

BINOCULAR VISION

Rahul Bhola, MD

Pediatric Ophthalmology Fellow
The University of Iowa
Department of Ophthalmology & Visual Sciences

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Binocular vision is one of the hallmarks of the human race that has bestowed on it the supremacy in the hierarchy of the animal kingdom. It is an asset with normal alignment of the two eyes, but becomes a liability when the alignment is lost.

Binocular Single Vision may be defined as the state of simultaneous vision, which is achieved by the coordinated use of both eyes, so that separate and slightly dissimilar images arising in each eye are appreciated as a single image by the process of fusion. Thus binocular vision implies fusion, the blending of sight from the two eyes to form a single percept.

Binocular Single Vision can be:

1. Normal – Binocular Single vision can be classified as normal when it is bifoveal and there is no manifest deviation.
2. Anomalous - Binocular Single vision is anomalous when the images of the fixated object are projected from the fovea of one eye and an extrafoveal area of the other eye i.e. when the visual direction of the retinal elements has changed. A small manifest strabismus is therefore always present in anomalous Binocular Single vision.

Normal Binocular Single vision requires:

1. **Clear Visual Axis** leading to a reasonably clear vision in both eyes
2. The ability of the retino-cortical elements to function in association with each other to promote the fusion of two slightly dissimilar images i.e. Sensory fusion.
3. The precise co-ordination of the two eyes for all direction of gazes, so that corresponding retino-cortical element are placed in a position to deal with two images i.e. Motor fusion.

The advantages of a Binocular vision are:

1. The first and the foremost advantage of a binocular vision is single vision.
2. In addition to single vision it results in stereopsis – the most precise kind of depth perception
3. Enlargement of the field of vision
4. Compensation for blind spot and other differences

Sensory Aspects of Binocular vision

The objects in space are localized by us in two ways –one is relative to one another and is called relative localization and the other is in relation to ourselves and is called egocentric localization.

Objective (Physical) & Subjective (Visual) space

Location of an object point in physical space was separated from its localization in visual space.

The objective lines of direction determine which retinal area will be stimulated, their subjective counterpart, the visual direction determines the direction in which the object will be seen in visual space.

Retinal Element:

It is defined as a retinocerebral apparatus engaged in elaborating a sensation in response to excitation of a unit area of retinal surface.

- ❖ The retinal area when stimulated by light entering the eye from an object is perceived not only as being of certain brightness, color and certain form, but also has a certain direction in visual space. This direction in which the visual object is localized is determined by the directional or spatial values of the stimulated retinal element called the Local signs of Lotze which is an intrinsic property inherent in the retinal element.
- ❖ Thus each retinal element when stimulated localizes the stimulus as a visual percept in a specific direction – a visual direction. This direction is relative to the visual direction of the fovea. Fovea, which is the area of the highest visual acuity, is the carrier of Principle Visual direction and is the center to which the secondary visual direction of the other retinal element relates.
- ❖ Fovea besides being the carrier of principle visual direction, is also the retinomotor center or retinomotor zero point i.e. once an image of the object of regard is on fovea there is no incentive for ocular movement.

Visual Axis (Line of direction or direction ray of Helmholtz)

It is the line which connects an object point with its image on the retina. If the visual axis of the two foveas also known as the principle visual axis intersects at the fixation point, it is said that there is binocular fixation.

If only one principle line of direction goes through the fixation point, then fixation is monocular. All object points that simultaneously stimulates the two fovea appears in one and the same subjective visual direction coinciding with the median plane of the head. This is known as the common subjective visual direction of the fovea. It lies in as imaginary plane passing through the root of the nose known as third central imaginary eye or the binoculus or cyclopean eye.

RETINAL CORRESPONDENCE

Retinal elements of the two eyes that share a common subjective visual direction are called corresponding retinal points. All other retinal elements are non-corresponding or disparate with respect to a given retinal element in the fellow eye for a particular visual direction.

Law of Sensory Correspondence

It states that existence of corresponding retinal elements with their common relative subjective visual direction is the essence of binocular vision.

Retinal Correspondence can be of two types:

1. Normal Retinal Correspondence

Retinal correspondence is called normal when both the fovea have a common visual direction and the retinal elements nasal to the fovea in one eye corresponds to the retinal elements temporal to the fovea in the other eye.

2. Abnormal Retinal Correspondence

Retinal correspondence is abnormal when the fovea of one eye has a common visual direction with an extrafoveal area in the other eye. This is generally seen if the angle of squint is small and the extrafoveal point is close to the fovea. It is an attempt to regain the binocular advantage, although anomalous (because it is foveo-extrafoveal and not foveo-foveal). This results in the eyes seeing binocularly single in spite of a manifest squint. In ARC under binocular conditions the fovea and the extrafoveal point share the common subjective visual direction. But when the normal eye is closed the extrafoveal element loses any advantage over the fovea of that eye, which retains its primary visual direction. Thus under monocular conditions the central fixation is retained by the fovea, this is the basis of the cover test.

The quality of binocular single vision obtained in ARC varies from patient to patient, in some there is useful gross stereopsis while in the others binocular vision is rudimentary. The quality of binocular vision is usually inversely proportional to the angle of deviation.

Concept of a Horopter

The term Horopter (the horizon of vision) was introduced in 1613 by Aguilonius. It is defined as the locus of all object points that are imaged on corresponding retinal elements at a given fixation distance. Thus a line can be drawn through the object of regard such that all the points on the line are imaged on the corresponding retinal elements and are seen singly.

Geometric Vieth Muller horopter

According to this model of horopter if corresponding points have a regular horizontal distance from the retina the horopter would be a circle passing through the center of rotation of the two eyes and the fixation point. Thus the circle becomes smaller as the point of fixation gets nearer.

Empirical Horopter Curve

The empirical horopter curve or the longitudinal horopter is slightly flatter than Vieth Muller geometric horopter i.e. it has a greater radius of curvature. The deviation of the perceptual from the geometric horopter is known as the Hering-Hillebrand deviation. This deviation is felt to be due to both neural and optical factors. The nasal hemi-retina at any given eccentricity contains more photoreceptors per unit area than the temporal hemi retina producing a deviation in the horopter mapping in the visual cortex.

Thus all the points not lying on the horopter are imaged by disparate retinal elements and are seen as double. This diplopia elicited by object points off the horopter is called Physiological diplopia. However we normally do not always experience this diplopia. This can be explained on the basis of Panum's Fusion Area. It is defined as a narrow band around the horopter within which the objects stimulation disparate retinal elements transmit the impression of single vision.

Thus the range of horizontal disparities around the horopter within which the stimulus will continue to be perceived as single is known as Panum's fusional area.

Panum's area is narrowest at the fixation point and becomes broader in the periphery at a rate of 1-2 arc min per degree of visual field eccentricity. Thus the horizontal extent of this area is small at the center (6-10 arc min near the fovea) and increases towards the periphery (30-40 arc min at 12° from the fovea). The increase in the Panum's area towards the periphery may be related to anatomic and physiologic differences known to exist between the monosynaptic foveal cone system and the rod and cone system of the periphery.

The increase in the spatial extent of Panum's area in the peripheral visual field serves three useful purposes:

- ❖ Increasing size of Panum's area matches increasing coarseness of peripheral vision. Receptive field size increases and the visual acuity decreases as a function of eccentricity.
- ❖ Increasing the thickness of Panum's area prevents bothersome peripheral diplopia when fixating flat targets held at close range.
- ❖ Increasing the extent of Panum's area peripherally makes cyclofusion possible despite cyclovergence errors of as much as 2 degrees between the two eyes.

Panum's area expands and contracts depending on the size, sharpness and speed of the stimuli. Panum's area for the stimuli that are fuzzy and slow moving is 20 times wider than it is for stimuli that are sharply focused and rapidly moving.

FUSION

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

Sensory Fusion

It is the ability to appreciate two similar images, one with each eye and interpret them as one. Single visual image is the hallmark of retinal correspondence. For sensory fusion to occur, the images not only must be located on corresponding retinal areas but also must be sufficiently similar in size, brightness and sharpness to permit sensory. Unequal images are a severe obstacle to fusion.

Motor Fusion

It is the ability to align the eyes in such a manner that sensory fusion can be maintained. The stimulus for these fusional eye movements is retinal disparity outside panum's area and the eyes

moving in opposite direction (vergence). Unlike sensory fusion, motor fusion is the exclusive 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.

DIPLOPIA

The simultaneous stimulation of non-corresponding or disparate retinal elements by an object point causes this point to be localized in two different subjective visual directions. An object point seen simultaneously in two directions appears double. Double vision is the hallmark of retinal disparity.

RETINAL RIVALRY / BINOCULAR RIVALRY

When dissimilar contours are presented to corresponding retinal areas fusion becomes impossible and retinal rivalry may be observed. Simultaneous excitation of corresponding retinal areas by dissimilar objects does not permit fusion and leads to confusion. In order to remove this confusion, image from one of the eyes is suppressed. This constant foveal suppression of one eye with cessation of rivalry leads to complete sensory dominance of the other eye, which is a major obstacle to binocular vision. Return of retinal rivalry is a requisite for re-establishment of binocular vision.

SUPPRESSION

It is a neuro-physiological active inhibitory mechanism in which when corresponding retinal areas are stimulated by dissimilar stimuli or when non-corresponding retinal areas are stimulated by similar stimuli, one or the other is temporarily inhibited or suppressed to prevent confusion or diplopia respectively. Suppression is foveal in order to tackle confusion and extrafoveal in order to avoid diplopia.

Suppression can be of two types:

- ❖ **Facultative**- Facultative suppression is only under binocular conditions with no persisting “hang over” under monocular conditions. Thus the visual acuity is not reduced under monocular conditions and there are no unocular scotomas in the visual field.
- ❖ **Obligatory**- Obligatory suppression is the effect which carries on even under monocular conditions resulting in diminution of visual acuity. Amblyopia is the fallout of this obligatory suppression.

STEREOPSIS (DISPARITY SENSITIVITY)

It is the ability to fuse images that stimulate horizontally disparate retinal elements within Panum's fusional area resulting in binocular appreciation of visual object in depth i.e. in the third dimension. The eyes are separated in the horizontal plane of the head and thus each eye has a slightly horizontally disparate view of the world. The sensory fusion of these horizontally disparate unequal retinal images results in a three dimensional percept. An object confined to the horopter is seen as flat because it projects to corresponding retinal regions, causing zero horizontal disparity.

Non-zero disparities giving rise to stereoscopic depth are divided into crossed and uncrossed.

Crossed disparities are created by objects in front of the horopter (near objects). The disparity is termed "crossed" because the monocular image of the object when viewed by the right eye is displaced to the left, whereas that viewed by the left eye is displaced to the right.

Uncrossed disparities are created by objects located behind the horopter (far objects). In this case the monocular image of the objects viewed by the right eye is displaced to the right and that viewed by the left eye is displaced to the left.

Stereoscopic acuity

It is the smallest binocular disparity that can be readily detected i.e. it is the minimum disparity beyond which no stereoscopic effect is produced. There are no standardized clinical stereoscopic acuity tests, but generally speaking, a threshold of 15 –30 arc sec. can be regarded as excellent. Since there is a stereoscopic threshold, it follows that stereopsis cannot work beyond a certain critical distance. This distance has been computed to be between 125-200 meters. The stereoscopic acuity also varies depending on whether the target is stationary or moving, and whether the eyes are stationary or moving. The stereoacuity threshold for static targets is in the range of 2-10 arc sec. For targets in motion towards and away from the observer the threshold increases to about 40 arc sec. Stereoacuity is maximal about 0.25 degrees off dead center in the foveola, and diminishes exponentially with increasing eccentricity along the x-axis. Stereopsis is nil beyond 15 degrees eccentricity. Stereoacuity diminishes in similar exponential fashion when the target is moved in front or behind the horopter along the y-axis.

Though stereopsis is essential for depth perception it is not the only mean for spatial orientation. The various monocular clues to spatial orientation can be:

Apparent size – Small retinal objects are interpreted as distant objects and large retinal objects as near objects. Objects progressively increase in size as they move towards us (looming).

Interposition – relatively nearer objects tend to conceal or overlay more distant objects.

Aerial perspective – water vapor, dust and smoke in the atmosphere scatter light and make distant objects indistinct and relatively color desaturated.

Shading – light falling on solid objects causes shadows to be cast, and on curved surfaces causes a gradation in the intensity of shadow.

Geometric perspective – physically parallel lines converge toward a vanishing point at the horizon, e.g. railroad tracks.

Relative velocity – the image velocity of a moving target in the distance is lower than the image velocity of the same moving target when it is nearby.

Motion parallax – translocation of the head cause the images of near objects to move opposite the head and the images of far objects to move with the head, assuming the fixation point is at an intermediate distance.

DEVELOPMENT OF BINOCULAR VISION

During the first few years of life certain normal anatomical and physiological conditions are required for the development of binocular vision. The factors concerned in the development of Binocular vision and which enable the eyes to function in a coordinated manner are:

A) **Anatomical factors:** The two eyes are so situated in the orbit that the visual axis is directed in the same direction. This is due to

- ❖ Shape of the orbit
 - ❖ Presence of adjacent ligaments, muscles and connective tissues.
- The extra-ocular muscles have an important role to play as they provide motor correspondence because of the reciprocal innervation of the extra-ocular muscles.

The aim of the motor correspondence is to-

- ❖ Enlarge the field of view by transforming the field of vision into the field of fixation.
- ❖ Bring back the object of attention on to the fovea and to maintain it.
- ❖ Position the two eyes in such a way that at all the times they are properly aligned.

B) **Physiological factors:** The development of binocular vision (BV) depends upon certain normal physiological binocular reflexes. The reflexes can either be inborn or acquired as a result of appropriate stimulation. The various binocular reflexes are:

1. Fixation reflexes

- ❖ *Compensatory fixation reflex* (Gravitational reflex) - The function of this reflex is to keep the eyes in a fixed position i.e. looking in the required direction compensating for the movement of the body, head, limbs etc. In man it is due to the frontal direction of the eyes and the utricles and saccules presiding over the tone of the vertical recti and obliques, respectively.
- ❖ *Orientation fixation reflex* -It can be demonstrated by the eye following a moving object or panorama, thus exhibiting a comparatively slow movement of continued fixation and not a rapid jerk fixation. This reflex relates to horizontal axis.
- ❖ *Accommodation convergence reflex*- It is aimed at correctly aligning the eyes and keeping them focused on the object. It includes vergence fixation reflex, accommodation reflex and fusional vergence reflex.

2. The refixation reflex –It relates the eye back to the original orientation point or to the new orientation point.

3. The pupillary reflex

Fusion Reflex and its Development: Fusional reflexes are conditioned reflexes, acquired and maintained by cerebral activity. They are developed by the individual on the basis of experience. Once formed, with continued reinforcement it becomes an unconditioned reflex. Also known as psychoptical reflexes, it consists of all the activities mediated from the retina through the brain to maintain the images received on the two foveas with the ultimate aim of attaining a single binocular vision.

The elements of fusion mechanism are:

- ❖ Fixation reflex
- ❖ Refixation reflex
- ❖ Conjugate fusional reflexes – maintains the parallelism of the two eyes in all positions of gaze.
- ❖ Disjunctive reflexes convergence/divergence reflexes.

At birth the fixation reflex is poorly developed, with the child having only random, non-conjugate and aimless ocular movements. There is inability to carry out pursuit movements during the first few weeks of life. The development of optomotor reflex is essentially a post natal event, with the approximate time schedule being :

- ❖ 2- 3 weeks –follows light unocularly
- ❖ 6 weeks to 6 months - follows light binocularly
- ❖ Convergence which is absent at birth starts developing at 1 month of age and is well established by 6 months.
- ❖ The development of accommodation lags behind the development of convergence due to the delay in the development of ciliary muscles, parallels with the convergence by 6 months of age.

Electrophysiological studies have shown that infants can detect retinal disparities between 2-5 months of age but little is known about the development of stereoacuity between the ages of 6 months to 3 years, when the child may sufficiently be able to comprehend subjective tests. However, it is generally agreed that there is a gradual improvement in stereoacuity up to the age of 9 years.

Thus it can be said that in human beings the sensitive period of development of binocular vision begins at about 4 months of age, peaks at 2 years, is well developed by 4 years of age and slowly declines to cease by 9 years of age. These estimates assume that a single sensitive period during which the binocular function appears to be at a risk is during the first 2 years of life. Any obstacle in the reflex pathway is likely to hamper the development of binocular vision.

The obstacles can be in the form of

1. Sensory obstacles

- ❖ Dioptric obstacles – e.g. media opacities, uncorrected errors of refraction.
- ❖ Prolonged unocular activity- e.g. severe ptosis, anisometropia
- ❖ Retinoneural obstacles – lesions of retina, optic nerve
- ❖ Proprioceptive obstacle

2. Motor obstacles

- ❖ Congenital craniofacial malformations

- ❖ Conditions effecting extra-ocular muscles
- ❖ CNS lesions- involving the nerve trunks, root of nuclei

3. Central obstacles

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

1. ARC
2. SUPPRESSION
3. AMBLYOPIA

Theories of Binocular Vision

1. *Correspondence and disparity theory*: According to this theory sensory binocular cooperation is based on system of correspondence and disparity. It assumes the presence of one to one retinocortical relationship between the two eyes. When stimulated simultaneously by one object point they transmit single visual impression with no depth quality. When stimulated simultaneously by two object points that differ in character – binocular rivalry occurs. When disparate elements are stimulated by one object point diplopia occurs. However if horizontal disparity remains within limits of Panum's area, a single visual impression is elicited with depth or stereopsis. The perceived depth increases with increasing disparity. However with increasing disparity quality of stereopsis decreases which may eventually lead to diplopia.
2. *Neurophysiological theory of binocular vision and stereopsis*: Animal experiments of Hubel and Wiesel showed that roughly 80% of the neurons in the striate cortex can be driven from either eye in response to a visual stimulus from the retina, assuming that there exists a precise and orderly arrangement of connections along the entire retino-geniculate striate pathway. 25% of these binocularly driven cells were stimulated equally from each eye, while 75% represented graded response from either left or right eye. 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 if it is presented to its two receptive fields simultaneously. Although two receptive fields are involved, only one object feature is detected by each cortical cell and assigned by it to a single locus in space. The two receptive fields do not always occupy anatomically identical regions in the two retinas. At a given locus in the retino-optic cortical map 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. This retinal field disparity which is caused by the difference in direction or distance of the fields in each retina forms the basis of Panum's fusion area and is detected by sensitive binocular neurons giving rise to binocular vision and stereopsis.

GRADES OF BINOCULAR VISION:

There are three grades of binocular vision as given by Worth's classification:

Grade I: Simultaneous macular perception is the most elementary type of binocularity. It occurs when the visual cortex perceives separate stimuli to the two eyes at the same time and concerns itself essentially with the absence of suppression. SMP is not the same as superimposition, whereby the two different pictures are seen simultaneously in the same direction. SMP in the true sense just represents simple sensory fusion.

Grade II: It represents true fusion with some amplitude. Not only are the two images fused, but some effort is made to maintain this fusion in spite of difficulties. Thus the second grade implies a motor response added to simple sensory fusion.

Grade III: In the highest type of binocularity, not only are the images of the two eyes fused, but they are blended to produce a stereoscopic effect. This involves a perceptual synthesis at a higher level.

These three grades are not necessarily mutually exclusive, since fusion in the periphery, even showing motor responses, may exist coincidentally with the total absence of simultaneous foveal perception.

INVESTIGATIONS FOR BINOCULAR VISION

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

- ❖ Normal or abnormal retinal correspondence
- ❖ Suppression
- ❖ Simultaneous perception
- ❖ Fusion with some amplitude
- ❖ Stereopsis

Before any test is undertaken it is essential to assess the:

- ❖ visual acuity
- ❖ fixation in the squinting eye
- ❖ direction and size of deviation

TEST FOR RETINAL CORRESPONDENCE

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. This includes:
 - ❖ Bagolini's striated glasses test
 - ❖ red filter test
 - ❖ Synaptophore using SMP slides for measuring the objective and subjective angles
 - ❖ Worth's 4 dot test
- B) Assessment of the visual directions of the two foveas. Included in this are:
 - ❖ After image test (Hering Bielschowsky)
 - ❖ Cuppers binocular visuoscopy test (foveo-foveal test of Cuppers)

Bagolini's Striated Glasses Test: For this the patient fixates a small light, after being provided with plano lenses with narrow fine striations across one meridian (micro Maddox cylinders). These glasses do not affect the vision or the accommodation of the patient. The fixation light is seen as an elongated streak. The lenses are usually placed at 45 degree OS and 135 degree OD (cover the patients glasses, if he wears any) and the patient fixates for distance or near. The interpretation of this test is as follows-

- ❖ Crossing of the lines at right angles to each other
 - If cover test reveals no shift and fixation is central, the patient has NRC
 - If cover test reveals a shift, harmonious ARC is present
- ❖ Foveal suppression scotoma (fixation point scotoma) with peripheral fusion, if no shift occurs with cover test, NRC exists, if shift occurs, ARC exists
- ❖ Single line represents suppression

Red Filter Test: If one examines the visual field of a patient with heterophoria by placing a red filter in front of the habitually fixating eye while the patient is looking at a small light source, number of different responses can be elicited.

- ❖ The patient may report that two lights are seen, a red one and a white one. In esotropia the images appear in homonymous (uncrossed) diplopia, with the red light to the right of the white one when the red filter is in front of the right eye. In exotropia the images appear in heteronymous (crossed) diplopia, with the red light to the left of the white light when the red filter is in front of the right eye. This represents NRC.
- ❖ The patient may report that only one pinkish light in the position of the white fixation light is seen i.e. the red and white images appear to be superimposed. This is clearly an abnormal response in presence of heterophoria. This is termed Harmonious ARC.
- ❖ The patient may report that two lights in uncrossed or crossed diplopia are seen, depending upon the direction of deviation but the measured distance between the double images proves to be smaller than expected from the magnitude of deviation. This represents unharmonious ARC.
- ❖ Suppression is said to occur when the patient reports only a single light (usually the white light) but occasionally red depending upon the density of the red filter and the degree of the dominance of the fellow eye.

Measurement of Angle of Anomaly: The angle of anomaly denotes the degree of shift in visual direction. It is determined by calculating the difference between the objective and subjective angles of deviation.

Procedure of estimating the angle of anomaly -

For this the use of SMP slides is made. The arms of the synaptophore are set at zero. Both the arms of the instrument are moved by the examiner while alternately flashing the light behind each slide until there is no further fixation movement of the patient's eye (alternate cover test). The reading of both the arms is noted at this moment and the sum total of the reading of both the arms gives the objective angle of anomaly. The subjective angle of anomaly is the angle at which the visual targets are superimposed.

The interpretation of this test is as follows-

- ❖ Angle of Anomaly = Objective Angle – Subjective Angle
- ❖ If Subjective Angle = Objective Angle → NRC
- ❖ If Subjective Angle < Objective Angle → ARC
- ❖ If Angle of Anomaly = Objective Angle → Harmonious ARC (full sensory adaptation)
- ❖ If Angle of Anomaly < Objective Angle → Unharmonious ARC

Worth Four Dot Test: This is a simple test utilizing red-green color dissociation. It is more dissociating than the bagolini glasses and so less physiological. The apparatus for this test consists of a box containing four panes of glass, arranged in diamond formation, which are illuminated internally. The two internal panes are green, the upper one is red and lower one is white. The patient wears red and green goggles (as a convention red in front of right and green in front of left). The test can be performed separately for distance and near vision. The interpretation of this test is as follows-

- A) The patient sees all the four dots.
 - normal binocular response with no manifest deviation (NRC with no heterotropia)
 - Harmonious ARC with manifest squint.
- B) The patient sees five dots.
 - uncrossed diplopia with esotropia, red dots appear to the right
 - crossed diplopia with exotropia, red dots appear to the left of the green dots.
- C) The patient sees three green dots, suppression of right eye.
- D) The patient sees two red dots, suppression of left eye.

Hering Bielschowsky After-Image Test: This is a highly dissociating orthoptic test in which battery- powered camera flash is used to produce a vertical after image in one eye and a horizontal after image in the other eye. The center of flash is covered with a black mark (serves as a point of fixation and protects the fovea). Once an afterimage is created in each eye, the position of the images in relation to each other no longer depends on whether the eyes are open, closed, straight or crossed. The interpretation of this test depends on the fixation behaviour.

Procedure -

Each eye fixates on the center black mark of a glowing filament, first presented horizontally to the eye with a better visual acuity and then vertically to the poorer eye for 20 sec in a darkened room while the fellow eye is occluded. The patient indicates the relative position of the two gaps in the center of each afterimage.

The gaps correspond to the visual direction of each fovea if central fixation is present.

Interpretation of results -

- **Cross response:** A symmetrical cross with the central gaps superimposed indicates a normal bifoveal correspondence (if eccentric fixation is excluded). This is irrespective of any deviation between the two eyes, i.e. any eso or exo-deviation with NRC still gives a symmetrical cross response.
- **Asymmetrical crossing:** In case of ARC the horizontal and vertical lines have their center separated, the amount of separation dependent on the angle of anomaly. A patient with right esotropia sees the vertical afterimage displaced to the left and a case of right exotropia sees the vertical afterimage displaced to the right.
- **Single line with a gap:** A single line with a gap indicates suppression in the fellow eye.

Foveo-Foveal Test of Cuppers: Cuppers test for retinal correspondence determines whether the two foveas have common or different visual directions. It permits quantitative analysis of the angle of anomaly when eccentric fixation is present.

Procedure -

The patient fixates with the normal eye on the central light of a Maddox scale via a plano mirror, which for the convenience of the examiner is turned in such a manner that the amblyopic eye looks straight ahead. The visuoscope asterisk is projected by the examiner onto the fovea of the amblyopic eye. The figure of the Maddox scale on which the patient sees the asterisk indicated the angle of anomaly.

Modification -

To determine which parts of the peripheral retina in the deviating eye have acquired a common visual direction with the fovea of the fixating eye, the patient is asked to guide the Visuoscope until he sees the asterisk superimposed on the central light of the Maddox cross. The examiner views the fundus when this task is completed and notes the position of the asterisk, which indicates the location of retinal elements having a common visual direction with the fovea of the sound eye.

SUPPRESSION

Suppression is the active cortical inhibition of the unwanted stimuli, to avoid binocular diplopia and confusion. While the former is overcome by peripheral suppression, the latter is overcome by central/foveal suppression. Tests used to diagnose the suppression are:

1. Worth's four dot test
2. Synaptophore
3. Friend test
4. Amsler Grid
5. 4 Δ prism base out test
6. Red filter test
7. Bagolini's striated glasses

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:

- Prisms to displace the central object peripherally till it can be visualized in different directions.
- Synaptophore: charting of one eye, while the other eye is used for fixation
- Lee's screen or Hess screen
- Polaroid Scotometer
- Phase difference haploscopy of Aulhorn

The various responses that can be observed are:

- With more dissociating tests like prisms, Lee's etc. single large coarse scotomas are seen; these extend from fovea to the diplopia point.
- With less dissociating tests like Aulhorn phase difference haploscope and Polaroid scotometer, two discrete scotoma are seen. These are foveal scotoma about 2-3 degrees in size and diplopia point scotoma.

Depth of Scotoma - The depth or intensity of scotoma can be seen by using differential stimulation of the two eyes. The graded density filter bar of Bagilini is useful. As the denser filters are brought over the dominant eye, the relative scotoma of the amblyopic eye start disappearing or shrinking in size.

4 Δ prism base out test - Image displacement with a weak base out prism, while one observes the resulting binocular (version) and monocular (fusional) eye movements, is a quick, sensitive screening test to assess whether bifoveal fusion or suppression of one fovea is present. Sudden displacement of an image with a base out prism from one fovea onto the parafoveal temporal retina will elicit a refixation movement if the image has been shifted within a normally functioning retina, but no movement will occur if the image has been shifted within a nonfunctioning (that is, scotomatous) area. According to Hering's law the movement of the fellow eye will be biphasic, that is, it will move outward simultaneously and symmetrically (version) when the eye under the prism refixates and then will perform a slow fusional movement (duction) in the opposite direction to correct for the image displacement. However if a central scotoma has impaired foveal function, the second phase (the fusional movement) does not occur, and the eye remains slightly turned out.

SIMULTANEOUS MACULAR PERCEPTION

This is the most elementary type of binocularity and is tested with the help of SMP slides on the synaptophore, which depicts objects which are dissimilar, but mutually agnostic (e.g. presenting a picture of a square to one eye and a circle to other). The commonly used slides are bird and cage, lion and cage, butterfly and net.

If superimposition occurs, it is necessary to make a more accurate assessment by using target slides of different sizes.

- Simultaneous foveal perception slide – subtend an angle of 1 degree at the nodal point
- Simultaneous parafoveal perception slides – subtend angle of 1-3 degree
- Simultaneous paramacular perception slides – subtend angle of 3-5 degree
- Simultaneous peripheral perception slides – subtend angle greater than 5 degrees

The term simultaneous perception does not necessarily mean bifoveal fixation as it can also occur in ARC. It merely indicates the presence or absence of suppression. This term is erroneous as it embraces both foveal and parafoveal perception in the same definition.

Tests for Fusion: Fusion is demonstrated by using slides in which similar pictures with different controls are presented to the eyes simultaneously e.g. letter L and F fused into E, rabbit with a tail and rabbit with flower in hand, fused into one rabbit having tail and flower.

Normal fusion amplitudes are:

A) Horizontal vergences:

- Convergence → 35 Δ to 40 Δ
- Divergence → 5 Δ to 7 Δ

B) Vertical vergence:

- Supravergence → 3 Δ
- Infravergence → 3 Δ

C) Cyclovergence → 2-3 Δ

Fusion assessment is essential both for the prognosis and management of strabismus. Fusion is essential for the restoration of BSV. Various tests used to find out the presence of fusion are:

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

Tests for Stereopsis: Tests on stereopsis can be based on two principles-

- Using targets which lie in two planes, but are so constructed that they stimulate disparate retinal elements and give a three dimensional effect, for example:
 - Circular perspective diagram such as the concentric rings
 - Titmus fly test, TNO test, Random dot stereograms, Polaroid test
 - Langs stereo test
 - Stereoscopic targets presented haploscopically in major amblyoscope
- Using 3 dimensional targets (e.g. Lang's two pencil test).

Stereopsis tests may be qualitative or quantitative. Stereopsis is measured in seconds of arc.

- **Qualitative tests for Stereopsis:**

- Lang's 2 pencil test
- Synaptophore

- **Quantitative tests for Stereopsis:**

- Random dot test
- TNO Test
- Lang's stereo test

Methods using Polarization: Targets are provided as vectographs and images seen by one eye is polarized at 90 degree using polarized glasses.

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

Stereograms: Stereogram with three concentric circles and a check dot for each eye is to be seen with both eyes together. Stereograms with three eccentric circles are to be seen with each eye separately. If the patient reports seeing concentric circles, it means stereopsis is present. If they are seen eccentrically one may ask whether the inner circles are closer to the right or left of the outer circle. It determines whether the disparate elements are suppressed in the right or the left eye.

Vectographs: Consists of Polaroid material on which the two targets are imprinted so that each target is polarized at 90 degrees with respect to the other. Patient is provided with Polaroid spectacles so that each target is seen separately with the two eyes.

Titmus stereo test – A gross stereoscopic pattern representing a housefly is provided to orient the patient and check for gross stereopsis (threshold 3000 sec of arc). Can be used in young children. Disadvantage of this test is that it can test only near stereopsis.

Polaroid test – Two common types:

- ❖ Contain three rows of animals, one animal in each row imaged disparately (threshold 100, 200 and 400 sec. of arc respectively). The child is asked which one of the animals stands out. The animal figures contain a misleading clue. In each row one of the animals correspondingly imaged in two eyes is printed heavily black. A child without stereopsis will name this animal as the one that stands out.
- ❖ Contains nine sets of four circles arranged in the form of a diamond. In this sequence the upper, lower, left or right are disparately imaged at random with thresholds ranging from 800 to 40 sec of arc. The child is now asked to push down the circle that stands out, beginning with the first set. A child with limited stereopsis will make mistakes or find no circle to push down.

E- Random Dot Test - This test consists of two cards, one with a 'E' stereo figure and the other stereoblank. A model of the figure is shown to the child before the test. The child is provided with Polaroid glasses and seated at 50 cms from the cards is required to point out the card which contains the "E".

Random Dot Stereogram of Julesz - Random dot stereogram, when viewed monocularly, convey no visual information and is seen as scattered random dots. When viewed binocularly, a square pattern appears in vivid depth above or below the level of

the page. This test exposes the child to visual demands that are more difficult than those that occur under more casual conditions of seeing.

References

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3. Duane's Clinical Ophthalmology. New York: Lippincott Williams & Wilkins, 2005.

<http://webeye.ophth.uiowa.edu/eyeforum/tutorials/Bhola-BinocularVision.htm>