Brien Holden Vision Institute

# THE EMPIRICAL HOROPTER

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## REVIEW THE THEORETICAL HOROPTER

**Q** What is the horopter?

**Q** What is the Vieth-Müller circle?

**Q** What are some assumptions 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.

**Q** Based on Hering's Laws of oculocentric visual directions, can you explain why they would fall on non-corresponding points?

**A** Since the points on the horopter have no disparity (that is, the same visual direction in each eye), points off the horopter have disparities, which increase the farther you move away from the horopter. However, in spite of this, if the disparities are not too large, the brain is still able accomplish sensory fusion. The zone on either side of the horopter within which it is still possible to see objects singly, (i.e., sensory fusion), is known as **Panum's space**. This corresponds to an area on the retina, called **Panum's area**.

Panum's space is a narrow zone on either side of the horopter at the fixation point and expands in the periphery. This reduces the likelihood of diplopia in the periphery while fixating flat targets, such as a book or page. Since the horopter is curved, flat planes, such as a book, increasingly depart from the horopter in peripheral vision, but remain within Panum's space. Recall that receptive fields and visual acuity is also poorer in the periphery.

Panum's areas do not have a fixed size, but vary depending on stimulus conditions. It is larger for big, moving objects, but is narrower for detailed and stationary objects.

Objects far from the horopter, that is, objects that are outside Panum's space (Panum's area), cause very large disparities and cannot be fused. They are therefore seen in diplopia. Recall that large disparities mean that there are large differences in the visual directions for each eye to the diplopic object. One object seen in two different visual directions is by definition diplopic.

## STEREOPSIS

For small amounts of disparity, that is, for objects located in a region on either side of the horopter, the brain analyzes the disparities 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**.

In 1838, Wheatstone discovered this when he observed that a small amount of retinal disparity in the images of an object generated 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 19.1.

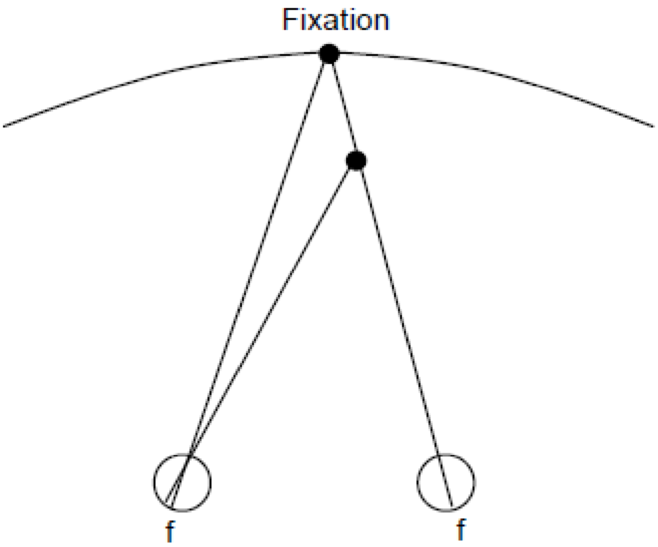


***Figure 19.1*** *Moving an object slightly off the horopter creates a small retinal disparity that stimulates stereoscopic depth perception.*

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 19.2 as the difference between the convergence angle to the fixation point and the stereoscopic stimulus (angle α angle β).

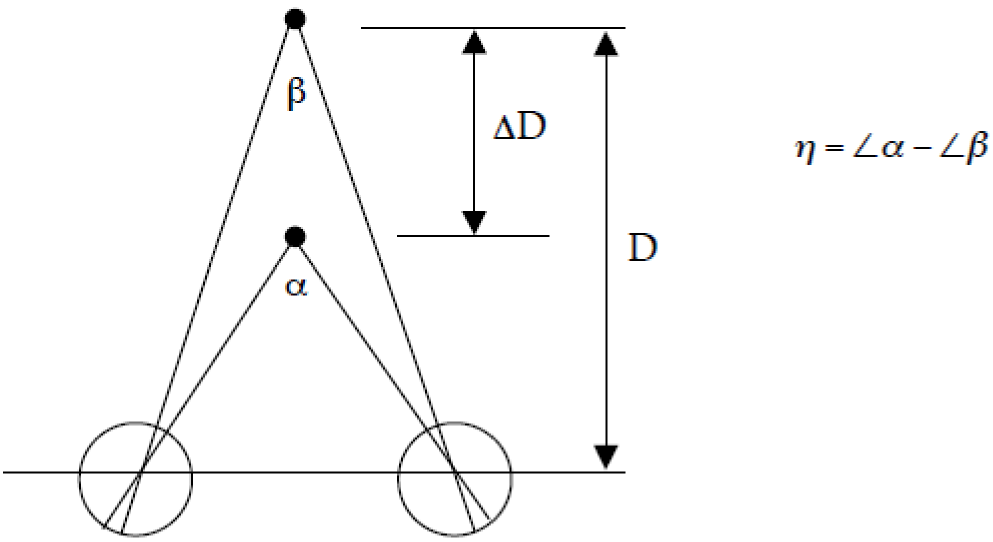

***Figure 19.2*** *Geometry of disparity. The small Greek letter eta (η) is used for disparity.*

Figure 19.3 shows the range, on either side of the horopter, for stereopsis and Panum's area. This is for stationary objects located near the fixation point. Panum's areas 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.

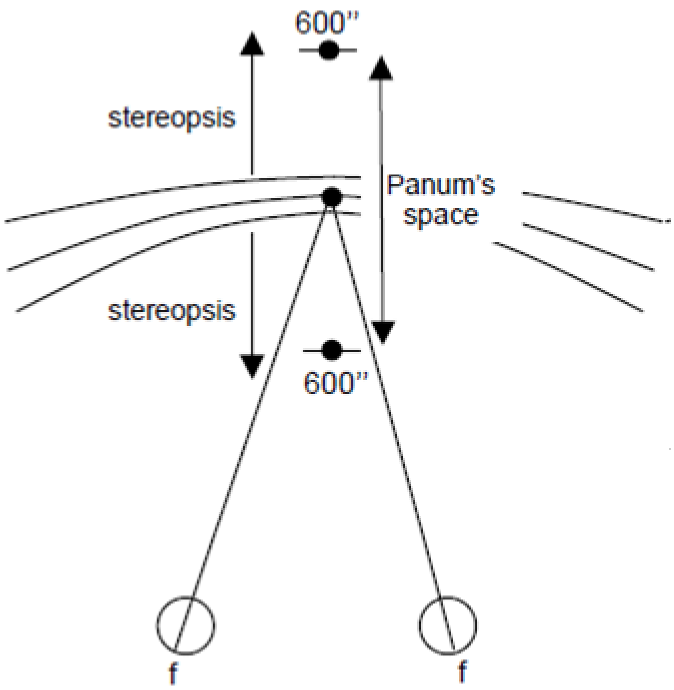


***Figure 19.3*** *Relationship between the horopter, Panum's area and the zone of stereopsis.*

## THE EMPIRICAL HOROPTER

The Vieth-Müller circle represents the theoretical horopter, but you can also measure the horopter in a laboratory. A horopter that you actually measure is referred to as an **empirical horopter**. Several techniques have been developed to measure the horopter of a subject.

### AFPP Technique

Hering attempted to measure an empirical horopter by aligning a small number of points located on either side of the fixation point. In this case, points that are equidistant from the observer should appear to fall in a plane that is parallel to the observer's face. A horopter measured by this technique is known as an **apparent fronto-parallel plane (AFPP) horopter**. Among horopter methods, this is the most popular, 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 empirical 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 many times; the near and far diplopia thresholds are plotted to delineate Panum's space, and the midpoint is computed to find 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**)

**Nonius Horopter**
The nonius technique is considered the most accurate method for measuring the empirical horopter. It is named after Nuñez, a Portuguese mathematician who developed a type of 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 halves of the lines are only seen by one eye, and the lower half are seen only by the other eye. This can be accomplished using polarizers or masks. While fixating the center rod, the subject must align the top and bottom halves of each peripheral rod. (See **Fig. 24-7**, **in Bishop**, Binocular Vision, and in Adler's Physiology of the Eye, 8th edition, p. 626); for additional references, see Steinman **Fig. 4-2** (p. 84).

This is a kind of vernier task, and is therefore very precise. Since the upper and lower rods are all seen monocularly, the rods are never fused and stimulate non-corresponding points (different oculocentric visual directions) as long as they are off the horopter. They therefore appear to be misaligned. 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 beyond about 15° degrees of eccentricity. Even at 12°, the AFPP and diplopia techniques are very difficult to use, but nonius alignment is still possible.

## COMPARISON OF THE EMPIRICAL & THE THEORETICAL HOROPTERS

Figure 19.4 shows how several empirical horopters, measured at different fixation distances by the AFPP method, compare to the Vieth-Müller Circle (theoretical horopter). Recall that in theory, the horopter should be a 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 theoretical horopter in several ways:

- 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 19.4.

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. The nonius horopter also becomes flatter with greater viewing distance.

Theoretically, for symmetric fixation in the midline, the horopter exists only in the horizontal plane and in a vertical line that passes through the fixation point. All other points in space will stimulate disparate retinal locations. With asymmetric fixation, the horopter becomes twisted into a complex curve (Tyler's Fig. 2.5, 6, in Christopher Tyler's chapter, The Horopter and Binocular Fusion, in Binocular Vision, edited by Regan, 1991). The horopters shown in Tyler's figures plot zero disparity points in three-dimensional space and are known as point horopters.

Our goal is to understand the basic principles of binocular fusion, and for this purpose, it is sufficient to limit consideration of the horopter to the horizontal plane. The horizontal horopter is usually measured by aligning vertical rods, such as those in the Howard Dolman apparatus.

Because it uses vertical rods to measure the horopter, the horizontal horopter is sometimes also called the longitudinal horopter (See Steinman Fig. 4-3 or Fig. 24-4 in Adler's Physiology of the Eye, ninth edition, 1992, p. 776).

## REASON 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. Recall the original assumptions of the Vieth-Müller circle:

- Both retinas are spherical.
- Both retinas have symmetric distribution of local signs across nasal and temporal retinas.
- Right and left retinas are the same size with the same local sign geometry.

### Spherical Retinas

The assumption of round eyeballs is a close first-order approximation for most normal eyes, but it may not hold for everyone, especially for myopes. They may have globes that are slightly elongated, and this could distort the horopter. But the Hering-Hillebrand deviation is seen even with normal eyes.

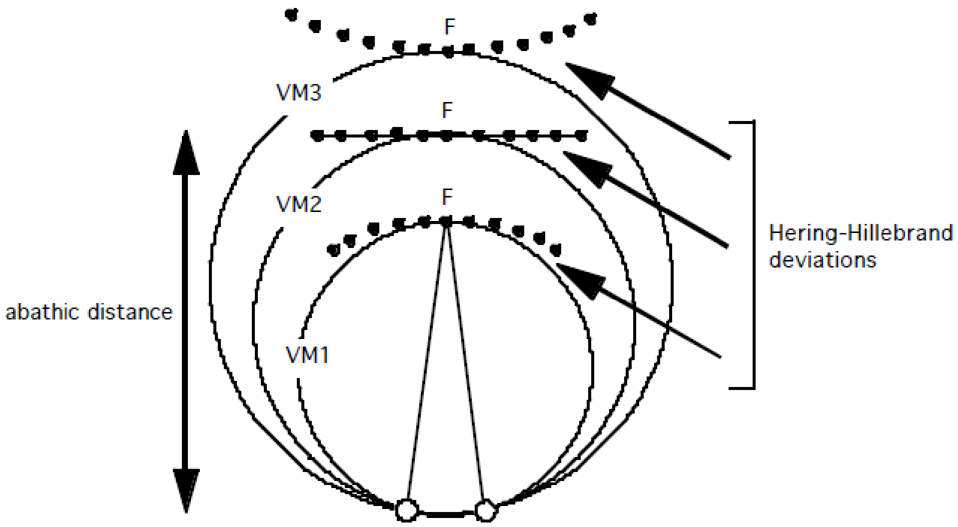


***Figure 19.4*** *Examples of the AFPP horopter (dots) measured at different fixation distances. Also see **Steinman Fig. 4-17**.*

### Retinal Asymmetry

One explanation for the Hering-Hillebrand deviation is the asymmetric distribution of oculocentric visual directions (local signs) within each retina. 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 and then to convex, with different viewing distances (Figure 19.5).

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 retina to cortex in the two eyes could also make the horopter deviate from the Vieth-Müller circle.

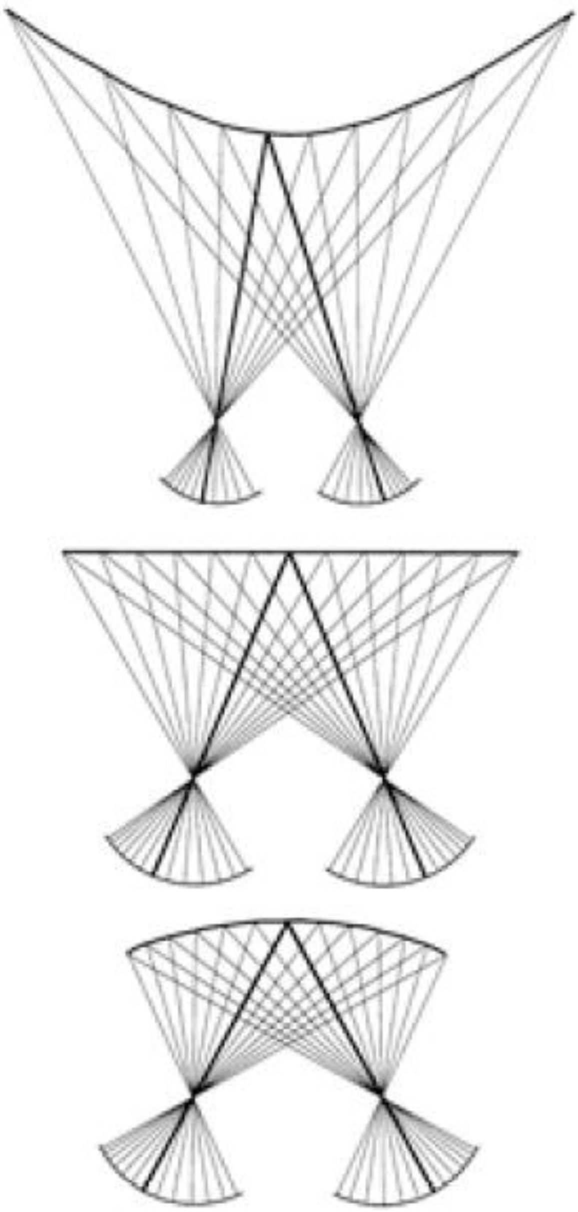

***Figure 19.5*** *shows the expected distortion in the horopter caused by compression of the temporal local signs. (From Fig. 2.16 in Howard & Rogers, Binocular Vision, p. 54 and* http://www.perceptionweb.com/perc0599/editorial.html)

**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 19.6 (redrawn from 11-6 in Reading). The true endpoints of the fronto-parallel plane 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 line, we can determine the perceived location of the fronto-parallel lane. **The magnified side appears to be farther away**.

Because a fronto-parallel plane appears to be tilted away from the eye with greater magnification, the subject will move those rods closer to match the apparent fronto-parallel plane. So if the horopter is tilted, it indicates greater retinal magnification on the side tilted closer to the eye.

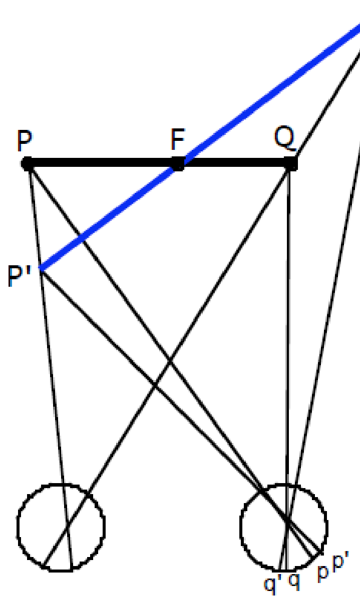


***Figure 19.6** Optical distortion causes the apparent fronto-parallel plane to tilt. (**See Borish Fig. 5-18**)*

**Fixation Disparity**

A fixation disparity can also cause the empirical horopter to depart from the theoretical horopter. In a 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.

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