Vision Science III - Binocular Vision Module

Lecture 7 - Introduction to Fixation Disparity

(Steinman Ch. 3. p. 58-62, 87-88; Borish Chapter 5, p. 136-137; Chapter 20, p. 739-742)

LAB 1 RESULTS

Experiment 1: Finding the Egocenter

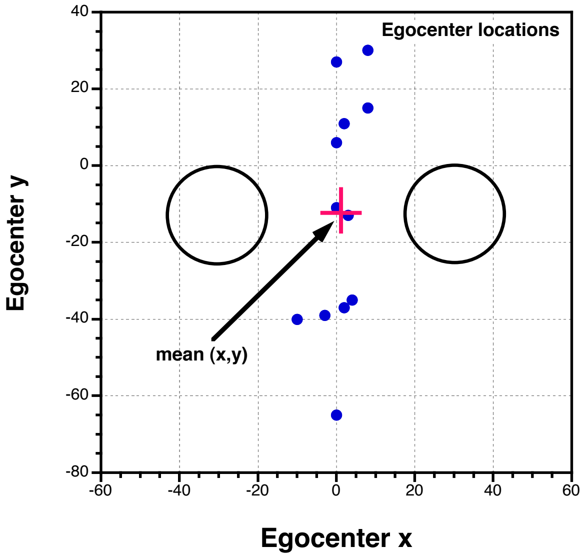

Figure -2. Location of each egocenter reported in Lab 1. The cross marks the mean of all the egocenters.

What do you observe about the location of the egocenters?

- Generally along the midline
- Individual variablility
- Average location is almost centered between the eyes
- In some cases the egocenter is out in front, in the air!

Experiment 2: Ocular orientation and perceived visual direction

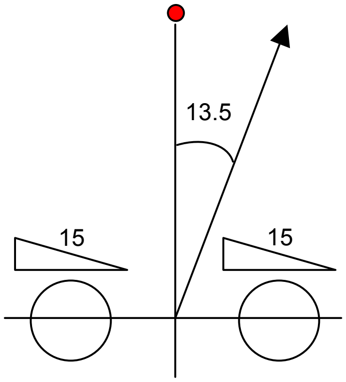

Figure -1. Average result for Experiment 2. 15 PD of yoked prism shifted (base left) the perceived location of the fixation point and average of 13.5 PD to the right.

What did this result demonstrate to us about the binocular sense of visual direction?

That rotation of the eyes contributes to the perceived location of objects.

HAPLOPIA & PANUM'S AREA

Objects located on the horopter give rise to **haplopia**, which means fused single vision. The opposite of haplopia is **diplopia** or double vision. A **haploscope** is an instrument that presents a different target to each eye. By doing so, it is possible to control the two retinal images and their disparities independently. The images may be fused binocularly, giving the subject a perception of haplopia. Haploscopes are sometimes used clinically for vision therapy (VT), and by scientists to study binocular vision and space perception (Figure 1a). Some interesting modern applications of haploscopic principles are seen in virtual reality and head-mounted displays, such as those used by the military (Figure 1b).

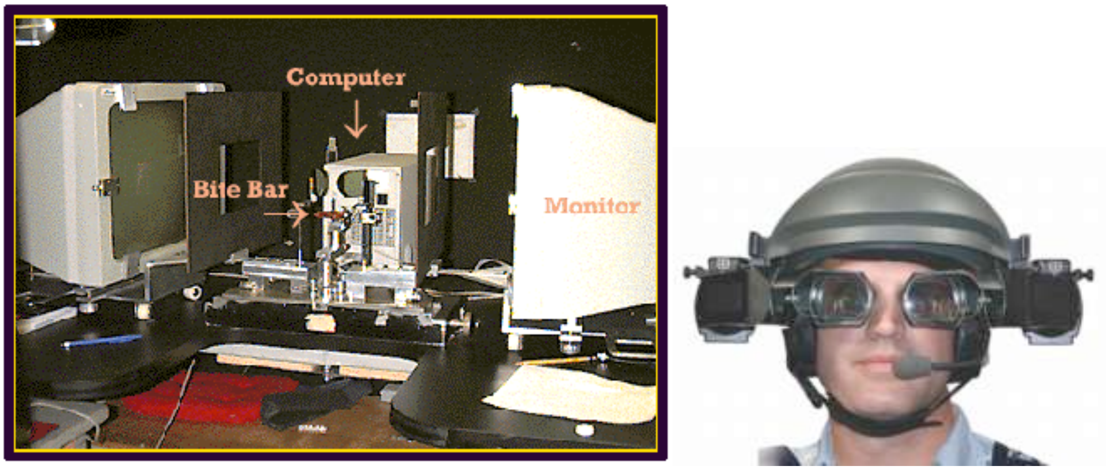

Figure 1. (a) Example of a laboratory haploscope used in binocular vision research. (b) Examples of a helmet mounted display. (http://www.keo.com/SIMEYE100A.htm)

In the normal visual environment, a single object is viewed by the two eyes, and the brain must fuse the images into one. If the object is located on the horopter, the right and left eye images will be fused to haplopia because they fall on corresponding points. If the observer holds fixation, and an object is moved forward or backward off the horopter, the images will begin to fall onto non-corresponding points. In spite of the increasing retinal disparity, the perception will remain haplopic within limits. When the retinal disparities become too large for the visual system to fuse, diplopia will begin. This marks the limit of **Panum's space/area** (Figure 2).

Some normal characteristics of Panum's area are:

- It is smallest near the fovea, about 6-10 arc minutes on either side of the horopter.
- Stereopsis begins about 2-10 arc seconds on either side of the horopter, near the center of Panum's space.
- Panum's space expands peripherally to about 30-40 arc minutes at 12° from the fovea. In some cases, objects with up to 2-3° of disparity can still be fused.
- The width of Panum's space is not fixed. It can vary depending on the individual, test conditions and test methods.

FIXATION DISPARITY

When measuring the horopter we often assume that the visual axes are correctly converging on the fixation point, which is the center point on the horopter. It is possible however that in some cases the horopter does not pass through the fixation point, as we will see in a coming lab. In these cases, even when the subject attempts to fixate the center rod, there is still some retinal disparity between the two foveas. That is, the intersections of the visual axes were not exactly on the horopter, and the visual axes can be slightly over or under converged with respect to the fixation point. This residual misalignment <u>during bifoveal fixation</u> is called **fixation disparity**.

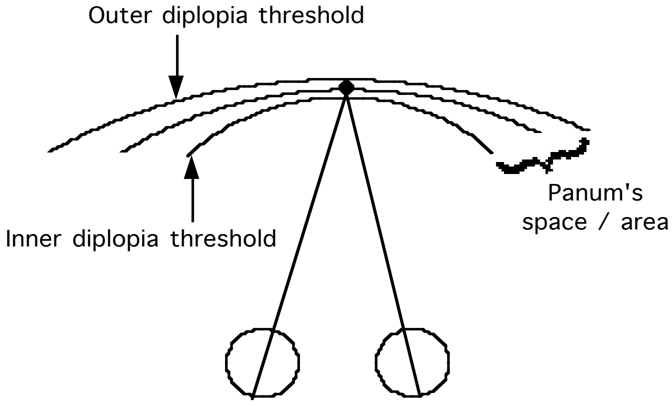

Figure 7. Panum's space

FIXATION DISPARITY AND DISPARITY VERGENCE

Since it is possible to fuse images that fall within Panum's area, it is not absolutely necessary for both foveas to point exactly at the fixation point to achieve binocular fusion. In fact, a small amount of fixation disparity may be beneficial.

Recall that motor fusion is one of the prerequisites for binocular fusion. Motor fusion turns the eyes so that both foveas point at the object of regard. In other words, motor fusion turns the visual axes of each eye toward the fixation point.

Disparity vergence is subdivided into **coarse** and **fine disparity vergence**. Fine disparity vergence is closely related to fixation disparity, because it is the mechanism that responds to retinal disparity and works to fine-tune the visual axes.

Figure 3, redrawn from Saladin's Chapter on <u>Phorometry and Stereopsis</u> (*Borish*, Chapter 20) is similar to the system's analysis chart (Borish Fig. 5-16) that you have seen already.

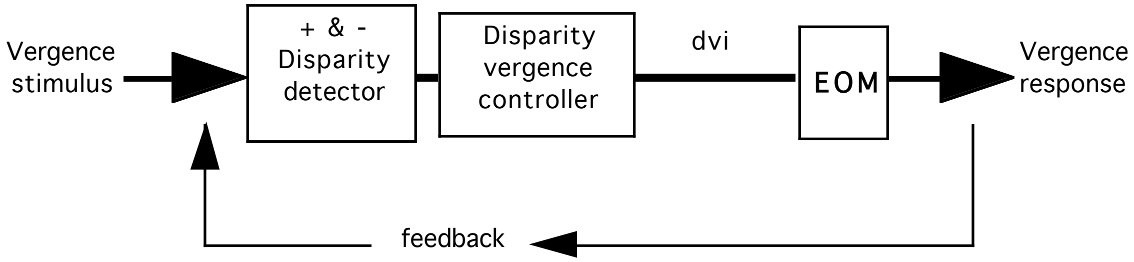

Figure 3. Disparity vergence system considered in isolation from other components.

When shifting attention from a distant to near fixation point, a convergence demand, or *stimulus to vergence*, is created. A *disparity detector* system senses the positive disparity (**crossed disparity**) and relays the data to the *disparity vergence controller*. The controller estimates the required magnitude of convergence and issues *disparity vergence innervation* (dvi) for an initial coarse vergence movement, which reduces the disparity.

Shortly after the controller issues an innervation for a fine motor response, the EOMs reduce the disparity to nearly zero. Recall, however that it usually does not reduce the disparity all the way to zero. If so, the stimulus for the disparity vergence system would be zero and the eyes would drift back to their physiological position of rest. If so, then they would drift out a certain amount, and the disparity would again stimulate the disparity vergence detector and turn disparity vergence back on again. In this situation, the eyes might be continually wobbling back and forth. Instead the visual system does not usually reduce the disparity perfectly to zero, but leave a slight amount or uncorrected disparity.

Generally the disparity vergence endpoint for exophoric patients is just beyond fixation, but within Panum's space. That is, you expect to see a slight **exo fixation disparity** with exophoric patients. This leaves a small amount of positive disparity that stimulates a continuing fine fusional convergence.

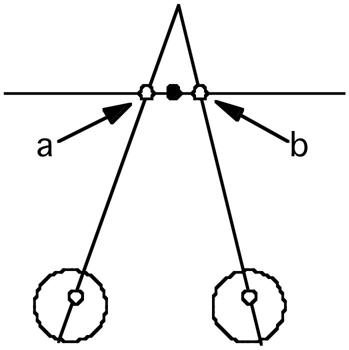

Figure 4. Example of exo fixation disparity.

In the case of esophoria, the eyes tend to favor an over convergent posture relative to the fixation point. During binocular fusion, fine disparity vergence reduces this, but not perfectly. Usually a small amount of residual negative, or **eso fixation disparity** is left, and this helps stimulate a divergent response.

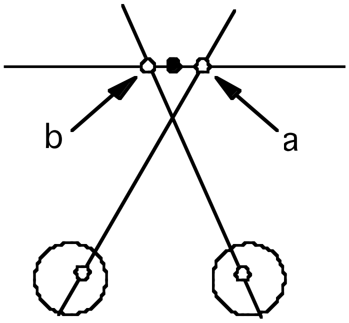

Figure 5. Example of eso fixation disparity.

If the patient maintains fixation at the same distance for more than a few minutes, vergence adaptation begins to take over, and this takes some of the demand off the disparity vergence controller.

A small amount of fixation disparity is to be expected, but an excessively large fixation disparity could place excessive demands on the disparity vergence system.

VISUAL DIRECTION AND FIXATION DISPARITY

In the presence of a fixation disparity, the images fall on non-corresponding retinal points, and they have slightly different oculocentric visual directions. Where will they appear to be located in space? According to Hering's law of binocular visual direction,

> *The visual direction of fused images that fall on slightly disparate retinal points is the average of the two visual directions.*

Therefore, in the presence of a fixation disparity (assuming that the disparity if split equally between the two eyes), the apparent location, of the binocularly fused images, will be the true fixation point. (See Figures 4,5.)

MEASUREMENT OF FIXATION DISPARITY

Measurement of fixation disparity is useful since it provides information on how well the disparity vergence system is working and can help in the diagnosis and treatment of clinical binocular problems.

If you can determine where the visual axes intersect, you can describe how large the fixation disparity is in terms of angular disparity. The angle of disparity would be the difference between the vergence angle to the fixation point and the vergence angle to the actual intersection point.

Several clinical tests are designed to measure fixation disparity, but rather than finding the point where the two axes intersect, they usually determine the relationship of the two eye's visual axes to each other.

In Figure 4, notice the locations of Point a (on the OS visual axis) and Point b (on the OD visual axis) relative to the fixation point. In this case of an exo fixation disparity, Point a is to the left and Point b is to the right. From the geometry (assuming the PD and fixation distances are known) you can compute the angular fixation disparity from the positions of Points a and b. This is also illustrated in **Adler's Fig. 24-35**.

Because fixation disparities must occur within Panum's area, they are very small, usually only a few minutes of arc.

Refer to Figure 5 for the example of an eso fixation disparity. In this example, Point a (OS visual axis) falls to the right of the fixation point and Point b (OD axis) falls to the left. Again, the binocularly perceived direction is straight ahead, but the oculocenteric direction for each eye is different.

If you could put a tag on the visual axis of each eye, you would see that the tag for OD (b) now falls to the left of the fixation point; the tag for OS (a) falls to the right of the fixation point. In effect, clinical tests that measure fixation disparity somehow tag, or mark the visual axis of each eye, and show where they are located, relative to the fixation point, during binocular fixation.

Fixation disparities are important because they can help clinicians determine the correct amount of prism to prescribe to correct horizontal and vertical phorias. In the presence of a large fixation disparity, it may be the cause of eyestrain.

Quoting from Tychsen (Binocular Vision, Ch.. 24 in Adler's 9th edition):

> *Fixation disparity should not be confused with binocular disparity: fixation disparity is a misalignment of the visual axes; binocular disparity is non-correspondence of the retinal regions stimulated by a target located off the horopter.*

DESIGNING A CLINICAL TEST TO MEASURE FIXATION DISPARITY

Since fixation disparity is a misalignment of the visual axes that occurs during normal binocular fusion, tests to measure fixation disparity must,

- Allow for binocular fusion, that is, portions of the test target must be seen and fused binocularly.
- Have some way to tag or mark the oculocentric visual direction of each eye, to show its deviation relative the fixation point. Somehow the monocular visual direction of each eye must be identified while the eyes are binocularly fusing.

Most clinical fixation disparity tests accomplish this using polarizers. A portion of the target, known as the **fusion lock**, is unpolarized, and seen by both eyes. Another part is polarized and seen only by the right eye; another part is cross-polarized and visible only to the left eye. Figure 6 shows how this might be accomplished. Several examples of clinical fixation disparity test are shown in **Borish Figs. 20-15, 16, 17, 18.**

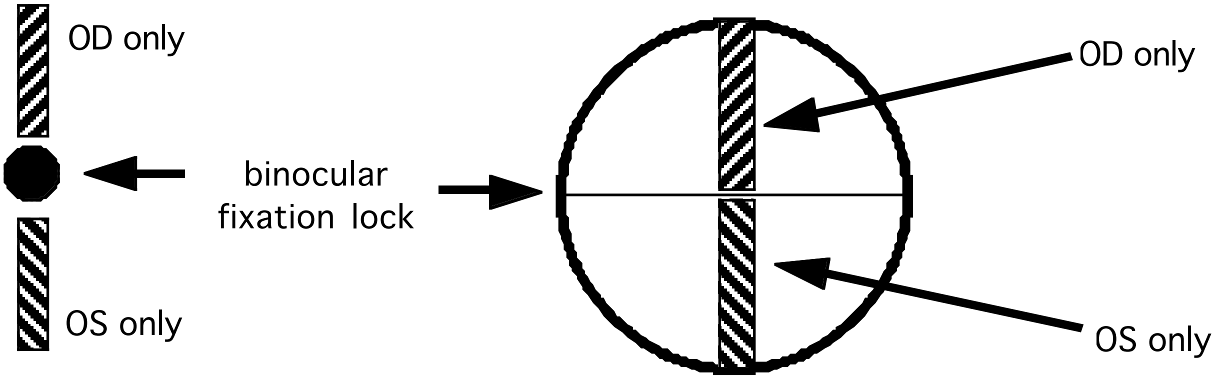

Figure 6. Two horizontal fixation disparity tests designed for use with polarized spectacles.

Generally clinical tests for horizontal fixation disparity are designed so that the right eye sees the upper target, and the left eye sees the lower one. You should verify this before performing a fixation disparity test.

The measured fixation disparity can vary depending on the size of the fixation lock, but a clinical standard is to use a **1.5° fusion lock**. This is about the size of the rod-free fovea, and for a 40 cm test distance, a 1.5° circle has a diameter of approximately 1 cm. Many of the fixation disparity tests do not have a small central fixation dot, as seen in Figure 6-left, but use the round aperture containing the polarized lines as the fixation lock (Figure 6, right).