Table 3-1. Monocular Depth Clues

1. Apparent size: The known size of an ordinary object can be compared to its apparent size (if it appears smaller, it must be farther away).
2. Interposition: An object must be in front if it blocks the view of other objects.
3. Aerial perspective: Distant objects appear more hazy, less distinct.
4. Shading: Objects further from the light source may be shaded by those nearer.
5. Geometric perspective: Just as parallel railroad tracks seem to converge to a vanishing point in the distance, spacing appears closer, more crowded in the distance.
6. Relative velocity: Distant objects appear to move more slowly than near objects at the same speed.
7. Motion parallax: Movement of the observer produces greater apparent motion of near, rather than distant, objects.

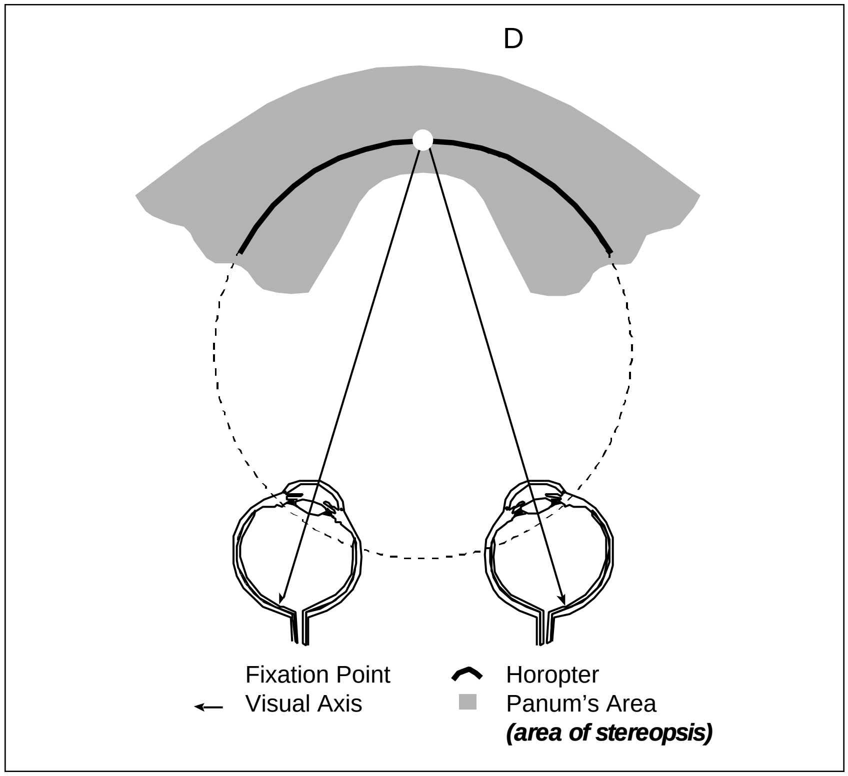
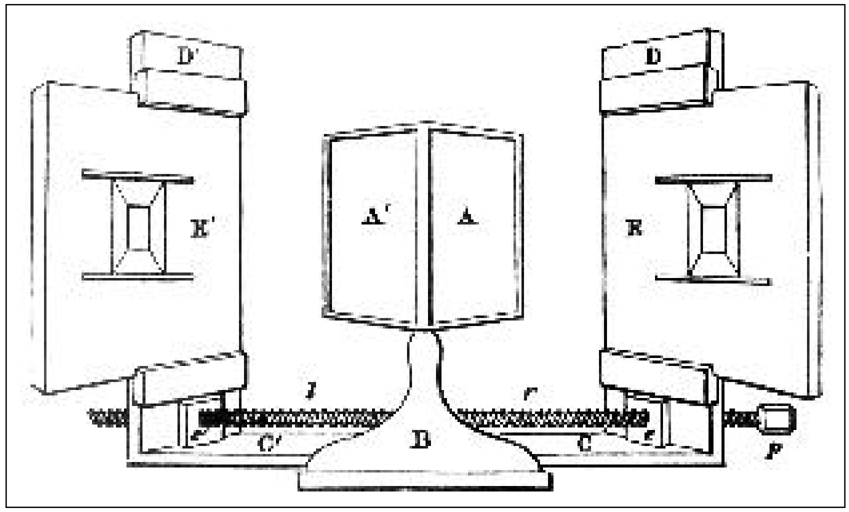
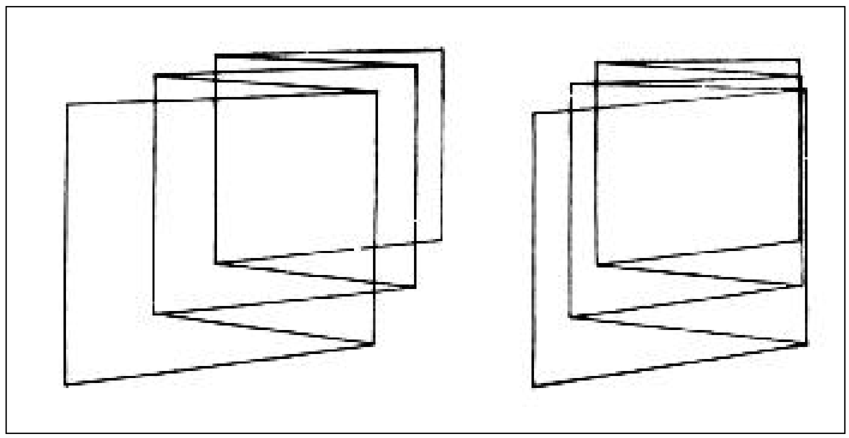


FIGURE 3-1
Schematic representation of Panum's area and its relationship to important components in the physiology of stereopsis. Physiologic diplopia would be present for objects D and N, both lying outside Panum's area (not to scale).

Through a common fixation point (the intersection of the two visual axes), one can construct a curved surface on which any point would be focused or mapped to precisely corresponding points on the two retinas. This surface is the *horopter*, often simplified as a curved line in the horizontal plane (Figure 3-2). For example, a point 4 degrees to the right of fixation on the horopter would be imaged on each retina precisely four degrees to the left of each fovea (point A in Figure 3-2). Any points lying in front of this surface would not fall on anatomically corresponding points but would be shifted temporally on each retina. Any points beyond the horopter would be shifted nasally, again to noncorresponding retinal points. The further from the horopter, the greater the anatomical retinal disparity. The complex neural circuitry associated with vision is capable of synthesizing depth information from these disparate images, giving the sensation of stereopsis.



A



B

FIGURE 3-3
This diagram of Wheatstone's stereoscope (A) illustrates his use of mirrors to view stereoscopic drawings (B). (Reprinted from J Jones. ***Wonders of the Stereoscope.*** New York: Knopf, 1976.)

Historical Review of Stereoscopic Fundus Photography

While stereoscopic vision was first described by the Greek mathematician Euclid (280 B.C.), it was not until the 1830s that Charles Wheatstone (inventor of the linear motor and concertina) described a device for the stereoscopic display of visual information (Figure 3-3).[4] Wheatstone's first experiments were limited to drawings, since the photographic media of his time, daguerreotypes, were difficult to illuminate evenly. In 1850, David Brewster developed a more practical stereoscope, one that used lenses for the direct viewing of photographs placed in a darkened box (Figure 3-4).[5] Stereo viewing became a popular parlor pastime in Victorian England after Brewster introduced his lenticular stereoscope at the Great Exhibition of 1851,[6] and it became popular across the Atlantic after Oliver Wendell Holmes, Sr. (physician, poet, and essayist) described (but did not patent) the familiar Holmes stereoscope (Figure 3-5).[4] Among the many types of stereo cards that were published was an elaborate set of fundus paintings in stereo.[7]

Early fundus photography (see Chapter 1) was such a technical challenge that the first stereoscopic photographs (by Thorner[8]) were not published until 23 years later in 1909 (Figure 3-6). Thorner's stereo technique included an elaborate scheme for flipping the camera upside down between exposures. A more practical sequential technique involving side-to-side shifting was described by Metzger in 1926.[9] Better stereoscopic

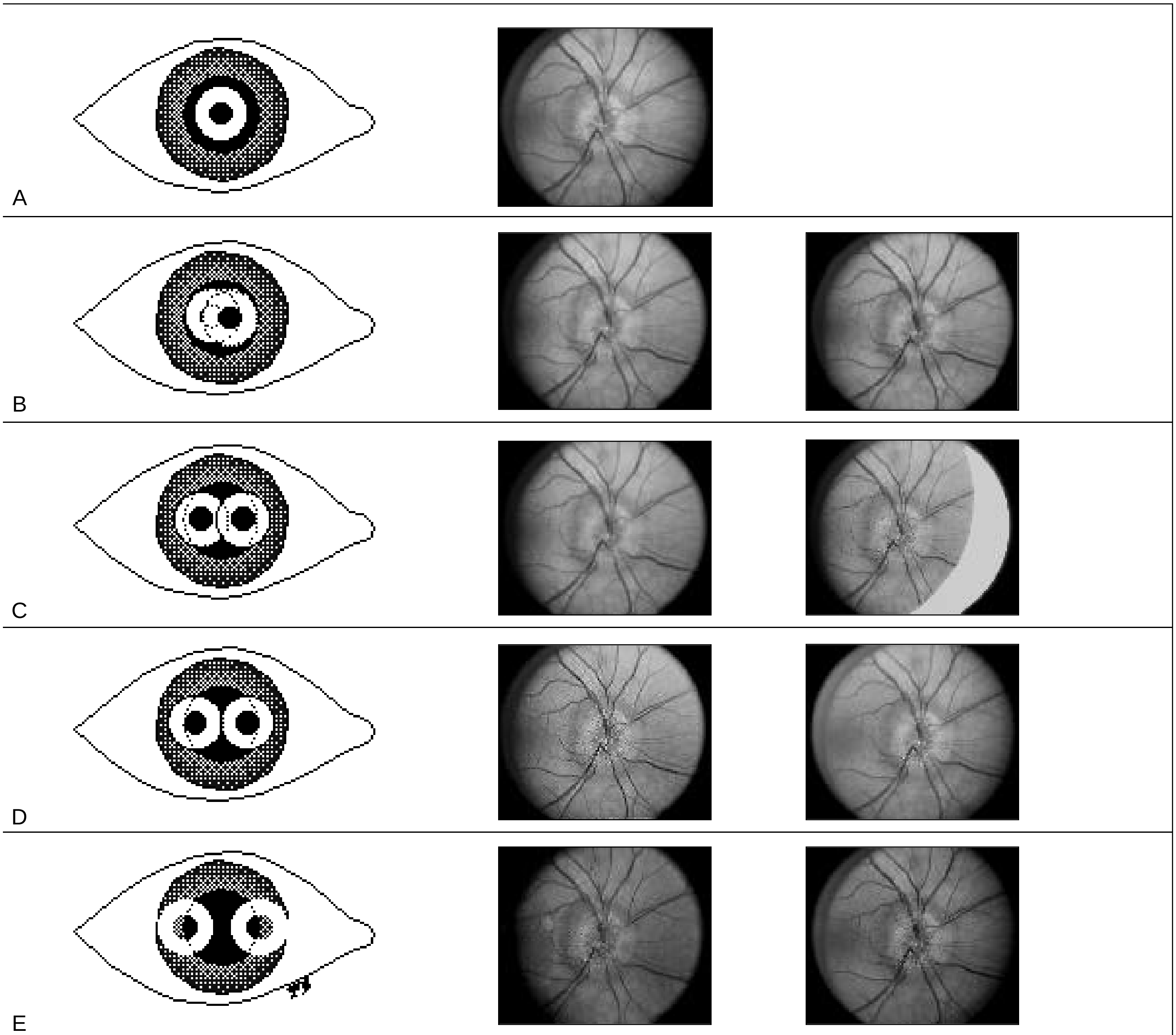


FIGURE 3-11
Illumination positions through a dilated pupil. Amonocular photograph results when you center the illuminating ring in the pupil (A). Asmall stereo separation (B) reproduces a minimal stereo effect (hypo-stereo) in the final photographs and images will be evenly illuminated. Shifting each view slightly to each respective side (C) creates a crescent-shaped artifact. Further shifting to each side, past the crescent artifact, produces a wide-based stereo pair (D). Notice that the images are unevenly illuminated due to amputation of the illuminating ring. Further sideways camera movement reduces both the illuminating and imaging light rays, resulting in an underexposed image that cannot be used (E).

repeat for left disc and macula. This provides a backup set of stereo disc images in case of a patient blink.

Diagnostic Interpretation: Limitations with Sequential Stereo Photography

The stereo base (the separation between the center of the lenses) of sequential stereo frames, and therefore the three-dimensional effect, may be inconsistent between photographic pairs taken at the same session, as well as at different patient visits. When interpreting visit-to-visit photographs, the physician should judge only relative changes in position of various anatomic structures and should not attempt to determine any absolute depth perception information between stereo images. Measurements are also invalid because of potential variability of stereo bases.

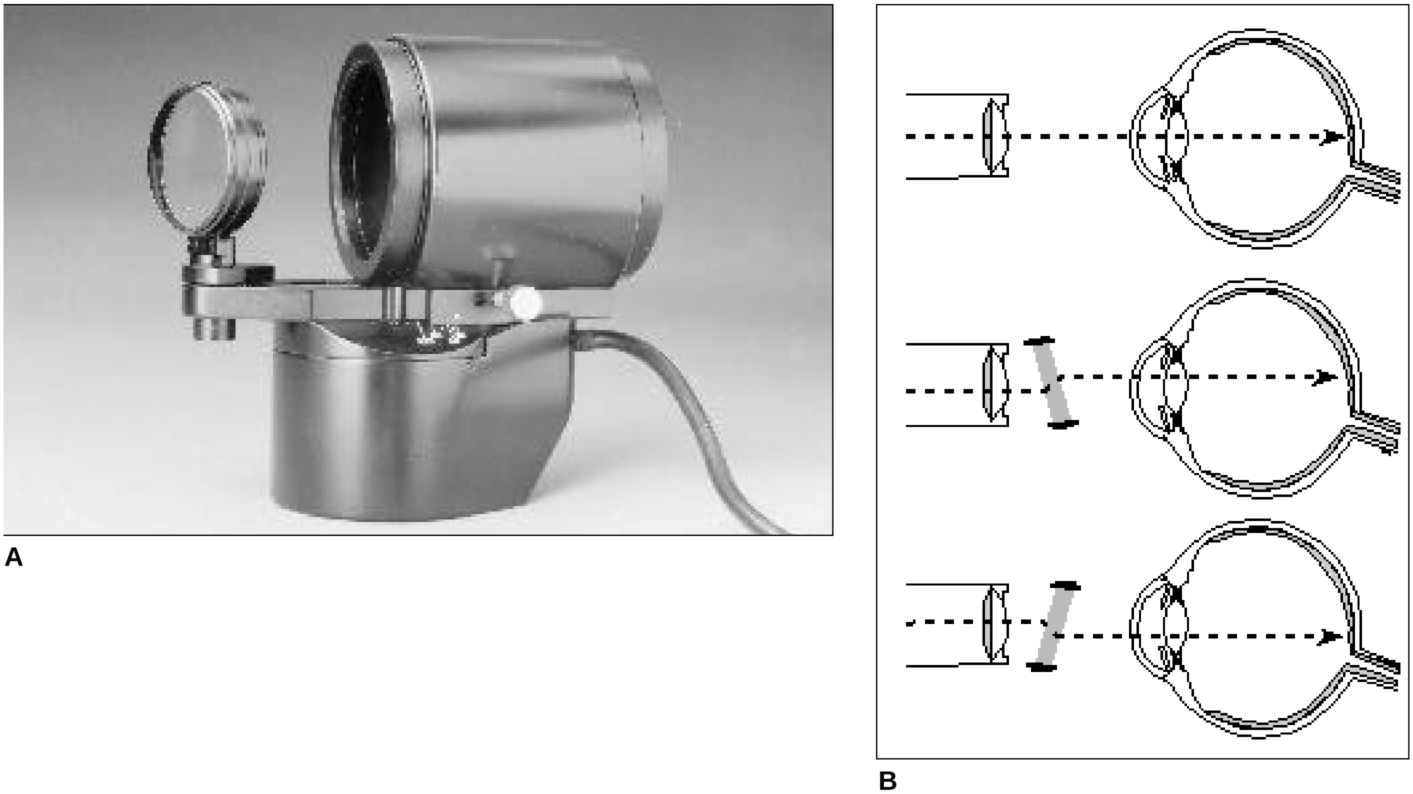


FIGURE 3-13
Allen stereo separator. A. Photograph of the solenoid-activated plano glass plate mounted in front of the Zeiss fundus camera. B. Optical path using the Allen stereo separator shows how the camera is optically shifted in front of the patient's eye.

The separator improves the repeatability of the stereo base between stereo pairs, but there is still no guarantee of a consistent stereo base, since there may have been some patient movement when the pairs were taken. Additional issues concern the fact that the glass plate is another surface for children's fingerprints and adults' nose-prints. Some photographers feel that it is an advantage to have the "lens protector" in place for pediatric patients while others prefer to use a true lens cap whenever the camera is not in use.

Some fundus camera manufacturers have a small locking knob that limits the camera's lateral movement to a stereo base of about 3 mm. The steps needed to take a stereo pair using this method are the same as for any other sequential stereo pair, and the patient movement problems are the same. Only stereo photographs obtained simultaneously can guarantee a repeatable stereo base.

Fluorescein Angiograms in Stereo

Shooting Order

The same techniques to align the camera in color fundus photography are used in stereo fluorescein angiography (FA). The film in most fundus cameras travels from left to right (photographer's point of view). Film FAstudies are usually cut into strips of five or six frames to be placed into negative sleeves. To have the first image at the upper right corner of the contact sheet so that the images are right side up, the first image is to the right of the second image. The right side of the stereo pair must be

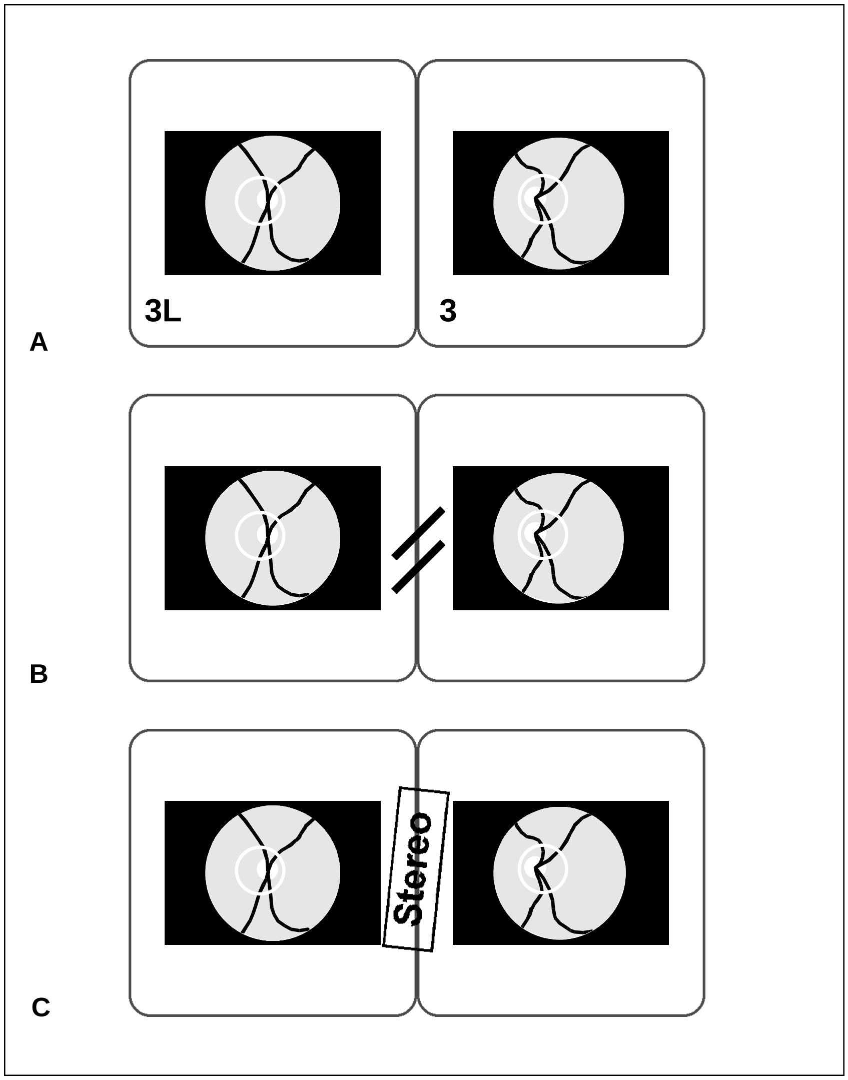


FIGURE 3-21
Labeling conventions for indicating stereo on the pairs of 2 × 2 slides. Slide pairs labeled with sequential pair numbers and L& R (A), a simple set of lines (B), or a rubber stamp with the word stereo (C).

which is the left image, try to identify a structure that is deep (posterior) in the image. This "deep" structure will be laterally to the left on the left slide.

This monocular technique for identifying stereo pairs can be tedious and time consuming. It will, however, enable the photographer who is monocular or unable to see in stereo to orient the slides properly into stereo pairs.

Labeling of Stereo Slides

Stereo slides should be edited, marked, and placed into the chart so that they are easily identifiable. This is very helpful to the clinician.

Marking of the stereo pairs can be accomplished using a variety of methods. Pairs for a particular patient from each visit can be numbered sequentially and identified as to whether the individual image is the left or the right image (Figure 3-21). If the slides are not to be removed from the plastic slide pages, then a simple line[23] or a pair of lines may be used to indicate stereo pairs. The word *stereo* can be written or rubber stamped between the two slides. Avoid time-wasting mix-ups due to not marking your stereo pairs; pick a method and use it consistently.

FIGURE 3-27
LCD glasses used with a computer-controlled monitor to display color stereo images. (Courtesy of StereoGraphics, Inc.)

images that have a full spectrum of colors, the effect on the mostly red fundus images is not as good.

Software that both stores the aligned stereo images and allows their printing on paper or onto slide film is useful.

Computers can use other viewing systems that are not possible with either prints or slides. These techniques require electronically controlled glasses. In one technique, the computer alternately displays the images comprising the stereo pair at a rate of at least 30 images per second, and the image is viewed on a single screen by a person wearing computer-controlled liquid crystal device (LCD) glasses. The stereo images are first processed to create two half-height images, one over the other. An electronic device is inserted between the computer and the monitor and displays the two images alternately. This control box sends out an infrared timing signal to the LCD glasses to control the opacity of the lenses. The LCDs have the ability to turn opacity on and off and therefore permit the two stereo images to be sequentially viewed through the appropriate eye (Figure 3-27).

Another system uses a polarized LCD panel placed over the computer monitor screen while the person viewing it wears standard polarized stereo glasses. With this system, the glasses must be horizontal to create maximal image extinction, the same as for stereo slide projection. The glasses are inexpensive, so this system may be useful if a large audience is involved.

Prints and Publications

While prints are not commonly used to view stereo images in a clinical setting, there are a variety of viewing methods that may be available to see the stereo images found in publications.[25] An understanding of these viewing methods will assist you in selecting the appropriate publishing method for stereo images and will allow you to tell the person reviewing your images how to look at them. It is important to be able to inform the publication's editor and printer of size requirements for easy viewing.

Acommonly used stereo printing method involves two images printed just less than 2 inches in width with a small space between them (see the sidebar on stereo in publications). It is important to make sure that the distance between common points on the stereo images is not greater than the average PD of 60 mm. A good working rule is that each of the images should be no wider than 55 mm. If you have a narrow PD or the printer has

Stereo in Publications

Below are sample instructions that you might use to convey your stereo reproduction needs to the publisher and your explanatory text for the viewer:

INSTRUCTIONS TO THE PUBLISHER:
This figure is a stereo pair. The two images, while they may appear similar, are different. The figure has been submitted to you precisely and correctly aligned so that the readers can view the image in stereo (three-dimension). Exact sizing must be followed in order to have the image viewable by the greatest number of readers. The image must be run at 100%, so that the final images will be reproduced as two 55-mm–wide (2-inch or 12-pica) squares with a 4-mm (1/6-inch or 1-pica) gap between the images. Please include the two black dots that are positioned directly over the exact center of each image. These are important aids to assist readers in viewing this image. ***Caution: under no circumstances should you strip the two images separately or reverse their placement, as that will destroy the scientific integrity of the image.***

INSTRUCTIONS TO THE READER:
These two images comprise a stereo pair. When viewed properly you will see a three-dimensional view of the subject. To do this, you must look at the left image with your left eye and the right image with your right eye. The following steps may assist you in viewing this stereo image:

1. Use stereo viewing glasses of +5 to +8 diopters.
2. Situate yourself in a comfortable viewing position with good lighting on the stereo image.
3. With both the print and your eyes level, place the image very close (2 inches) to your face with the left image in front of your left eye and the right image in front of your right eye. You should see a single out-of-focus image.
4. Slowly increase the distance between your eyes and the image until you see a sharp stereo image.