BrienHoldenVisionInstitute

HERING'S LAWS; CROSSED & UNCROSSED DISPARITY

AUTHOR

Thomas Salmon: Northeastern State University, USA

PEER REVIEWER

Scott Steinman: Southern California College of Optometry, USA

INTRODUCTION

Nearly 100 years after Wells, Hering developed his well-known laws of visual direction, which help us understand the apparent location of objects in normal binocular vision.

HERING'S LAWS OF VISUAL DIRECTION

The fundamental concept in Hering's laws is that of a **visual line.** It is defined as a line passing from an object in the visual field of one eye, through the nodal point, (Steinman says entrance pupil) to the retina. Visual lines may be used for objects located anywhere in the visual field, including the fixation point as well as peripheral objects. The *visual axis* is the **primary visual line,** since it passes from the fixated object to the fovea (Figure 16.1). Other visual lines point to objects located off the visual axis, and these are associated with points on the retina other than the fovea.

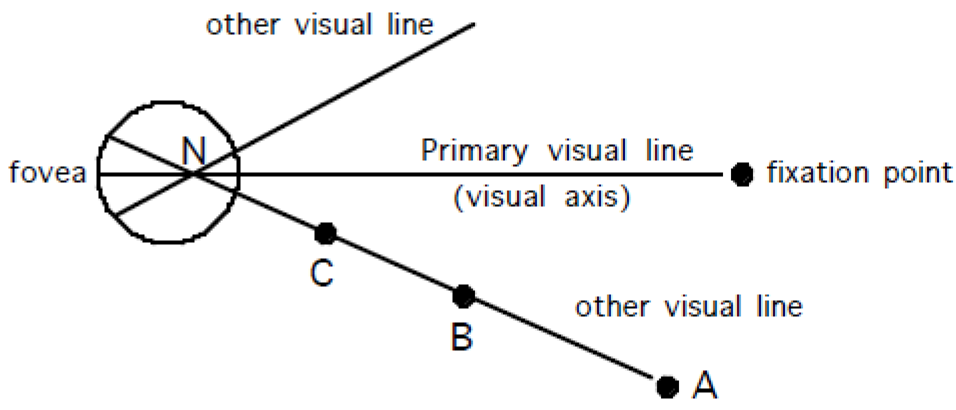

Figure 16.1 *Hering's terminology for one eye*

The following is a brief summary of Hering's laws of visual direction:

1. LAWS OF OCULOCENTRIC VISUAL DIRECTION	▪ All objects that lie on a particular visual line in object space, form images on the same retinal point and therefore have the same visual direction (points A, B, C in Figure 16.1). ▪ Each visual line and its retinal point have a unique oculocentric visual direction associated with it. ▪ Images that fall on different retinal locations are perceived to have different directions. Each retinal neuron is associated with it a particular visual direction. Whether a neuron is stimulated by an image, extraneous light, or something else, it always elicits the same sense of direction. The direction associated with a particular neuron is known as its local sign. (See Steinman, Foundations of Binocular Vision, p.10) Other higher-order neurons (LGN, visual cortex) also have **local signs** associated with them.
2. LAWS OF EGOCENTRIC (CYCLOPEAN) VISUAL DIRECTION	▪ The positions of all objects in space are judged as if seen by the cyclopean eye. ▪ An object on the primary visual line of either eye will appear to be on the primary visual line of the cyclopean eye. ▪ If a peripheral object and its visual line make some angle with the primary visual line in one eye, it will appear to make the same angle with a corresponding visual line relative to the cyclopean eye primary visual line. These laws help you understand how oculocentric visual direction contributes to egocentric direction, using the concept of a cyclopean eye.

3. LAWS OF IDENTICAL VISUAL DIRECTIONS OR BINOCULAR VISUAL DIRECTION

- Every visual line in the visual field of one eye has a corresponding visual line in the other eye, and the corresponding visual lines have identical perceived visual directions.
- The visual direction of fused images that fall on slightly disparate retinal points is the average of the two visual directions. This allows the eyes to maintain binocular fusion, even if the two eyes are not fixating absolutely perfectly.

Binocular fusion refers to the phenomenon in which an image seen by the two eyes is "fused" into one image. If there is a conflict in the visual direction of two images, the binocularly perceived direction is that of the dominant image. Widely disparate images (significantly non-corresponding visual lines) are seen in two different visual directions (diplopia). That is, they cannot be fused. Hering described a classic binocular vision experiment in his book, Spatial sense and movement of the eye (1879). See the English translation by Hurvich and Jameson (1942. p. 38) Harvard University Press, Cambridge, MA.

Let the observer stand about half a metre from a window which affords a view of outdoors, hold his head very steady, close the right eye, and direct the left to an object located somewhat to the right. Let us suppose it is a tree, which is well set off from its surroundings. While fixing the tree with the left eye, a black mark is made on the window pane at a spot in line with the tree. Now the left eye is closed and the right opened and directed at the spot on the window, and beyond that to some object in line with it, for example, a chimney. Then with both eyes open and directed at this spot, this latter will appear to cover parts of the tree and chimney. Both will be seen simultaneously, now the tree more distinctly, now the chimney, and sometimes both equally well, according to which eye's image is victor in the conflict. One sees therefore, the spot on the pane, the tree and the chimney in the same direction. (From Howard & Rogers, p. 594)

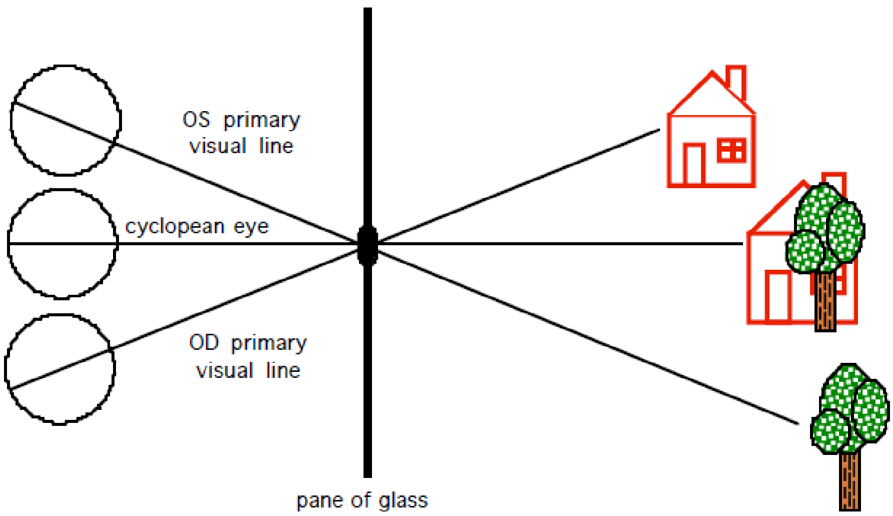

Figure 16.2 *Illustration of Hering's famous experiment.*
(See Steinman, Foundations of Binocular Vision Fig. 2-9.)

Herings laws help us transfer visual information to the cyclopean eye, so see what the person should see in normal binocular vision.

To summarize, the brain uses oculocentric directional data from each eye, and creates a new egocentric sense of direction that may be different from either oculocentric direction. Normally the binocular perception of direction is egocentric; that is, visual directions are all relative to a point in our head referred to as the egocenter. Our brain computes the visual direction of objects based on:

1. Oculocentric (retinal) direction in each eye, and
2. The directional orientation of each eye.

CROSSED AND UNCROSSED DIPLOPIA

Figure 16.3 illustrates how we perceive the position of objects that are actually located at some point other than the fixation point. It shows both eyes fixating on an object on the midline, with another object to the right.

Based on Hering's principles of visual direction, a visual line from the peripheral object may be drawn to the left and right eyes. The left eye visual line makes an angle (α) with the primary visual line. The right eye visual line also makes an angle (also α) with respect to its primary visual line. Both of these visual lines are transferred to the cyclopean eye. The cyclopean eye visual axis is straight ahead.

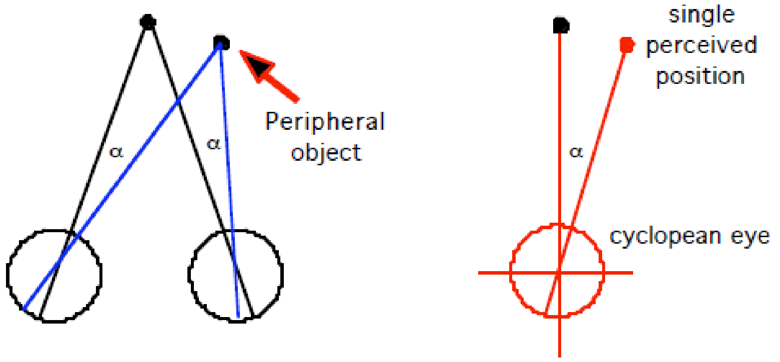

Figure 16.3 *How we perceive the position of objects that are actually located at some point other than the fixation point. It shows both eyes fixating on an object on the midline, with another object to the right*

The visual line to the peripheral object for the left eye is inclined at an angle of α, to the right in the cyclopean eye. The visual line from the right eye is also inclined at an angle alpha to the right. The two visual lines superimpose, and the cyclopean perception is of one peripheral object located at an angle α to the right

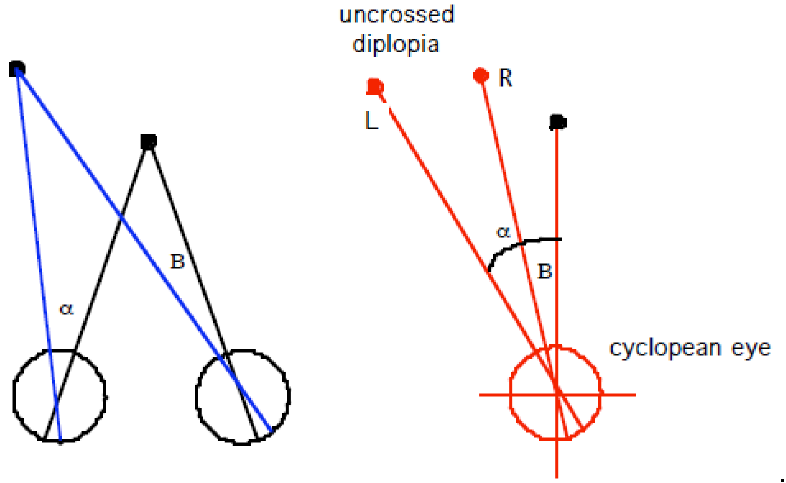

Figure16.4 *Both eyes fixate straight ahead, but also see an object that is beyond and to the left of the fixation point*

In Figure 16.4, both eyes fixate straight ahead, but also see an object that is beyond and to the left of the fixation point. The angles for the two oculocentric visual lines are α and B. As the two visual lines are transferred to the cyclopean eye and since the angles are different, the object is seen in two different visual directions at the same time. The person perceives diplopia. Since the diplopic image to the left is the one seen by the left eye and the diplopic image seen to the right is seen by the right eye, this is known as **uncrossed diplopia.**

*** Objects located beyond the fixation point are seen in uncrossed diplopia.**

In Figure 16.5, both eyes fixate straight ahead, but see another object located nearer than the fixation point. The angles for the two oculocentric visual lines are α and B. They are equal in magnitude, but in opposite directions (one to the right, one to the left). The visual lines, each with a different angle, have a different visual direction. These are transferred to the cyclopean eye, and the near object is seen in two different visual directions (diplopic). The image to the left is seen by the right eye, while the image to the right is seen by the left eye. This is known as **crossed diplopia.**

*** Objects nearer than the fixation point are seen in crossed diplopia.**

Crossed and uncrossed diplopia are normal consequences of how the visual systems combines input from the two eyes, therefore they are examples of **physiological** diplopia.

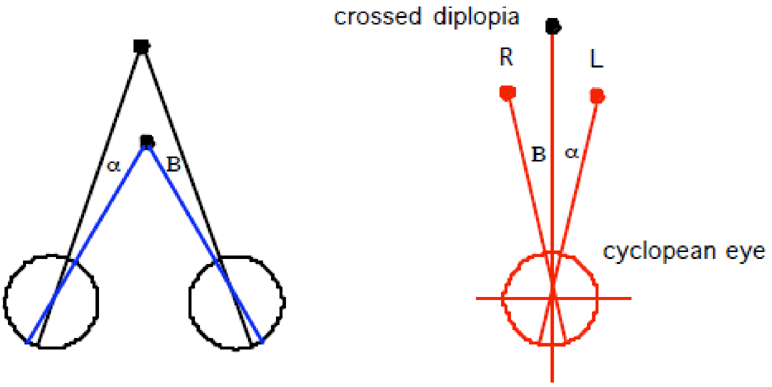

Figure 16.5 *Both eyes fixate straight ahead, but see another object located nearer than the fixation point*

From these analysis, based on Hering's laws and the cyclopean eye concept, we may conclude that an object will appear to be single in binocular vision if the angle of the visual line in each eye is the same and in the same direction (Figure 16.3). This is true for objects on the primary visual lines (visual axes) or for peripheral objects on other visual lines.

When the visual lines in the two eyes are not equal, we expect the person to perceive diplopia when viewing binocularly. This is consistent with Well's observation that, an image will appear single if it lies on the intersection of the two visual axes, but it may be double when it is not in the intersection.

COMBINING INPUT WITH OFF-AXIS FIXATION

The same principles apply when the eyes are fixating an object to the right or left, but in addition to the oculocentric (local sign) information, the visual system will also take into account the direction that the eyes are pointing. Recall that when the brain computes the binocular direction of an object, it uses two sets of data from the two eyes:

- Oculocentric or retinocentric visual direction **(local sign)**
- Proprioceptive and neural data that indicates the direction that the eyes are pointing. The direction of the cyclopean eye is the average of the directions of the two eyes. This is summarized in Figure 16.6, below.

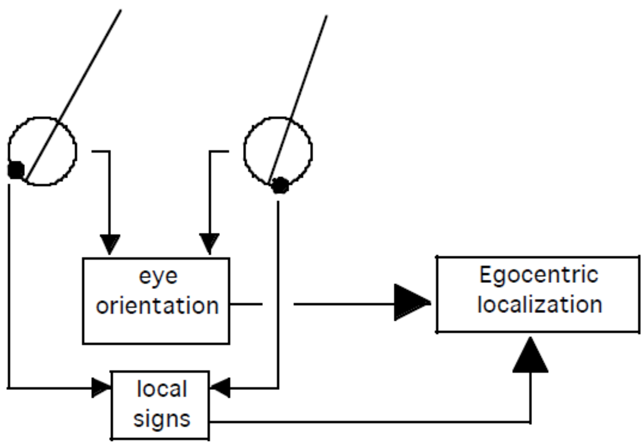

Figure 16.6 *The direction of the cyclopean eye is the average of the directions of the two eyes*

These principles, as well as Hering's laws and the concept of a cyclopean eye, may be illustrated by several clinical examples.

CLINICAL APPLICATIONS

a) COVER TEST AND PHI MOVEMENT

This knowledge helps us understand why, during the alternating cover test, the exophoric patient sees "with" motion and the esophoric patient sees "against" motion.

Figure 16.7 shows the example of an exophoric person fixating on a near object. Since the right eye is covered, it deviates to its position of rest, which is in the exo direction. The left eye is foveally fixating the object.

Q. What position data will the brain receive from the two eyes in formulating the location (direction) of the object?

1) Local sign information from the left eye says the object is on-axis. Its oculocentric visual direction is straight ahead. There is no local sign data available from the right eye since it is covered.

2) Proprioceptive information says that the left eye is pointing to the right, for example 7 prism diopters, while the right eye is pointing to the left at a smaller angle, perhaps 4 prism diopters (exo posture). The net sum of both directions causes the cyclopean visual axis to tilt slightly to the right.

   Combining the information from 1) and 2) above, the cyclopean projection and perceived binocular direction of the object is slightly to the right of its true position.

When the cover is shifted to the left eye (Figure 3.7 bottom), the right eye takes up fixation, while the left eye moves outward to its exophoric position. Local sign input from the right eye indicates that the object is on axis, while the mean orientation of the two visual axes is slightly to the left. Combining this information, the binocular perception is that the cyclopean axis is oriented slightly to the left, and the object is on axis. Therefore, the object appears to be slightly to the left of the center.

Note that **the object appears to move in the same direction that the eye moves.** When the exophoric eye is uncovered and takes up fixation it moves inward, which is the same direction that the occluder moves. Therefore the patient says the fixation object appears to move "with" the cover paddle.

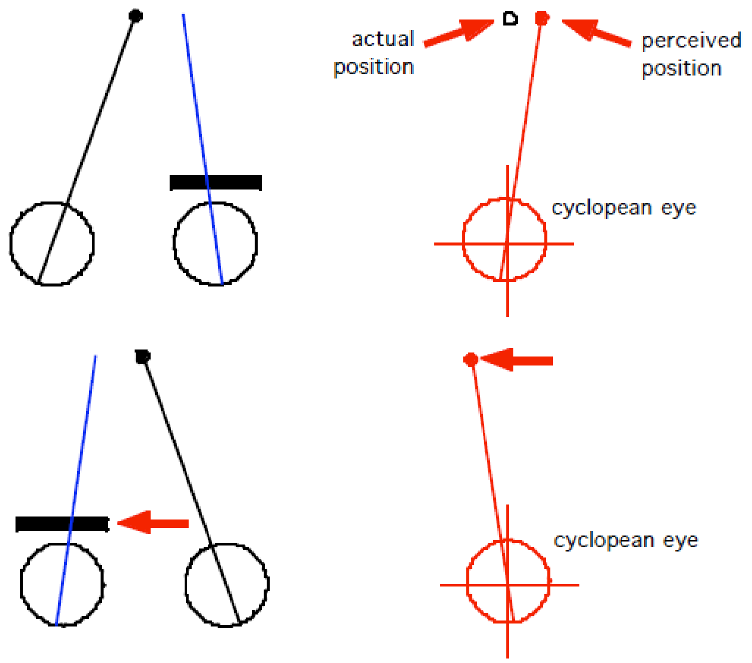

Figure 16.7 *When the cover is shifted to the left eye, the right eye takes up fixation, while the left eye moves outward to its exophoric position*

In the case of an esophoric patient, the covered eye will turn inward. When it is uncovered, that eye will swing outward, which is opposite to the direction of the cover paddle. The patient will therefore say that the object appears to move “against” the cover paddle.

As an exercise, you should use the same logic illustrated in Figure 3.7 with a case of an esophoric patient to understand why he/she will see an “against” motion. These illustrate the well-established fact that the sense of binocular direction depends, not only on the retinal local sign from each eye, but also on the directions that the eyes are pointing. Interestingly, this is also true under monocular viewing conditions, which is what the alternating cover test is, since the object is seen by only one eye.

b) FUSION VERGENCE TESTING (BASE IN/OUT TO BLUR, BREAK, RECOVER)

The same principles can be used to explain why, during fusional vergence testing (base in or base out to blur/break/recover), the object appears centered when the person is fusing with both eyes, but, as soon as the person begins suppressing, the object will appear to move in the direction of the prism apex as you continue increasing power. For example, if equal amounts of BO prism are increased before each eye, the object will appear to shift nasally for each eye and both eyes will rotate nasally to maintain foveal fixation. The local sign information from both eyes says, "foveal fixation." Since both eyes will be converging equally, but in opposite directions, the net direction assigned to the cyclopean eye is straight ahead. The object therefore appears to remain on the midline.

Suppose the right eye begins to suppress, and it gives up fusion. At that moment, local sign and ocular orientation information from the right eye is lost. The left eye will still have foveal fixation, and it will be rotating nasally (to the right). This rightward orientation, by the left eye, is not balanced by the leftward orientation (convergence) of the right eye. In fact, once fusion is broken, both eyes will begin rotating to the right. The visual direction data from the two eyes moving to the right will make the object appear to move to the right. It will continue to move to the right as BO prism power is increased.

Remember then, if you are doing the blur/break/recovery test, and the patient never sees double, ask him/her if and when the target begins to move. When he/she notices movement, you will know that he/she is beginning to suppress one eye, and that is the limit of binocular fusion (See Steinman p. 145).

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