STEREOSCOPIC PHENOMENA AND STEREOGRAMS

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PULFRICH PHENOMENON (EFFECT)

An interesting binocular phenomenon occurs when you observe a swinging pendulum under the following conditions:

- Pendulum is swinging in a plane parallel to the face
- A neutral density (ND) filter is placed over one eye.

If the filter is placed over the right eye, the pendulum will appear to swinging in an oval trajectory rather than parallel to the face, as illustrated in Figure 28.1-left. This is the **Pulfrich effect** and is explained based on the fact that the ND filter reduces the retinal illuminance to one eye, which causes the neural signal from that retina to be slightly delayed compared to the other eye. It is important to note that the direction of the perceived oval path (clockwise vs. counterclockwise) should be related to the eye with the delay, especially for diagnosis of optic neuritis. Referring to Figure 28.1-right, although both eyes are fixating the pendulum (black dot), the left eye processes the image for where it is, but the right eye processes the signal for where the pendulum was a moment before. In effect, it is as if the right eye sees the pendulum as slightly to the left. This sets up a retinal disparity in the two images. Based on the disparity information, the apparent location of the object is slightly nearer to the observer than the actual pendulum location.

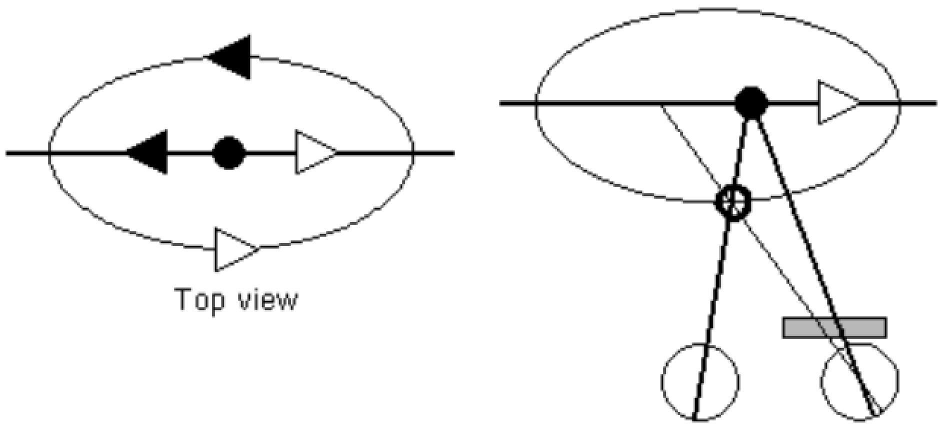

Figure 28.1 *Pulfrich phenomenon.*

Any situation that induces a difference in the retinal illumination between the two eyes has the potential to cause the Pulfrich effect. Some examples include:

- A large anisocoria
- Optic neuritis
- Head-mounted displays or virtual reality goggles with mismatched luminances

CHROMOSTEREOPSIS

When viewing a vivid pattern that includes highly saturated blue and red, you might notice that the colors appear to be located at different distances, even though they are actually in the same plane. You may be able to appreciate that the words, “Chromo-” and “stereopsis” in the color version of Figure 28.2 seem to be floating in space at different distances. Some observers see the red text floating in space nearer than the blue. Some will observe the opposite effect. This is known as **chromostereopsis**.

Chromostereopsis is based on the chromatic aberration of the eye and requires that the optic axis and visual axes of the eyes be offset from each other. This is illustrated in Figure 28.3. Several nice examples of chromostereopsis can be found at the following web site: http://www.ritsumei.ac.jp/~akitaoka/scolor-e.html

Figure 28.2 *An example of chromostereopsis.*

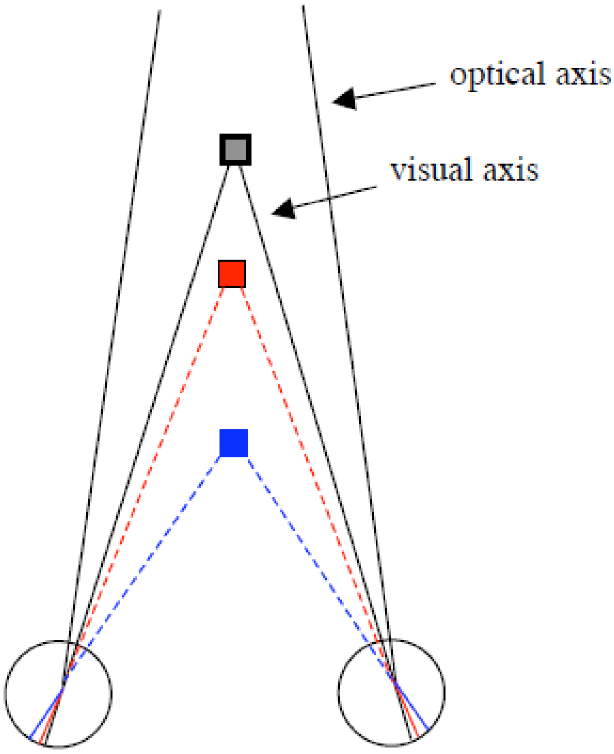

Figure 28.3 *Explanation of chromostereopsis.*

By positioning pinholes correctly in front of the eyes, it is possible to enhance chromostereopsis, and stimulate a strong sense of stereoscopic depth when viewing ordinary color photographs. One company has patented special “3-DVG” spectacles that do just that. Read more about it at their web site: http://www.3-dvg.com/

FREE-FUSION STEREOGRAMS

It is not necessary to use a stereoscope, polaroids or anaglyph glasses to view pairs of stereo images. With practice, you can learn to look at the two images of a stereo pair that are simply placed side by side. These are called **free-fusion stereograms**. Normally the right eye looks straight ahead at the right image while the left eye looks straight at the left image. It is also possible to cross your eyes so each eye sees the image on the opposite side.

Steinman's textbook contains many examples of free-fusion stereograms, and there are examples in Borish as well. They are also frequently used in ocular disease textbooks to help students and doctors practice diagnosis of diseases such as glaucoma.

You can easily create your own free-fusion stereogram by the following steps. An example is shown below in Figure 28.4.

1. Draw a field in a frame, which will be the background to be seen by both eyes.
2. Place an object inside that frame.
3. Copy the entire picture and paste it beside the original. The two frames are the stimuli for the two eyes.
4. Select the object in the frame and shift it slightly to one side. This creates a disparity in its location with respect to the background. The eyes fuse the backgrounds, but the object is seen in slightly disparate directions in each eye. The disparity stimulates a perspective of stereoscopic depth.

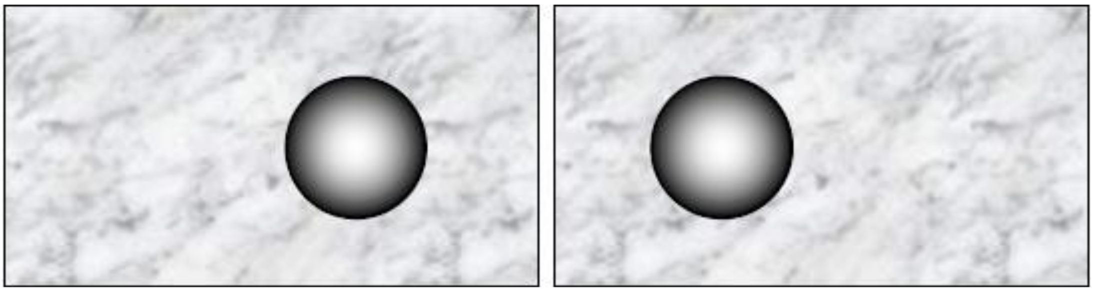

Figure 28.4 *A simple free-fusion stereogram. If the right eye sees the right frame and left sees the left, it should stimulate crossed disparity, with the "black pearl" floating in front of the marble background*.

RANDOM DOT STEREOGRAMS

In order to perceive an object in stereopsis, is it necessary that the object first be visible or recognizable to each eye monocularly? For example, to see a square stereoscopically, must the square also be identifiable in each monocular retinal image?

Julesz, who investigated stereopsis in the 1960s, demonstrated that monocular visibility is not required for stereopsis. He did this by creating random dot stereograms, in which the pattern seen by the right eye is just a pattern of random dots with no apparent form. When viewed binocularly, the binocular disparities in the random dot pattern between the right and left images stimulates a stereoscopic perception of an object.

Steinman Figs. 7-28 and Adler's Fig. 24-7 illustrate how to design a random-dot stereogram, and an example is shown below in Figure 28.5. Steinman shows a completed random-dot stereogram in Fig. 7-29.

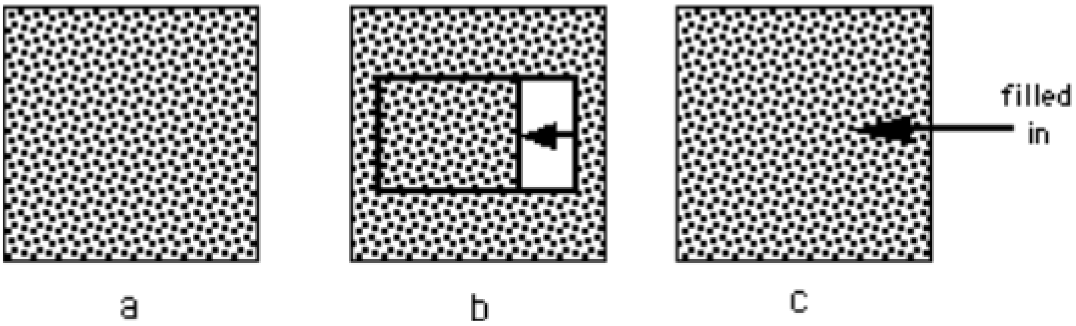

Figure 28.5 *The same random dot pattern is prepared for both eyes, but the pattern for one eye (a) must then be modified. A portion is shifted (b) to create a disparity; then the uncovered white space is filled in with random dots (c).*

In most natural viewing situations, monocularly visible objects and their features are fused binocularly. The visual system is able to match corresponding features in the right and left eye images to generate a sense of stereoscopic depth. This point-by-point matching, which occurs between similar details in the right and left image, is referred to as **local stereopsis**.

Random dot stereograms demonstrate that, the visual system is also able to compute disparities across a much large area of the scene, even when there is no object available for local stereoscopic matching. That is, there is a large area of points within one eye's image that has disparity relative to the corresponding region in the other eye's image. The larger overall disparity computation between the images of the two eyes is called **global stereopsis**.

AUTOSTEREOGRAMS

It is possible to put the two patterns of random dots on the same page, or even within the same picture, as long as each eye looks at different parts of the picture. This leads to the idea of the **autostereogram**. Based on the same principles of the random dot stereogram, Dr. Tyler and Dr Clarke developed autostereograms. Examples of these are the "MagicEye" figures, which can elicit a sense of stereoscopic depth without using polaroids, a stereoscope or separate right and left eye images. In effect, the left and right eye images are both contained within a single picture. The principle requires:

- A repetitive pattern.
- The eyes must converge or diverge one repetitive width.
- Then the different left and right eye images will contain disparities.
- The disparities give the perception of stereoscopic depth.

This is also known as the wallpaper phenomenon, and you may have observed this when staring at wallpaper with a repetitive pattern. Quoting from Tyler's chapter in Regan (Chapter 3 - Cyclopean Vision):

"*To generate an autostereogram, it is possible to go beyond the basic wallpaper phenomenon and control the disparity profile by varying the repetition width at each point in the field. Any stereoscopic surface with variations in both the horizontal and vertical directions may be generated by this means*."

Random-dot stereograms and autostereograms demonstrate the important principle that perception of a stereoscopic form does not need to be preceded by monocular perception of that form. Listed below are several web sites that have nice examples of stereograms, including autostereograms, stereo pairs and random-dot stereograms. Some images are referred to as **single image stereograms** (**SIS**) or **single image random dot stereograms** (**SIRDS**). Many other interesting sites are available on the web.

http://www.colorstereo.com/
http://www.magiceye.com/
http://www.st.rim.or.jp/~oso/3dcg.html
http://www.vision3d.com/sgwall.html

STEREOPSIS AND OTHER DEPTH CUES

Since stereopsis is stimulated by simple retinal disparity, reversing the disparity should reverse the direction of perceived depth. However, if you show someone a stereogram that has abundant monocular depth cues, reversing the disparity may have no effect on the depth and distance of objects.

Suppose you look at a polarized stereogram showing farmers working in a field such that normal disparity shows them in the foreground, with the field extending beyond and mountains in the distance. If you reverse the glasses, will the mountains appear nearer and the farmers beyond? This does not occur.Why?

CLINICAL TESTS OF STEREOPSIS

Various clinical tests have been developed to evaluate the stereoacuity threshold of patients. These may be categorized as **real-depth** tests or **projected-depth** tests. Real-depth test use objects that are separated in space by a certain amount to stimulate a specified amount of retinal disparity. Some are similar to the Howard-Dolman devices used in the lab to measure horopters and real stereoscopic thresholds. **See Fig. 20-18 in Borish**.

For use in the clinic is the Frisby Test, which can measure up to 20 seconds of arc. The results can be checked by reversing the disparity or changing the location of the stimulus. It can also be used easily in young children and infants as a preferential looking test.

Projected-depth tests use flat images that are fused when viewing them with polarizer or in a stereoscope. These create retinal disparity, which stimulates a sense of stereoscopic depth. Examples include the Titmus Stereo Fly test, and the Reindeer Test.

Research has shown that the mean stereoacuity threshold for a population is 14.4 arc seconds. Their research suggests that 98% of the population should have a maximum stereoacuity (threshold disparity for stereopsis) between 2 and 38 arc seconds. Based on this, 40 arc seconds may be used as the general pass-fail cut-off for adults, though some stereo tests include a 20 arc second target.

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