

# The Effects of Backgrounds on Sensitivity and Brightness

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One of the primary accomplishments of the retinal circuitry is to transform the light signal to one which reflects contrast, or variation around the mean level, rather than the mean level itself. This transformation determines not only visual sensitivity, but also is an important factor in the suprathreshold visibility ie, the brightness of objects. Historically, most work on the problem has concerned measurements of threshold sensitivity. I will review our current understanding of the determinants of visual sensitivity, and then examine how far we can extend these conceptions to the perception of brightness.

Our understanding of precisely how the transformation to contrast is accomplished is still fairly limited, but it is clear that a number of mechanisms are involved. Another gain change mechanism, one which is important in attenuating the masking effects of a sudden light onset also isolated a very rapid mechanism which acted in a multiplicative fashion.<sup>1</sup> It is not clear where in processing this mechanism is located, but it is presumably very early, perhaps in the receptor synapse. Other processes which protect the visual system from saturation by sudden onset lights can be classified as subtractive, in the sense that they attenuate the background signal without attenuating the response to the increment, that is, without changing the gain. Such mechanisms become important whenever there are significant nonlinearities in the system, as indeed are revealed by the masking effects of temporal transients. One such subtractive mechanism is center-surround antagonism, which is probably instantaneous and acts at the level of the outer plexiform layer. Another slower subtractive process removes most of the residual signal over a period of several seconds, for lights of moderate intensities. These two processes can be thought of as spatial and temporal filtering.

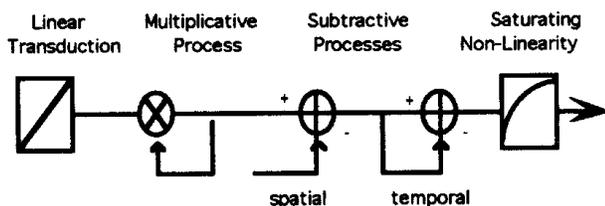


Figure 1.

A schematization of these ideas is shown in Fig. 1. Following linear transduction, the signal at light onset is attenuated by a multiplicative gain control mechanism. The signal is further reduced by subtractive lateral inhibition (centersurround antagonism), followed by another subtractive mechanism which slowly removes most of the residual

signal. At higher intensities (above about 3.5 log td) a slower multiplicative process (not illustrated) appears to come into play, probably related to pigment bleaching. The final non-linearity reflects the limited operating range of the stage or stages of the visual system responsible for the instantaneous saturating effect at the onset of a light. (In the absence of a representation of both photon and neural noise in the model, this non-linearity also implicitly incorporates the effects of noise.) The adaptation mechanisms accomplish the gain in sensitivity during the transition to steady state sensitivity following light onset.

The conception of adaptational transformations outlined in Fig. 1. was developed to account for sensitivity in the presence of achromatic adapting fields. If the same mechanisms were responsible for sensitivity, brightness, and color, this would result in a simple and elegant picture of retinal transformations, with immediate implications for constancy. However, this is unlikely for several reasons. One of the primary functions of adaptation is to preserve sensitivity over a wide range of illuminances. The problem for both sensitivity and brightness constancy is to cope with a wide range of absolute levels. For color constancy it is only required to compensate for changes in the distribution of excitation across the three cone types. Light adaptation requires both fast and slow mechanisms. It must be fast so that the organism is not incapacitated by sudden large changes in illumination. At the same time if it were all accomplished within a single fixation scenes would undergo rapid fading and revival with every eye movement. Color constancy, however, calls for rather slow adaptation processes. Many algorithms for constancy depend on adaptation to the average light reflected from a scene. If the space average reflectance is spectrally flat, then the average light will have the chromaticity of the illuminant, and adaptation to the mean can then allow recovery of reflectance. D'Zmura & Lennie (1986)<sup>2</sup> suggest that this can be achieved with localized but sluggish adaptation processes. The rapid gain changes observed in sensitivity experiments would subvert adaptation to the space average light. That is, we do not want a system for chromatic adaptation which adapts significantly to individual objects. We might therefore expect to find different mechanisms underlying color and brightness constancy.

I have investigated the adaptational mechanisms which underlie the color appearance and brightness of lights, and compared them to the adaptational mechanisms which determine sensitivity as outlined in Fig. 1. The mechanisms which regulate sensitivity probably determine brightness as well, but the mechanisms for color appear to be quite different.

In a classic experiment, Whittle & Challands (1969)<sup>3</sup> measured the effects of background adaptation on the brightness of incremental flashes. They found evidence for both gain changes and a background discounting (subtractive) process. In order to see if these mechanisms could be identified with those operating for threshold measurements, Whittle and I examined the time course of background adaptation on the brightness of increments. For backgrounds of moderate intensity where bleaching is insignificant, these data can be accounted for by a very similar model to that used for thresholds. There appears to be a very rapidly acting multiplicative (gain) change and a subtractive process which takes several seconds to asymptote. The rapid multiplicative adaptation means that there will be significant adaptation to individual objects as the eye moves around a scene, and that the state of adaptation is only partially set by the mean light level.

This contrasts with the effects of adaptation on color appearance, where all the processes appear to be much slower. Experiments on the color of increments on colored backgrounds in the chromatic induction paradigm show that the gain changes in this paradigm are not complete by 10 sec and clearly result from a different mechanism than do those in the light adaptation experiments with white backgrounds. A similar conclusion has been reached by other investigators<sup>4,5</sup>. An interesting implication of this is that it requires revision of the universally accepted notion that luminance and chromatic pathways share an initial stage of receptor-specific adaptation. We can't have fast receptor gain changes for sensitivity and slow ones for chromatic induction, although the von Kries changes are almost universally referred to as receptor gain changes. There must be

two different gain mechanisms involved with different time course and they cannot both be in the receptors. It seems we must postulate parallel pathways rather early in the retina. It is possible for example, that the two types of cone bipolar synapse subserve different gain control mechanisms. The slow chromatic gain changes observed here are much better suited to adapting to the space-averaged chromaticity than the fast adaptive changes observed with white backgrounds. The fast changes appear to be confined to a luminance system, and have separate implications for brightness constancy. In brief, it appears that light adaptation on white fields is very different from chromatic adaptation, despite their superficial similarity.

## References

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