Theoretical and practical aspects of constructing colored stereoscopic slides

John E. Holte
Pacific University
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Abstract
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Theoretical and Practical Aspects
of
Constructing Colored Stereoscopic Slides

John E. Holte
Thesis
May 9, 1975
Stereoscopic scenes are useful in training both sensory and motor areas of strabismics. Being able to measure the stereoacuity as an indicator of the quality of binocularity is very useful. Slides with depth due to disparity alone and no monocular cues to depth can be used for training and provide a valuable check on the patient's binocularity.

My purpose is to discuss the theoretical aspects of the amount of disparity used to produce varying depth effects and to discuss the practical aspects of how one can easily make colored stereoscopic slides.

The sensation of depth is a complex response. There are several things one must keep in mind when making stereoscopic slides. The disparity must be above the minimum but must not be so great as to produce obvious diplopia or a reduced sense of depth. The disparity also varies with retinal location being larger peripherally.

When disparity is gradually increased the perception of the scene gradually changes. Ogle (1952, 1958) has described the stages of perception. A disparity of less than threshold is undetectable; then as increasing disparity is introduced the sense of depth increases proportionately to the change in disparity. At a disparity of one half of
Panum's fusional area (termed disparity threshold for diplopia (DTD) by Mitchell-1966) the image of one of the disparate points is seen as double when the other point is fixated. Further increases in disparity produce continued proportional increases in depth (Ogle,1953) until suddenly the strong sense of depth fades. This disparity is the limit of patent stereopsis. Further increases in disparity are not accompanied by a true sense of stereopsis, yet it is still possible to tell which point is closer. If disparity is then increased further, even the ability to tell which is closer fades. This extreme disparity is the limiting disparity of stereoscopic vision and is termed the extent of qualitative stereopsis. Blakemore (1970) referred to it as the upper limit of stereopsis.

The stereoscopic threshold is the smallest difference in disparity that can be discriminated. It varies depending upon the type of test and the peripheral angle. In general, stereoscopic acuity declines with increasing lateral separation of the disparate points. Hirsch and Weymouth (1948) found that stereoacuity was maximal, not at the fovea, but at a peripheral angle of about 19 minutes of arc. At 19' of arc the stereoacuity was about 10". At 1" and at 8' angular separation the stereoacuity was about 15". The threshold increases more rapidly for separations less than 19' than for separations greater than that. Ogle (1950) has measured the stereoscopic threshold for varying angular separations of point light sources presented for two second durations.
He measured thresholds of about 15" for a 2° separation, 25" for 4°, 35" for 6°, and 50" for a 10° separation. The values varied considerably depending upon the observer.

If one fixates a point and a second point is then brought closer to the subject, eventually the second point will appear double. If the second point is moved further away it will also eventually appear double. These are the temporal and nasal disparity thresholds for diplopia respectively and their sum is Panum's fusional area. The average of the two is what Mitchell (1966) calls the "disparity threshold for diplopia" or DTD. These can also be measured using a stereogram with two vertical lines seen by one eye and two vertical lines with a slightly different separation seen by the other eye. The angular difference in separation when three rather than two lines are seen is a measure of the DTD. If the separation is increased and then decreased until three lines are seen, the average of the two values is the DTD and the sum is Panum's fusional area. Unless the two values are averaged, a fixation disparity will mislead one as to the DTD. Confusion between DTD and Panum's fusional area is discussed and clarified by Mitchell (1966). Ogle (1950) measured the DTD and found it to be 3' to 6' when a lateral separation of 1° was used. Mitchell (1966) has graphed the values of the DTD found by various authors for various angular separations. If one looks at all the data then a peripheral angle of about 5° corresponds to a DTD of about 5' to 15' and 10° results in a DTD of about 10'
to 20'. The results of various experiments vary greatly. This is probably due to differences in target size, lighting, and control of eye movements. The DTD is larger under scotopic than under photopic conditions (Mitchell, 1966).

As disparity is increased above the disparity threshold for diplopia (DTD) the sense of depth increases until it begins to fade at the limit of patent stereopsis. This limit has not been widely measured. Ogle (1952) found the limit to patent stereopsis to be about 10' of arc at the fovea and about 70' of arc at a peripheral angle of 6°.

More recently, Richards (1971) found that the maximum depth effect was produced by central stimuli with a disparity of about 3/4° (45'). He flashed vertical lines 6' by 75' and their apparent depth was determined by adjustment of a probe 4° to the left of the fixation point. The depth effect decreased until it was nearly zero at a disparity of about 3°.

Further increases in disparity are not accompanied by proportional changes in depth but it is possible to tell which point is closer until the limit of qualitative stereopsis is reached. This limit has been measured by many researchers. Ogle (1952) found the limit to be about 15' at the maculas and about 2° at a peripheral angle of 6°. He used a thin, highly polished needle about 3 cm in length seen at a distance of 50 cm. Westheimer and Tanzman (1956) found the upper limit of stereopsis to be about 7° in the center of the field. They used flashed spots of light 11mm in diameter at a distance of 135cm. Blakemore (1970) has summarized previous studies.
and has experimentally found the limit to be about 8° at the fovea, 10° at a peripheral angle of 5°, and about 14° at a peripheral angle of 10°. He flashed bright slits of light for targets. Richards (1971) found that normal observers in a forced choice situation performed well above chance in telling if the flashed stimuli was closer or further for disparities of 2 4°. Extrapolation of his curve gives a limit of qualitative stereopsis of about 6 1/2°. Richards used flashed pairs of vertical lines 2° wide by 2° high which were symmetrical about the fixation point. Most authors who have used large targets have found relatively large values for the various disparities measured. Ogle's disparities are smaller than those more commonly found. This is probably due to the small targets he used.

The following graph summarizes representative disparities for various angular separations of disparate points.

<table>
<thead>
<tr>
<th>Angular separation</th>
<th>fovea</th>
<th>5°</th>
<th>10°</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stereoacuity</td>
<td>15&quot;</td>
<td>30&quot;</td>
<td>50&quot;</td>
</tr>
<tr>
<td>DTD</td>
<td>7°</td>
<td>10°</td>
<td>15°</td>
</tr>
<tr>
<td>Patent stereo limit</td>
<td>45°</td>
<td>60°</td>
<td>90°</td>
</tr>
<tr>
<td>Qual. stereo limit</td>
<td>7°</td>
<td>10°</td>
<td>14°</td>
</tr>
</tbody>
</table>

These values are important considerations when deciding upon the disparity of stereoscopic slides. Most targets used in stereoscopic slides are relatively large and separated laterally by at least 5°. To achieve a large but realistic depth effect a disparity of about 20° to 30° would seem
Methods and Materials

I used a technique of taking two pictures of the same scene each from a different angle. One view was exposed on the lower half of the film, then the double exposure button was depressed, the camera was moved laterally and cocked, and the second view was exposed to the upper half of the film. Each scene was marked so that it had an upper and lower extent equal to one half of the vertical height of the scene in the camera viewfinder. Consistency in this results in the same vertical separation for each slide.

Two general types of scenes were constructed (A&B). Both types consisted of various colored objects of ambiguous size supported by "invisible" black threads in front of a black felt mat. The idea was to eliminate monocular cues to depth. Scene A had varying size plastic rings at two different distances. The rings were about 10 cm in diameter and were separated laterally by about 5 to 9 cm which corresponds to about 1.4° to 2.5° at the camera to subject distance of 206 cm. Scene B was composed of a yellow rectangular paper frame within which four colored paper bars of random widths and lengths were hung. The bars averaged 1 cm by 8 cm in size and were laterally separated by about 4½ cm which is about 1½°. One of the bars was hung at a further distance than the other three.

I used a Minolta SR-T 102 35 mm camera mounted on a tripod. When used with a 2X teleconverter it has an effective
focal length of 100 mm. The double exposure mechanism is very useful but not essential to make the stereo slides.

Several stereoscopic slides were made by cutting two individual slides in half horizontally and mounting them one above the other in a glass mount. The procedure to take the slides is identical to that already described. I ordered the film developed but unmounted for all the slides. An Electronic flash was used for illumination. It was located at a constant position behind the camera. It did not move when the camera was moved laterally.

The stereoscopic slide projected on a screen was viewed with a vertical prism of about 9 prism diopters. This results in the upper and lower scene being fused. The patient sees three nearly identical scenes, one above the other, with the middle one in depth. This technique is similar to the one used by Dr. Oakley to make visual training movies currently being sold. I constructed slides with disparities ranging from 24" to 24'. The disparity was calculated according to the following formula:

\[
\text{Disparity (radians)} = \frac{(PD) \Delta}{D(D-\Delta)} = \frac{(PD) \Delta}{D^2}
\]

PD is equal to the lateral separation between camera locations.
This formula may be applied directly only if the angular magnification of the projected image is the same as the angular magnification of the original scene viewed with the naked eye. This is the case if the focal length of the slide projector is equal to the focal length of the camera and if the observer sits beside the slide projector. If the camera \( f = 100 \text{ mm} \) and if the projector \( f = 5''(125 \text{ mm}) \), the scene will have about 25\% less disparity than calculated unless the observer sits 25\% closer to the screen. The disparities given have been corrected for this minification by the projector. Very small disparities are the most difficult to accurately produce. This problem can be circumvented simply by locating the projector closer to the screen than the observer. To make a slide with a disparity of 24'' I used a PD of 6 cm, \( \Delta \) equal to 1.03 cm, and \( D \) equal to 206 cm. Relatively large disparities such as 24' require a PD of 40 cm and \( \Delta \) equal to 9.35 cm. Since PD and \( \Delta \) are linear and inversely related for a given disparity and distance, the actual values are chosen for convenience and to maximize accuracy.

Nearly all observers could tell which ring or bar was closer at a disparity of about 50''. At smaller disparities, most observers could still tell but more misses were made. Color seemed to be a strong monocular cue to depth especially at disparities close to threshold. The yellow objects appeared closer and the blue objects appeared further away. If all objects in a display were the same color, then this problem would be eliminated. In the case of the disparate
bars within the rectangle, beneath each bar on the rectangle could be a colored identifying arrow. The larger disparities of about 24' produced a strong sense of depth. Physiological diplopia was not obvious but present. The yellow figures were easiest to see especially if projected in a partially lighted room. White or yellow would be good colors to use to maximize the contrast between the stereoscopic figures and the screen.
Literature Cited


Below are two prints of representative slides. Slide A has a disparity of 18' (min) when viewed with a slide projector with \( f = 125\, \text{mm} \). The print has a disparity of about 22' when viewed at 40 cm with an 11° vertical prism. Slide B has a disparity of 6'. The print has a disparity of about 7' when viewed at 40 cm. One may vary the disparity by varying the viewing distance and vertical prism simultaneously.

Slide A

Slide B