Vision Science II - Monocular Sensory Aspects of Vision

Lecture 22 – Temporal Vision

10/12/04

INTRODUCTION TO TEMPORAL VISION

The field of spatial vision studies how we perceive changes in luminance across space (images), but **temporal vision** deals with how we perceive changes in luminance over time. This is closely related to motion perception.

We saw that spatial vision could be tested using a variety of stimuli—letters, square wave grating, etc. Sine wave gratings are preferred by scientists, however because

- they are basic building blocks of images,
- they lend themselves well to Fourier analysis, and
- if the test target is a sine wave grating, the retinal image will be a sine wave grating of the same spatial frequency, though its contrast will be reduced.

The basic stimulus used to study temporal vision is a **flickering light** with a luminance profile that changes sinusoidally over time (Figure 1, below).

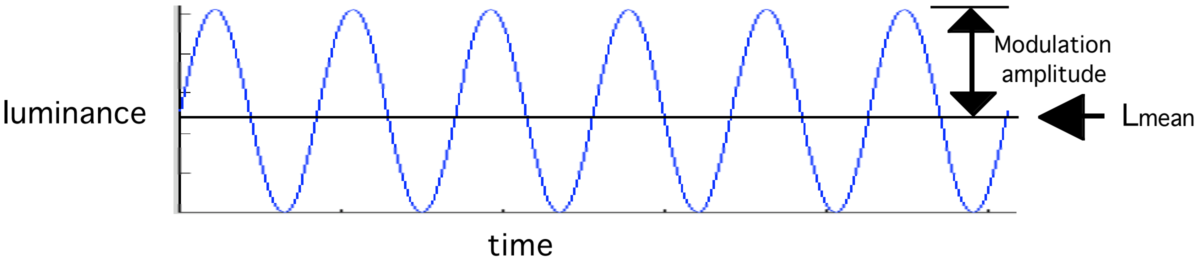

Figure 1. The stimulus used to study temporal vision is light whose luminance modulates sinusoidally over time.

In spatial vision we sometimes referred to contrast as modulation. The modulation transfer function (MTF) describes the amount of contrast (modulation) transferred from object to image by an optical system. Contrast, expressed as percent, could have a value between 0 and 100%.

The temporal equivalent of spatial contrast is called **percentage depth of modulation**. You could think of it as **temporal contrast**. It is computed similarly to spatial contrast, except that the contrast varies over time, rather than space. The formula below, for temporal contrast, is basically the same as Michelson contrast, except that contrast varies over time.

$$(\% \text{ modulation}) = (\text{Modulation amplitude})/(\text{mean luminance})*100$$

In addition to temporal contrast (percent depth modulation), a stimulus used to study temporal vision can vary in terms of **temporal frequency**. Temporal frequency may be easier to understand than spatial frequency. Another reason that temporal vision is less complex than spatial vision is that it is a one-dimensional, rather than two-dimensional function. Schwartz Fig. 8-3 shows examples of high and low temporal frequency profiles.

Basic features of temporal stimuli

- Frequency refers to the number of on-off flicker cycle per second. The unit for cycles per second is the **Hertz (Hz)**.
- Low frequency refers to a slow flicker; high means a rapid flicker.

- At some frequency the flicker becomes so rapid that you can no longer perceive the flicker—it appears to be a steady light. This frequency is called the **critical flicker fusion frequency (CFF)**.
- This is the temporal resolution limit. It is analogous to the spatial frequency resolution limit, or the high frequency cut-off.

THE TEMPORAL MTF

In the case of a flickering light, the retinal illuminance caused by the image falling on one particular retinal location, changes over time. The variation in retinal illuminance at that point could be plotted as a one-dimensional function.

Consider the example of someone watching a single flash of a fireworks display (Figure 2).

- At first he is looking at a black sky. Retinal illuminance at this time is nearly zero.
- Suddenly the firework explodes, and there is an instantaneous increase in retinal illumination.
- The high level of foveal illumination persists for a fraction of a second.
- The brightness then rapidly declines. After a few seconds it falls back to zero.

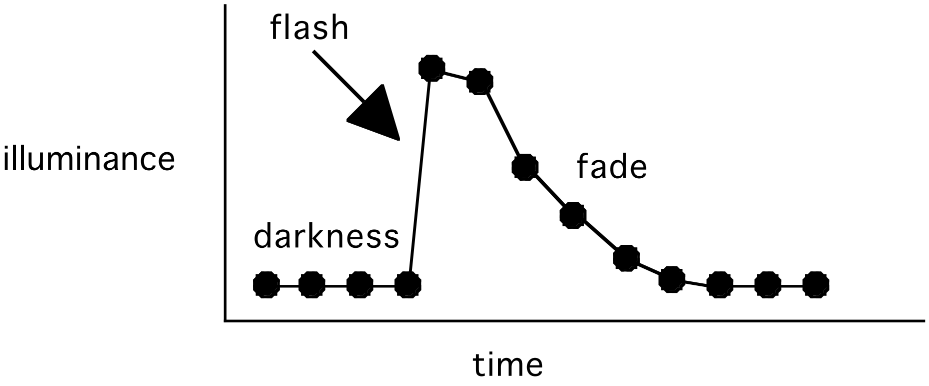

Figure 2. Retinal illumination at one point on the retina, plotted as a function of time, for the example of a fireworks display.

As with <u>any</u> function, this one-dimensional function could be Fourier analyzed.

- The function can be broken down into fundamental components.
- Each component would be a sine wave showing retinal illuminance as a function of time.
- Since any function (in this case illumination as a function of time) can be broken down into sine waves, it is logical to use sinusoidal temporal stimuli to study the basic temporal responses of the visual system.
- In other words, the basic stimulus used to study how the visual system perceives changes in luminance over time is a flickering light whose luminance changes sinusoidally over time.

The two basic stimulus parameters for a sinusoidal temporal stimulus are

- temporal contrast (percent depth modulation) and
- temporal frequency (rate of flicker)

To study how the visual system perceives changes in luminance over time, we need to test the eye with various sinusoidally flickering lights that have various modulations and frequencies. This leads to the concept of a **temporal modulation transfer function** (TMTF). It plots the limits of our ability to <u>perceive flicker</u> as the stimulus varies in terms of modulation (temporal contrast) and frequency. The TMTF is analogous to the CSF, which plots the limit of our ability to perceive a sine wave grating of different contrasts and spatial frequencies.

Referring to Figure 3, we can see how to build a temporal MTF.

- The subject views an illuminated patch of light, which flickers at a low frequency, and has very low modulation (temporal contrast). Perhaps the contrast is just ±1 nit relative to the background. This subtle change in luminance (contrast) is so small that the subject won't detect the flicker.

- Keep the frequency the same, but increase contrast (modulation) until the subject detects the flicker. This gives the temporal contrast (modulation) threshold for that frequency.
- Repeat for other frequencies and plot a graph of threshold as a function of frequency (Figure 3, left).
- The reciprocal of threshold is sensitivity, so we may also plot the sensitivity as a function of frequency (Figure 3 right). This is the temporal MTF for the visual system.

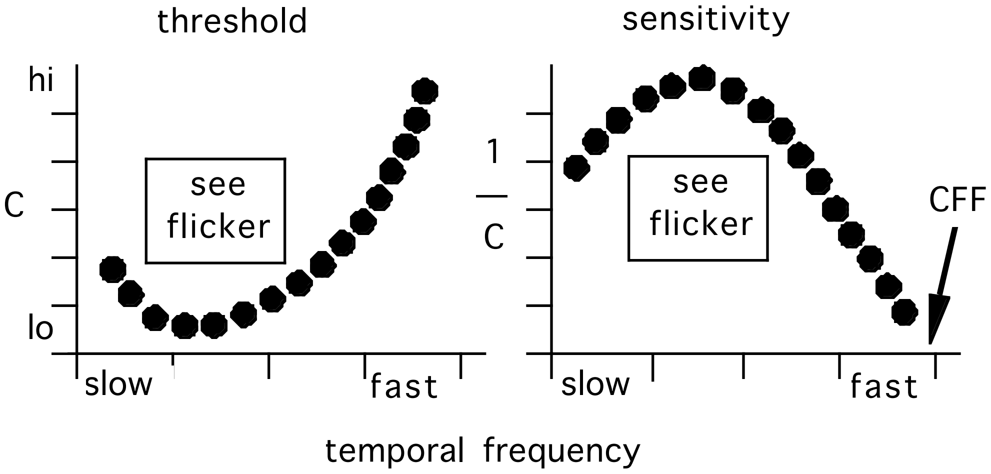

Figure 3. Example data from a threshold experiment used to plot the TMTF.

Looking closely at the **left** graph, we can note the following:

- On the y-axis, high values represent high modulation (high temporal contrast); low values represents low modulation (low temporal contrast).
- *In spatial vision, high contrast is always easier to see than low contrast.* Similarly, *in temporal vision, high modulation is always easier to see than low modulation.*
- All modulation values above the threshold curve represents modulation that can be seen. The curve represents the lowest modulation that can be seen.
- Stimuli with modulation values below the curve *cannot* be detected. Flicker is not seen and the light appears steady.

Similarly, examine some of the features of the TMTF (Figure 3, right or Schwartz Fig. 8-4).

- Since the y-axis plots the inverse of modulation, high values corresponds with low modulation (low temporal contrast) and low values represent high modulation.
- High sensitivity means the subject can see low modulation.
- Modulation values corresponding to the area under the curve represent the range of flicker and contrast values that the person *can* see. Sensitivity values above the curve represent stimuli for which flicker is not visible. The light appears steady.
- Note the similarity to the CSF. Peak sensitivity occurs at mid-range frequencies but is worse at lower and higher frequencies.

The highest spatial frequency that a person can resolve is indicated by the extreme right value on the TMTF curve. This is referred to as the critical flicker fusion frequency (CFF), and is shown, for high temporal contrast in Figure 3 right. Normally when we refer to the CFF, we have in mind the high-contrast CFF, as shown in the figure above. However, as shown in Schwartz Fig. 8-7, if you are using a lower contrast flicker, the CFF could refer to either the lowest or highest flicker detectable.

DECREASED SENSITIVITY AT LOW TEMPORAL FREQUENCIES

Low temporal frequencies refer to very slowly changing luminance levels. Some examples include:

- Day-night "flicker." You could consider the day-night illumination cycles caused by the sun as a very low frequency flicker. If you observed a patch of sidewalk on a cloudless day, its luminance would be changing very gradually, due to the changing irradiance caused by the sun's 24 hour cycle. It would not be necessary to watch the patch for a full cycle, the rate of change would still be based on the very low frequency of 1 cycle / 24 hours, which is equal to 1.0 cycle/86400 seconds, or a frequency of 0.000016 Hz. It is obvious that you would have great difficulty perceiving this change in luminance.
- Slowly moving object. Foveally fixating on a point on a clock as the minute hand passes by. It is moving so slowly that you would have great difficulty detecting the change in retinal illuminance that accompanies the motion.

It is intuitively obvious that very slow changes in luminance are difficult to detect. The reduced sensitivity to low temporal frequencies seems to be caused by lateral inhibitory processes in the retina (similarly to spatial vision). An example of this are **stabilized retinal images**.

The retinal vasculature casts a shadow on the photoreceptors, yet we can't see them. Since the retinal shadows don't move, they have a temporal frequency of 0, and the eye is very insensitive to non-moving (non-changing) luminance patterns. Sometimes, as during ophthalmoscopy or during a slit-lamp exam, light can enter the eye at an unusual angle and the shadows shift. With the sudden (high temporal frequency) change in local illumination, the shadows become visible. They appear to the patient as a branch-like pattern known as the **Purkinje tree**. This is based on the principles of perception described in the temporal MTF.

The visual system's insensitivity to low temporal frequency is also the basis for the **Troxler phenomenon** or **Troxler's effect**. This is defined by the Dictionary of Visual Science as: "The temporary and irregular fading or disappearance of a small object in the visual field during steady fixation of another object, e.g., during fixation of one of several spots drawn on a sheet of paper with disappearance and reappearance of the other spots."

This is also nicely described by William Hart, in Adler's Physiology of the Eye (9th Edition), on page 509.

> *A related phenomenon of contrasting borders is termed "Troxler's phenomenon." If a spot of light is presented in the peripheral visual field at a fixed increment above an adapting background light, and if the position of the spot remains unchanged for a period of several seconds, it will begin slowly to disappear from view. As soon as the spot of light is changed in position, or if the point of fixation of the eye is changed, the spot will reappear immediately. At first one might think that this phenomenon could be explained by local bleaching of photoreceptors at the position of the stabilized spot stimulus. However, the fact that the spot appears immediately on movement of the eye shows that recovery of sensitivity is nearly instantaneous and does not follow the time course of regeneration of photopigments. Rather, this appears to be a rapid mechanism that is presumably neutral in its basis.*

You may notice this while watching a stage performance. While staring at one actor, other non-moving characters seen by your peripheral vision will disappear, until you refixate on them.

Figure 4 below (and Schwartz Fig. 8-5), helps demonstrate the eye's relative insensitivity to low temporal frequencies. If you stare at the black dot on the left, the edges of the gray region quickly fade from view. In the right pattern, however the dotted line doesn't.

Q. Why?

Figure 4.

DECREASED SENSITIVITY AT HIGH TEMPORAL FREQUENCIES

What causes the reduced sensitivity of the eye to high temporal frequencies? For example, the overhead fluorescent lights are flickering at about 60 Hz, but they appear steady. They exceed the eye's CFF, so the flicker cannot be resolved. The temporal MTF **high frequency cut-off** represents the highest flicker that can be resolved when modulation depth is 100%. *When you hear references to the CFF that do not specify with the modulation, you can assume that they are referring to the 100% modulation high frequency cut-off.* The high frequency cut-off is due to the limitation in the nervous system's processing speed.

The faster a neuron can conduct and process data, the faster its CFF will be, and it will also be better at detecting motion. Data from retinal cones (photopic vision) are relayed to the brain via two categories of neurons, the **magnocellular** and **parvocellular** neurons. The magnocellular neurons primarily carry data from cones in the periphery, and have larger diameter axons that conduct signals faster than the parvo neurons. The magnocellular system therefore is better at detecting motion than the parvocellular system.