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VISUAL ACUITY

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THIS CHAPTER WILL INCLUDE A REVIEW OF:

- Basic types of visual acuity
- Snellen visual acuity test design

REVIEW

The figures below (Fig 17-1) show the mean results for a class for contrast sensitivity measured by three methods, and the normal expected values as posted on the Vector Vision web site.

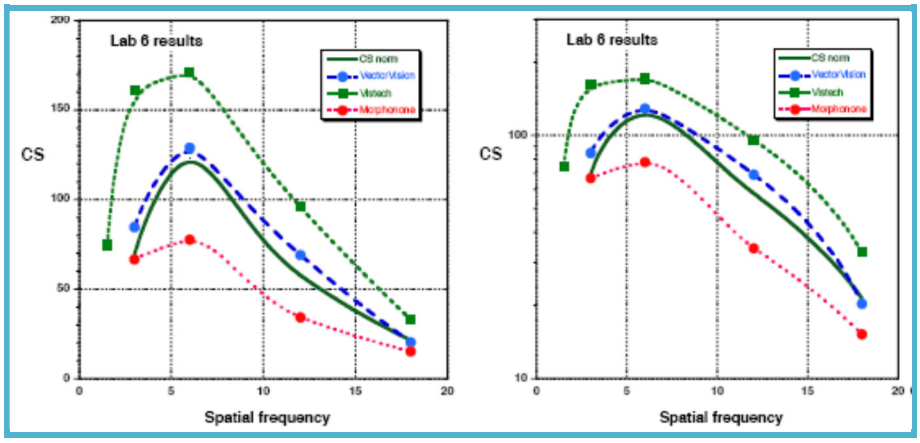

Figure 17-1: *CSF measured three different ways and the normal expected values*

Q. How do the three curves compare with the expected norms?

A. _____

Q. If you were going to order a contrast sensitivity test for your office, which one would you choose and why?

A. _____

BASIC TYPES OF VISUAL ACUITY

Acuity is defined as sharpness or keenness of thought, vision or hearing. Visual acuity tests assess vision by measuring the finest, most detailed features we can see. This can be tested in several different ways.

RESOLUTION ACUITY

The high frequency cut-off of the CSF is sometimes called the **resolution limit** of the visual system. When measuring the resolution limit, we normally use high contrast targets and attempt to find the smallest separation between two features that can be resolved, that is, seen as two. Perhaps the simplest stimulus for resolution acuity would be two small dots. The subject's task is to find the minimum distance between two dots at which they can be resolved as two. This type of visual acuity test is known as **resolution acuity**.

Under ideal conditions, the resolution acuity limit, that is, the angular size of the minimum separation (or **minimum angle of resolution**, abbreviated **MAR**) that the human eye can see is about ~0.5 arc minutes or ~30 arc seconds. This equates to about 20/10 vision or 60 c/d.

Figure 17-2 (below) and Schwartz, 2004 Fig. 7-19 illustrate the MAR for a Snellen E and a square wave grating. The MAR is equal to the width of one bar, or the width of one leg of the Snellen E. The 20/20 letter is designed so that the angular size of one limb of the Snellen E is 1 arc minute. It therefore has a MAR of 1 arc minute. Note that the *MAR in arc minutes is equal to the reciprocal of the Snellen fraction*.

Snellen visual acuity is a kind of resolution acuity test, but in addition to being able to resolve the gaps between letter strokes, the patient must also be able to identify the letter. This kind of visual task is known as **recognition acuity**. So Snellen visual acuity uses both resolution and recognition acuity.

Figure 17-2: *The MAR is the angular width of one bar*

MINIMUM DETECTABLE OR MINIMUM VISIBLE ACUITY

There are other visual tasks that can be used to assess spatial vision. For example, what is the smallest angular size of a single object that the eye can detect? Classically we test this by finding the minimum angular size of a wire that can be detected against a uniform background. This is called **minimum detectable** or **minimum visible** acuity. The limit for this kind of acuity is ~ 1 arc second, which is much smaller than the diameter of a single cone. Although the object is a line, the retinal image will be a fuzzy band, and the task is mainly one of detecting a contrast increment against a background, as illustrated in Schwartz, 2004 Fig. 7-21. When the image size and contrast are enough to exceed the person's contrast threshold, the object will be visible.

Q. Although the profile of the object is basically a square wave (sharp distinct edges), the retinal illumination profile shown in Schwartz Fig. 7-21 shows it as a bell-shaped curve. Why?

A. _____

HYPERACUITY OR VERNIER ACUITY

In this visual test, you determine the minimum offset of two lines that can be detected. For example, in the following figure, which line is higher?

Figure 17-3: *One example of a vernier acuity target*

The objective is to detect the minimum difference in positions that can be discriminated. These thresholds are about **2-10 arc seconds** (again, much smaller than one cone diameter). This is called **vernier acuity** or **hyperacuity** (Fig. 17-3) since it is far better than you would expect based on the cone spacing.

BASIC TYPES OF VISUAL ACUITY (CONT.)

Since the eye is so good at discriminating small displacements, vernier scales are sometimes used in measurement devices. For example, some camera viewfinders create a split image that will be aligned only if the camera is in focus (Figure 17-4). It is difficult for the eye to judge very subtle amounts of optical blur, but aligning a split image is easy. The same principle may be used in used in the keratometry (Figure 17-5 right), to very precisely measure the axis and power. Figure 17-6 shows an application of vernier acuity to military aviation.

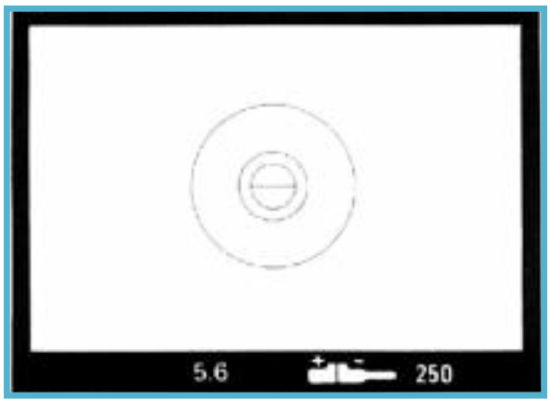

Figure 17-4: *The Nikon F2A camera viewfinder. It allows very precise focusing since an out-of-focus object will appear split, in proportion to the focusing error. This takes advantage of our extremely good acuity for vernier tasks.*

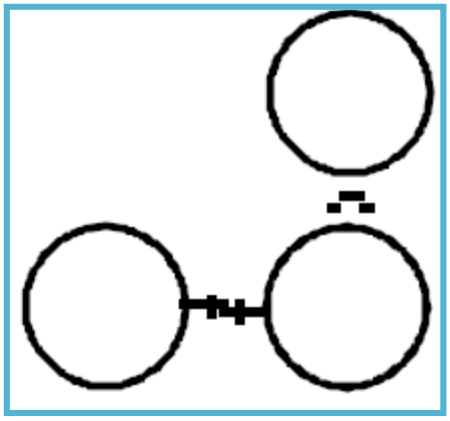

Figure 17-5: *The principle of vernier alignment can be used to improve accuracy in measuring the axis in keratometry*

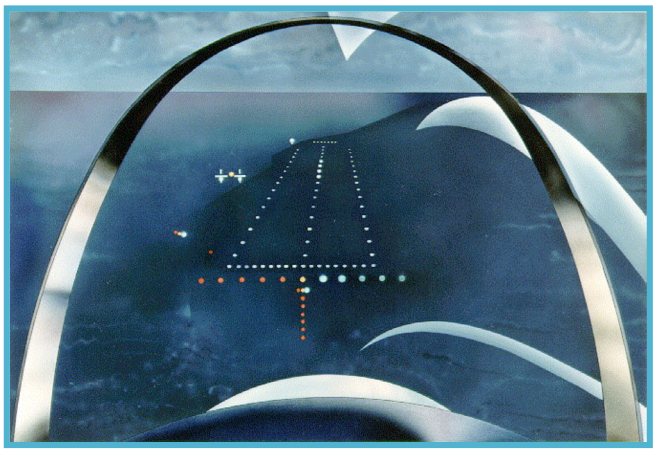

Figure 17-6: *Navy pilots judge the alignment of landing lights to verify their glide path during a carrier landing, a vernier alignment visual task*

BASIC TYPES OF VISUAL ACUITY (CONT.)

(From Chapter 7, Visual Function, in Helmet-Mounted Displays: Sensation, Perception and Cognition Issue, CE Rash, 2009. Original from http://www.lakehurst.navy.mil/nlweb/icols.gif)

Schwartz, 2004 Fig. 7-23 illustrates an important difference between resolution and vernier acuity thresholds. The top figure shows *that blur can significantly degrade resolution acuity*. As the blur circles become larger, it is more difficult to resolve the two dots. Vernier acuity, on the other hand, is largely unaffected by blur. Whether the upper and lower lines of dots are blurred or not, the visual system is equally able to detect a difference in their positions.

Based on this principle, some scientists have proposed using vernier acuity to test the integrity of the macula in cataract patients. For example, consider a patient who complains of blurred vision, and can achieve a best corrected Snellen (resolution acuity) of only 20/80. During the slit-lamp examination, you note sclerosis (whitening) of the lens. This may be the cause of the poor VA, and if so, the patient would benefit from cataract surgery and implantation of an intraocular lens (IOL).

But it is also possible that macular disease is causing the poor acuity. In that case, surgery might not help—even with a clear lens acuity would be poor due to the macular disease. If you could see the macula, you could evaluate its health, but cataracts obscure a good view of the macula. It is for this reason that instruments have been developed to measure the visual acuity of the macula, while bypassing the cataract.

The **interferometer** and **Potential Acuity Meter (PAM)** both project resolution acuity targets directly onto the retina. Clarity of the targets should not be affected by media opacities. Since vernier acuity is also largely unaffected by blur, you could test the patient's vernier acuity threshold to evaluate macular integrity. A normal vernier acuity threshold would indicate that the macula is functioning normally and that the blurred vision is probably due to the cataract. The patient would therefore benefit from cataract surgery.

Table 17-1: *Types of visual acuity*

TYPE OF ACUITY	DEFINITION	EXAMPLE	BEST PERFORMANCE
Resolution	Minimum separation to resolve two objects	Snellen VA, tumbling E, sine or square wave gratings	MAR = 0.75 to 0.5 arc min. 20/15-20/10, 40-60 c/d
Recognition	Smallest object that can be identified	Snellen VA, pediatric picture charts	Same as Snellen
Detection	smallest object visible (increment threshold task)	Thin wire against sky	~1.0 arc second
Vernier (hyperacuity)	Minimum detectable misalignment	Slightly displaced lines	2-10 arc seconds

SNELLEN VISUAL ACUITY TEST DESIGN

WHICH LETTERS TO USE?

In designing a Snellen acuity chart, you must keep in mind that some letters are easier to read than others. Some charts therefore limit the letters used to those that have approximately equally legibility. To be even more precise, you should also specify the font used since the same letters written in different fonts can vary in legibility.

One well known set is the **Sloan letter set** which uses the 10 letters, C, D, H, K, N, O, R, S, V, Z.

Size progression: The progression between lines on the VA chart is also an important design consideration. It would be nice to design a chart such that the progression of letter sizes represent equal steps in terms of difficulty. This is not true for the commonly used clinical VA chart. Have you noticed that the increment of difficulty between 20/30 to 20/25, 20/25 to 20/20 to 20/15 are all similar, but the interval from 20/15 to 20/10 is a much greater increment in terms of difficult.

A more logical progression would be to have letter sizes increase as a logarithm of the MAR. Some charts therefore use a **logMAR** progression such as the ETDRS chart. This chart was developed by the National Institutes of Health (NIH) for use in the Early Treatment of Diabetic Retinopathy Study (ETDRS), and it has become a popular configuration for clinicians and scientists who require a well-designed standard for measuring visual acuity.

Figure 17-7 shows a high contrast ETDRS logMAR chart. Notice the following important design features of this chart:

- Five letters on every line
- All letters have equal height and width
- Spaces between letters are equal to one letter width
- Letters are limited to the Sloan letter set
- The lines progress in 0.1 logMAR steps. Table 17.2 lists the progression of letter sizes, in terms of both the logMAR and the equivalent Snellen acuity used in the ETDRS chart.
- On this chart, every letter read counts as one-fifth or 0.02 of a line. This avoids the use of pluses or minuses appended to the Snellen fraction. For example, if a person sees all of the logMAR 0.3 line (20/40) and two letters from the next line (20/40+2), it is scored as 0.3 *minus 0.02 for each additional letter read from the next line*. That is, 0.3 minus (0.04) or 0.26. If the person could read all of the next line, his/her logMAR acuity would have been 0.2. Similarly, if a person reads logMAR line 0.2 (20/32), but misses two letters, *you would add 0.02 for each letter missed*. In example, the equivalent of 20/32-2 is a logMAR score of 0.2+0.04 = 0.24.

Figure 17-7: *The ETDRS chart*

SNELLEN VISUAL ACUITY TEST DESIGN (CONT.)

In some countries, visual acuity is expressed using a different notation. In the UK, a visual acuity of 20/20 is recorded as 6/6. In Japan and most other countries, visual acuity is expressed as a decimal that is equal to the corresponding Snellen fraction. For example, 20/20 is expressed as 1.0 and 20/40 corresponds to 0.5. This is sometimes referred to as **decimal visual acuity**.

You should be familiar with the following facts:

- MAR is the width of one bar on a Snellen E (Schwartz Fig. 7-19)
- On a 20/20 letter, the MAR is equal to 1.0 arc minute
- The MAR, in arc minutes, is equal to the inverse of the Snellen fraction.
- On a logMAR chart, the 20/20 letter has a value of 0.
- On a logMAR chart, as acuity becomes worse, the value of the logMAR increases.
- As acuity improves beyond 20/20, the logMAR score will be increasingly negative.

Table 17-2: *Progression of lines on the ETDRS chart*

20/X	10	12.5	16	20	25	32	40	50	63	80	100	125	160	200
logMAR	-0.3	-.02	-0.1	0	.1	.2	.3	.4	.5	.6	.7	.8	.9	1.0

You should be able to covert between Snellen (20/x) acuity and logMAR. Do this in the following steps:

1. Divide the Snellen denominator by 20—this is the MAR
2. Compute the log of this number; it is the logMAR

You should be able to convert back between logMAR to Snellen (20/x) acuity. Use the following steps.

1. Compute the anti-log of logMAR. This is the same as computing 10 raised to the logMAR power. This gives the MAR.
2. Multiply this by 20 to get the Snellen denominator.

FACTORS THAT CAN INFLUENCE THE MEASUREMENT OF CLINICAL VISUAL ACUITY

- Part of retina used
- State of adaptation (photopic, scotopic, mesopic)
- Retinal illumination
- Contrast
- Size
- Colour
- Refractive error
- Pupil size
- Exposure time
- Test distance
- Type of object used (sine-wave gratings, square-wave gratings, letters (which letters? Font?), pictures, etc.)
- Motion or static
- OD, OS or OU
- Isolated or multiple letters and their spacing
- State of accommodation / cycloplegia

SELECTED READING/REFERENCES

- Schwartz SH. **Visual Perception - A Clinical Orientation, 3rd Edition**. Appleton & Lange, Stamford, Connecticut, 2004

- CE Rash, Chapter 7, Visual Function, in **Helmet-Mounted Displays**: Sensation, Perception and Cognition Issue, 2009