FECHNER'S COLORS ARE INDUCED BY FLICKERING MONOCHROMATIC LIGHT

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Abstract

Fechner described the phenomenon of inducing illusory colors by means of rotating black-and-white disks. The induced spectral illusions were later termed 'Fechner's colors'. Similar color perceptions can be induced by non-rotating stimuli even on computer screens. We performed an experiment to investigate whether a uniform 'Ganzfeld' formed by means of rhythmically generated, unstructured, monochromatic light (i.e. flicker) is sufficient to induce perceptual phenonemoa analogous with Fechner's colors. Ten human observers participated in the experiment, reporting both color and form illusions despite the absence of particular spectral and spatial variations in the 'Ganzfeld'. Moreover, particular illusions were induced reliably at particular frequencies, which may be taken to indicate that visual experience of different qualities may be subserved by mechanisms with different temporal sensitivities. In conclusion, rhythmic visual stimulation is sufficient to induce form-based illusions and illusions analogous with Fechner's colors, while the qualitative nature of those illusions may necessarily depend upon the frequency of stimulation

Fechner (1838) described how color perception can be induced by rotating a black-and-white disk at a certain velocity. This phenomenon was subsequently referred to as the so-called Fechner's colors. Benham (1985) designed a more complex disk which also induced colors when it was rotated (cf. Fig. 1). Collectively, the color perceptions induced by Fechner's or

Benham's disk were termed subjective, illusory or flicker colors and have been widely used in psychophysical experiments (Cohen and Gordon, 1949; Festinger et al., 1971; Jarvis, 1977). Recently, Nieke (1986) demonstrated that the inducing black-and-white stimulus does not have to rotate to generate illusory colors which can also be induced by means of presentation on CRT technologyRotgold and Spitzer (1997). Following the induction of illusory color perception on computer screens, a number of demonstrations have been programmed, some of which can be accessed via internet, a very nice example of which can be viewed at the website of Krantz (1999).[1]

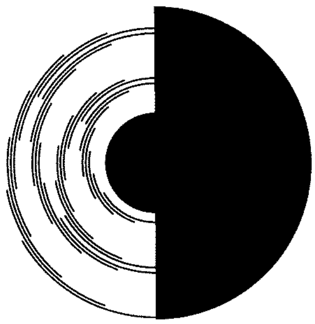

Figure 1: Benham's disk induces subjective colors when rotated.

The objective of this study was to examine whether flicker can induce subjective colors. This study was prompted by the subjective reports of observers in a previous electroencephalographic (EEG) study designed to examine the characteristics of the EEG steady-state response to flickering stimulation (Herrmann, 2001). In this experiment, observers were presented with monochromatic, rhythmically-generated, unstructured light of varying frequencies via light-emitting diodes (LEDs). A flickering 'Ganzfeld' was achieved when observers wore defocusing goggles, such that the entire visual field was filled with flickering light. Under these circumstances, observers reliably reported, not only the perception of different colors, but also of geometric forms in the flicker. Furthermore, the reports given by observers under these conditions suggested that illusory form and color were quite specific to different flicker frequencies.

[1] http://psychlab1.hanover.edu/Krantz/BenhamTop/version1.html

Methods

Ten observers with a mean age of 24.5 years (19 - 34 years, 6 female) took part in the experiment. All observers had normal or corrected-to-normal vision and showed no signs of neurological or psychiatric disorders. All gave written, informed consent and observers were explicitly informed that flicker stimulation might lead to seizures in epileptics. In no case was it reported that either they or any members of their families had ever suffered from epilepsy.

The special goggles employed in this experiment were constructed with defocused lenses and with one LED placed in front of each eyepiece. White LEDs with a light intensity of 3000 mcd (# 153745, CONRAD Electronic, 92240 Hirschau, Germany) were mounted in polished, concave metal reflectors. In this way, the entire visual field (the Ganzfeld) was illuminated by the two LEDs, A frequency generator (Wavetek, 10 MHz Function generator, model 29) was used to drive the LEDs at frequencies from 1 to 100 Hz in 1 Hz steps i.e. we presented unstructured stimuli driving predominantly magnocellular (M) cells (Silberstein, 1995). The presentation order of the frequencies was pseudo-randomized for each observer and each stimulation frequency was presented for 30 seconds with 5 seconds pause between presentations. The observers were asked to report whether or not they perceived form and or color for each presentation frequency.

Results and Discussion

For frequencies of around 40 Hz and above observers reported constant illumination and no specific illusory phenomena. However, for frequencies of less than 40 Hz alongside flicker, all observers reported experiencing both form and color illusions. The probability of reporting an illusory color was found to be approximately normally distributed around a flicker frequency of 12 Hz (lower and upper standard deviations falling at 6.75 and 16.6 Hz respectively). In contrast, illusory forms were reported across a bandwidth of 5 - 39 Hz with a non-normal distribution centered at around 22 Hz. The reported colors were in the range from 'red' to 'blue' with most observers reporting both 'red' and 'blue' or 'purple'. No observer reported to have perceived 'green'. In this respect the reported colors are very similar to bi-phasically generated Fechner colors computed with a mathematical model of retinal ganglion cells (Grunfeld and Spitzer, 1995). While Grunfeld and Spitzer (1995) were able to compute 'red', 'green' *and* 'blue' in their model, only 'red' and 'blue' were generated by simple, bi-phasic on-off patterns. In order to generate 'green', a more complex, tri-phasic on-off pattern was required. This goes well in line with our simple, bi-phasic on-off pattern of the flickering LEDs.

The form illusions were usually simple geometrical shapes. Most observers reported to initially perceive a horizontal and a vertical line which separated the visual field into four quadrants. The partitioning subsequently became more fine-grained for some observers until the whole field was separated into hexagons (honeycombs). Some observers reported that the forms started to rotate after a while giving them the impression of flying through a tunnel. The reported geometrical shapes resemble those described for 'phosphenes' (Eichmeier and Höfer, 1974). The phenomenon of illusory form perception is also known from certain kinds of epilepsies and has been simulated in mathematical models (Tass, 1995, 1997). Our observers were retrospectively shown the hallucinations calculated in (Tass, 1995) and reported them to be identical to the ones observed.

Due to the fact that rhythmic electrical stimulation of the retina also results in illusory color perception (Young, 1977), we assume the retina to be the basis of illusory color generation in this study. Adamczak (1981) argued that amacrine cells in the retina are responsible for the generation of the color response to flicker, which has also been argued to occur as a function of lateral inhibition between retinal cells (von Campenhausen et al., 1992). The relation of the general class of illusory phenomena described here with particular patterns of neural activity in the retina is also supported by evidence that illusory 'form' perception, of the phosphene-class, can be induced by electrical stimulation of the retina. For a description of these effects in the context of retinal cybernetics see Eichmeier and Höfer (1974).

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