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VISUAL DIRECTION

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WHY STUDY VISUAL DIRECTION?

Most of us take normal binocular vision for granted, so it is hard to appreciate the complexity involved in achieving binocular vision, for example, getting single vision from two eyes. Each of our eyes sees a separate image, and the two images are slightly different from each other due to the different positions of each eye. Hence, the brain receives two different images of the world from each eye. If the brain receives two images, why do we normally see one, rather than two images of everything? Ono describes this fundamental problem:

Thinking of the eyes as two separate optical instruments suggests that diplopia or double vision should be the rule rather than the exception. Our usual experience, however, is seeing an object as single.

(From, Ono, H. 1991 Binocular Visual Directions of an Object when Seen as Single or Double, in Regan D (ed). Binocular Vision Vol. 9 in Vision and Visual Dysfunction), a 17 volume series

Seeing an object as single means that in spite of the fact that the image of that object may have a different visual direction in each eye, our brain assigns it a single sense of direction. On the other hand, when we experience diplopia, we see two objects, each with a different visual direction. Again quoting from Ono:

... knowing the laws of visual direction is critical to the understanding of single and double vision, because single vision consists of seeing an object in one single direction and double vision consists of seeing an object in two different directions. Therefore, a logical place to begin our study of normal binocular vision is to consider visual direction.

EGOCENTRIC & OCULOCENTRIC DIRECTION

The two main purposes of vision are to see what things are and where they are, so a basic visual function is the sense of direction. Any system that specifies location or direction must define these with respect to some reference point. For example, one can make reference to the Optometry school that is located north of the main campus. For an individual, combined sensory input provides information about where objects are located relative to him, e.g. the lecturer referring to the whiteboard that is located behind him.

If we consider vision in isolation from the rest of the senses, the binocular sense of visual direction uses, as its reference point or origin, a point in the head known as the **egocenter. Egocentric localization** is the system that specifies the position of objects relative to the egocenter; that is, where things are located with respect to you. For the purposes of studying visual direction, let us assume that the head is stationary, but the eyes may be moving. The brain receives directional information from the two eyes and combines them into one unified sense of direction. It is as if we see things from a single eye that is located at the egocenter. In describing our binocular sense of visual direction, some scientists employ the concept of a **cyclopean eye,** which represents a single hypothetical eye located approximately midway between the two eyes. (See Benjamin, W. Borish's Clinical Refraction. WB Saunders, Philadelphia. 2006.; Figure 5-2)

It is interesting to note that, when you ask 2-3 year old children to view an object through a tube, many of them first bring the tube to a point between the eyes, then shift it to either one eye or the other to see. This has been interpreted as evidence that the visual system processes visual direction as if it had a cyclopean eye. (Howard IP, Rogers BJ. 1995; pp 595 Binocular Vision and Stereopsis, Oxford University Press, New York)

The brain receives input from the two eyes, and computes the egocentric direction of an object based on two critical kinds of data:

1. The retinal location of the object's image in each eye, and
2. Each eye's orientation or direction of gaze. The brain receives direction of gaze information, possibly from proprioception within the extraocular muscles and/or from the oculomotor neurons that drive the muscles. Each retina has its own sense of direction. The retinal position of all images can be specified with reference to the fovea. The fovea represents the origin in the field of vision for one eye, since it corresponds to the fixation point, or straight ahead**. Direction relative to the fovea of one eye is called oculocentric localization**. If the eye is pointing straight ahead, and the image falls on the fovea, the binocular system will interpret the object's direction as straight ahead. What happens if the object is located to your right, and you foveally fixate it (assuming your head doesn't move)? Obviously the object will not be seen as being straight ahead, but to the right, in spite of the fact that its image still falls on both fovea (Figure 2.1). Therefore, to correctly compute visual direction, the brain must also take into account the eye's orientation.

The perceptual computation of the egocentric direction of an object begins with the determination of the object's image position on the retina. ... Oculocentric direction is not a perceived direction as such, but rather, is a factor used by the brain in the perceptual computation of egocentric direction.That is, all judgements of visual direction are ultimately egocentric. (From: McCormack GL. 2006; pp 148 Fusion and Binocularity, in Borish's Clinical Refraction, ed. Benjamin WJ, WB Saunders Company, Philadelphia.)

It is important to make a distinction between egocentric and oculocentric localization; they may or may not be the same, depending on the viewing situation. For example (Figure 15.1), while gazing at an object located directly in front of the right eye, the oculocentric direction will be straight ahead for each eye, but the egocentric direction is slightly to the right.

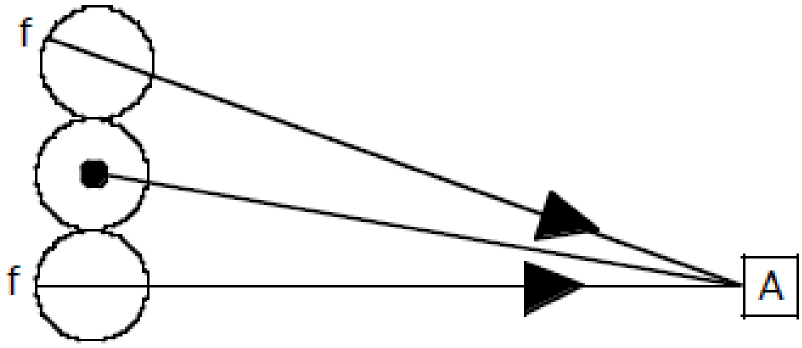

Figure 15.1 *The eyes rotate right to foveally fixate an object.*

It is also possible for an object to appear straight ahead by egocentric localization, but have a different oculocentric direction in each eye. This is illustrated in Figure 15.2.

While the eyes are looking straight ahead at a distant object, a nearer object (A), is still perceived to be directly in front of the person (egocentric localization), even though the oculocentric direction for the right eye is left (temporal retina) and for the left eye it is right (temporal retina). Relative to the cyclopean eye, shown between the two eyes, object A is straight ahead. We can use the imaginary cyclopean eye to helps us understand the perceived or egocentric direction.

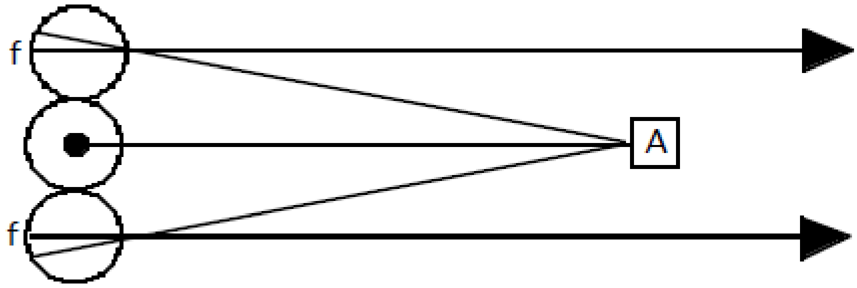

Figure 15.2 *It is also possible for an object to appear straight ahead by egocentric localization, but have a different oculocentric direction in each eye*

To summarize, the brain uses oculocentric directional data from each eye, and creates a new egocentric sense of direction that may be different from each 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.

WELLS' LAWS OF VISUAL DIRECTION

Hering (1879) is usually recognized for developing the laws of visual direction, but nearly a century earlier Wells (1792) developed several basic rules for describing the binocular sense of direction. He wrote three propositions to describe what he observed about binocular visual direction based on input from the two eyes.

- **Proposition 1:** Objects situated on the oculocentric axis of each eye do not appear to be on that line but on the egocentric axis.
- **Proposition 2:** Objects situated on the egocentric axis do not appear to be on that line but on the oculocentric axis of the opposite eye.
- **Proposition 3:** Objects situated on any line drawn through the intersection of the oculocentric axes to the visual base, do not appear to be in that line, but in another, drawn through the same intersection, to a point in the visual base distant half this base from the ocular end of the former line, toward the left, if the objects be seen by the right eye, but towards the right, if seen by the left eye. (The visual base is the line connecting the nodal points of the two eyes).

Figure 15.3 illustrates one of Well's simple experiments. A subject looks at a black dot through a card with two holes, one for each eye's visual axis (Fig. 15.3a and b). A black square is painted in the center of the card. What the person with normal binocular vision should see is illustrated by Figure 15.3c.

The black dot's perceived direction is straight ahead, centered in a hole. This illustrates Well's Proposition #1, which says (paraphrased), "Objects on the oculocentric axis do not appear on that axis, but on the egocentric axis."

Two black squares are seen on either side of the central aperture. This illustrates Well's Proposition #2, "Objects on the egocentric axis do not appear to be on that axis, but on the oculocentric axis of each eye."

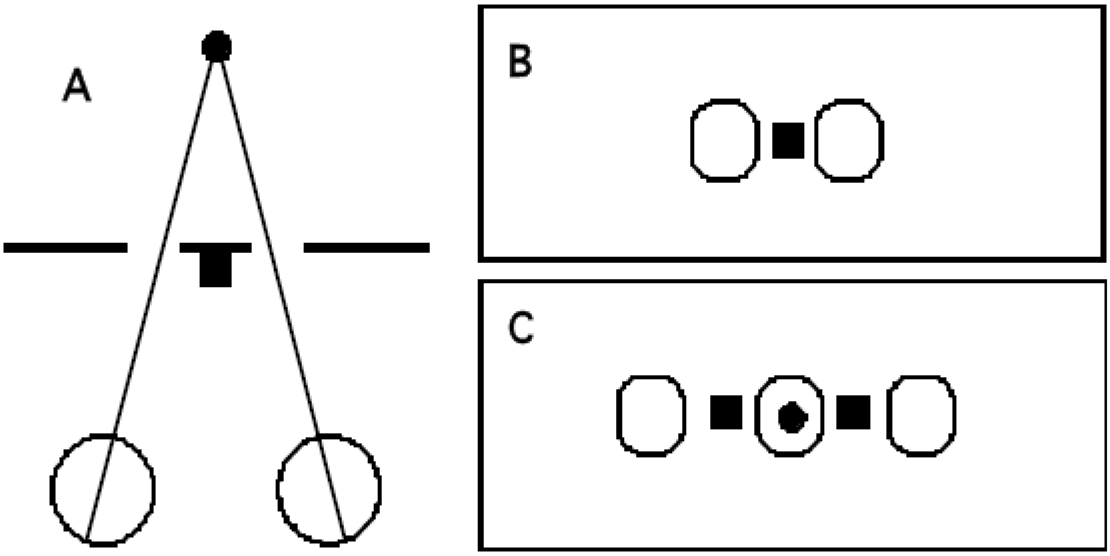

Figure 15.3 *(A) Stimulus layout. (B)The eyes look at a spot through a card with two apertures. (C) Shows what the person perceives binocularly. Adapted from Ono, 1991 in Regan, p. 5.*

Finally, Proposition #3 is used to explain the apparent location of the three circular holes. Figure 15.4 below illustrates this.

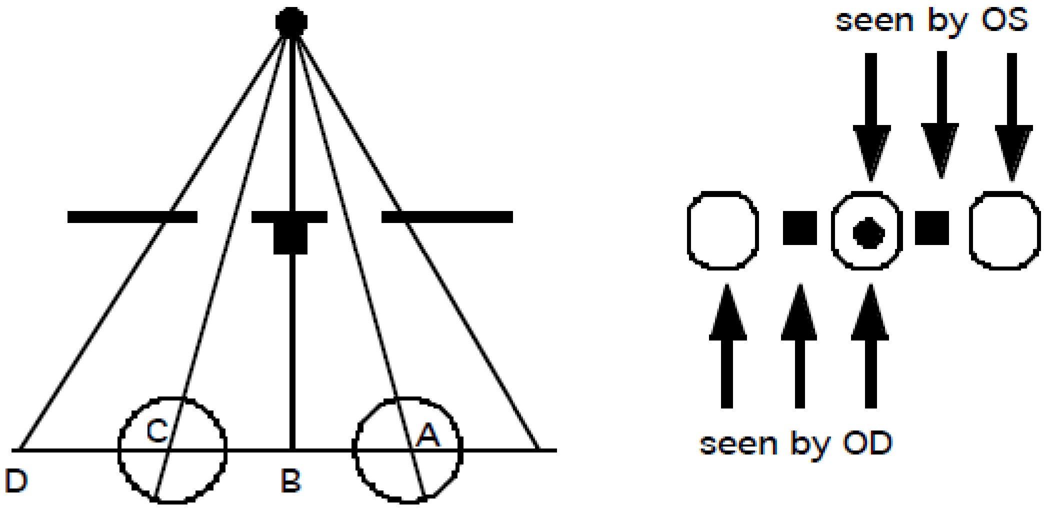

Figure 15.4 *Objects situated on any line drawn through the intersection of the oculocentric axes to the visual base, do not appear to be in that line, but in another, drawn through the same intersection, to a point in the visual base distant half this base from the ocular end of the former line, toward the left, if the objects be seen by the right eye, but towards the right, if seen by the left eye. (The visual base is the line connecting the nodal points of the two eyes).*

Proposition #3 is more general that either #1 or #2 and can explain the perceived location of all the objects.

Consider the location of images seen by the right eye alone. It sees two holes in the card. The right hole is located on its oculocentric axis, and the left one is to the left of the right visual axis. The intersection of the oculocentric axes is indicated by the dot. A line from the dot, through the right hole, intersects the visual base at point A. Point B is a point, one half the visual base to the left of A. The right hole appears to fall on this line. The line from the fixation point, through the left hole, intersects the visual base at point C. Point D is the point, one half the visual base to the left of C. The left hole appears to be located on that line. You can use the same logic to explain why the left eye sees the two holes located to the right of their true locations. Based on this, we can conclude that, with binocular viewing, an image will appear single if it lies on the intersection of the two visual axes and double when it is not on the intersection.

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