Flicker Sensitivity

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Contents

Abstract

The visual system is sensitive to temporal changes in stimuli. The image appears to be continuous as the visual system integrates the responses with respect to time. A crucial factor is the CFF – critical flicker fusion frequency – and refers to the temporal frequency beyond which flicker is no longer perceived. CFF is a measure of the minimum temporal interval that can be resolved by the visual

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system. This chapter discusses the CFF and the effect of various parameters such as luminance, refresh rate of the monitor, wavelength, and retinal eccentricity on flicker perception.

Keywords

Adaptation • Ambient illumination • Band-pass shape • Bloch's law • Broca-Sulzer effect • Brucke-Bartley phenomenon • Critical flicker fusion frequency • Ferry-Porter law • Flicker perception • Function • Granit-Harper law • Limiting factor • Phosphor persistence • Regeneration rate • Retinal eccentricity • Retinal illuminance • Stimulus area • Stimulus luminance • Talbot brightness • VDT phosphors • Wavelength

List of Abbreviations

CFF Critical Flicker Fusion Frequency
CSF Contrast Sensitivity Function

Introduction

As is well known, images on a monitor are not continuous and the images are continuously refreshed. The rate at which the image is refreshed plays a crucial role in making the image appear continuous, even though the actual luminance of a point on the screen is intermittent. Because the visual system is sensitive to temporal changes, it integrates the responses with respect to time. Flicker arises when the display images are not repeated quickly enough. Flicker perception can be studied using grating stimuli whose luminance varies sinusoidally with time. Flicker perception depends upon stimulus size, luminance, retinal location, and temporal modulation among other factors. It has been found that chromaticity has little or no effect on CFF if the luminance is held constant (De Lange 1958).

Temporal Resolution Acuity and Critical Flicker Fusion Frequency

If we present to an observer alternating repetitive cycle of low and high luminance of a temporal square (or sine) wave stimulus, the light will appear to flicker (be intermittent) when the temporal frequency (in Hertz) is low. If we increase the temporal frequency, it will appear to be steady beyond a certain frequency. Psychophysically, we define the CFF (critical flicker fusion frequency) as the frequency at which the stimulus is seen flickering 50 % of the time and as steady or fused 50 % of the time. The CFF is a measure of the temporal resolving power of the visual system. This minimum interval of resolution is analogous to the minimum angle of resolution in spatial vision (see chapters "▶ Spatial Vision and Pattern Perception" and "▶ Visual Acuity"). In this sense, temporal acuity is analogous to grating acuity in spatial vision. The neural basis of CFF is the modulation of firing rates of retinal neurons (Tyler and Hamer 1990; Lee et al. 1989).

When a light is flickering above the CFF, it will appear steady, and the time-averaged luminance of a flickering light determines its brightness above the CFF. This time-averaged luminance is called the Talbot brightness. The Talbot brightness can be easily calculated using:

$$\text{Talbot brightness} = L_{min} + ([L_{max} - L_{min}] \times f)$$

Here L_{max} and L_{min} refer to the maximum and minimum luminance of the grating, and f is the fraction of time that Lmax is present during the total period.

Some Properties of the CFF

The CFF depends upon a number of factors. In this section, some of the basic laws governing the behavior of CFF and flicker issues will be discussed.

CFF and Stimulus Luminance

The CFF increases linearly with the log of the stimulus luminance (Fig. 1). This is known as the Ferry-Porter law and is expressed as:

$$\text{CFF} = k \log L + b$$

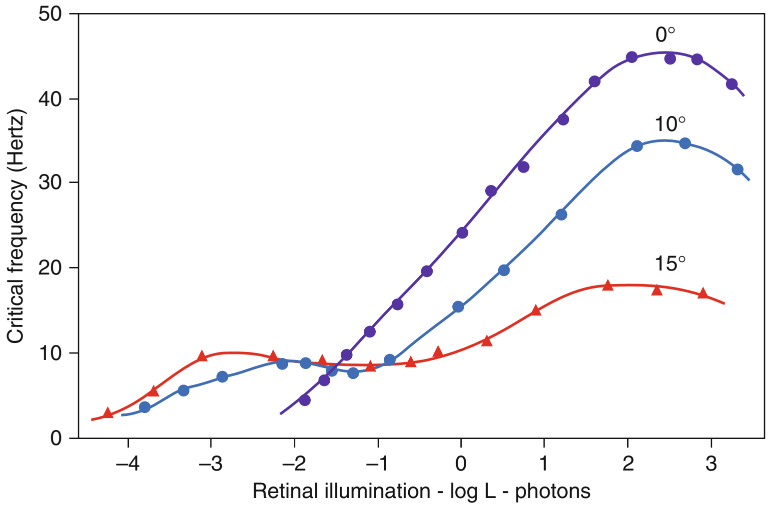

Fig. 1 Critical flicker frequency as a function of retinal illuminance and retinal position (From Hecht and Verrijp 1933)

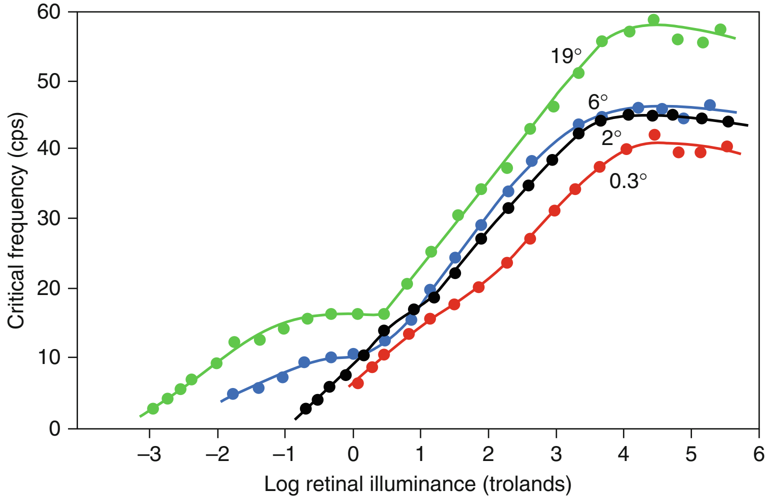

Fig. 2 Critical flicker frequency as a function of retinal illuminance and stimulus size (From Hecht and Smith 1936)

Experimental results hold over a range of approximately 4 log units of luminance. Here, k is the slope of the line and b is a constant; L is the stimulus luminance (Tyler and Hamer 1993). This law implies that the temporal resolution acuity improves as the flickering stimulus luminance increases. This law holds at many stimulus eccentricities.

CFF and Area of Stimulus

CFF increases linearly with the logarithm of the stimulus area (Fig. 2). This is known as the Granit-Harper law and is written as:

$$\mathrm{CFF} = \mathrm{k}\,\log \mathrm{A} + \mathrm{b}$$

Here, k and b are constants (different from those in the equation for Ferry-Porter law). A is the area of the flickering stimulus. The Granit-Harper law holds for approximately a 3 log unit range of luminance for stimuli presented in the fovea and up to about 10° eccentricity.

CFF and Retinal Eccentricity

The slope of the CFF luminance function changes being steeper outside the fovea, changing from a k of about 10 Hz/log unit at the fovea to about 20 Hz/log unit at about 10° eccentricity (Fig. 1). This implies that the peripheral retinal neurons respond with greater temporal acuity than central neurons. Tyler (1985) speculates that this might be due to the larger peripheral cone diameters. The maximum CFF measured at approximately 35° is about 90 Hz. The CFF is higher in the periphery at high luminance levels. At low luminance levels, there is not much change in CFF with eccentricity.

CFF and Wavelength

In general, flickering lights with equal photopic luminance but different wavelengths have equal CFFs. For intensities in the photopic range greater than 1 log troland, CFFs are independent of the wavelength. At low stimulus intensities, CFFs are highest for shorter wavelengths (Hecht and Shlaer 1935).

CFF and Adaptation

Given the relative densities of rods and cones in the different retinal areas, their different retinal sensitivities and their neural interactions, the CFF will depend in a complex manner on the adaptation state of the eye. It has been found that the CFF is the highest when the eye is completely light adapted or when a uniform background of high luminance surrounds the flickering stimulus. As a result, a flickering stimulus at a fixed intensity can appear to be flickering when the observer is light adapted and steady when the observer is dark adapted (Coletta and Adams 1984; Goldberg et al. 1983). It is found that the adaptation effects on flicker are evident at frequencies above 15 Hz.

CFF and Ambient Illumination

At high levels of display illumination, ambient illumination has a small or negligible effect on perception of flicker perception (Isensee and Bennett 1983). The ANSI standards for room illumination are $\sim$ 200–500 lx. Illumination affects flicker perception on a CRT screen only to a small extent under these conditions.

CFF and Refresh Rates of Monitors

The refresh rate (regeneration rate) is one of the most important factors in the perception of flicker on a display. If the rate at which the screen is refreshed is greater than the CFF of the observer, the observer will not perceive flicker. Refresh rates need to be higher for displays with higher luminance and wider field of view in order to make the display flicker free. Refresh rates can be decreased by an increase in phosphor persistence.

CFF and Phosphor Persistence

It has been found that the medium-short phosphors P20 and P4 cause maximum flicker effect (Turnage 1966). Many modern CRT phosphors contain a blend of two or more phosphors, and hence the ripple ratio is considered to be a better index to describe the persistence effect in a CRT. The modulation index of the fundamental frequency gives the ripple ratio (De Lange 1958). Pearson (1991) gives a list of ripple ratios for various refresh frequencies. In general, the smaller the ripple ratio, the less susceptible the monitor is to flicker. It should be emphasized that the ripple ratio alone does not give much information on perceived flicker; other factors such as luminance and angle of viewing also play a major role.

Brightness Enhancement Effects Because of the Temporal Properties of Vision

Two brightness enhancement effects that are known: the Brucke-Bartley phenomenon and the Broca-Sulzer effect.

If one views a flickering light and the flicker rate is varied without changing the time-averaged luminance, the brightness of the flickering light appears to be enhanced at certain frequencies. This is the Brucke-Bartley phenomenon. The maximum brightness enhancement appears for flicker rates at around 5–20 Hz (Wu et al. 1996).

The second brightness enhancement effect, the Broca-Sulzer effect is one wherein the brightness of a suprathreshold flash depends upon its duration (when compared to the brightness of a steady light of the same luminance). Here, it is found that flash durations of a test light shorter and longer than 50–100 ms produce less brightness effect and the effect becomes stronger, and the peak brightness occurs at short durations with increasing luminance levels (Wu et al. 1996; Aiba and Stevens 1964).

The Temporal Contrast Sensitivity Function

A complete description of the temporal responsiveness of the human visual system is given by the temporal contrast sensitivity function (temporal CSF). Like its counterpart the spatial CSF (see chapter "▶ Spatial Vision and Pattern Perception"), the temporal CSF has a band-pass shape, with a peak, a high temporal frequency cutoff (the CFF), and a low temporal frequency roll-off (Fig. 1).

In Fig. 3, the amplification scale on the right is nothing but the contrast sensitivity and the threshold modulation is the threshold contrast. The peak contrast occurs at an intermediate flicker frequency; the cutoff high temporal frequency is the limit of temporal acuity above which flicker cannot be resolved (even if contrast is 1) and also shows a reduction in sensitivity at low temporal frequencies.

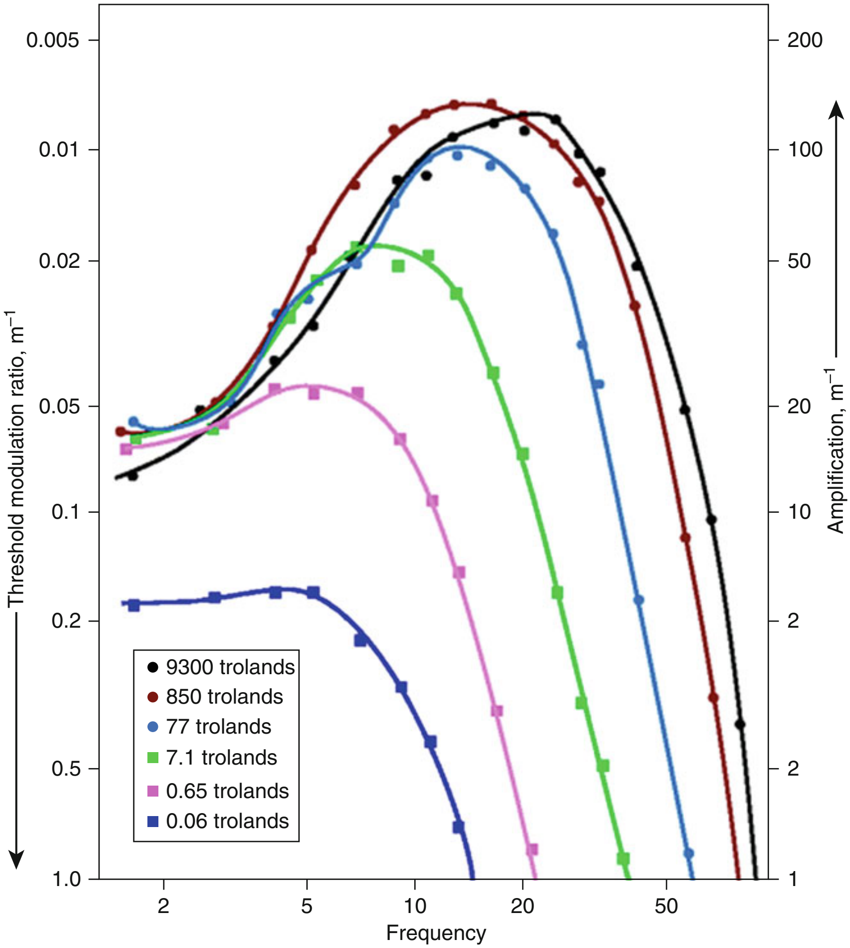

Fig. 3 The human contrast sensitivity function for several mean luminance levels (From Kelly 1961)

The temporal peak frequency shifts from approximately 20 to 5 Hz as the mean luminance decreases. The cutoff high temporal frequency goes from 60 Hz to about 15 Hz as the luminance decreases.

Because the visual system has a low CSF at low luminances, we can only see low temporal frequencies of medium to high contrast.

Kelly (1961), in his classic experiments on flicker, used a large flickering field with blurred edges to measure the temporal CSF functions (see (De Lange 1958)). If a sharp-edged field is used, the visibility of low frequency flicker is enhanced. The presence of spatial detail improves the visibility of flicker at low temporal frequencies.

Temporal Summation

The visual system does not distinguish the temporal shape of light flashes shorter than a critical duration. This is inferred from Bloch's law. The law essentially states that the visual system summates visual inputs over a brief time period and is given by:

$$L \times t = C$$

Here, L is the threshold luminance of the flash, t is the duration of the flash, and C is a constant. Bloch's law has a spatial analogy, namely, the Ricco's law in spatial vision (see chapter "▶ Spatial Vision and Pattern Perception").

Bloch's law holds for flashes that are shorter than a critical duration t_c for approximately 30–100 ms. During this time period, the visual system adds together the effects of the absorbed quanta regardless of the temporal pattern in which they arrive. Bloch's law is a consequence of the temporal filtering properties of the visual system. For more detailed description, see Roufs (1972).

Flicker in Monitors

Phosphor persistence can affect flicker modulation. In general, as phosphor persistence decreases, flicker increases. Now, persistence can vary widely depending on the colored VDT phosphors. In general, phosphor persistence are classified as long, medium, medium short, and short in terms of persistence (see chapter "▶ Luminescence of Phosphors"). For example, the P22 blue phosphor is classified as medium short (10–100 μs) while the P22 red and green phosphors are classified as medium (1–100 ms). Therefore, even if luminance is held constant, CFF may vary as a function of the specific color that is displayed on the color VDT. Another important factor is that in many VDTs the green channel's maximum luminance is greater than the red channel which is greater than the blue channel. Therefore, the colors displayed will differ in luminance and hence the CFF will vary. Usually greens, whites, and yellows will have higher luminance and therefore will be a limiting factor. Recall from above that CFF increases with luminance.

Various empirical methods have been proposed to predict whether a particular VDT will appear to flicker in a given environment (Rogowitz 1986). Many of these methods are cumbersome and time consuming. Farrell (1986, 1987) has developed analytic methods for predicting whether a VDT will flicker given screen phosphor persistence, refresh frequency, distance to VDT from the observer, etc. These predict a maximum screen luminance and minimum refresh frequency that will generate a flicker free display for a theoretical standard observer and is based on Kelly's pioneering work on flicker (Kelly 1961,1969, 1971). The model predicts that if the absolute amplitude of the fundamental temporal frequency of the VDT luminance modulation E_{obs} is greater than E_{pred} then observers will perceive flicker. Here,

$$E_{pred} = (1/a)\exp(2\pi fb)^{1/2}$$

where a and b are constants that depend upon the size of the display and f is the display refresh frequency. Also, if the amount of energy in the fundamental temporal frequency of the VDT is E_{obs}, then the lowest refresh frequency that will render a VDT flicker free is given by:

$$[\ln(aE_{obs})]^2/[2\pi b].$$

Summary

The detection of temporal changes is important for the organism. In this chapter, we have discussed the factor most important in use with VDTs, namely, the perception of flicker. The crucial factor is the critical flicker fusion frequency (CFF). The CFF depends upon a number of parameters, and these were discussed along with the temporal CSF (the temporal analogue of the spatial CSF). The CFF is the temporal analogue of the minimum angle of resolution.

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