Chapter

Binocular Functions

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Abstract

Binocular single vision is the ability to use both eyes simultaneously so that each eye contributes to a common single perception. Normal binocular single vision occurs with bifoveal fixation and normal retinal correspondence in everyday sight. There are various anatomical and physiological factors concerned in the development of Binocular vision. The development of binocular function starts at 6 weeks and is completed by 6 months. Any obstacles, sensory, motor, or central, in the flex pathway is likely to hamper the development of binocular vision. The presence of these obstacles gives rise to various sensory adaptations to binocular dysfunction. Clinically the tests used can be based on either of the two principles: (A) assessment of relationship between the fovea of the fixing eye and the retinal area stimulated in the squinting eye, viz. Bagolini striated glasses test, red filter test, synoptophore using SMP slides for measuring the objective and subjective angles, and Worth 4-dot test; and (B) Assessment of the visual directions of the two foveae, viz. after image test (Hering Bielschowsky); and Cuppers binocular visuoscopy test (foveo-foveal test of Cuppers). Anomalies of binocular vision results in confusion, diplopia, which leads to suppression, eccentric fixation, anomalous retinal correspondence, and amblyopia.

Keywords: accommodation, binocular vision, stereopsis

1. Introduction

Binocular single vision is the ability of both eyes to contribute to simultaneous perception by contemporaneous use of each of them. Normal binocular single vision results due to the presence of bifoveal fixation and normal retinal correspondence and vice versa. Romano and Romano described binocular vision as—state of simultaneous vision with two seeing eyes that occurs when an individual fixes his visual attention on an object of regard.

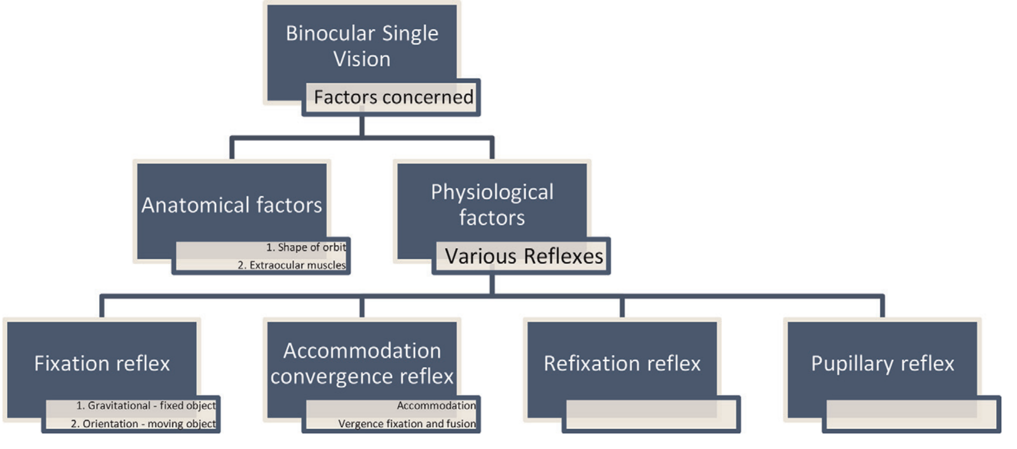
Historically, there are two schools of thought with regard to the origin and development of normal binocular vision and spatial orientation.

1. **Theory of empiricism:** This theory describes that binocular vision depends on ontogenetic development. One describes that humans are born without binocularity or spatial orientation and these functions are acquired as a result of experiences from everyday life. This acquisition of this function is aided by all other sensations especially kinesthetic sense.

2. **Theory of nativistic teaching:** This theory states that simultaneous perception and binocular vision occur as result of innate process viz. anatomicophysiological arrangement of components of visual system. This describes that binocular vision is acquired phylogenetically and not ontogenetically [1]. In simple words empiricism states that binocular function develop due to self- learning with trial and error and nativistic theory states that binocular function develops due to coordinated effort of the visual pathway.

2. Binocular vision and its development

During the **initial few years of life** certain normal anatomical and physiological conditions are required for the development of binocular vision [2]. The **factors required** for the development of Binocular vision and which enable the eyes to function in a coordinated manner are as follows [3, 4]



A. **Anatomical factors:** The eyes are spruced up in the orbit in such a way that the visual axis of both eyes is aligned. This occurs as a result of multiple anatomical factors viz.

i. Architecture of the orbit

ii. Ligaments, muscles and connective tissues, i.e., adjacent ocular structures.

The extra-ocular muscles play an important role as they provide motor correspondence because of the reciprocal innervation of the extra-ocular muscles [4].

Following are the aims of motor correspondence:

i. To convert field of vision into field of fixation thereby widening the view.

ii. To ensure that the object of attention is sustained and maintained on fovea.

iii. To ensure that both the eyes are aligned at all times.

B. **Physiological factors:** Normal physiological binocular reflexes determine the development of binocular vision. These physiologic reflexes can be either innate or acquired as a result of appropriate environmental stimulation. Different physiological binocular reflexes are described as below:

i. **Fixation reflexes**

   a. *Gravitational reflex, i.e., compensatory fixation reflex:* Whenever there is a movement of body, limbs, etc., this reflex helps maintaining the position of eyes in such a way that the eyes look in the compensating direction to the movement. This reflex occurs as a result of frontal position of eyes as well as utricle and saccule presiding over the tone of vertical rectii and obliques respectively.

   b. *Orientation fixation reflex:* A slow continuous movement of eyes can be demonstrated while observing a moving object or a panorama maintaining continuous fixation as opposed to a jerky movement.

ii. **Accommodation convergence reflex:** The aim of this reflex to align the eyes in such a way that the fixation on the object of interest is maintained. It includes three reflexes, viz., (a) vergence fixation reflex, (b) accommodation reflex, and (c) fusional vergence reflex.

iii. **The refixation reflex:** The aim of this reflex is to bring the eye back to the original orientation point or to the new orientation point.

iv. **The pupillary reflex**

3. Fusion reflex, i.e., psycho-optical reflex and its development

Cerebral activity maintains the fusional reflex which are either conditioned or acquired. They develop as a result of experience gained from environmental stimulus. Once these reflexes are formed as a result of continuous reinforcement they transform into unconditioned reflexes. Aimed to form binocular single vision, it consists of all the activities generated from the retina through the brain to maintain the images received on the fovea of both the eyes.

The *elements of fusion mechanism* are:

i. Fixation reflex

ii. Refixation reflex

iii. Conjugate fusional reflexes: the alignment of the two eyes in all positions of gaze is maintained by this reflex.

iv. Disconjugative reflexes: this includes convergence and divergence reflexes.

At birth, the child has random, nonconjugate and aimless ocular movements and the fixation reflex is very poorly developed. During the first few weeks of life there are no pursuit movements. The optomotor reflex is essentially a postnatal event, and it follows the following time schedule:

- First 2–3 weeks—follows light uniocularly

- 6 weeks to 6 months—follows light binocularly

- Convergence reflex is absent at birth. It starts developing during the first month of age and is well developed by 6 months of life.

- The accommodation lags behind the development of convergence due to the delay in the development of ciliary muscles, it develops by 6 months of age.

Various electrophysiological studies have been done in infants, which be proved to be promising in detection of stereoacuity between the age of 2–5 months. But from the age of 6 months to 3 years when the child can sufficiently comprehend to subjects the knowledge about the development of stereoacuity is miniscule. However, it was found that there stereoacuity improves gradually up to the age of 9 years. From the above literature, it is noticed that the sensitive period of development of binocular vision in human beings begins at about 4 months of age, peaks at 2 years, it is well developed by 4 years of age and slowly stops by 9 years of age. Hence it was found that the first 2 years of life is very critical for the development of binocular single vision and any obstacle during the first 2 years can hamper the development of binocular vision. The obstacle in the reflex pathway is likely to hamper the development of binocular vision can be due to the following reasons.

There can be many forms of obstacle in the development of binocular vision viz.

1. Central obstacles

2. Sensory obstacles

    - Dioptric obstacles—e.g., opacities in the media, refractive errors that are uncorrected.

    - Prolonged uniocular activity—e.g., severe ptosis, anisometropia

    - Retinoneural obstacles—lesions of retina, optic nerve

    - Proprioceptive obstacle

3. Motor obstacles

    - Congenital craniofacial malformations

    - CNS lesions—involving the nerve trunks, root of nuclei

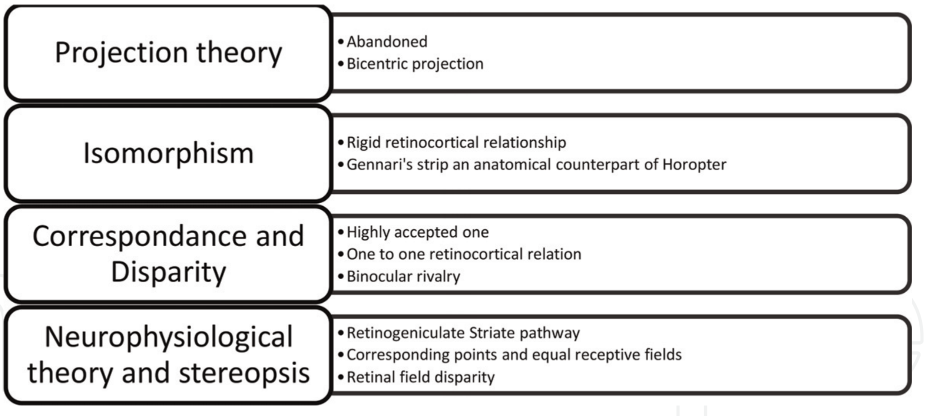
The presence of any of these obstacles gives rise to various sensory adaptations to binocular dysfunction disruptive factor is present in the sensitive period. This can be in the form of:

1. Anamolous retinal correspondence

2. Suppression

3. Amblyopia

4. Theories of binocular vision



4.1 Projection theory of binocular vision

This is an obsolete theory. According to this theory Visual stimuli are exteriorized along the lines of direction. If a person fixates binocularly, a "bicentric" projection is supposed to occur that places the impression of each eye at the point of intersection of the lines of projection [5, 6].

This theory fails to explain certain fundamental observations such as

1. Physiologic diplopia

2. The discrepancies between stimulus distribution and perception

3. Fails completely when interpretation of the sensory phenomena observed in strabismus is attempted.

The basic reason for the failure of the projection theory is that the distinction between physical and subjective space is disregarded and it does not explain the localization to a dioptic-geometric scheme.

4.2 Theory of isomorphism

This theory of binocular vision was developed by Linksz based on a rigid retinocortical relationship [7]. He believed that fusion is based on neuroanatomical connections in the cerebral cortex. The retinas of both the eyes are excited into close proximity within the visual cortex. The corresponding elements are consummated in Gennari's stripe, which he considered to be the anatomical counterpart of the horopter plane in objective space and of the nuclear plane in subjective space. But till date there is no evidence for the physiologic rigidity of the retinocortical relationship or the convergence of the pathways on which it is based.

4.3 Correspondence and disparity theory

According to this theory sensory binocular cooperation is based on system of correspondence and disparity [8]. It assumes the presence of one to one retinocortical relationship between the two eyes. They transmit single visual impression with no depth quality when stimulated simultaneously by one object point. Binocular rivalry occurs when stimulated simultaneously by two object points that differ in character. Diplopia occurs when disparate elements are stimulated by one object point. However, a single visual impression is elicited with depth perception, if horizontal disparity remains within limits of Panum's area. With the increasing disparity the perceived depth increases. However, quality of stereopsis decreases with increasing disparity which may eventually lead to diplopia.

4.4 Neurophysiological theory of binocular vision and stereopsis

Approximately [9] 80% of the neurons in the striate cortex can be stimulated from either eye in response to a visual stimulus, assuming there is a precise and orderly arrangement of connections along the retino-geniculate striate pathway. Of these 75% represented graded response from either left or right eye while 25% are binocularly driven cells and are equally stimulated from each eye. These 75% cells that could be driven by stimulation of either eye had receptive fields of nearly equal size and in corresponding positions of visual field. In normal binocular single vision, optical stimulus will excite a cortical cell only. Only one object feature is detected by each cortical cell and assigned by it to a single locus in space although two receptive fields are involved. Anatomically identical regions in the two retinas are not always occupied by the two receptive fields. There are cells whose fields have exactly corresponding points in the two retina and cells whose fields have slightly different position in the two eyes is seen at a given locus in the retino-optic cortical map. This retinal field disparity is detected by sensitive binocular neurons giving rise to binocular vision and stereopsis which occurs as a result of the difference in direction or distance of the fields in each retina forms the basis of Panum's fusion area.

5. Review of literature

1. Alhagen on binocular vision: In his book of optics, Allahgen followed Gallen in explaining that we have two eyes so that when one is harmed other remains intact and he added that two eyes beautify the face. He clearly described the concept of corresponding points in the image planes of two eyes. He stated that the eyes always move together and by an equal amount, so that visual axis converges on the objective of interest. He then discussed double images produced by an object nearer or farther away than the fixation point, with both the object and fixation point in median plane. He explained that two lines appear in the center because they lie on the visual axis therefore share a common visual direction in the fused image. Allahgen's—center is now called—egocentre and—common axis is called—cyclopean axis.

2. Aguilonius introduced the term—horopter to describe the locus in space within which both fused and diplopic image appear to lie.

3. Veith used the same Euclidean theorems to prove that theoretically the locus of equal angles of binocular subtense is the locus of fused image and both are a circle passing through the center of eyes.

4. In seventeenth and eighteenth century, clearly stated that binocular vision contributes to impression of visual depth.

5. First to specify clearly the geometry of corresponding points and horizontal horopter as the locus of object produced fused images

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6. Wheatstone demonstrated the relationship between binocular disparity and depth perception.

7. Stereopsis depends on the registration of disparities but argued that the coincidence of localization of the corresponding pictures received from the two eyes depends on the power of measuring distances of sight which we gain with experience.

8. Inputs from the corresponding regions from two retinas converged on what he called isodynamic cells and that his mechanism forms the basis of unified binocular vision

6. Fusion, diplopia, and the law of sensory correspondence

An object is positioned at a convenient distance in front of an observer at eye level and in the midplane of the head. An image will be received on matching areas of the two retinas if the eyes are properly aligned and if the object is fixated binocularly. The two images will be the same in size, illuminance, and color if both eyes are functioning normally and equally. Though two separate physical (retinal) images are formed, only one visual object is perceived by the observer. This phenomenon is so natural to us that the naive observer believes it to be normal, he is surprised only if he sees double. Yet the opposite—single binocular vision from two distinct retinal images—is the truly remarkable phenomenon that needs an explanation.

Binocular single vision occurs when the image formed in the retina from each eye contributes to a single, common perception. It is considered in three grades:

- **Sensory:** It is the ability to perceive an image formed from each eye simultaneously.

- **Motor:** It is the ability of both the eyes to maintain sensory fusion through a range vergence movements.

- **Stereopsis:** It is the perception of depth based on binocular disparity.

7. Prerequisites for binocular vision

1. Central fixation with normal visual acuity

2. Accurate oculomotor control-bifoveal fixation

3. Normal inter retinal correspondence of visual directions

4. Sensory mechanism to provide haplopia

5. Neural mechanisms to extract selective depth signals

Binocular single vision can be classified into three stages according to Worth's classification (**Figure 1**)

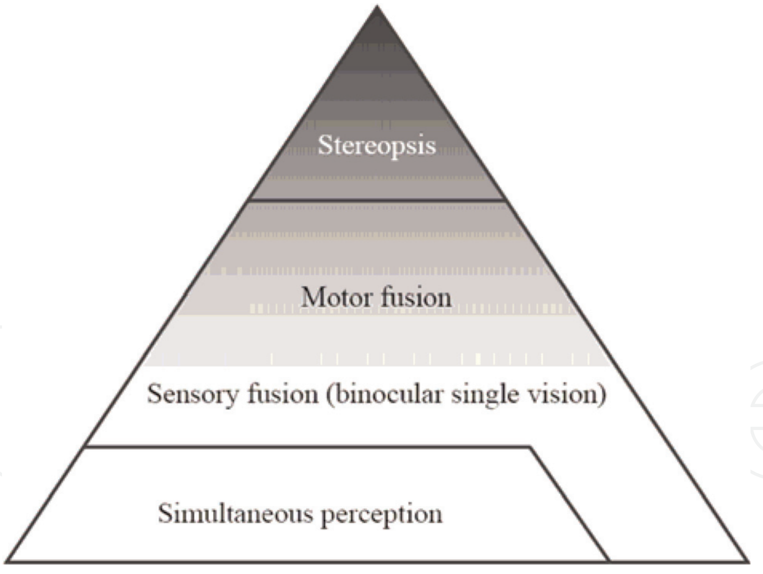

Figure 1.
The classical model of binocular visual function is composed of three hierarchical degrees.

1. Simultaneous perception and superimposition

2. Fusion

3. Stereoscopic vision

7.1 Simultaneous perception and superimposition

The ability of both the eyes to perceive simultaneously two images, one formed on each retina is defined as simultaneous perception. Simultaneous perception of the two images formed on corresponding areas, with the projection of these images to the same position in space is superimposition. This occurs based on the correspondence whether it is normal or abnormal. If fusion does not occur then two similar images are seen as separate but superimposed and no fusion range can be demonstrated.

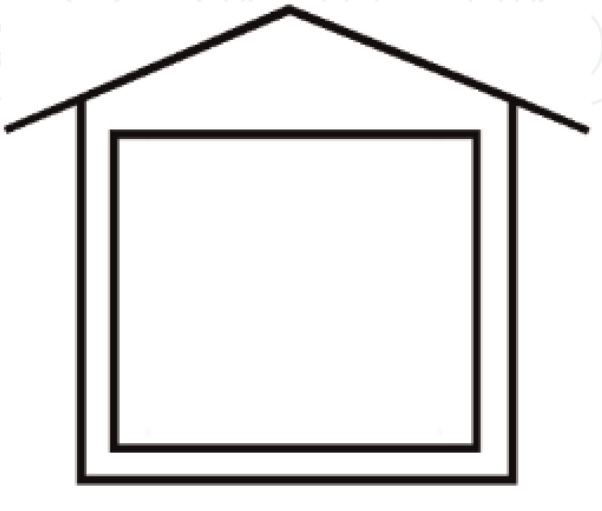

Image 1.
Simultaneous perception—image for the first eye.

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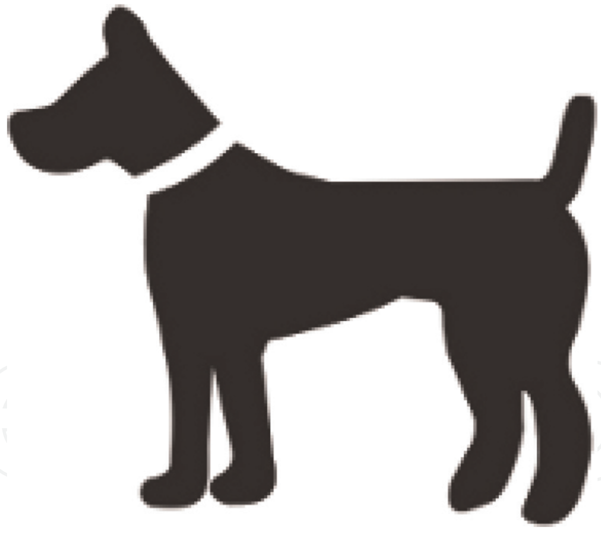

Image 2.
Simultaneous perception—image for second eye.

Image 3.
Simultaneous perception—binocular vision image.

Exemplary on **Image 1** there is element visible for one eye and on **Image 2** visible for second eye. Patient with ability to simultaneous perception should perceive image similar to **Image 3**.

7.2 Fusion

Fusion is defined as the unification of visual excitations from the corresponding retinal images into a single visual perception. Fusion can be either sensory or motor.

7.2.1 Sensory fusion

The hallmark of retinal correspondence is the sensory fusion which is defined as is the ability of both the eyes to perceive two similar images, one formed on each retina, when interpreted as one single visual image. The images not only must be located on corresponding retinal areas but also should be sufficiently similar with respect to size, brightness and sharpness to permit sensory are the prerequisites for sensory fusion. A severe obstacle to fusion are unequal images.

7.2.2 Motor fusion

The ability to align both the eyes in such a way that sensory fusion can be maintained is termed as Motor fusion. Retinal disparity formed outside Panum's area and the eyes moving in opposite direction which may be horizontal, vertical or cyclovergence is the stimulus for these fusional eye movements. Unlike sensory fusion, motor fusion is a function of the extrafoveal retinal periphery. Fusion, whether sensory or motor, is always a central process, i.e., it takes place in the visual cortex.

7.3 Stereopsis

The fused image will be perceived in vivid depth nearer or farther to the point of fixation within some range of limiting conditions, when two similar images are presented to both the eyes with a binocular disparity that has a horizontal component. The objects give rise to the stereoscopic depth from Horizontal binocular disparities, e.g., arrow at different distances and it gives rise to stereoscopic depth perception. Here the arrowhead has a lesser eccentricity on the nasal retina of the right eye than on the temporal retina of the left eye. The fovea is the site of fixation. The observer is aware alternately of the image to one eye and the image to the other if such dichoptic image formed is of high contrast, due to binocular rivalry that forms between the two monocular images. As a result of interocular suppression if one eye is strongly dominant as a result of either stimulus characteristics or organismic variables, perception of the image in the other eye may be entirely absent. Prolonged periods of dichoptic summation may be obtained, during which the different stimuli in the two eyes appear to be summed together as if their contrasts were added linearly throughout the dichoptic field. If however, the stimulus contrast is low for dichoptic stimuli. When the presentation time is brief (150 ms) dichoptic summation also is obtained for high contrast stimuli.

Where the image appears doubled but clearly at a different depth from zero-disparity targets stereoscopic depth from horizontal disparities is perceived both in the region of binocular fusion of the monocular targets into a single image and also in the region of diplopia, the smallest disparity interval that produces reliable depth discrimination under particular conditions is stereo acuity.

8. Sensory adaptations in binocular vision

8.1 Suppression

Suppression is a neuro-physiological phenomenon of the eye to prevent diplopia and confusion by suppressing the non-dominant image at the cortical level. Diplopia occurs when fovea of one eye and extra foveal point of the other eye is stimulated simultaneously. Confusion occurs when dissimilar image is projected on fovea of both the eyes.

8.1.1 Types of suppression

Facultative suppression: In Facultative suppression visual acuity is not affected under monocular conditions. Facultative suppression occurs only under binocular conditions.
Obligatory suppression: It occurs even under monocular conditions resulting in diminished visual acuity which further leads to amblyopia.
Central and peripheral suppression: To avoid confusion foveal image of the deviating eye is suppressed which is known as central suppression. Similarly to avoid diplopia extra foveal image of the deviating eye is suppressed resulting in peripheral suppression.
Monocular or alternating: Monocular suppression occurs when the image from the dominant eye always predominates over the image from the deviating eye, so that the image from the latter is constantly suppressed. This leads to amblyopia. When suppression alternates between the two eyes amblyopia is less likely to occur.

8.2 Anamolous retinal correspondence

Anamolous retinal correspondence is a type of sensory adaptation in which fovea of one eye shares a common visual direction with the extra foveal point of the other eye. This is an adaptation in manifest squint resulting in binocular single vision. It is known as anomalous because extra foveal point of one eye corresponds to foveal point of the other eye. But in contrast to eccentric fixation under monocular conditions, fovea of deviating eye takes the fixation which forms the basis for cover test.

Prerequisites for anomalous retinal correspondence:

1. Small angle of deviation
2. Constant deviation
3. Extra foveal point should be close to the fovea

8.3 Motor adaptations to strabismus

Motor adaptation is in the form of abnormal head posture and occurs primarily in children with congenitally abnormal eye movements who use the abnormal head posture to maintain the binocular single vision.

9. Retinal correspondence

Retinal correspondence occurs when the retinal points of both the eyes share a common visual direction. Non corresponding retinal points will never have a common visual direction.

9.1 Types of retinal correspondence

9.1.1 Normal retinal correspondence

Normal retinal correspondence is defined when fovea of one eye corresponds to the fovea of the other eye and they both share a common visual direction. In NRC, points located nasal to the fovea in one eye correspond to the points located temporal to the fovea of the other eye.

9.1.2 Abnormal retinal correspondence

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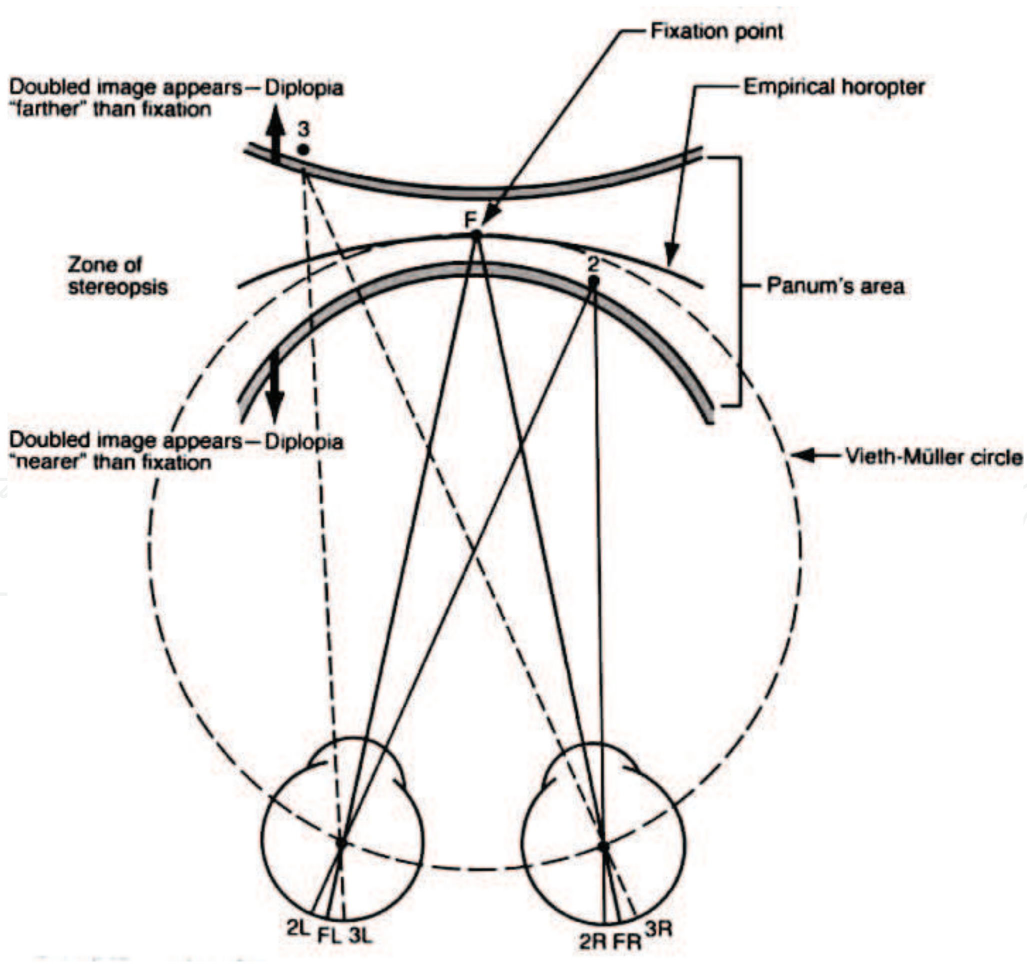


Figure 2.
Empirical horopter. F, fixation point; FL and FR, left and right foveae, respectively. Point 2, falling within Panum's area, is seen singly and stereoscopically. Point 3 falls outside Panum's area and is therefore seen doubly.

10. Concept of a Horopter

The term Horopter (**Figure 2**) is derived from Greek words, horos-boundary, opter-observer, was first introduced in 1613 by Aguilonius [5]. The horopter is a curved line formed when all the corresponding points are projected in space at a particular distance from the observer. Hence it is the locus of all points in the space that stimulates the corresponding points of the retina leading to a binocular single vision.

Geometric Vieth Muller horopter is a theoretical horopter. It is a geometrically constructed circle which passes through the corresponding points of the two eyes. But actually it is not spherical, it is flatter. The actual—**Empirical horopter** curve also known as the longitudinal horopter is slightly flatter than Vieth Muller Geometric horopter. It is formed by using longitudinal bars positioned such that they appear equidistant. The difference between the geometric and the empirical horopter is known as the Hering-Hillebrand deviation. Very small areas around the corresponding points can be binocularly fused to see singly. This is known as Panum's area of binocular fusion. Diplopia elicited by an object point off the horopter but within Panum's fusional area is known as physiological diplopia. Panum's area is narrowest at fovea (6–10° of arc) and broader in periphery (30–40° of arc). Objects lying outside the Panum's area will be perceived double when viewed binocularly. Even though the fusion occurs, a perceptual effort is made which is appreciated by the cortex as depth perception. So Panum's area is physiological basis for our depth perception.

11. Stereopsis (Figure 3)

It is the ability of both the eyes to fuse images that lie within Panum's fusional area resulting in three dimensional perception of the object. Diplopia elicited by an object point off the horopter but within Panum's fusional area is known as physiological diplopia. Images of a single object that do not stimulate corresponding retinal points in both eyes are said to be disparate; binocular disparity is defined as the difference in position of corresponding points between images in the two eyes.

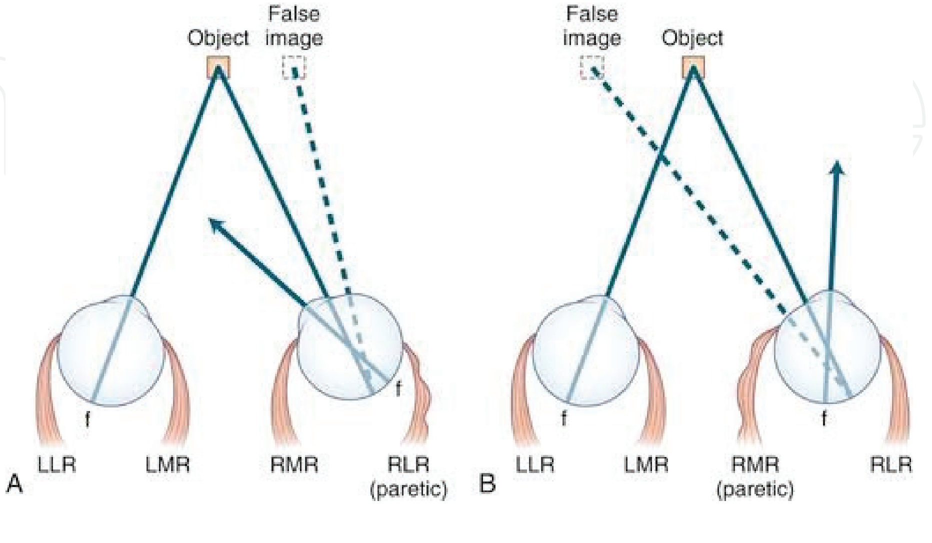


Figure 3.
Crossed and uncrossed disparities result when objects produce images that are formed on closely separated retinal points. Any point within Panum's area yields a percept of a single image, while points outside Panum's area produces diplopia.

Binocular disparity or Physiological diplopia can be of two types crossed (temporal or heteronymous) and uncrossed (nasal or homonymous). Crossed diplopia occurs when objects lie in front of the horopter. In crossed diplopia the monocular image of the object perceived by the right eye is displaced to left and the image perceived by the left eye is displaced to the right. Uncrossed diplopia occurs when objects lie behind the horopter. Hence in uncrossed diplopia the monocular image of the object perceived by the right eye is displaced to the right and the image perceived by the left eye is displaced to the left (**Figure 3**).

12. Stereoscopic acuity

It can be defined as the disparity beyond which no stereoscopic effect can be produced. A threshold of 15–30 arc seconds is considered excellent; however, there is no standardization for the same. There is a critical distance calculated to be 150–200 m beyond which the stereopsis does not work as there is a threshold for stereopsis. The threshold of stereoscopic acuity also depends on the motion of both eye as well as the target object. For static targets the stereoacuity ranges from 2 to 10 arc sec which increases to 40 arc sec for objects in motion. Stereoacuity is maximal about 0.25° off dead center in the foveola. As we move along the x axis the stereoacuity decreases exponentially. Stereopsis is not present beyond 15° from the center. There is a similar exponential decline in the stereoacuity when the target is moved in front or behind the horopter along the y-axis. Stereopsis although is very essential for spatial orientation, it is not the only means of it. The various monocular clues to spatial orientation can be:

Apparent size: It depends on the size of the object as well as the distance of the object from the retina. The objects that are closer to the retina appear larger in size and those farther away appear smaller. Similarly as the object move towards the retina it appears to be increased in size.
Interposition: The objects that are relatively near conceal the objects that are far.
Aerial perspective: Environmental factors like water vapor, dust and smoke cause scattering of the light and hence cause decrease in the color saturation as well as visibility of the distance object.
Shading: Whenever light falls on a solid object it casts shadow and when it falls on the concave surface the shadow is cast in a graded manner.
Geometric perspective: The line that is parallel pragmatically appears to join together near the horizon, e.g., railroad tracks.
Relative velocity: The velocity of image of a moving target that is at a distance is slower that the velocity of image of a moving target that is near.
Motion parallax: If the fixation point is at an intermediate distance the objects that are nearer to it move in the opposite direction when the head is moved and those that are farther away from the fixation point move along with the head.

13. Fusion

Fusion is defined as the amalgamation of visual impulses from the corresponding retinal images into a single visual percept.

13.1 Sensory fusion

When two similar images are formed on the corresponding areas of each eye, the ability to interpret them as one is termed as sensory fusion. Retinal correspondence can be certified from the fact that a single image is formed. Size, brightness and sharpness of similar degree are equally essential components required for sensory fusion to occur as is the retinal correspondence images of unequal size are a severe obstacle to fusion.

13.2 Motor fusion

For the sensory fusion to be maintained it is essential that the eyes are aligned and the ability to do so is termed as motor fusion. Retinal disparity outside Panum's area and the eyes moving in opposite direction (vergence) are the stimuli for the fusional movements. Motor fusion is the exclusive function of the extrafoveal retinal periphery, unlike sensory fusion which is dependent on fovea. However both sensory and motor fusion are central processes the control of which lies in the visual cortex.

13.3 Diplopia

When there is a simultaneous stimulation of two disparate retinal points by a point object, there occurs perception of the object in two different subjective visual directions. An object point seen simultaneously in two directions appears double. Double vision is the hallmark of retinal disparity.

13.4 Binocular rivalry

Retinal rivalry may be observed when dissimilar contours are presented to corresponding retinal areas and fusion becomes impossible. When areas of retinal correspondence are stimulated by dissimilar object, fusion fails to occur and leads to confusion. To surpass this confusion, image from one of the eyes is suppressed. The constant foveal suppression of one eye leads to complete sensory dominance of the other eye with cessation of rivalry, which is a major obstacle to binocular vision. For binocular vision to be functional presence of retinal rivalry is must.

14. Grades of binocular vision

Worth's classification of binocular vision:

Grade I: Simultaneous perception is the most basic essential prerequisite for binocular single vision. It is the power to see two dissimilar objects simultaneously.

Grade II: It represents true fusion with some amplitude. The two images are not only fused, but some effort is made to maintain this fusion in spite of difficulties. Addition of motor component to the sensory fusion represents second grade of binocular vision.

Grade III: This is the highest grade of binocular vision in which the images are not only fused but also a stereoscopic view of the image is produced. It is the ability to obtain an impression of depth by the superimposition of two pictures of the same object taken from slightly different angles.

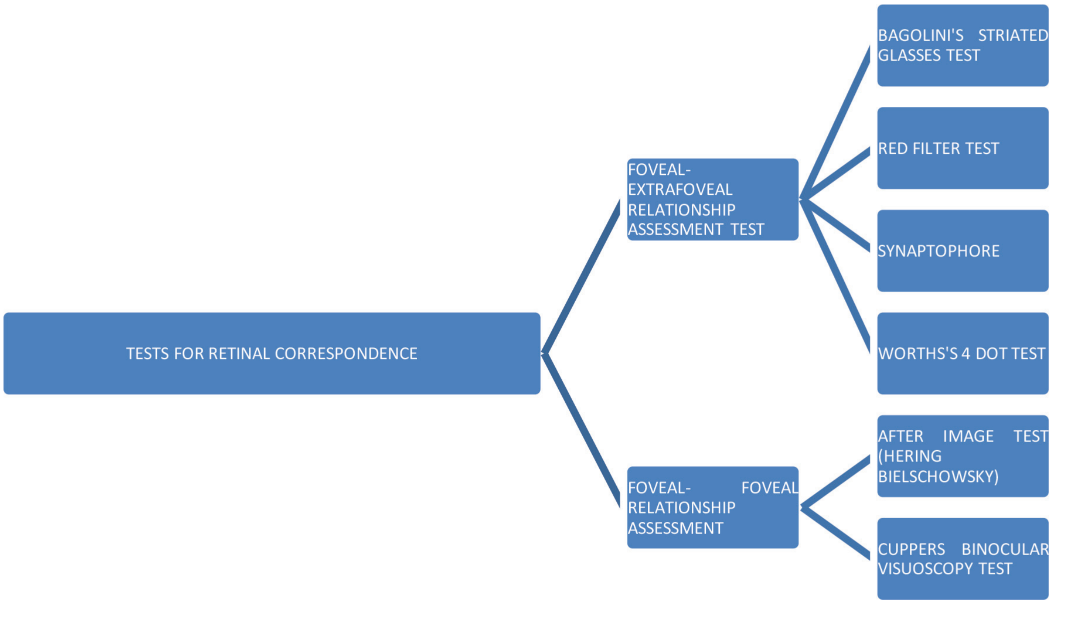
Binocular vision assessment:
All the tests are aimed at assessing the presence or absence of:

1	Normal or abnormal retinal correspondence
2	Suppression
3	Simultaneous perception
4	Fusion
5	Stereopsis

It is essential to assess the visual acuity, fixation in the deviating eye and direction and amount of deviation in every case.

Test for retinal correspondence:

Clinically the tests used can be based on either of the two principles:



1. **Bagolini striated glasses test:** The patient is asked to fixate a small light, after being provided

With plano lenses with narrow fine striations across one meridian (micro Maddox cylinders) a source of light is seen as a line at right angles to the striations. The axis of striations of the eyes is kept at right angles to each other. The interpretation of this test is as follows:

a. Symmetrical cross response

   i. In the absence of a manifest squint, a cross response indicates a normal bifoveal correspondence (NRC).

   ii. In the presence of a manifest squint, a cross response indicates an anomalous retinal correspondence (ARC) of harmonious type (subjective angle of deviation of zero).

b. Asymmetrical cross response or two lines cutting each other at some other point than midline, indicates an incomitant squint with normal retinal correspondence (diplopia response).

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c. Single line seen: If only one line is seen it indicates suppression of the other eye (suppression response).

d. Cross response with central gap in one line indicates a central suppression scotoma in that eye.

2. **Red filter test:** It is a characteristic test used to check dissociation between two eye. It is done by placing a red filter over the preferential fixating eye while it fixates over a small light source.

Results can be interpreted as:

a. *Normal retinal correspondence:* two lights are reported by the patient; one red and other white.

   i. In cases of homonymus (uncrossed) diplopia, patient reports red light to the right of white light when right eye is tested.

   ii. In cases of heterogeneous (crossed) diplopia, patient reports red light to the left of white light when right eye is tested.

b. *Abnormal retinal correspondence:* It can be of two types:

   i. In cases of harmonious heterophoria patient reports only single light which is pinkish in color because of superimposition of white and red light.

   ii. In unharmonious heterophoria patient reports two different types of light depending on the direction of deviation.

c. *Suppression:* Patient reports only single light source (more commonly white line). It depends on the degree of dominance of the other eye and the density of the red filter used.

Measurement of angle of anomaly: It is the difference between objective and subjective angle of deviation seen in cases of abnormal retinal correspondence. The angle of anomaly is a measure of the degree of shift in visual direction.

Procedure of estimating the angle of anomaly: This test is done with the help of synaptophore. The SMP slides are used in this test. The position of synaptophore arms is kept at zero. The examiner flashes light behind each slide and keeps on moving the arm till the time there is no further movement (alternate cover test). When there is no further movement the angle of each arm is noted. The sum total of the angles recorded of both the arms is the objective angle of anomaly. The angle at which the visual targets are superimposed is the subjective angle of anomaly.

Objective angle (D): Angle by which the visual axis of eye fails to intersect the target of regard.

Subjective angle (S): Angle between the zero measure of the deviating eye and point in that eye corresponding to the fovea of other eye.

Interpretation:

a. Normal retinal correspondence: D = S; Angle of anomaly is zero.

b. Abnormal retinal correspondence: D is not equal to S.

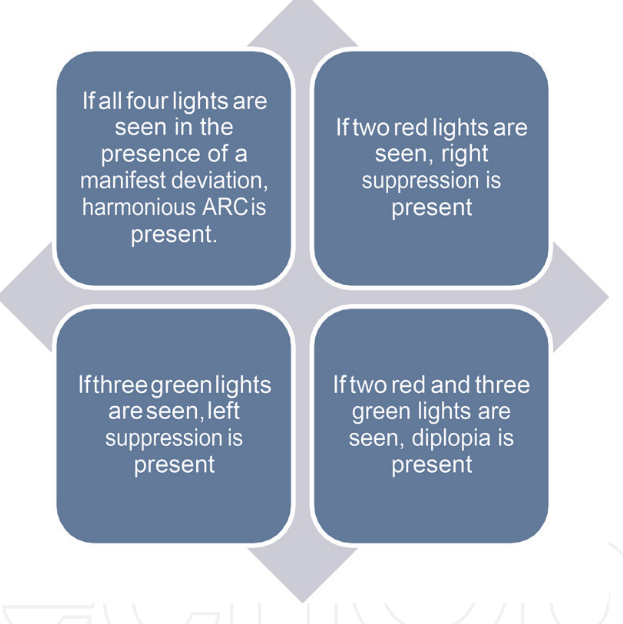
i. Harmonious ARC: Subjective angle is zero. Angle of anomaly is equal to objective angle.

ii. Unharmonious ARC: Angle of anomaly is less than objective angle.

iii. Paradoxical ARC: Angle of anomaly is greater than objective angle of duration.

3. **Worth 4-dot test:** This is a simple test using the principle of red-green color dissociation. It is more dissociating than the Bagolini's glasses and hence is less physiological. The apparatus for this test consists of a box containing four panes of glass, arranged in diamond formation, which are illuminated internally from a light source. The two internal panes are green, the upper one is red and lower one is white. The patient wears a green lens in front of the right eye, and a red lens in front of the left eye. The test can be performed separately for distance and near vision. The interpretation of this test is as follows:

    a. If BSV is present all four lights are seen



    b. If the green and red lights alternate, alternating suppression is present.

4. **Hering Bielschowsky after-image test:** This is a highly dissociating orthoptic test in which fovea of the two eyes is flashed with linear afterimage horizontal in right eye and vertical in left eye since each eye is individually stimulated, only the fovea are at the center of the after images.

Procedure: Subject is asked to concentrate on the central black spot of the glowing filament with alternate eye occluding the other eye. The stimulus is first presented to the better eye and then vertically to the opposite eye. This stimulus is presented for 20 s to each eye and then subject is asked to tell the distance between gaps of two images.

a. If central fixation is present, the gaps correspond to the visual direction of each fovea.

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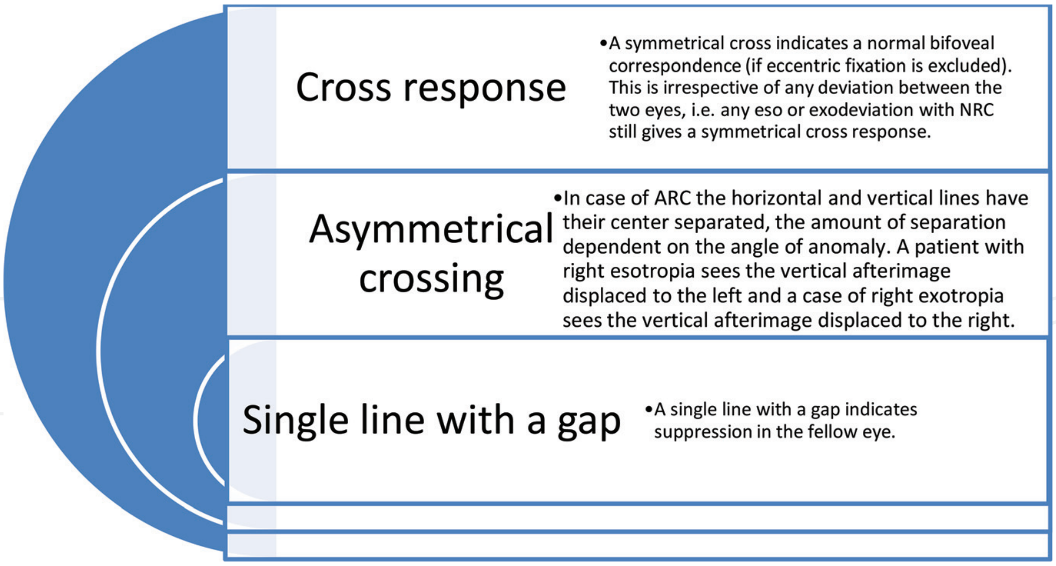
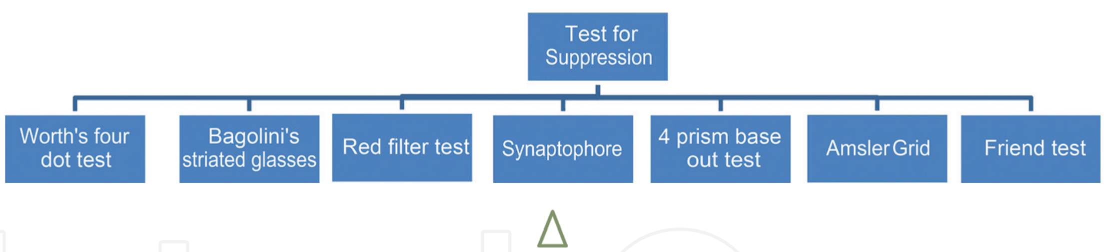
Results are as follows:



1. **Foveo-foveal test of cuppers:** This test is done to analyze the angle of anamoly in the presence of eccentric fixation. It determines whether the two foveae have same or different visual directions.

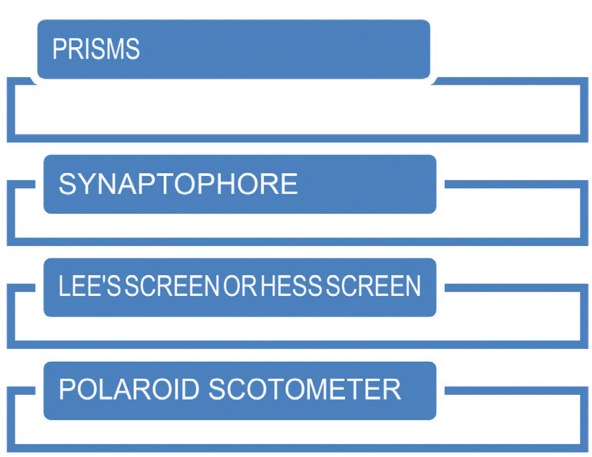
15. Suppression

Suppression involves active inhibition at the visual cortex level when the blurred image from one eye is inhibited under binocular condition. Pre requisite for suppression is large angle deviation, constant deviation and deviation that occurs in early childhood.



15.1 Testing extent of suppression

The extent or the area of suppression can be charted under binocular conditions (fixating with one eye while the field of other eye is charted). This may be done by different methods:



The various responses that can be observed are:

More the dissociation larger is the single scotoma in prism's, Lee's.

Lesser the dissociation, 2–3 discrete scotomas are seen, one is foveal scotoma about 2–3° in size and diplopia point scotoma, e.g., Aulhorn phase difference haploscope and Polaroid scotometer.

Depth/intensity of scotoma: Depth of scotoma is determined by Graded Density Filter Bar of Bagolini. In it as the denser filter is applied over dominant eye, the scotoma in amblyopic eye becomes small.

15.2 4 Δ base out prism test

This test is used for diagnosing a small facultative scotoma in a patient with monofixation syndrome and no manifest small deviation. In this test, a 4▲ Base out Prism is placed before one eye and then other under binocular viewing condition

Patient with bifixation show a bilateral version movement away from the eye covered by the Prism followed by unilateral fusional convergence movement of the eye not under the Prism.

In Monofixation no movement is seen when Prism is placed over the nonfixating eye. A refixation version is seen when Prism is placed over fixating eye but then fusional convergence does not occur.

16. Simultaneous macular perception

Simultaneous macular perception occurs when visual signals transferred from the two eyes to the cortex are perceived at the same time. It is the ability to see two dissimilar objects simultaneously. Commonly used synaptophore contain slides such as Bird and Cage, Lion and Cage. The interpretation is as follows:

Simultaneous macular perception	Subtend angle at nodal point
Simultaneous foveal perception slide	1°
Simultaneous parafoveal perception slides	1–3°
Simultaneous paramacular perception slides	3–5°
Simultaneous peripheral perception slides	<5°

The term simultaneous perception does not necessarily mean bifoveal fixation as it can also occur in Anamolous retinal correspondence. It just indicates the presence or absence of suppression.

Normal range of amplitudes of fusion:

Type of vergence		Amplitude range
Horizontal vergence	Convergence	35–40 Δ
	Divergence	5–7 Δ
Verticgence	Supravergence	3 Δ
	Infravergence	3 Δ
Cyclovergence	—	2–3 Δ

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It is necessary to assess fusion for both viz. determining the prognosis and outlining the management of the patients of strabismus.

To restore binocular single vision fusion is essential.

Following are the tests used to determine the presence of fusion are:

- Worth 4-dot test
- Bagolini striated glasses
- Synaptophore

Following tests can be used to determine stereopsis: Tests to determine stereopsis are based on two principles viz.

1. The targets used are such that they lie in two planes, but are constructed in such a way that they cause stimulation of disparate retinal elements which gives a three-dimensional effect, for example:
    - Concentric rings, i.e., circular perspective diagrams
    - Titmus fly test
    - TNO test
    - Random dot stereograms
    - Polaroid test
    - Lang's stereo test
    - Stereoscopic targets presented haploscopically in major amblyoscope
2. Using targets that are three dimensional (e.g., Lang's two pencil test)

Tests used to determine stereopsis can be qualitative or quantitative. The unit for measurement of stereopsis is seconds of an arc.

- Following are the qualitative tests for stereopsis:
    - Lang's 2 pencil test
    - Synaptophore
- Following are the quantitative tests for stereopsis:
    - Random dot test
    - TNO Test
    - Lang's stereo test

Polarization can also be used to determine stereopsis: Vectographs and images, used as targets seen by one eye are polarized at 90° using polarized glasses.

- Titmus stereo fly test
- Polaroid test
- Random dot stereograms
- TNO test

16.1 Stereograms

There are two stereograms

1. Both eyes should be used together to see the one with three concentric circles and a check dot for each eye.

2. One with three eccentric circles has to be seen with each eye separately. Interpretation:

    a. Patient sees concentric circles: Stereopsis is present.

    b. Patient sees eccentric circles: Should be asked whether the inner circles are towards right or left. This will help us determine whether the disparate elements are suppressed in right or left eye.

    c. Vectographs: Consists of two targets imprinted on a Polaroid material in such a manner that each target is polarized at 90° with respect to the other. A polarized spectacle is provided to the patient so that each target is seen separately with the two eyes.

A. **Titmus stereo test:** Gross stereoscopic is checked using a stereoscopic pattern representing a housefly. It aids to orient the patient (threshold 3000 s of arc).

    a. *Advantage:* Young children can also perform the test.

    b. *Disadvantage:* Stereopsis using this test is only near stereopsis.

B. **Polaroid test:** There are two types of test that are commonly used

    a. *With animals printed:* It consists of three rows of animals. There one animal in each row which is imaged disparately (threshold 100, 200 and 400 s of arc, respectively). There is also one animal in each row that is printed heavily black which forms the misleading clue. The child is then asked to point out which one of the animals stands out. A child without stereopsis will name the heavily printed animal as the one that stands out.

    b. *With circles:* It consists of nine sets of four circles arranged in the form of a diamond. In this test there are nine sets of four circles which are arranged to form a diamond. One of these circles is imaged dispared in each set randomly. The threshold ranges from 800 to 40 s of arc. The child is asked to push down the circle that stands out. If the stereopsis is limited the child makes mistakes.

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C. **E-random dot test:** In this test, there are two cards, one with E printed and the other is blank. The child is explained about the procedure using a test card. After explaining the procedure the child is provided with a polaroid glass and then child is shown the test cards. The child is asked to answer which card has E printed on it.

D. **Random dot stereogram of Julesz:** In this test when the child sees uniocularly, the stereogram reveals random dots scattered everywhere. When viewed binocularly, there appears a square that lies at various depth perception above or below the paper. This exposes child to the requirements similar to that in daily life.

16.2 Binocular vision anomalies

In anamolies of binocular vision there occurs in confusion, diplopia that results in suppression, eccentric fixation, anomalous retinal correspondence and amblyopia.

16.2.1 Classification

Duane's classification forms the basis of classification of anomalies of binocular vision in the field of optometry. This classification system evolved from a four category system to a nine-category system that was developed by Wick. Following parameters are used for classification: (a) distance phoria and (b) AC/A ratio. The accommodative classification system was developed by Donders3 and modified by Duke-Elder and Abrams. Ocular motor dysfunction is a distinct clinical entity in which fixation, pursuit and saccadic anomalies are included. **Table 1** is a summary of the classification system for binocular, accommodative and ocular motor anomalies.

AC/A ratio	Anomalies
Low AC/A ratio	Convergence insufficiency
	Divergence insufficiency
Normal AC/A ratio	Fusional vergence dysfunction
	Basic esophoria
	Basic exophoria
High AC/A ratio	Convergence excess
	Divergence excess
Accommodative anomalies	Accommodative insufficiency
	Ill-sustained accommodation
	Accommodative excess
	Accommodative infacility
Ocular motor anomalies	Ocular motor dysfunction

Table 1.
Summary of the classification system for binocular, accommodative and ocular motor anomalies.

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