Vision Science III - Binocular Vision Module

Lecture 6 - The Empirical Horopter

(Steinman Chapter 4, p. 83-100, 114-115; Chapter 3, p. 50-55)

REVIEW THE THEORETICAL HOROPTER

Q. What is the horopter?

Q. What is the Vieth-Müller circle?

Q. What are some assumption used in drawing a Vieth-Müller circle?

Q. What are some characteristics of the Vieth-Müller circle?

PANUM'S AREA

Objects located exactly on the horopter are seen as fused, but what happens if the object is very slightly off the horopter, either closer or farther away?

Within a short distance on either side of the horopter, objects will still be seen as fused. Strictly speaking, they fall on non-corresponding retinal points and there will be a small disparity in their visual directions. The zone on either side of the horopter within which it is still possible to see objects singly, (i.e., fused), is known as **Panum's space.** This region in space corresponds to areas on the retina, called **Panum's area**.

Panum's space is narrowed at the fixation point and expands in the periphery. This is consistent with larger receptive fields and poorer visual acuity in the periphery. Because Panum's areas are large in the periphery, you can experience larger amounts of disparity before experiencing diplopia. This can naturally occur when fixating flat targets, such as a book or page.

Panum's areas don't have a fixed size, but vary depending on stimulus conditions. Thyea re larger for big, moving objects, but smaller for detailed and stationary objects. Objects far from the horopter, that is, objects that are *outside of Panum's space (Panum's area)*, cause very large disparities that cannot be fused. They are seen in diplopia.

STEREOPSIS

For small amounts of disparity, that is, for objects located in a region on either side of the horopter, the brain analyzes the disparity data and is able to compute the relative distance of the object from the horopter. This sense of depth perception that is stimulated by small amounts of retinal disparity is known as **stereopsis**. The terms, "stereopsis" means "solid vision." *The fundamental stimulus required for stereopsis is **retinal disparity**.*

In 1838 Wheatstone discovered that a small amount of retinal disparity in like images presented to the two eyes generates a powerful perception of depth. *Objects located on the horopter, have no disparity, and they therefore appear to be located at the same relative distance from the observer as the fixation point*. If, however, while fixating one point on the horopter, another object is moved toward the observer off the horopter, a small amount of retinal disparity will be created in the retinal images of the near object. This is illustrated in Figure 1.

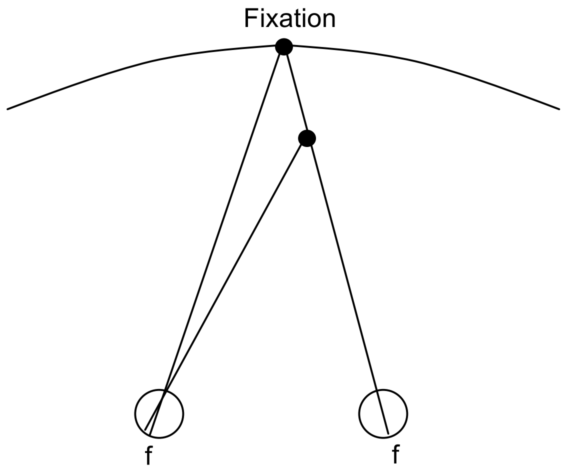
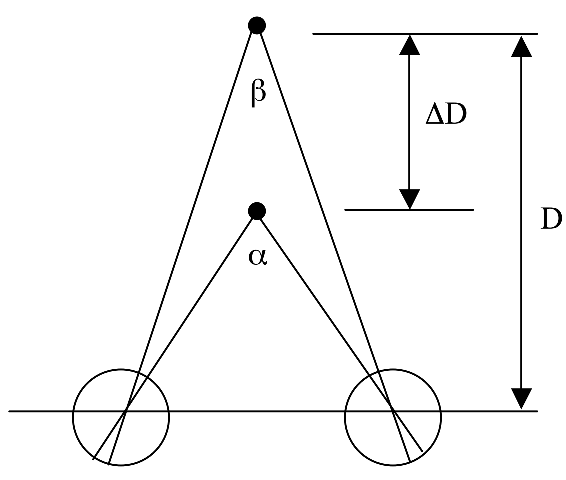


Figure 1. Moving an object slightly off the horopter creates a small amount of retinal disparity that gives rise to stereoscopic depth perception.

Q. To review, what is the definition of disparity in this context?

A. A mismatch (disparity) in the visual directions to an object seen by the two eyes.

If the disparity is too small, it will not be sufficient to elicit a sense of stereoscopic depth. The minimum distance that an object can be moved off the horopter and stimulate a sense of stereopsis is the threshold for stereopsis. Disparity is usually expressed in angular terms, for example, 40 arc seconds. It may be computed as shown in Figure 2 as the difference between the convergence angle to the fixation point and the stereoscopic stimulus (angle α-angle β).



$$\eta = \angle\alpha - \angle\beta$$

Figure 2. Geometry of disparity. Small Greek letter eta (η) is used for disparity.

Figure 3 shows the range, on either side of the horopter, for stereopsis and Panum's space. This is for stationary objects located near the fixation point. Panum's space extends approximately ±600 arc second (10 arc minutes) on either side of the horopter. Note that within a narrow range near the horopter, stereopsis does not exist. That is because the disparities are too small to stimulate stereopsis.

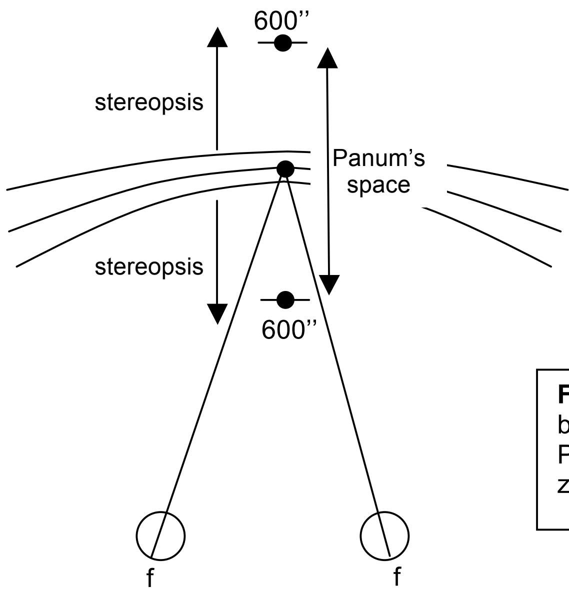


Figure 3. Relationship between the horopter, Panum's space and zone of stereopsis.

THE EMPIRICAL HOROPTER
The Vieth-Müller circle represents the theoretical horopter that you can compute based on the geometry of the eyes and viewing distance. You can also measure the actual horopter in a laboratory. An actual measured horopter is referred to as an **empirical horopter**.

AFPP Technique
Hering attempted to measure empirical horopters using a technique call the **apparent fronto-parallel plane (AFPP) horopter** method. In this technique, the subjects does the following:

- Maintain steady fixation on a central fixation point
- Aligns a number of stimuli on either side of the fixation point so that ...
- they all are in a plane parallel to the sujbect's face plane (fronto-parallel plane).

This one of the most popular laboratory methods to measure the empirical horopter, since it is relatively simple. **Steinman Fig. 4-5** illustrates the AFPP technique. Besides the AFPP method, other techniques have been developed to measure the horopter. These include the diplopia threshold horopter, stereoacuity horopter and nonius horopter.

Diplopia Threshold Technique
Since the true horopter should be at the center of Panum's space, another way to measure the empirical horopter is to find the limits of Panum's space, then compute its center.

- The subject fixates a center rod, and
- the peripheral rods are moved in or out until diplopia is observed.
- This is repeated several times.
- The near and far diplopia thresholds are plotted to delineate Panum's space and
- the midpoint is plotted at the horopter. (**Steinman Figs. 4-7, 4-8**)

The problem with this technique is that it is difficult for subjects to judge when they first see diplopia, especially in the periphery, where Panum's space becomes large.

Stereo Acuity Horopter
Another way to measure the horopter is to measure the proximal and distal limits of the zone of zero stereopsis. (**Steinman Fig. 4-9**) You can imagine that this is also a difficult visual task.

Nonius Horopter
The nonius technique is considered the most accurate method for measuring the empirical horopter. It was named after Núñez, a Portuguese mathematician who did research using a vernier scale in the 1500's. Tschermak, in 1900, was the first person to use this binocular vernier technique to measure the horopter.

The Nonius apparatus is similar to the Howard-Dolman device, except that the top half of the lines are seen by one eye, and the lower half are seen by the other eye. This can be accomplished using polarizers or apertures designed to restrict parts of the view to one eye or the other. While fixating the center rod, the subject must align the top and bottom halves of each peripheral rod. (See Figure 63 **in Bishop**, <u>Binocular Vision</u>, in *Adler's Physiology of the Eye*, 8th edition, p. 626) Also see **Steinman Fig. 4-2** (p. 84).

Recall that vernier acuity is extremely precise, so this is an ideal way to measure the empirical horopter. The upper and lower rods are all seen monocularly, not binocularly, so the rods are never fused. The rods will only appear to be aligned when they both have the same oculocentric visual directions, which is how the theoretical horopter is defined. *The nonius horopter is therefore considered the purest and most direct method for measuring the true horopter.*

In all of these techniques, horopters are usually not measured peripherally beyond about 15° degrees of eccentricity. Even at 12°, the AFPP and diplopia techniques are very difficult to use, but the nonius alignment is still possible.

DO THE EMPIRICAL AND THEORETICAL HOROPTERS AGREE?
Figure 4 shows examples of an empirically measured horopter (AFPP method) compared to the Vieth-Müller circle for different fixation distances.

Recall that in theory, the horopter should be a circle (Vieth-Müler Circle), though the diameter of the circle will increase with greater fixation distances. At infinity, it should approach a flat line.

The empirical horopter departs from the Vieth-Müller circle in several ways as shown in Figure 4. Note that

- the rods (dots) are not located on the Vieth-Müller circle.
- The departure from the Vieth-Müller circle is different for the different fixation distances.
- The shape of the empirical horopter changes for different fixation distances and is not always a circle.

For short fixation distances the arc is concave toward the observer. At some distance, known as the **abathic distance**, the AFPP horopter becomes flat. The abathic distance may be 1 to 6 meters, depending on the individual. Beyond the abathic distance the AFPP horopter becomes convex.

The difference between the measured horopter and the theoretical horopter for that test distance is known as the **Hering-Hillebrand deviation**. This is marked in Figure 4.

The nonius technique gives slightly different results from the AFPP method, but it still usually does not match the Vieth-Müller circle, though they are closer than with the AFPP or diplopia methods.

WHAT ACCOUNTS FOR THE HERING-HILLEBRAND DEVIATION?
Why don't empirical horopter measurements, even when done using the nonius method, agree with the Vieth-Müller circle? This may be due to irregularities in the distribution of visual directions in the two eyes, or to optical distortion in the retinal image. These were not taken into account in the Vieth-Müller circle.

Thehe Vieth-Müller circle assumes that,

- Both retinas are spherical (circular).
- Both retinas have symmetric distributions of local signs across nasal and temporal retinas.
- The distributions of local signs are also symmetric on nasal and temporal hemi-retinas in both eyes.

Spherical retinas
The assumption of round eye balls is a close first-order approximation for most normal eyes, but it may not hold for everyone, especially for myopes. Their eyes may be slightly elongated, and this could distort the horopter. But the Hering-Hillebrand deviation is seen even with emmetropic eyes.

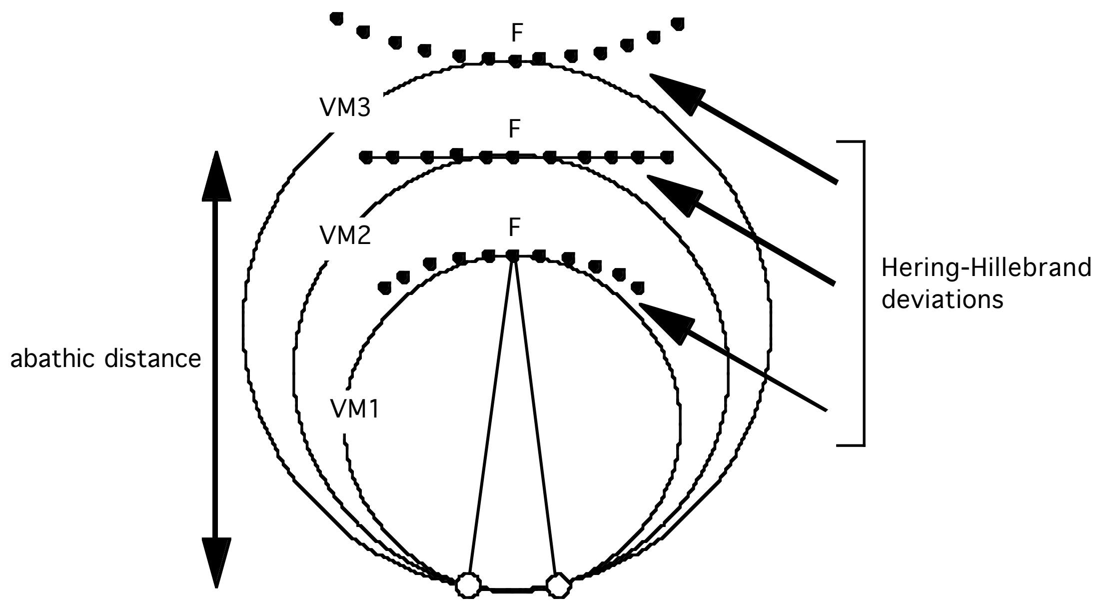


Figure 4. Examples of the AFPP horopter (dots) measured at different fixation distances. Also see **Steinman Fig. 4-17**.

Retinal asymmetry
One explanation for the Hering-Hillebrand deviation is the asymmetric distribution of oculocentric visual directions (local signs) in the nasal and temporal hemi-retinas.

Recall that in constructing the horopter, visual direction associated with the nasal retina in one eye is matched to the visual direction of the temporal direction of the other eye. Histological studies show that the photoreceptors are more densely packed in the nasal than temporal retina. This nasal-temporal asymmetry could cause the horopter to depart from the Vieth-Müller circle. This can also explain why the horopter's form can change from concave to flat, then to convex, with different viewing distances.

In addition to a regional asymmetry in local signs in one eye, the distribution between the two eyes may not be congruent. This would also cause distortion in the horopter. An asymmetric mapping from each eye's retina to the visual cortex could also make the horopter deviate from the Vieth-Müller circle.

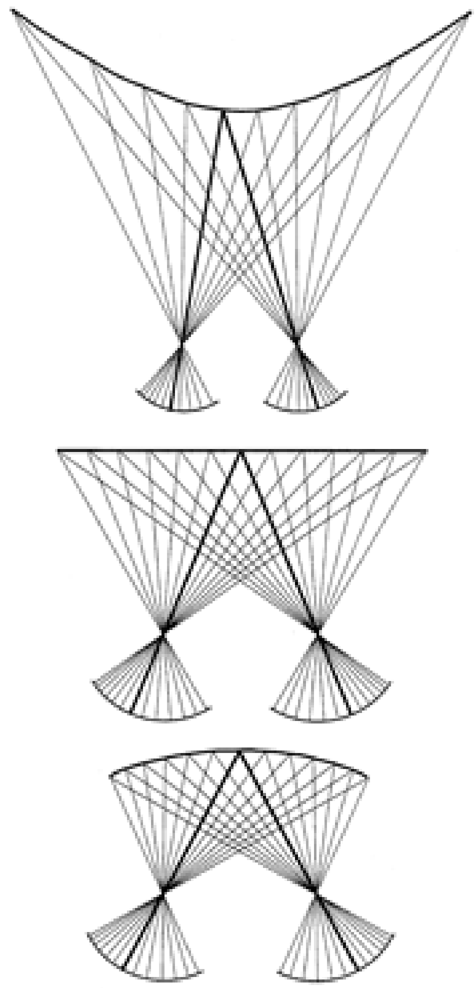


Figure 5. (from Fig. 2.16 in Howard & Rogers, Binocular Vision, p. 54 and http://www.perceptionweb.com/perc0599/editorial.html) shows the expected distortion in the horopter caused by compression of the temporal local signs.

Optical distortion

Optical distortion may contribute to the Hering-Hillebrand deviation, especially if the optical magnification between the two eyes is different.

If the image to one eye is magnified, the AFPP horopter will tilt around the fixation point, as shown in Figure 6 (redrawn from 11-6 in Reading). The true endpoints of the fronto-parallel lane are indicated by points P and Q. Assuming no image magnification, the retinal image of these points would be Points p and q on the two retinas. A magnified right image is represented by Points p' and q'. Tracing these out of the eye and finding the intersection with the corresponding left eye visual lines, we can determine the perceived location of the fronto-parallel lane. **The plane appears to be farther away from the eye with the greater horizontal magnification.**

To compensate a subject will move those rods closer, in an attempt to move them into the apparent fronto-parallel plane. So if the empirical horopter is tilted, it indicates greater retinal magnification on the side tilted *closer* to the eye.

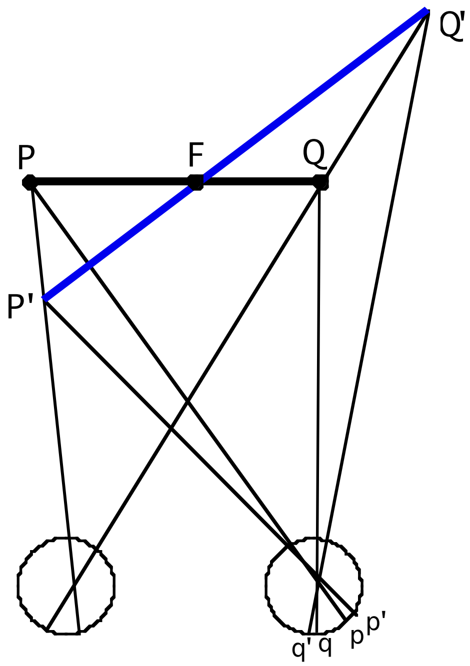


Figure 6. Optical distortion causes the apparent fronto-parallel plane to tilt. (See **Borish Fig. 5-18**)

Fixation Disparity
A fixation disparity can also cause the empirical horopter to depart from the theoretical horopter. In fixation disparity, the visual axes of the two eyes fail to perfectly converge on the fixation point, since they are still slightly under or over-converged with respect to the fixation point, they still have a residual disparity. Steinman explains this nicely on p. 87-88 of his book.