simultaneous contrast is an imperfect cancellation of intraocular scatter.

REFERENCES


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