Vision Science II - Monocular Sensory Aspects of Vision

Lecture 13 - Temporal Summation, Stiles-Crawford Effect

9/21/04

TEMPORAL SUMMATION AND BLOCH'S LAW

Just as the visual system sums the light it collects across an area, it also sums light collected over time. The time period over which light is summed is the **critical duration** or **critical period**. Summation over time is referred to as **temporal summation**.

The *scotopic system has a critical duration of 100-200 msec;* all the light collected within this time period is summed and treated as one. If the total quanta exceeds the detection threshold, the light will be seen. No matter how many flashes are presented within the critical duration, they will all be seen as one light. In order for two flashes to be temporally resolved as two, they must be separated in time by at least the critical duration. This is illustrated by Schwartz Fig. 3-18.

The *photopic system has a much shorter critical duration of 10-50 msec* as illustrated in Schwartz Fig. 3-19. In order for the quanta from two flashes to sum, they must be presented in very rapid succession. This gives the photopic system high temporal resolution, but poorer sensitivity than the scotopic system.

The critical duration for temporal summation can vary with test conditions. It is longer under scotopic conditions, which means that the scotopic system is designed to collect photons over time, when few photons are available. The critical duration is not affected by wavelength.

The temporal equivalent of Ricco's law (spatial summation) is **Block's law**. It states that, *within the critical duration*, the *total number of quanta* needed to reach threshold remains the same for different flash durations. Beyond the critical duration, the light required for detection increases (Schwartz Fig. 3-20). This is expressed by the formula:

$$I(t) = K$$

Since I is expressed in terms of quanta/time, the product of I and t is the total number of quanta required for detection. Bloch's law is also known as **time-intensity reciprocity**, since a decreasing intensity (I) is needed to detect the light as the duration (t) increases. Within the critical duration, intensity and duration are inversely proportional; that is, they have a reciprocal relationship.

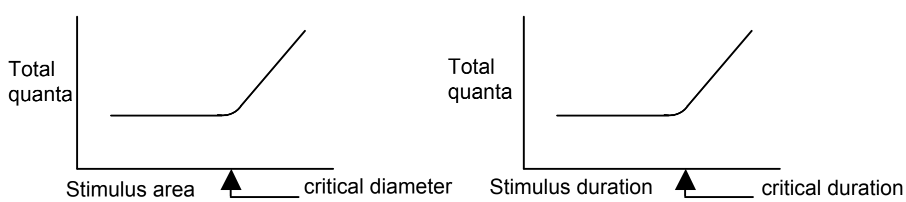

Figure 1. Side-by-side comparison of spatial and temporal summation.

STILES-CRAWFORD EFFECT

Narrow pencils of light that enter the peripheral parts of the pupil, after refraction, strike the retina at increasingly oblique angles compared to axial pencils. Because cones behave like **wave-guides**, and funnel light into their lumen, they capture photons most effectively when the incident beam strikes directly along its axis. This is illustrated in Schwartz Fig. 3-21.

Beams that enter the cone at a larger angle are less effective at stimulating cones. Because of this, light that enters the periphery of the pupil appears dimmer than light entering axially. This is known as the Stiles-Crawford effect of the first kind, or just the **Stiles-Crawford effect (SCE)**. The Stiles-Crawford effect of the second time relates to color vision.

Quoting from an article in the *Journal of the Optical Society of America* by He, Marcos and Burns (October, 1999 issue, p. 2363-2369)

> *The apparent brightness of a light changes as its entry point is moved from one location to another within the pupil of the human eye. This change in the relative luminous efficiency as a function of pupil location is called the Stiles-Crawford effect of the first kind (SCE-I). The change in entry-pupil position for the incident light is associated with a change in the angle of the light at the retina, and thus the luminosity change with pupil-entry position is a measure of the angular sensitivity of the cone photoreceptors. The peak location of the luminous efficiency function is interpreted as the location in the pupil toward which the cone photoreceptors are oriented. The luminous efficiency function is typically modeled as a Gaussian distribution (or, equivalently, log sensitivity is represented by a parabolic change with pupil location); that is,*

$$S_{pupil} = S_0 \cdot 10^{-\rho\left\{(x-x_0)^2+(y-y_0)^2\right\}},$$

> *where S_0 is the sensitivity at the location in the pupil with maximal luminous efficiency (located at position x_0, y_0), x and y are the test positions within the pupil, and rho (in inverse millimeters squared) represents a space constant (the larger the rho, the higher the directionality).*

Considering only a two dimensional cross-section of the pupil, two examples of the SCE are plotted in Figure 2, below. The narrower curve (greater directionality) shows the SCE measured objectively (ρ=0.1), and the upper curve shows the results of psychophysical measurements (ρ=0.06).

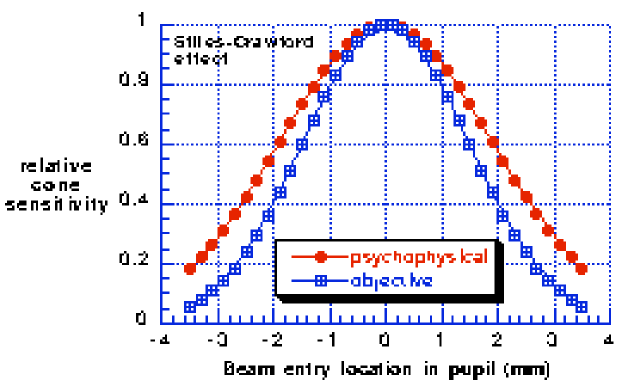

Figure 2. Horizontal cross-section of the SCE with rho values of 0.06 (upper, red curve) and 0.1 (lower, blue curve).

Clinical importance of the Stiles-Crawford effect

Susana Marcos, a scientist working at the Instituto de Optica "Daza de Valdéz" (CSIC) in Madrid, Spain, suggested that measurement of the Stiles-Crawford effect might allow early detection of diseases of the photoreceptors: *"Since normal photoreceptor directionality requires a normal cone morphology and relation to extracellular space, photoreceptor directionality has been of clinical interest. "*

(Marcos S, Burns SA. Cones spacing and waveguide properties from cone directionality measurements. J Opt Soc Am A16, 995-1004 (1999).

There are other important clinical applications of the SCE. In refractive surgery, patients may experience poorer vision with large pupils because of large optical aberrations in the peripheral cornea. Patients with smaller pupils will probably have better vision following refractive surgery than those with large pupils. The SCE helps mitigate the adverse effects of peripheral aberrations since it reduces the light intensity of rays entering the peripheral pupil; rays entering the aberrated peripheral optics are therefore dimmer and will be less annoying. It is almost as if the pupil was covered with **apodizing neutral density filter** (Figure 3). The SCE can therefore reduce the **effective pupil size** to be smaller than the actual physical pupil size. The chapter by Salmon and West gave examples of the difference between actual and effective pupil sizes.

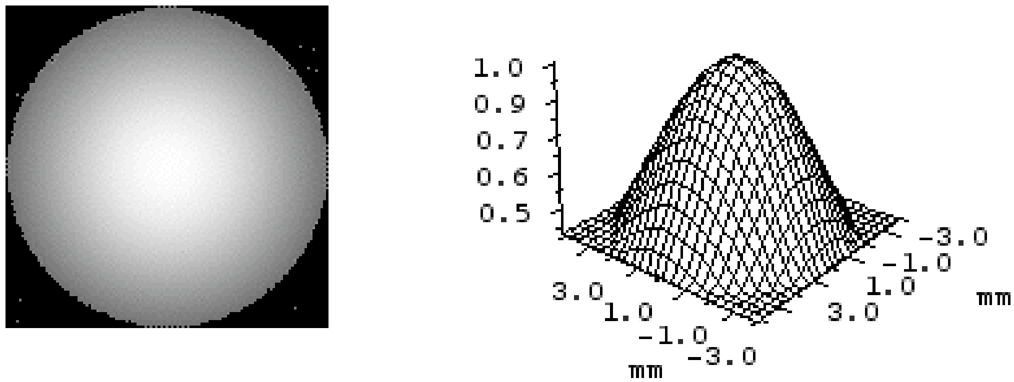

Figure 3. The SCE is sometimes described as an apodization of the pupil, shown here by the gray-scale plot (left) or the surface plot (right).

Another benefit of the SCE is that it helps to reduce the effect of intraocular scattered light on the retinal image. Light scattered within the eye strikes the cones at an oblique angle, but because of the SCE, this light won't interfere as much with the light that forms the retinal image. Without the SCE, scattered light would "wash out" the image, reduce image contrast and degrade vision.

Cones are normally pointed toward the pupil center to maximize photon capture. If for some reason the pupil is decentered, the cones will gradually shift their orientations to point toward the new pupil center. Experiments have shown that if the pupil center is temporarily displaced, the cones will shift, and if the centrally located pupil is restored, the cones will re-orient themselves to the original positions (Schwartz Fig. 3-22). This shows that cones can move and orient themselves for maximum effectiveness.

There is no SCE for rods, and as a result, rods do not receive any aberration-reducing benefit from the SCE. This, however is not a problem for scotopic vision since it is incapable of good visual acuity, due to the larger spatial summation zones. If, for example, aberrations blur the retinal image to the equivalent of a 20/40, the affect of the aberrations will not be noticed since the scotopic system is only capable of 20/200.

In the case of scotopic vision, *it is beneficial that the rods do NOT have a SCE*. They accept light from a wider angle and therefore can collect more photons than cones. They, in effect, take full advantage of the full pupil diameter. The result is better sensitivity under reduced illumination.

Sample test questions on the SCE from the <u>Optometry Examination Review</u> book, by Casser, Chang, Gerstmann, Pietsch and Bradley.

#418. Which of the following contributors to "stray light" within a young eye has the least effect on vision because of the Stiles-Crawford effect?
A. Scatter from the cornea
B. Scatter from the lens
C. Reflections from within the retina
D. Transmission through the iris
E. None of the above

#453. The visual effect of intraocular stray light that originates from light scattered by the neural retina may be reduced by
A. Maxwell's spot
B. The Stiles-Crawford effect
C. Birefringence of the fibers of Henle
D. The Troxler phenomenon
E. The Broca-Sulzer effect

SUMMARY OF THE DUPLEX RETINA

The duplex nature of our retina enables us to see over a very large range of illuminances, from the very low luminance on a dark night to that of a bright sunny day. Our eyes can adjust and see well over a 10 log unit difference in object luminance.

The scotopic system has been optimized to operate in very low light conditions. It specializes in high sensitivity; that is, detection of objects in dim illumination, when photons are sparse. The following unique features of the scotopic system enhance sensitivity, but compromise visual resolution

- spatial summation, which collects photons over a large area
- temporal summation, which collects photons over a relatively long time period
- absence of a SCE, so rods can collect photons over wide angle

The photopic system operates when light is abundant, so there is no need to "scrounge" for photons. It is designed to provide detailed information from the visual scene. Photopic vision provides us with excellent spatial resolution (visual acuity), high temporal resolution (motion perception) and color vision. The following features enhance resolution and detailed vision, but compromise sensitivity.

- smaller spatial summation zones (in fovea, one cone per ganglion cell)
- shorter critical period for temporal summation
- The cone wave-guide structure and motility give rise to the SCE, which reduces the influence of optical aberrations and scattered light (but also reduce photon capture).
- three classes of cones, with different photopigements that are the basis for color vision