CONTRAST SENSITIVITY – LOW FREQUENCIES

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THIS CHAPTER WILL INCLUDE A REVIEW OF:

- Contrast sensitivity and low spatial frequencies
- Fourier analyzing property of visual system
- Neurological spatial filtering
- Visual acuity versus contrast sensitivity
- Articles

REVIEW

Figure 16-1, below, shows an MTF and two hypothetical CSFs for a human eye. They are essentially the same at the low spatial frequencies, but differ greatly at high frequencies. Refer to this figure and answer the following questions.

Q. Which of the three curves indicates the eye with the best optical quality? The worst?

A. _____

Q. Explain what limits the resolution for each of the three cases.

A. _____

REVIEW (CONT.)

Q. Assume that the center-to-center spacing of the foveal cones is 2 µm and that a span of 300 µm on the retinal surface corresponds to a visual angle of 1 degree. Calculate the maximum Snellen visual acuity this eye would be capable of if all its refractive errors (including higher-order aberrations) were perfectly corrected.

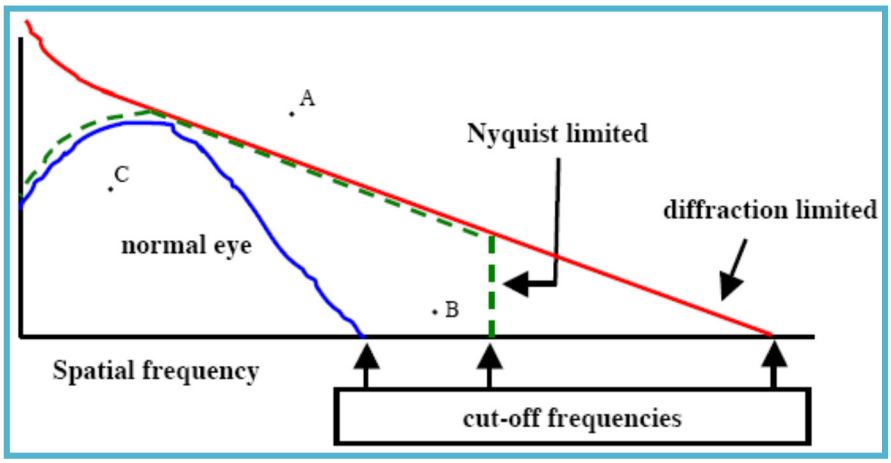

Figure 16-1: *Example of an ocular MTF and two CSFs limited by different factors*

DATA COLLECTION METHOD

Any point on the CSF defines two key parameters that determine the visibility of a sine wave grating – its contrast and spatial frequency (size). Recall that points outside the CSF (Points A and B, Fig. 16-1) correspond with gratings that cannot be seen by the eye, but points within the CSF (Point C) are visible.

Q. If Points A and B represent objects that the person cannot see, what can be done to make them become visible?

A. _____

Q. Can you give examples of how these principles are used to improve clinical examination in optometry?

A. _____

CONTRAST SENSITIVITY AND LOW SPATIAL FREQUENCIES

An important difference between the MTF and CSF of the human eye is the drop-off at low spatial frequencies. This is apparent in Figure 16-1, which shows two CSFs and a hypothetical MTF. What causes the reduction in contrast sensitivity below about 4 cycles/degree? This must be due to neural rather than optical factors, since the MTF, which show optical quality only and not neural processing, does not have a low-frequency drop off.

A possible explanation for the low frequency decrease in contrast sensitivity is illustrated in Schwartz Fig. 7-14. It shows the **receptive field** for a ganglion cell, which is the area in a person's visual field that elicits a response from a ganglion cell.

It is organized with a central excitatory area (+ sign) and a surrounding inhibitory area (- sign). When light falls on the excitatory area, vision is stimulated; when it falls on the inhibitory area, sensitivity decreases. This is called **lateral inhibition**. The ganglion cell will respond most strongly when the spatial frequency of the stripes is such that a white stripe is as wide as the excitatory area, and the black stripes fall on the inhibitory area. Scientists have found that this corresponds to a mid-sized spatial frequency, such as about 4 c/d.

CONTRAST SENSITIVITY AND LOW SPATIAL FREQUENCIES (CONT.)

Note, however, that if the stripes become wider than this (lower spatial frequency), the white part will stimulate both the inhibitory and excitatory regions, and the overall response will decrease. This may account for the decrease in sensitivity for low spatial frequencies.

FOURIER ANALYZING PROPERTY OF VISUAL SYSTEM

Experiments indicate that the visual system has neural channels that process specific spatial frequencies. This is illustrated by Schwartz, 2004 Fig. 7-15, which shows multiple narrow curves under the CSF. Each represents one channel that is sensitive to just a narrow range of spatial frequencies in the image.

Blakemore and Campbell (1969) performed an interesting experiment to prove this. They had subjects stare at a sine wave grating of just one spatial frequency (such as 6 c/d). This would cause the visual system to adapt, and become relatively insensitive to that specific spatial frequency. They then measured the CSF, and the result is illustrated in Schwartz, 2004 Fig. 7-16A.

The notch in the CSF curve shows reduced sensitivity to a narrow range of spatial frequencies near 6 c/d. This could only be explained if the visual system processes that one spatial frequency (6 c/d) separately from all others.

Q. What if there were no spatial frequency specific channels and the retinal image was relayed to the brain as a whole? What effect would adaptation to a grating have on the CSF?

A. _____

SQUARE WAVE GRATINGS

Recall that if a square wave grating (Schwartz Fig. 7-4) is Fourier analyzed, we will find that it contains sine wave grating components (Schwartz Fig. 7-5). The complete Fourier spectrum of a square wave grating contains an infinite number of sine waves, and if added together, they would perfectly reconstruct the square wave. Figure 7-5 in Schwartz shows only the lowest frequency sine wave gratings. As additional frequencies are added, the profile becomes more and more like a square wave, with 'sharp' edges.

Returning to Blakemore's famous experiment, they observed a very interesting result when they had the subject stare at a 6-c/d square wave (rather than sine wave) grating. The result is illustrated in Schwartz Fig. 7-16 B. Now there are two notches in the CSF, indicating reduced sensitivity at both 6 and 18 c/d.

MACH BANDS

The experiments by Blakemore and Campbell (1969) provided strong evidence that the human visual system works like a Fourier analyzer and processes visual information along separate spatial frequency channels.

Mach bands are also taken as evidence for Fourier processing by the visual system. An example is illustrated in Schwartz, 2004 Fig. 7-17. The luminance profile of the pattern in Fig. 7-17 A is shown in B. Note the bright region on the left, the decline in luminance in the center, and a dark region to the right. Although it doesn't exist in the actual luminance profile (B), it appears that there is a narrow bright band to the left side of center and a dark band to the right of the center (C). These phenomena are called **Mach bands**, and can be explained by the Fourier analyzing behavior of the human visual system. Figure 16-2 shows other examples of Mach bands.

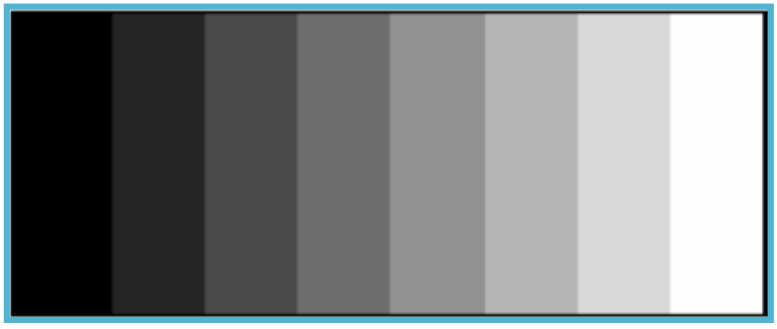

Figure 16-2: *Mach bands*

NEUROLOGICAL SPATIAL FILTERING

All optical systems, including the human eye, perform a Fourier transformation of light passing through the system. The distribution of light in the pupil is the Fourier transform of the object luminance pattern, and the retinal image is the inverse Fourier transform of the pupillary light distribution.

Q. What would happen to the retinal image if a patient was taking pilocarpine for glaucoma and had a very tiny 1-mm pupil?

A. _____

As described above, the neural part of the visual system also acts like a Fourier analyzer. It analyzes the retinal image into its spatial frequency components (sine wave gratings), and separate spatial frequency channels process these. The brain must then perform an inverse Fourier transform to reassemble the image that we perceive.

Suppose the person had some neurological condition that affected the parts of the visual system that carried certain spatial frequencies. In that case, the person might see a spatially filtered image of the world. When preparing band-pass filtered images, the resulting unusual image looks similar to a van Gogh painting (Fig.16-3). Vincent van Gogh had multiple health problems that could have affected his brain, including epilepsy, bipolar disorder, alcohol poisoning, toxicity to digitalis and other substances, and syphilis. Many people have speculated that he had a visual condition that affected the way he painted. Because of the resemblance of some of his paintings to band-pass filtered images, van Gogh may have had damage to certain neurons in his visual system that, in effect, spatially filtered the images he saw.

Figure 16-3: *Van Gogh self-portraits from 1886 (left) and 1888 right. He committed suicide in 1890. The right painting looks like I's been band-pass filtered*

NEUROLOGICAL SPATIAL FILTERING (CONT.)

Figure 16-4, below shows one of his most famous paintings, 'Starry Night.'

Figure 16-4: *Starry Night, by van Gogh. Copied from the following web site: http://www.vangoghgallery.com/painting/starryindex.html*

VISUAL ACUITY VERSUS CONTRAST SENSITIVITY

We previously learned that clinical high contrast visual acuity measures just one point on the CSF, but it tells you nothing about the rest of spatial vision. Does this mean that we should stop using the Snellen acuity test and instead test everyone's CSF using sine wave gratings? It depends on what the goal of your vision test is. The majority of patients who visit an optometrist have an uncorrected refractive error and the optometrist's job is to correct the optical blur.

Q. How do refractive errors affect spatial vision?

A. Recall that defocus causes a reduction in sensitivity at high spatial frequencies. Therefore the part of the CSF that is most sensitive to errors of defocus is the far right side of the CSF, that is, the high spatial frequency cut-off. This is what Snellen visual acuity tests (high contrast, small letters), therefore it is a useful way to evaluate the quality of the refractive correction.

Q. What would happen if you tried to perform a subjective refraction by having a myopic patient view a very low frequency sine wave grating?

A. Depending on the magnitude of the defocus, it might have no effect on the low spatial frequencies. Therefore, whether the person were corrected or left uncorrected, the grating would look the same. This would be an insensitive test for defocus in a myopic patient. So for the purposes of correcting a refractive error, there is little benefit to testing vision at lower spatial frequencies.

VISUAL ACUITY VERSUS CONTRAST SENSITIVITY (CONT.)

On the other hand, what if the patient complains of decreased vision, but when you test him/her, he/she can see 20/20? You should not be too quick to dismiss his/her symptoms. Perhaps he/she is having a reduction in vision at some other part of the CSF than the high frequency cut-off. Just as it would be foolish to refract using a low spatial frequency chart, it would be foolish to test only high frequency vision for a condition that affects mid or low frequencies.

An example of this comes from an article in the American Journal of Ophthalmology, by Dr. Mark Bullimore (professor at The Ohio State University College of Optometry and former editor of Optometry and Vision Science, the scientific journal of the American Academy of Optometry.) From the abstract:

Results: Twelve months after photorefractive keratectomy, best spectacle-corrected high-contrast visual acuity with natural pupils showed no significant change from preoperative values. ... Best spectacle-corrected low-contrast visual acuity with natural pupils was significantly reduced compared to baseline. ... The low-contrast loss was larger with dilated pupils. ... Conclusion: Reductions in visual performance occur after photorefractive keratectomy with a 6-mm zone. ... These changes are greatest for low-contrast visual acuity with dilated pupils. ... Best-spectacle-corrected low-contrast visual acuity is a sensitive measure for evaluating visual performance after refractive surgery. (Bullimore MA, Olson MD, Maloney RK. Visual Performance After Photorefractive Keratectomy With a 6-mm Ablation Zone. Am J Ophthalmol 1999;1281-7)

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