Failure of Brightness and Color Constancy Under Prolonged Ganzfeld Stimulation

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Abstract

We investigated sustained hue and brightness perception in a uniformly-illuminated sphere (*Ganzfeld*) covering the entire visual field. Under these conditions the perceptions of both brightness and hue do not remain constant, but fade with time due to local adaptation (Troxler effect). Our aim was to quantify the magnitude and time course of hue and brightness fading in physical units.

In a first experiment, subjects used magnitude estimation to rate perceived hue and brightness of the sphere when illuminated by constant amounts of red (674 nm), yellow-green (547 nm), or blue (431 nm) light. Within 2-7 minutes the perception of hue was found to become desaturated and replaced by a sensation of grey before brightness fading leveled off as well. This final plateau was reached after 5.5-7.5 min. depending on wavelength. It was higher for short-wavelength light and lower for long-wavelength light. However, in each case, it was above the intrinsic dark light or *Ezgengrau*. In a second experiment, *Ganzfeld* luminance was logarithmically reduced with time to obtain correlated brightness estimates in the absence of fading. When the results from Expts. 1 and 2 were combined in a Crawford-like transformation, the total perceived brightness loss was found to be equivalent to a luminance decrease of about 1.5 log units and 1.3 log units for *Ganzfeld* luminances of 0.1 cd/m^2 and 1.0 cd/m^2, respectively, and for all wavelengths tested. In comparison, the time at which the hue disappeared corresponded to a decrease of luminance ranging from 0.4 - 1.2 log units depending on wavelength.

Keywords: color constancy, *Ganzfeld*, color and brightness fading

1. Introduction

The concepts leading to our work may be traced back to the Gestaltist Wolfgang Metzger[1] who pioneered the study of brightness perception under prolonged, uniform stimulation. His use of a *Ganzfeld*, an empty, contourless field devoid of any spatio-temporal modulation, eliminated the need for strict fixation which allowed only for brief periods of observation because of involuntary eye movements. In a *Ganzfeld*, eye movements do not change retinal illumination because of the uniformity of the surface. In spite of this improvement, apparatus limitations often restricted early investigators to merely qualitative descriptions of the phenomena.

Metzger[1] reported that under *Ganzfeld* conditions, the brightness of a sphere will gradually decline despite the constant illumination, similar to Troxler-type fading[2] for small, peripheral targets. Ultimately, brightness will approach a value similar to the *Eigengrau*. The term *Eigengrau*,[3] or subjective gray,[4] is defined as the residual brightness perceived in an absolutely dark room after dark adaptation. It has been attributed to the spontaneous activity of the visual neurons,[5] presumably caused by the thermal isomerization of rhodopsin[6] or the spontaneous random release of neurotransmitters.[7]

These findings appear in a new light if one considers modern ideas about parallel processing of visual information by two neuronal subsystems, magnocellular and parvocellular. It was hoped that by quantifying the time course and the amount of fading of a sustained stimulus, such as a constant luminance, we would be able to determine the functional limits of the parvocellular system as defined by the underlying neurons. This was to be done for three different wavelengths of the *Ganzfeld*, short, medium, and long.

What is known about color perception under *Ganzfeld* conditions? Metzger's results for brightness fading were qualitatively confirmed and extended to colored lights by Hochberg, Triebel and Seaman,[8] Cohen,[9] and Gur[10,11] among others. These authors variously reported a sensation of black, dark grey or medium grey for the residual percept of a colored *Ganzfeld*. Except for an occasional faint hue sensation all studies report that the perceived color completely desaturated under *Ganzfeld* stimulation. This loss of hue is not surprising if one considers that the physiological mechanisms mediating color perception are rather insensitive to stimuli which are not modulated in space or time.

2. Material and Methods

2.1. Ganzfeld

To produce a *Ganzfeld* we adopted a method that consists of fitting half ping-pong balls snugly over the eyes.[4,8,12] The plastic shell of a ping-pong ball is perfectly diffuse, so that no spatial borders from the cheek, nose or eye brows can be seen. It also prevents the cornea from becoming dry. If needed, a film of highly viscous artificial tear fluid can be applied to the eye to further minimize the blink reflex. Before the experiment, pupils were dilated using a mydriaticum (Mydriaticum Roche, Grenzach-Whylen, Germany) to rule out changes of retinal illumination due to changes in pupillary diameter.

2.2. Experimental Set-Up

To illuminate the ping-pong balls with a daylight-like spectrum of high intensity, a 450 W Xenon arc lamp (Heinzinger, Rosenheim, Germany) was used in conjunction with a large Styrofoam sphere. This is shown in Figure

1. The collimated light beam was first passed through a waterbath plus IR- and UV-filters. The beam was then focused onto a pair of neutral density wedges (Reynards Corp., San Clemente, USA) mounted on the axles of computer-controlled stepping motors. By counter-rotating the wedges, luminance could be gradually changed over 6 log units at variable speeds. Thereafter, the light beam was recollimated and passed through one of three broadband color filters with dominant wavelengths of 431 nm, 547 nm, and 674 nm (Schott, Mainz, Germany). The colored beam was projected onto a milky diffusing glass (volume scattering glass, Spindler & Hoyer, Gottingen, Germany), which admitted the light into a Styrofoam sphere of 0.8 m diameter. This technique approximated an Ulbricht sphere[9] and ensured that the light was diffusely reflected from the inner surface of the sphere to every part of the ping-pong balls and from there into the eyes.[11] Observers steadied themselves on a chin-headrest to keep their head position constant while looking with both eyes into the sphere. Luminance of the inner surface of the ping-pong balls was measured with a calibrated photometer (Grasby Optronics, Orlando, Fl., USA).

To make sure that the subjects relied exclusively on the perceived brightness, they were kept unaware of the nature, as well as of the beginning and end of the experiment. Additionally, earphones were used with white noise to mask any auditory cues, which might reveal manipulations of the stimulus by the experimenter. This procedure also helped to keep attention at a steady, passive level. To control for inner state, we monitored the pulse frequency of the subjects by using an arm collar. The verbal reports by the subject were continuously recorded on tape.

2.3. Subjects

Two subjects participated in our study, OK and HW (31 and 64 years old). OK had normal vision, whereas HW was presbyopic. Hue perception was tested with the Ishihara pseudoisochromatic plates[13] and found to be normal. Before the actual experiment, subjects participated in several training sessions to familiarize themselves with the stimulus situation and the procedure. In separate sessions, they were also dark adapted for 30 min to experience their *Eigengrau.*

2.4. Preadaptation

Before each session subjects were preadapted for 20 min to a room luminance comparable to that which they were subsequently exposed to in the *Ganzfeld*. Preadaptation was without the half ping-pong balls and with free viewing. It served to neutralize the effects of individual light history and to provide an initial brightness sensation appropriate to the adapting luminance used in the experiment. In this way photochemical processes were stabilized permitting the study of brightness and hue fading due to neural adaptation. *Ganzfeld* luminances were either 0.1 or 1.0 cd/m^2.

3. Magnitude Estimation of Brightness Fading

3.1. Procedure

The time course of relative brightness change during adaptation was quantified using magnitude estimation.[14] The subject's task was to give a running report of each

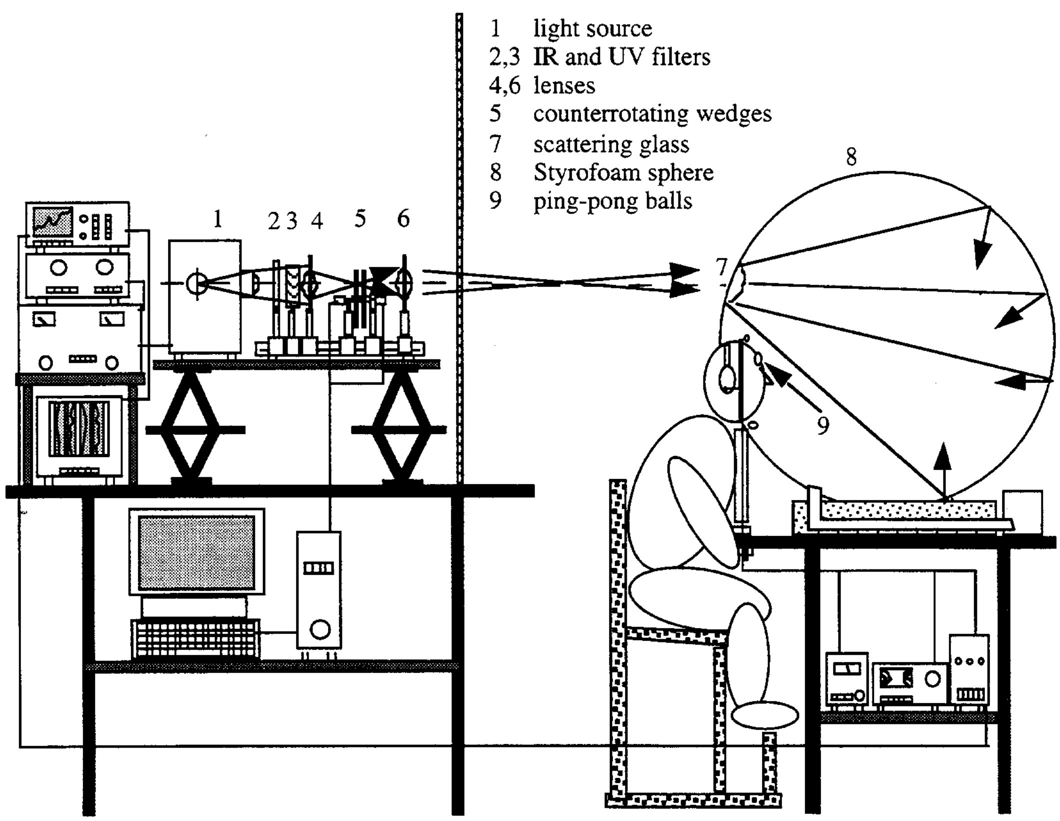

Figure 1.

change of brightness by assigning it a value between 100 and 5 (*Eigengrau*). Values below five were reserved for a still greater darkness such as the black sensation seen when the eyes were closed for several seconds.[10,15] An upper modulus of 100 was chosen as the starting value for the two luminance levels tested, since we were interested in the relative brightness loss, not in absolute brightness judgments. Qualitative observations on brightness and hue were also invited.

3.2. Results

Almost from the beginning subjects reported that their visual field was getting darker while hue became increasingly desaturated until the *Ganzfeld* appeared achromatic. After some more time, brightness fading leveled off as well and reached a plateau. Figure 2 shows magnitude estimates for subject OK plotted as a function of adapting time for a *Ganzfeld* luminance of 0.1 cd/m^2. The filled symbols refer to light of 431 nm, the open symbols to light of 674 nm. Different symbols within a data set refer to different trials on subsequent days. Data were fitted with regression lines to obtain the time (t_{end}) required to reach the final plateau as well as the corresponding brightness value.

Figure 3 summarizes the adapting times for complete loss of hue (t_{desat}) and to reach the final plateau (t_{end}) as a function of the wavelength used. Plotted are averages and standard deviations for a total of six values obtained from both subjects. Open symbols refer to a *Ganzfeld* luminance of 0.1 cd/m^2 and closed symbols to a luminance of 1.0 cd/m^2. Overall, the time to fade-out (t_{end}) tends to decrease as wavelength increases. Moreover, adapting times for the higher luminance tend to be higher than for the lower luminance. Curves for complete loss of hue (t_{desat}) show a similar pattern, with shorter adaptation times.

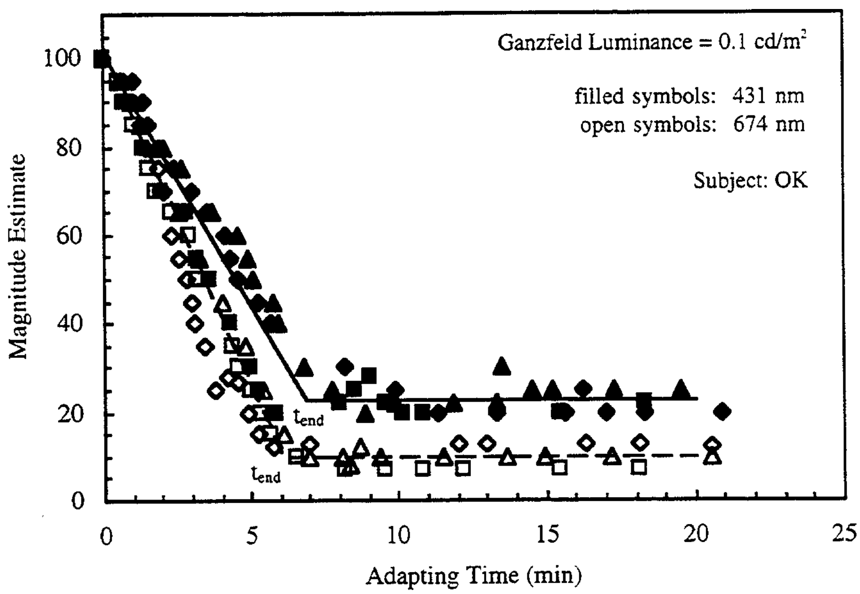

Figure 2.

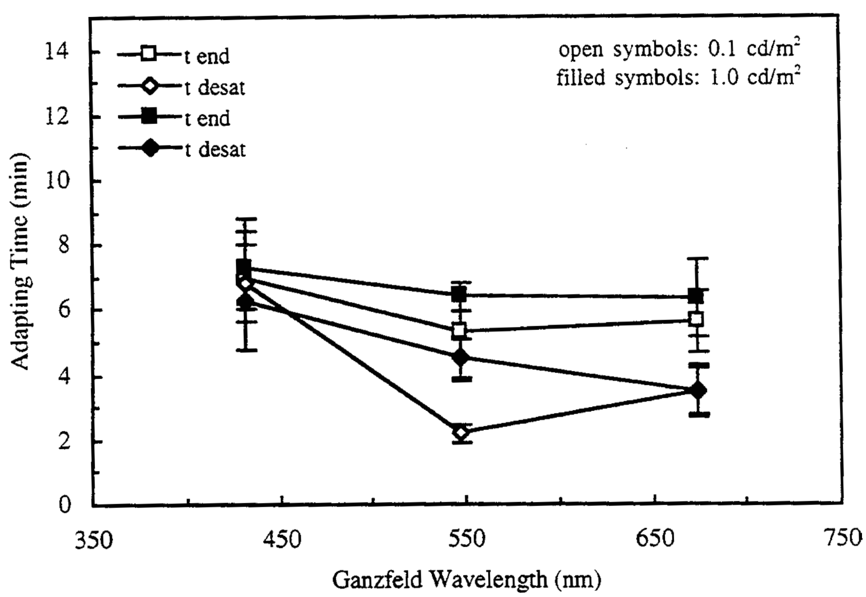

Figure 3.

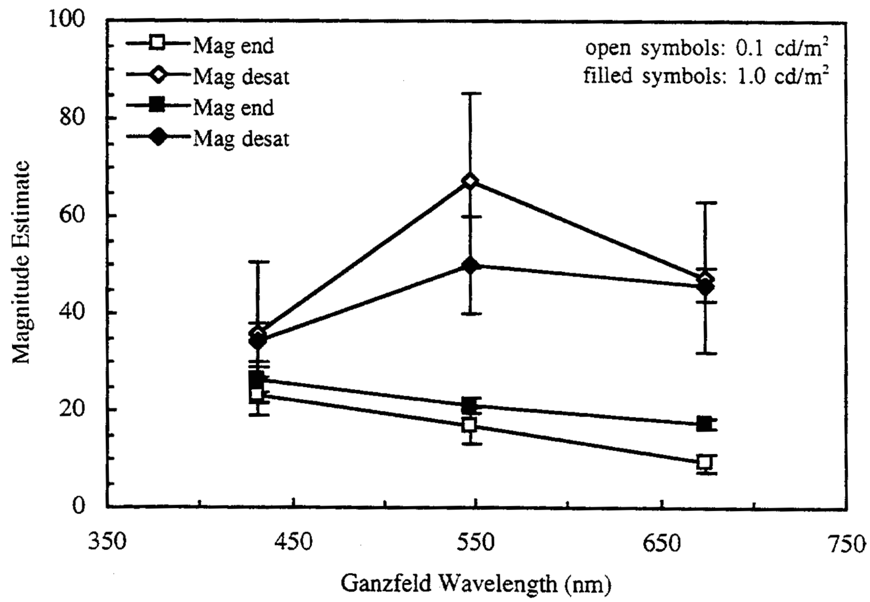

Figure 4.

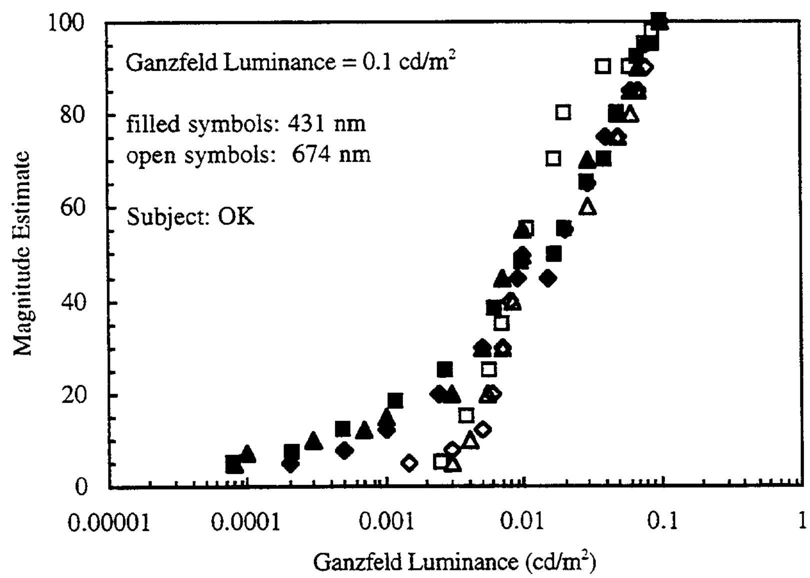

Figure 5.

Figure 4 shows the magnitude estimates corresponding to the time when the *Ganzfeld* appeared achromatic (Mag_{desat}) and the estimates corresponding to the finally attained brightness levels (Mag_{end}) both as a function of wavelength. Mean values and standard deviations (n = 6) for both subjects are plotted. Again, there is a tendency for the final brightness estimates to decrease with increasing wavelength. It should be noted, however, that the true *Eigengrau* (magnitude estimate of 5) was never reached in any of these conditions. The final brightnesses were always higher. As in the previous figure, the higher *Ganzfeld* luminance produced higher values than the lower *Ganzfeld* luminance. The magnitude estimates corresponding to the time of complete loss of hue suggest that red and yellow-green light desaturates at a higher brightness level than blue.

4. Magnitude Estimation for Decreasing Luminances

4.1. Procedure

In this experiment, the luminance of the *Ganzfeld* was not kept constant, but was gradually decreased to prevent fading and to obtain brightness estimates appropriate to the luminance at any given time. A logarithmic decrease was chosen with a slope conforming approximately to the time course of brightness fading in Exp. 1. For brightness estimation, 20 s periods were interspersed during which the luminance was kept constant. Starting luminances were the same as in the first experiment (0.1 and 1.0 cd/m^2) and were again assigned a modulus of 100. To further counteract fading, subjects frequently closed and reopened their eyes.[10]

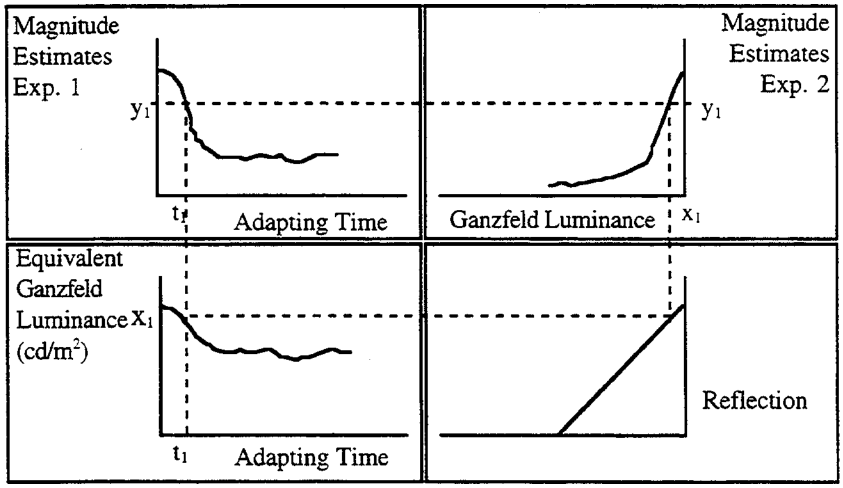

Figure 6.

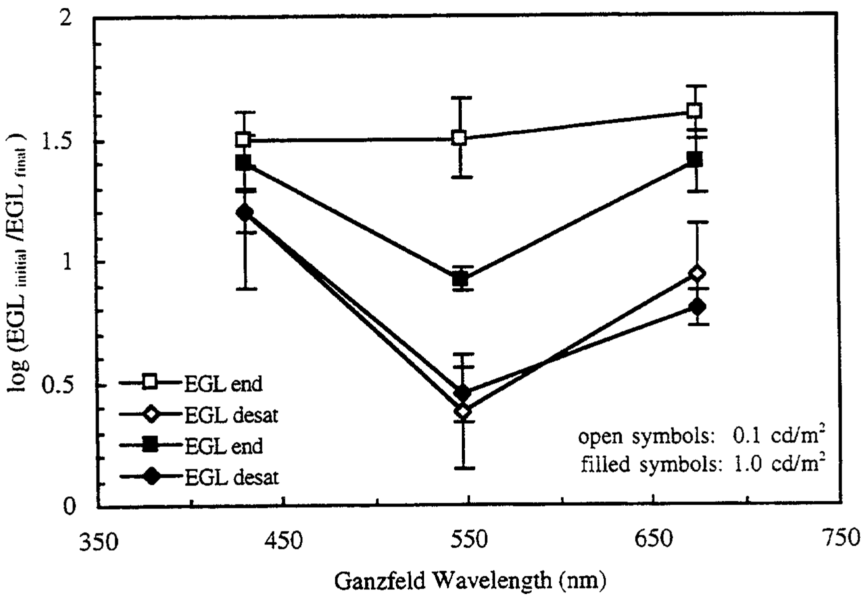

Figure 7.

A trial was terminated when the subject had arrived at a brightness estimate of 5.

4.2 Results

Figure 5 shows the data obtained for one subject and two different wavelengths (431 and 674 nm). Magnitude estimates are plotted as a function of *Ganzfeld* luminance. The main difference between the two wavelengths occurs in the lower part of the plot where estimates for the red light decrease more rapidly than for the blue light.

To express the loss of brightness and color in physical units, the final magnitude estimates from the first experiment (Figure 4) were substituted by the correlated *Ganzfeld* luminances obtained in the second experiment using a Crawford-like transform.[16]

The four panels in Figure 6 illustrate how this transformation is performed. For example, magnitude estimate y_1 at time t_1 (top left) is replaced by the *Ganzfeld* luminance x_1 corresponding to the same magnitude estimate y_1 (top right). The 45°-line at the bottom right serves to graphically project the values from the abscissa of the panel on the top right onto the ordinate of the panel on the top left. In this way, the equivalent *Ganzfeld* luminance (EGL) at time t_1 may be obtained (ordinate at bottom left).

The results of the Crawford-like transformation are shown in Figure 7 based on the data from both subjects. On average, we found that the total perceived brightness loss in Exp. 1 corresponded to a decrease of equivalent *Ganzfeld* luminance (EGL_{end}) of 1.5 log units and 1.2 log units for luminances of 0.1 cd/m^2 and 1.0 cd/m^2, respectively, and all wavelengths tested. The amount of faded brightness preceding the loss of hue due to desaturation corresponds to a decrease of equivalent *Ganzfeld* luminance (EGL_{desat}) of about 1.2 log unit for blue, 0.4 log unit for yellow-green and 0.9 log unit for red. These values are about the same for both luminance levels.

Discussion

This study shows that under prolonged *Ganzfeld* stimulation the perception of hue is lost before the perception of brightness approaches its final value. The total decrease in equivalent luminance ranges from 0.4 - 1.2 log unit for hue desaturation depending on wavelength and from 1.5 - 1.2 log units for brightness fading measured on backgrounds of 0.1 cd/m^2 and 1.0 cd/m^2, respectively. The residual brightness perception was always above the *Eigengrau*.

These findings are generally consistent with earlier reports from the literature. For example, Hochberg et al.[8] described that a green *Ganzfeld* changed to a dark grey after 6 min, whereas a red *Ganzfeld* lost its color already after 3 min. Similarly, Cohen[9] reported that bright red and green monochromatic *Ganzfelder* became achromatic after 3 min. whereas a blue *Ganzfeld* sometimes retained a tinge of hue to the end of observation. If the blue hue desaturated completely, the residual brightness was still higher than for red. Gur[10,11] found as did we that hue desaturation was complete before brightness reached its final plateau. He also observed that for both hue and brightness the fading time was longest for blue and shortest for red. However, fading in each case was completed within the first minute. Different criteria defining the end of fading may be responsible for the short adapting times in his study.

The relatively slow fading of hue and brightness plus the observation that the finally attained brightness level is above the *Eigengrau* suggests a relatively slow adaptation of the underlying neuronal mechanisms with a maintained firing rate of the mediating neurons above their resting activity. Neurons akin to the "luminance units",[17] "luxotonic units"[18,19] or "W-cells"[20] of the parvocellular system may potentially mediate the sustained brightness perception observed in this study. The finding that color is lost completely before brightness reached its final level may imply adaptation mechanisms of different subgroups of cells within the parvocellular system. Thus the neurophysiological basis of brightness and color perception in the *Ganzfeld* remains a challenge for future study.

6. Conclusion

Under prolonged *Ganzfeld* illumination, the color of the illuminant becomes desaturated while its brightness continues to decrease to a dark-to-intermediate grey depending on luminance and wavelength. However, in each case, the finally attained brightness is above that of the *Eigengrau* suggesting that the steady state signal determining perceived brightness is different from the neuronal resting activity. It might be attributed to the sluggish sustained or luxotonic cells of the parvocellular pathway. Since color perception is lost faster and more completely than brightness, other processes may also contribute.

7. Acknowledgment

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