THE HOROPTER AND ITS CLINICAL APPLICATIONS

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INTRODUCTION

Binocular vision space is organized through corresponding points. The corresponding points are oculocentric in nature[1], meaning that the perceived direction is based on retinal position of the image of the object and not on the object position in space. This concept gave rise to the surface called a horopter.

The term horopter was coined by Franciscus Aguilonius, the Jesuit priest.[1] The word is derived from 'horos' meaning boundary and 'opter' meaning observer. The horopter is now defined by the loci of points in space that project onto corresponding retinal points in the two eyes for a given position of the eyes.[2] In other words, for a given fixation distance, the horopter is the spatial array of objects in physical space which would form images on corresponding retinal points and produce identical visual directions in subjective space.[3] Corresponding retinal points could be defined by geometry as points that have the same positions on two idealized spherical retinas that are superimposed. [3-4]

There are two well-known models for the surface defined by corresponding. The surface defined by geometrical corresponding points is the Vieth-Müller circle.[3-4] Thus; this geometrical horopter would be a circle passing through the point of fixation and the nodal points of both eyes **(Figure 1)**.The Vieth-Müller circle provides a theoretical prediction of the position of objects that stimulate corresponding points. A lack of stereoscopic depth could define corresponding retinal points. The horopter that is subjectively defined by the functional properties of corresponding points is an empirical horopter **(Figure 2)**.

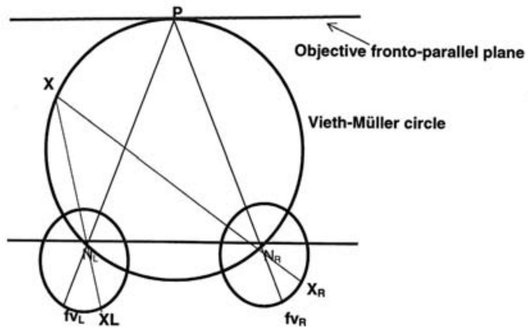

Figure 1: Illustration of the Vieth-Müller circle. The circle passes through the fixation point (P), nodal point of the right eye (NR) and nodal point of the left eye (NL). The image points of P are formed on the right fovea (fvR) and left fovea (fvL). X is a point that lies on the circle, whose images (XL and XR) are equidistant from the two foveae.

EMPIRICAL HOROPTER

Corresponding points along horizontal retinal meridians define the longitudinal horopter, which in principle, may be established by using any of the valid properties of corresponding retinal points.[3,5] The corresponding points along the vertical retinal meridians define the vertical horopter, which will not be discussed in this paper. The various strategies or criteria used to obtain empirical longitudinal horopter data illustrate the important properties of corresponding points. The specific criterion utilized to establish the location of corresponding points is commonly included as part of the description of the horopter. Five ways of measuring the empirical horopter are nonius, apparent frontoparallel plane, haplopia, minimum fusional vergence eye movement and region of maximal steroacuity.

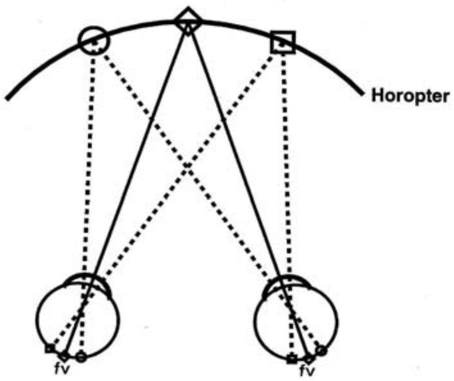

Figure 2: Illustration of the Empirical horopter. The images of the fixation point which is a diamond are formed on the foveae (fv) of the right and left eyes, whilst the images of the square and the circle are formed at their corresponding points on the retinas of each eye. The fixation point and the objects that stimulate corresponding points will form the horopter. (From Harwerth & Schor[6])

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The nonius horopter is the horopter where the corresponding retinal points are defined by the perception of identical visual directions.[2,3,6] In this measurement, one line is presented to the right eye and the other line to the left eye. These lines are called nonius lines- named after Pedro Nunez, a Portuguese mathematician who invented the Vernier scale. The subject looks at the fixation point and the lines are moved until the two lines appear to be aligned. [2,3,6] When the lines are aligned, the visual directions in the two eyes are equated.
This method best meets the definition

The apparent frontoparallel plane (AFPP) horopter is the horopter where all objects on the horopter should appear equidistant from the observer because corresponding points are points of zero functional disparity, i.e., no depth from stereopsis. The subject is presented with three rods and is required to fixate at the centre rod. The subject will move the two peripheral rods until they appear to be equidistant from the fixation point. This is the most popular method of measuring the horopter. Most vision scientists use the Howard-Dolman apparatus to measure the AFPP horopter.

The haplopia horopter is based on the concept that the extent of Panum's fusional area should be equal in the crossed and uncrossed disparity directions.[3,5,6] This method involves determining the boundaries of single binocular vision and therefore the center of the region of single binocular vision is the horopter.

The minimal fusional vergence eye movement horopter is based on the logic that the stimuli with zero binocular disparity should not elicit disparity vergence eye movements.[3] This criterion is rarely used and it is difficult to measure.

The maximal stereoacuity horopter is based on the concept that the absolute stereo-thresholds (zero disparity reference) are lower than increment stereo-thresholds with a non-zero disparity reference. [5,6] This criterion is rarely used as it is time consuming.

The Vieth-Müller circle is the standard reference for the analysis of the empirical horopter. Although the Vieth-Müller does not coincide with the horopter, the characteristics of the empirical horopter are assumed to be similar to those of the Vieth-Müller circle. These characteristics are that the horopter is a portion of a conic surface and that it is symmetrical about the fixation point. Another reference is the objective fronto-parallel plane **(Figure 1)**. It is a defined by a line that passes through the fixation point and parallel to a line passing through the entrance pupils.

The curvature of the horopter may deviate from the Vieth-Müller circle and it is called the Hering-Hillebrand horopter deviation. The Hering-Hillebrand horopter deviation is a result of nasal-temporal asymmetries in retinal distances between corresponding points.[1] The nasal-temporal asymmetries in corresponding points can be predicted from monocular partitioning measurements.

Typically, the nasal retinal eccentricity is larger than the temporal retinal eccentricity-for every pair of corresponding retinal points and the radius of curvature for the empirical horopter is longer than the radius of the Vieth-Müller circle. The Hering-Hillebrand horopter deviation varies systematically with fixation distance. Thus, the shape of the horopter is concave at near fixation distance, and convex at greater distances.

CLINICAL APPLICATIONS OF HOROPTER CONCEPTS

Measurement of fixation disparity

During binocular fixation, small vergence errors can occur without causing diplopia as long as they do not exceed Panum's fusional limits. This 1`vergence error under binocular vision is defined as fixation disparity.[7] The presence of a fixation disparity does not alter visual perception; however, its presence may be indicative of an imbalance in the innervation pattern to the oculomotor system. Thus, patients with significant oculomotor imbalances can maintain binocular vision, but they may do so with headache, blur, ocular discomfort and/or intermittent diplopia. The clinical management may involve a prismatic correction to reduce or eliminate the fixation disparity. The amount of prism required to reduce the fixation disparity to zero is a measure of the associated phoria.

The location of the horopter will be displaced from the fixation point if the subject has a fixation disparity. The location of the empirical horopter will be displaced from the fixation point in the direction and amount equal to the fixation disparity. The horopter pass through the point where the visual axes cross. The location of the horopter will be less than the fixation distance with eso-fixation disparity **(Figure 3)** and greater than the fixation distance with exo-fixation disparity. Thus, the measurement of the fixation disparity establishes the position of the horopter in the presence of fusional vergence and sensory fusion. Measurement of the associated phoria establishes the amount of fusional vergence stimulation required to make the horopter coincide with the fixation point.

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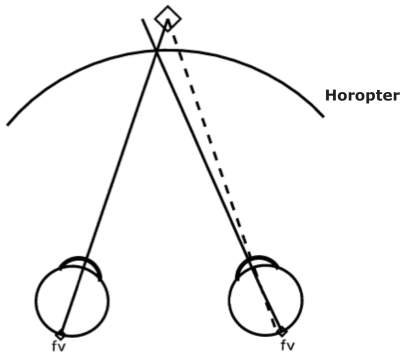

Figure 3: Illustration of eso-fixation disparity. The visual axes intersect before the fixation point (a diamond) and the diamond is seen as single because the images are falling in Panum's fusional area. The horopter does not pass through the fixation point but through the point where the visual axes intersect. (From Harwerth & Schor[6])

Patients with a fixation disparity have normal binocular vision and the presence of fixation disparity probably is not a result of a deviation in the shape of the horopter. Fixation disparity will also affect the stereothresholds since the horopter does not pass through the fixation point.8 The presence of a fixation disparity changes stereo-vision from a perception of depth based on absolute binocular disparity information to a perception of depth based on differential (increment) binocular disparity information.

Measurement of aniseikonia.

The term aniseikonia was first described by Lancaster.[9] Aniseikonia is defined as a difference in the size and/or shape of the two ocular images. The term 'ocular image' refers to the cortical representation of the image, which is influenced by the optics of the eye, as well as the retinal receptor mosaic and cortical magnification.[3,6] The most usual cause of aniseikonia is anisometropia and the image size differences may be an overall magnification or a meridional aniseikonia. The amount of aniseikonia can be determined clinically or estimated. The estimation is based on the rule of thumb: 1% magnification per dioptre difference. Significant aniseikonia is defined as image size difference greater than 4%.[6]

There is a large range of tolerance among patients with aniseikonia. However, for many patients, retinal images of unequal sizes in the two eyes may cause spatial distortions headaches and/or eyestrain.

The horopter may be skewed or tilted about the fixation point, with respect to the Vieth-Müller circle as a result of unequal retinal images sizes.[3]

The magnitude of the tilt of the longitudinal horopter due to aniseikonia in the horizontal retinal meridian is predictable from the lateral binocular disparity created by the image size difference. Thus, the magnification difference between the two eyes may be quantified by measurements of the rotation of the horopter around the fixation point. If the retinal image sizes are equal, then the apparent frontoparallel plane should be symmetrical about the fixation point. Thus, the ratio of the magnification of the image size in one eye relative to the image of the other eye (R0) is equal to 1. If the retinal image sizes are unequal (R0 ≠ 1), then the empirical horopter will be skewed around the fixation point by an amount and direction determined by the characteristics of the aniseikonia. Three components of the effects of aniseikonia may be measured, namely geometric, induced and declination (oblique) effects.[3,6]

The adaptation of the patient to spatial distortions due to aniseikonia varies from one patient to another patient. Adaptation also varies based on components of the effects of aniseikonia. Patients show greater adaptation with geometric effects and minimal adaptation with declination effects.[10, 11]

Measurement of horopters in strabismic patients

The strabismic patients can develop anomalous retinal correspondence (ARC) or suppression to eliminate constant diplopia. During binocular viewing, a patient with ARC perceives identical visual directions from retinal images on the fovea of the fixating eye and a peripheral retinal area of the deviating eye especially in a patient with harmonious anomalous retinal correspondence. ARC restores some form of binocular vision in the presence of misalignment of the visual axes especially in strabismus of early onset.
The investigations of the horopters of strabismic patients may provide important information about the nature of the sensory and motor adaptations in strabismus.

Measurement of horopter in strabismic patients utilizes the nonius or identical visual direction criterion. It has been shown that there is a shift in retinal correspondence in the periphery and the angle of anomaly decreases near the fovea.[12] The horopters of intermittent exotropes have very sharp curvature and lie inside the Vieth-Müller circle. Constant esotropes with normal retinal correspondence exhibit horopters that pass through the intersection of the visual axes and lie outside the Vieth-Müller circle. The horopters of patients with esotropia and anomalous retinal correspondence do not pass through the intersection of the visual axes but are parallel to the Vieth-Müller circle with sharp localized notch near the visual axis of the fixating eye **(figure 4)**.[12] The notch may be the result of anomalous correspondence. It has been reported that the horopter notch disappears when the objective angle of strabismus is reduced.[13]

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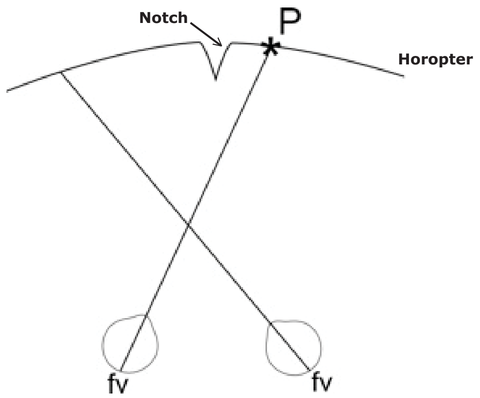

Figure 4: Illustration of the horopter of an esotrope with anomalous retinal correspondence. The horopter pass through the fixation point (P) but there is a notch that lies close to the visual axis of the fixating eye. (Adapted from Flom[12])

CONCLUSION

The difference between the Vieth-Müller circle and the empirical horopter indicates that the corresponding points are not even spaced between the two eyes. The concept of the horopter plays an important role in understanding the process of binocularity. The separation of the eyes in the head results in different perspective for objects not on the horopter. Objects on the horopter will give rise to identical visual direction for each eye. In abnormal binocular vision such as in aniseikonia and strabismus, the skewness and the tilting of the horopter may result in distortion of the visual space. In addition, there is skewing of the horopter in patients corrected for high astigmatism with spectacles. These patients may experience spatial distortions due to having unequal power in different meridians. The horopters of strabismic patients vary according to the nature of sensory and motor adaptations.

TUWANI A. RASENGANE

1. Why did you choose optometry as a career?

I liked the term 'optometry' and enroled as an optometry student. After graduating, I got motivated to learn more about the rationale behind most concepts in optometry.

2. What is your specialty and why did you choose it?

Pediatric and Binocular vision. It is a fascinating and interesting.

3. What do you enjoy most about your job?

Doing things that excite me in this profession.

4.What is the best advice you have ever received?

'Keep focused on the positives'

5.Who has had the most influence on your career?

All my optometry lecturers.

6. What are your plans and goals for the next five years?

Continue to contribute too the profession through active participation in professional matters, and lobby for the inclusion of optometry in community service.

7.How do you spend your spare time?

With my family.

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