# A Performance-Based Study Of Stereopsis and Fixation Disparity

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A need exists for suprathreshold tests of stereoscopic performance that have application to everyday situations. Such tests should emphasize the quality (strength and robustness of the depth sensation) rather than the quantity (threshold) of stereopsis. Tests commonly used today in the clinical setting test on the order of one or a few minutes of disparity angle, while everyday use of stereopsis requires a more suprathreshold disparity angle closer to 10 to 20 minutes of disparity angle in a normally functioning binocular system (e.g. Ogle, 1964). We also note the need to take account of the differences between exophores and esophores for performance on quantitative stereoscopic tests which rely on crossed or uncrossed disparity (Shippman and Cohen, 1983).

The very tight relationship between stereoscopic threshold and fixation disparity is well known; less understood is that same relationship at the suprathreshold levels, in which we all live and work. Studies (Shippman and Cohen, 1983) indicate that esophores have better stereoacuity with uncrossed disparity and exophores have better stereoacuity with crossed disparity. The difference between esophoric and exophoric performance may be due to the asymmetric distribution of Panum's areas about the fixation point. Exophores usually have exo fixation disparity and esophores usually have eso fixation disparity. Exo fixation disparity moves the collective centers of the Panum's areas behind the plane of regard and eso fixation disparity moves them in front of the plane of regard (Mitchell, 1966). Stereopsis is at its best at points at or near the horopter. It can be theorized that a subject with eso fixation disparity would have better stereoacuity if an entire scene was in uncrossed disparity thus causing most points of the scene to fall on or near that persons horopter. Likewise, the reverse can be expected with subjects having exo fixation disparity. Exophores should prefer most of the points to have crossed disparity in a scene.

Stereoscopic performance also has a relationship to the amount of the heterophoria present within a system (Saladin, 1995). Moderate amounts of exophoria (6 pd) and mild amounts of esophoria (less than 2 to 3 pd's) have lesser effect on stereopsis, while the heterophoric values above these amounts do have a more profound effect. Similarly, levels above mild amounts of fixation disparity contribute to decreased stereoscopic perception (Saladin, 1990). Symptomatic amounts of fixation disparity (greater than 6'exo and 4' eso) appear to correlate to exophoria above moderate amounts and esophoria above mild amounts.

We designed this study as a pilot to guide us in our study of stereopsis and fixation disparity at suprathreshold levels and to help us develop a suitable test and accompanying task. We ask: can a subject successfully arrange a series of anaglyphs made with successive disparity gradients and can the same sense of depth quality difference be used to investigate the effect of fixation disparity on suprathreshold stereopsis.

## Method

A series of photographs were taken of an outdoor scene with the camera station separations of 0, 3, 6, 9, and 12 cm. Such camera station separations are analogous to the interpupillary distance of a human observer at the scene. A computer program was used to make anaglyphic (blue, red) pairs of the photographs and to superimpose the pairs. The result was printed. Two sets of five stereoscopic anaglyphs were made. The first set (the IPD set) was made setting the reference plane in the middle of the front-to-back depth of the scene at each of the five camera station separations. This set was used to determine the reliability of this series of photographs in testing quantitative amounts of stereopsis. The depth seen between the two vertical contours (such as trees) can be likened to the experiments done by Howard (1919) who judged the relative placement between two vertical rods. The second set (the RP set) used the 6-cm camera station separation pair but set the reference plane at five locations in the scene. The reference plane was set at the very front of the scene for the first anaglyph, between the front and middle for the second, in the middle for the third anaglyph, between the middle and back for the forth anaglyph, and at the back of the scene for the fifth anaglyph. If the data gathered using the IPD set displays evidence of being an effective qualitative stereoscopic test, the RP set might provide additional qualitative data based on the placement of the reference plane. When the anaglyphs were held at the test distance of 40 cm, the maximum disparity was approximately 12 minutes of arc. A similar computation of the real scene yields about 18 minutes of arc. Therefore the anaglyphs and the real scene were comparable with respect to the disparity amount and evaluation of the depth in the scene was comfortably suprathreshold.

The 3" x 4" anaglyphs were mounted on a 6" x 8" black paper backing and the composite was covered in plastic protective material. The subject viewed the anaglyphs against a white background on a desk at the usual 40-cm viewing distance. Illuminance on the desk was 85 foot-candles.

A data taking session began with a measurement of horizontal fixation disparity with a Disparometer. The subject was then given the IPD set and was asked to arrange them on the desk in order of his/her impression of depth in the scene. For most subjects this was a fairly easy task and acquainted them with the ordering task at each session. The subject was then given the RP set and was asked to order them in the same way. A concluding measurement of fixation disparity was taken. The first data taking session served for teaching purposes and that data was discarded. At least five data sessions were then performed on the subjects with no more than on session per day. All sessions, after the training session, randomly allowed the subjects to start with either the IPD or the RP set first. This was accomplished by allowing the subject to choose the administrator's right or left hand while the sets were held out of sight.

## Analysis

The order was scored by assigning values 1 through 5 to the anaglyphs, multiplying by the rank-order position, and then adding the products to compute the score. In the case of the IPD set, the 0-cm IPD anaglyph was given a value of 1 the 3-cm IPD anaglyph was given a value of 2, and so forth up to the 12-cm IPD anaglyph being given a value of 5. After the subject had assigned a rank-order of 1 through 5 from least depth sensation to greatest, the value of an anaglyph was multiplied by its rank order and all five individual products were added to make up the subject's score for that session on the IPD set. A completely correct ordering of the IPD set yielded a score of 55 and a complete reversal a score of 35. A similar scoring system was used for the RP set. Here, the anaglyph with the reference plane in the front of the scene was given a value of 1, and successively back to the anaglyph with the reference plane at the back of the scene being given a value of 5. Thus a perfect score for a subject who preferred uncrossed disparities to crossed disparities on the RP set would be 35 and the perfect score of a subject who preferred crossed disparities would be 55. Those who had absolutely no preference would tend to score 45.

As a test for the scoring system, five numbered pennies were tossed 100 times to represent possible scores and distribution of scores. The result was a Gaussian distribution about the average score of 45. Thus the scoring system did not bias the results.

## Results

Five subjects with fixation disparity between 1' and 6' exo are included in the following analysis (See Appendices for subject scores and graphics). The average score of the exo fixation disparity subjects on the RP set was 48.2 with a standard deviation of 3.9. Five subjects having between 1' and 4' eso fixation disparity were also included. The average score of the eso fixation disparity subjects was 40.8 with a standard deviation of 2.6. An unpaired Student's t test indicated that this difference is significant at the $p<0.01$ level.

Two subjects with eso fixation disparity greater than 4 minutes of arc were also investigated. Both complained of a very difficult time doing the IPD task and scored in the mid-40 range. Interestingly both exhibited a strong preference for uncrossed disparities on the RP task. Three additional subjects had greater than six minutes of arc exo fixation disparity. These all did moderately well on the IPD set. On the RP set, one preferred crossed disparities, and the other two, against the prevailing pattern, exhibited a modest preference for uncrossed disparities. Clearly, more investigation is warranted on persons with higher amounts of fixation disparity.

## Discussion

Subjects with reasonable amounts of fixation disparity could arrange the IPD set in order according to the angular strength of the disparity depth cue. Thus, this rank-ordering task has potential as a component of a suprathreshold stereoscopic test. Accuracy, speed and IPD separation could be the dependent variables.

There is a difference in the rank-order preference between those with eso and exo fixation disparity on the RP task. Given acceptable amounts of fixation disparity, those subjects with eso fixation disparity preferred the reference plane to be in front, thus the whole scene was in uncrossed disparity with respect to the rim of the photograph. Similarly, those subjects with exo fixation disparity preferred the reference plane to be in back and the entire scene to be in crossed disparity. Is the explanation straightforward in that the subjects prefer to use their accustomed direction of disparity? If so, what about those who have different directions of disparity at different distances. Would they switch preference with observation distance? Another approach would ask if those who prefer to use uncrossed disparity have a smaller stereoscopic threshold in the "farther than" direction. A Howard-Dolman test situation using a JND criterion would shed light on this question. If a good correlation was found, one could say that uncrossed disparity is relatively well developed and therefore was preferred if the subject is given a choice in operational direction.

On the other hand, maybe the subjects do not use the rim of the target as the reference plane. They may move their reference plane about the scene as they examine the scene. One can conceive of the situation in which a subject with exo fixation disparity sets his reference plane (fuses on) a point near the back of the scene and thereby puts much of the scene in both crossed and uncrossed disparity near his horoptor. If this were the case, we could say that the better impression of depth comes about because of the fact that stereoscopic precision is best near the horoptor. A person with exo fixation disparity could achieve the same result by directing his attention onto a point near the front of the scene. This hypothesis could be examined by directing the subjects to order the RP anaglyphs twice: once keeping fixation toward the back of the scene and once by fixation near the front of the scene. We would ask that they not look about the scene as they were accomplishing the ordering task. Another means would be to limit the subjects' exposure time to each photograph.

Neither of the above two possible explanations is helped by the suggestion that subjects with very small fixation disparities seem to have less of a preference for ordering the anaglyphs in one particular direction. Inspection of the data (table 1) suggests that those with moderate amounts of fixation disparity have the strongest directional preference bias. As mentioned before, those with larger fixation disparities have trouble simply accomplishing the ordering task, especially on the IPD set. Those with very small fixation disparities seem to have little problem with the IPD set but don't seem to have a directional preference with the RP set; therefore they tend to have scores toward the middle of the scoring range. There is also the suggestion with the very large exo fixation disparity subjects that they may not use the same direction of fixation disparity when they attempt the very challenging rank-ordering task as when they made the nonius alignment on the Disparometer. Much more data needs to be collected and analyzed before the statements above can be said to hold with any degree of confidence.

The use of the IPD principle as a suprathreshold test of stereoscopic ability seems to be viable. Whether it is practicable is another question. Certainly the principle will work. Note that those with large amounts of fixation disparity have difficulty; those with small amounts find the task easy. Obviously, there is a question of the test's sensitivity. How much degradation in binocularity is needed to cause a problem in ordering on the IPD task? How does one determine if the subject is not intellectually capable or sufficiently experienced at psychophysical distinctions to accomplish the task? Such a lapse of capability could be mistaken for poor stereoscopic appreciation. The IPD task could be used, however, when the same subject must perform the task under different test conditions and can serve as his own control. Again, much more data needs to be collected and analyzed before these questions are answered.

References

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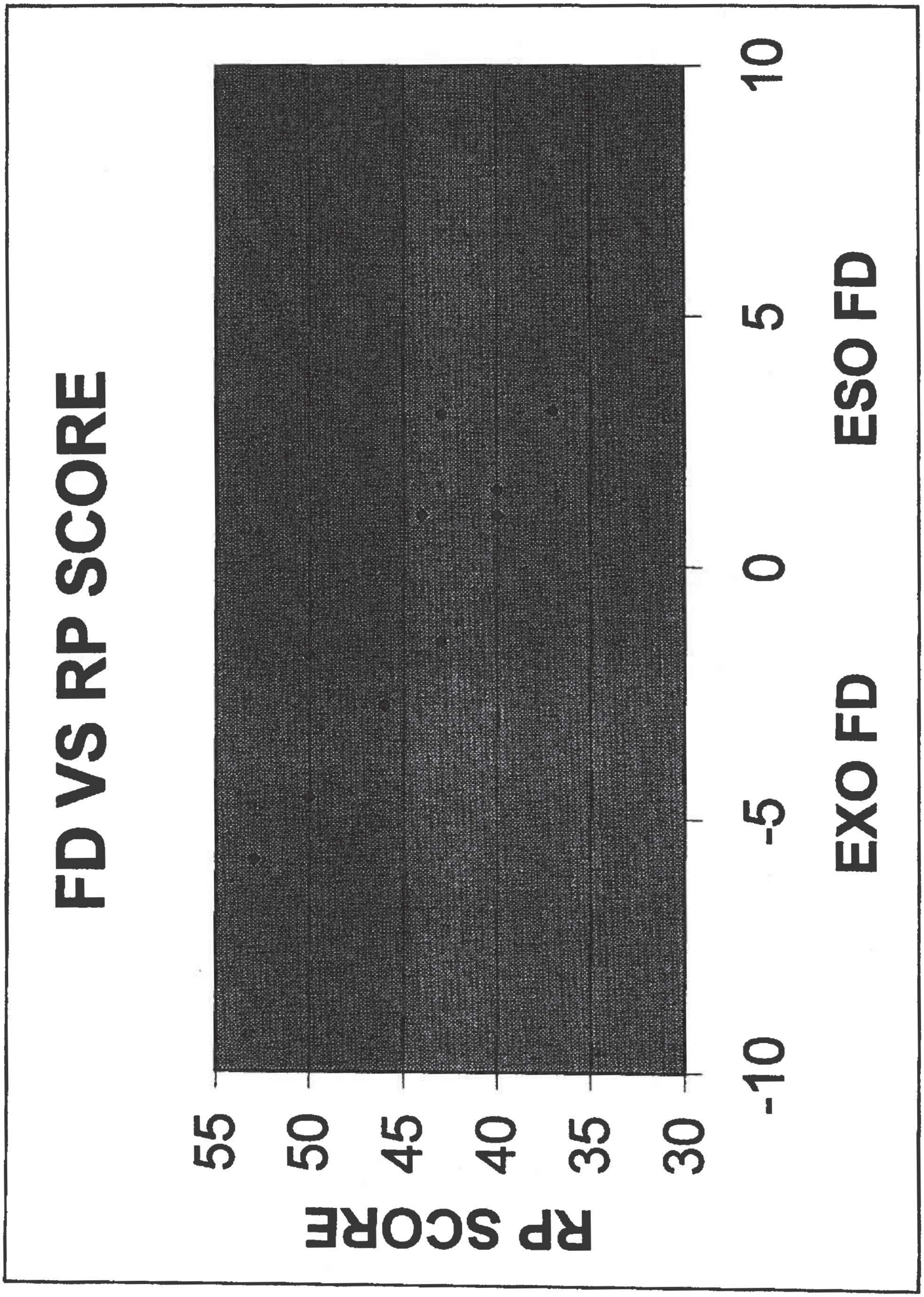
| | IPD score/σ | RP score/σ | FD'/σ |
|---|---|---|---|
| 1. | 54 / 1.8 | 43 / 3.1 | 3.0 eso / 1.0 |
| 2. | 54 / 1.5 | 40 / 4.5 | 1.0 eso / 2.0 |
| 3. | 54/ 1.2 | 37 / 1.9 | 3.1 eso / 1.9 |
| 4. | 54 / 1.1 | 44 / 5.7 | 1.0 eso / 2.1 |
| 5. | 53 / 1.9 | 40 / 1.7 | 1.5 eso / 0.9 |
| 6. | 50 / 4.1 | 43 / 3.7 | 1.5 exo / 1.2 |
| 7. | 48 / 7.0 | 50 / 3.1 | 4.6 exo / 3.2 |
| 8. | 54 / 0.8 | 53 / 2.5 | 5.8 exo / 2.9 |
| 9. | 54 / 2.2 | 46 / 4.2 | 2.8 exo / 2.8 |
| 10. | 54 / 0.8 | 50 / 2.5 | 1.8 exo / 2.0 |


FD VS RP SCORE
RP SCORE
55
50
45
40
35
30
-10
-5
0
5
10
EXO FD
ESO FD