STEREOSCOPIC VISION TESTING

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ABSTRACT

This paper makes a case for enriching the clinical investigation of stereopsis. A rationale is provided for extending the use of currently available tests to include the speed of attainment in the assessment of stereoacuity both behind and in front of the plane of regard. A research study on a group of university students using these additional parameters on three different stereoacuity tests is described.

KEY WORDS

stereoacuity, stereospeed, crossed disparity, uncrossed disparity, stereotest index, stereopsis, stereovectograms

Optometrists are accustomed to test stereoacuity in front of the plane of regard while using one type of test. In this paper we propose reasons for evaluating stereoacuity behind the plane of regard as well as in front of it; to use more than one type of test and also to assess time of performance. Clinically utilized stereo tests come with viewers set to assess stereoacuity in front of the plane of regard (crossed disparity mode), while stereoacuity behind the plane of regard (uncrossed disparity mode) is virtually never measured. Consequently, a potentially important aspect of stereopsis is ignored. In the same manner that base-out and base-in fusional ranges give important diagnostic information, so might assessment of these two types of stereoacuity be clinically valuable. There is evidence that an individual's crossed and uncrossed stereoacuities differ.[1]

There are three types of stereoacuity tests commercially available and clinicians most frequently use only one of these. However, each of these tests provides different stimulus conditions and might well yield different qualitative and quantitative measures of stereoacuity. Use of all of these tests on a patient would give information about the individual's stereoacuity under different form and contrast conditions.

The importance of assessing the time it takes for a patient to reach optimal performance on a given probe is becoming increasingly recognized.[2,3] Evaluating the time it takes to complete a test of stereoacuity should enrich our understanding of the quality of an individual's binocular vision.

VECTOGRAPHIC TESTS OF STEREOPSIS

Three types of Polarized vectographic tests have been developed in the last 40 or so years. The first of these was based on the principle of the Wirt circles.[4] This consisted of a series of binocularly dissociated disparate circles presented in a step-wise sequence of increasing difficulty. The measure of stereoacuity is directly related to the degree of disparity. A large disparity gives rise to the circle appearing a further distance from its non-disparate ground, while with a smaller disparity the circle appears at a lesser distance from its ground. The threshold measurement is the level at which the patient is able to recognize the smallest disparity; i.e., where the disparate circle can still be recognized in relief to its non-disparate fore- or background. The Titmus Stereotest[a] is such an example and is illustrated in Figure 1. This test contains clearly defined contoured circles in high contrast to their backgrounds. While the Titmus type instrument is extensively used by clinicians, evidence has been documented that it is possible to achieve correct answers on the first three to four targets by monocular cues alone.[5]

The answer to this problem of testing was apparently solved with the development of random dot element stereograms in the early 1960s through the research of Bela Julesz.[6] He demonstrated that when a pair of random element dissociated stereograms were produced with the same form displaced horizontally from each other, the form remains invisible monocularly, and appears in relief to a patient with stereoscopic appreciation. This discovery placed Worth's theory of the development of binocular vision in doubt for the first time since it was propounded in 1903.[7] Worth reasoned that the first step towards the developoment of binocular vision was the diplopic and simultaneous appreciation of form. This was followed by fusion of the two images and the eventual attainment of stereopsis, which Worth considered to be the highest grade of binocular vision. On the other hand, Julesz[8,9] considered stereopsis to be a lower level of binocular vision than form perception because his experiments showed that without stereopsis the form could not be appreciated monocularly. By incorporating the idea of random element stereograms, it was possible for the first time to produce a fool-proof test where there were no monocularly visible disparity cues and the ability of a patient to recognize the shape of an object was evidence that the patient saw binocularly and stereoscopically.

The Randot[6] test, illustrated in Figure 3 is an example of such a test. It has been reported that this test is difficult for some individuals.[10] This appears the reason for production of the third type of stereoscopic testing instrument which has become clinically popular during the last decade. The Randot Circle testb illustrated in Figure 2 appears to have been designed to meet the best of two worlds. By placing the contoured circles on a random dot background, a form of camouflage of the monocular disparities has been effected and at the same time the test of stereopsis has been easier to understand and administer than the pure Randot test

COMPARING THE PERFORMANCE ON THE THREE TYPES OF STEREO TESTS

It has been reported that most observers who do not have ocular abnormalities can discriminate depth differences produced by a relative disparity of as little as 10 seconds of arc.[11] However, the literature which provides this evidence does not describe the types of tests on which these acuities are attainable. It is our contention that stereoacuities should differ on tests which have different stimulus demands. Our study has therefore set out to test the three main types of stereoscopic tests in use today to determine whether most of our subjects, who were screened to rule out ocular abnormalities, could attain the 20 seconds of arc that was threshold on the tests we used.

METHODS

The stereoscopic tests used in our study were those manufactured by Stereo Optical Company.[b] These were:

1. the contour design (see Figure1);
2. the contour design with random dot background (see Figure 2);
3. the contourless design (random dot) (see Figure 3).

Each of these tests was manufactured so that the targets are presented in crossed disparity when viewed through the provided polarized filters. Consequently, the stereoscopic effect is one of recognizing the form in front of the background. By reversing the right and left polarized filters we were able to create an uncrossed disparity effect which enabled us to assess form lying behind the foreground. In this manner we extended the three testing conditions to six (see Table 1).

Research Population

The population for our experiment consisted of university students, in an age range of 17 years to 27 years, who met the criteria of a questionnaire and a vision screening (namely, that they were not aware of presenting with or had ever been treated for strabismus and that, in the screening they achieved at least 6/6 binocular distance visual acuity with or without spectacles). The first 60 males and 60 females who met these criteria were selected to act as our subjects.

The subjects were then assigned randomly to six male and to six female age-based groups so that the six tests could be carried out in different sequences to prevent any particular bias or learning effect.

Test Procedure

The stepwise instructional set was explained to each subject who was allowed to hold the test plate at his or her own comfortable working distance.The crossed or uncrossed disparity polarized

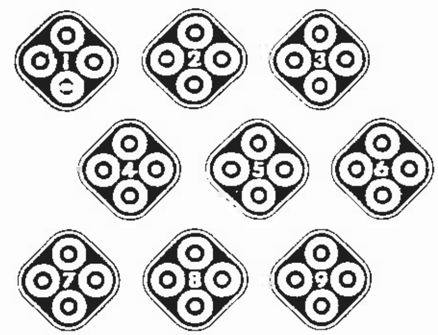


Figure 1. The contour design target.

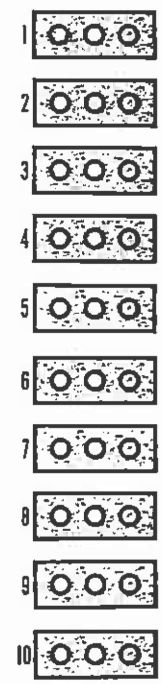


Figure 2. The contour design target with random dot background

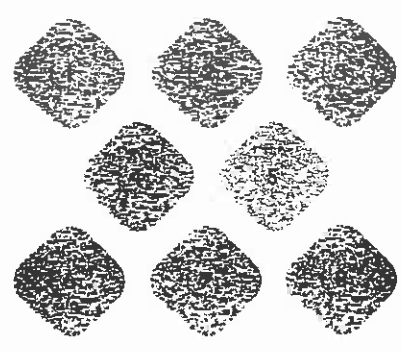


Figure 3. The contourless design target (random dot)

filters were then placed in front of the subject's eyes and the subject was required to work through the increasing difficulty sequence as quickly as possible while being timed in the process.The last correct response of his or her stereoacuity and the subject's near working distance at the completion of each test were recorded. The process was then repeated with the reversed polarizers for the same test design and was followed in the same manner for the other two test designs.In this way all six test procedures were carried out on each of the 120 subjects, but in a different sequence for the six groups.

Hypotheses

On the basis of our understanding of the various dimensions of stereopsis we hypothesized the following:

1. There would be differences in the performances of the subjects when using the same test design, with crossed as opposed to uncrossed disparity.
2. There would be differences in performance of the subjects when using the different test designs.
3. There would be male/female differences in performances because males are said to be more visually analytic and spatially aware than females.[12]
4. There would not be any significant age-related performance differences because of the narrow age range of our sample.

Derived Index

In order to assess the significance of our findings we derived an index relating the stereoacuity and speed of performance. The stereoacuities of all the tests we used were computed for a working distance of 40 cms. Because we allowed the subjects to choose their own working distances, this too had to be taken into account when deriving the following index

$$I = \frac{1000 \times d}{40 \times A \times S}$$

where

- I = index
- d= subject's working distance in cms.
- A= manufacturer's specified target stereoacuity in seconds of arc for a working distance of 40 cms.
- S= speed in seconds of time.

By using this procedure an index could be taken to mean that a subject had achieved a high level of stereoacuity at a high speed or was able to hold the test plate at a further working distance than 40 cms, or combinations of these. Examples of this can be shown by illustrating three hypothetical performances:

Subject A achieves 20" arc in 20 secs. at 40 cms which gives an index of 4000/1600 = 2.5

Subject B achieves 40" arc in 10 secs. at 40 cms which gives an index of 4000/1600 = 2.5

Subject C achieves 60" arc in 10 secs. at 60 cms which gives an index of 6000/2400 = 2.5

RESULTS

Stereo/speed Performance Index

Table 1 provides a description of the six test conditions.

The histograms (Figures 4-9) of all six test procedures show clearly that stereopsis does not follow a Gaussian curve of normal distribution. Further, while there are noticeable inter-test differences, they are not statistically significant. Each appears to indicate a mean index of approximately 2.5 with fairly wide standard deviations. This is shown clearly on the bar graphs (see Figure10).

Male/Female Differences (Table 2)

No significant differences were found between the male and female performances. While it has long been thought that males are more spatially aware than females and have a greater sense of directionality, our results do not confirm this on tests of stereopsis.

Crossed Disparity/ Uncrossed Disparity Differences (Table 3)

Of the three test designs, only one, namely the contour against random dot background test proved to be statistically significant at the p = 0,0093 level when comparing crossed as opposed to uncrossed disparity. In this test the subjects performed significantly better on the crossed disparity patterns, i.e. seeing the targets appear in front of the plane of regard, than with the uncrossed disparity patterns with pattern appearing behind the plane of regard.

The reason for this may be a tendency to overconverge when having to identify

Description of the stereotest conditions	
Test A	Crossed disparity/contour
Test B	Uncrossed disparity/contour
Test C	Crossed disparity/contour with random dot background
Test D	Uncrossed disparity/contour with random dot background
Test E	Crossed disparity/random dot
Test F	Uncrossed disparity/random dot

Table 1.

Levels of significance in male/female stereoacuity/time index performance

Test A crossed disparity/contour: not significant (p = 0,1724)

Test B uncrossed disparity/contour: not significant (p = 0,4539)

Test C crossed disparity/contour with random dot background: not significant (p = 0,2280)

Test D uncrossed disparity/contour with random dot background: not significant (p = 0,3645)

Test E crossed disparity/random dot: not significant (p = 0,1879)

Test F uncrossed disparity/random dot: not significant (p = 0,3245)

Table 2.

Levels of significance in stereoacuity/time index performances comparing crossed and uncrossed disparity on the same test

Test A crossed disparity/contour: **test B** uncrossed disparity/contour: not significant (p = 0,4494)

Test C crossed disparity/contour with random dot background: **test D** uncrossed disparity/contour with random dot background: significant (p = 0,0093)

Test E crossed disparity/random dot: **test F** uncrossed disparity/random dot: not significant (p = 0,9696)

Table 3.

Levels of significance comparing inter-test differences
Test A - Test C = not significant (p = 0,1231)
Test A - Test E = not significant (p = 0,0943)
Test C - Test E = not significant (p = 0,7991)
Test B - Test D = significant (p = 0,0007)
Test B - Test F = not significant (p = 0,3900)
Test D - Test F = significant (p = 0,0080)

Table 4.

AGE RELATED DIFFERENCES IN STEREOACUITY/SPEED PERFORMANCES

Stereotest	Group 1	Group 2	Group 3	
A	x_4:2,18	x_4: 3,16	x_4: 2,80	SIGNIFICANT (F=0,00)
B	x_4: 2,24	x_4: 2,26	x_4: 2,52	NOT SIGNIFICANT (F=0,009)
C	x_4: 2,01	x_4: 3,09	x_4: 2,69	SIGNIFICANT (F=0,003)
D	x_4: 1,67	x_4: 2,34	x_4: 2,27	SIGNIFICANT (F=0,042)
E	x_4: 2,25	x_4: 2,70	x_4: 2,64	NOT SIGNIFICANT (F=0,255)
F	x_4: 2,25	x_4: 2,71	x_4: 2,66	NOT SIGNIFICANT (F=0,303)

Table 5.

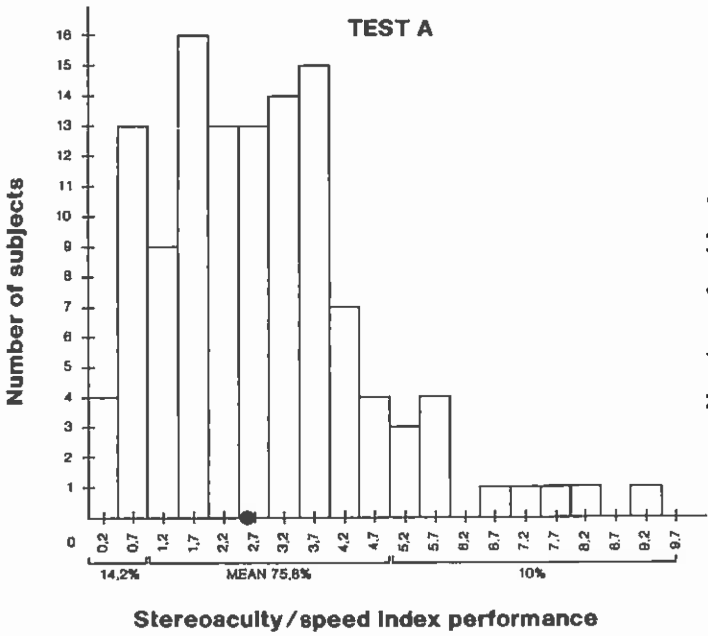


Figure 4.

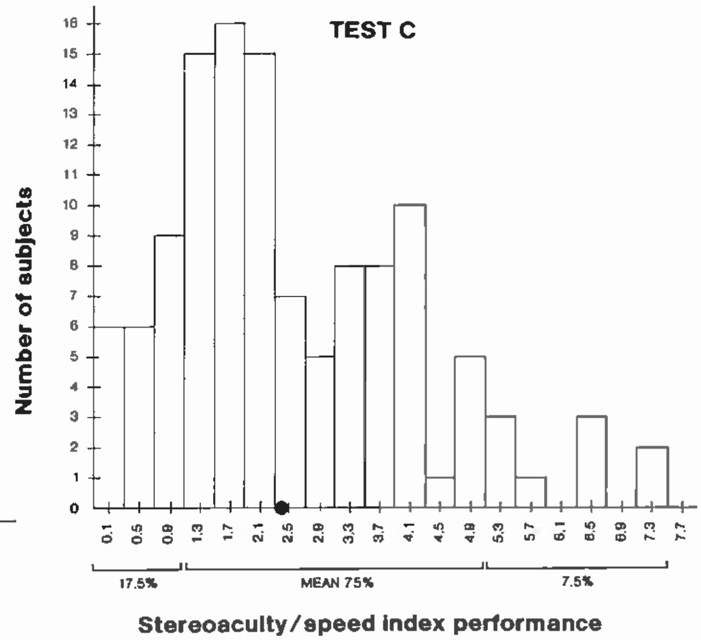
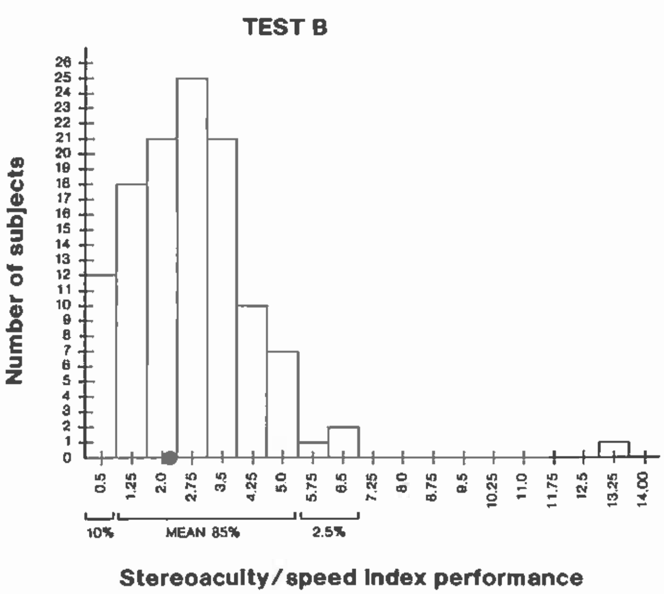


Figure 6.



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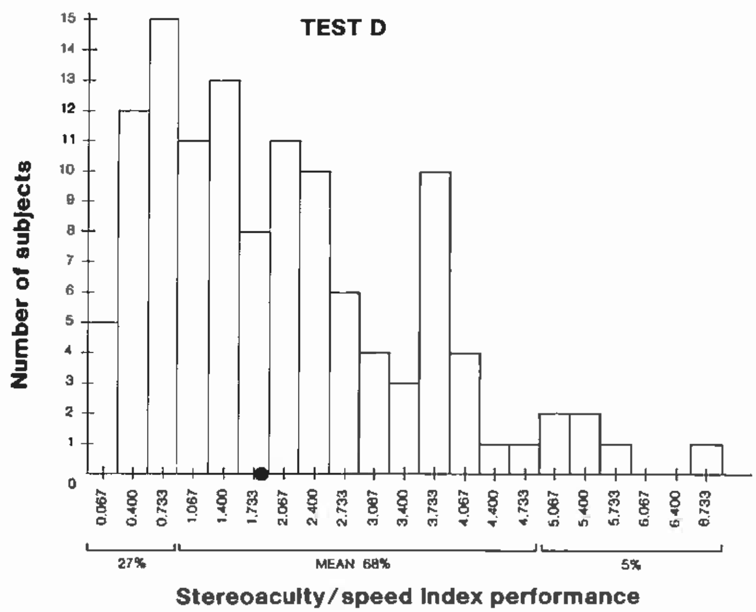

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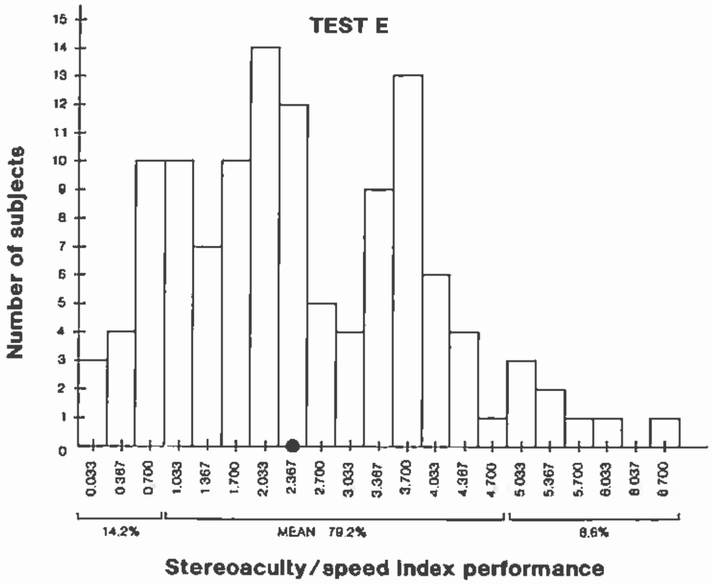

Figure 8.

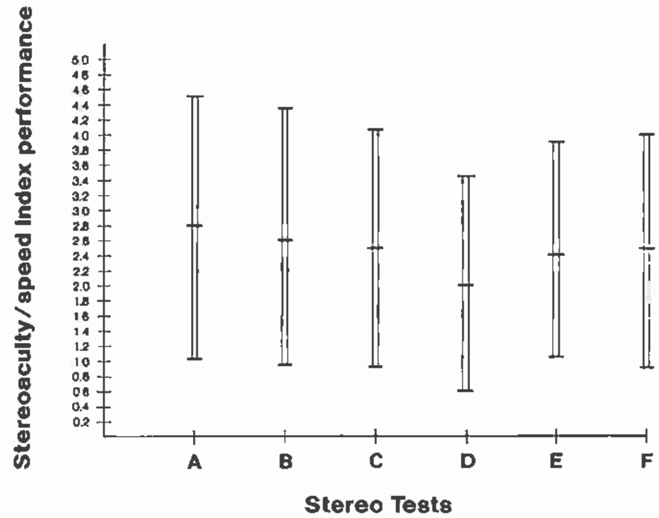

Figure 10.

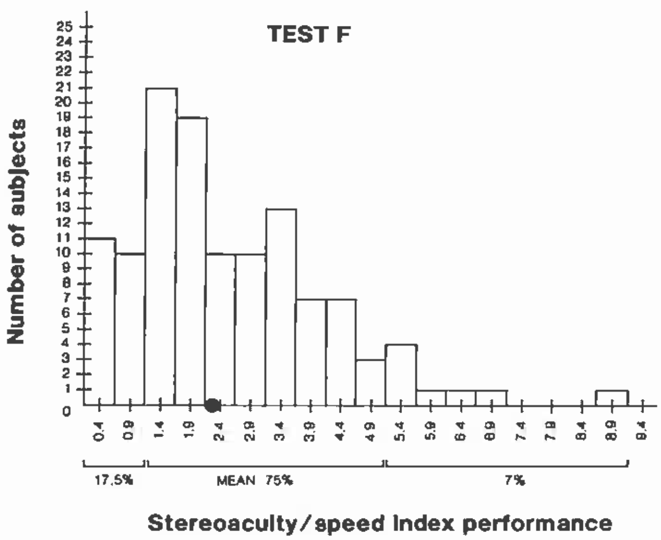

Figure 9.

Learning Curve: (t Test)

Test 1	Test 2	Level of Significance
1A	6A	not significant (p = 0,2742)
2B	5B	not significant (p = 0,6018)
5E	4E	not significant (p = 0,5850)
6F	1F	significant (p = 0,0034)

Table 6.

an object against a poorly contrasted ground and where disparity cues have intentionally been masked.

The reason why no significant differences are present with the contour test and the contourless test patterns would seem to be that each relies on unambiguous disparity, albeit distinctly noticeable in the case of the contour test and completely absent monocularly in the contourless test.

Inter-test Differences (Table 4)

Significant differences were found when comparing the uncrossed contour test with the uncrossed contour against random dot backround test with p = 0,0007; and with the uncrossed contour random dot background test compared to the uncrossed contourless test with p = 0,008.

The reason for this would appear to lie in the"noise" which occurs when the object cannot be separated easily from its ground in the case of the contour against random dot background and which does not occur in the other two tests.

Age Differences (Table 5)

Although we did not expect to find any significant age-related differences, we were surprised to find that our group two (ie. those between the age of 19 and 23 years) performed significantly better than group one (17- to 18-years) or our group three (over-23-years) on two of the six tests. In using the contour test, the middle order group yielded a freedom from error score, F = 0,000 for crossed disparity, and F = 0,009 for uncrossed disparity. For the contour against random dot background tests the scores were also impressive, namely, F = 0,003 for crossed disparity and F = 0,042 for uncrossed disparity. We have rationalized these findings by recognizing that we unintentionally drew our middle order group from optometry students who are familiar with the test patterns, where significant differences were found. This was substantiated by the fact that there were no significant differences found when the contourless series were used and which were just as unfamiliar to the optometry students as the other students used in the study. These findings may also have been the result of the small numbers of subjects in the younger and older groups (n = 18 and 14 respectively) when compared to the middle group (n = 88).

Learning Effect (Table 6)

Because of a mistake in our experimental design, we were not able to assess the learning effects of all six groups, but had to be content with comparing four groups. Out of this analysis we found that only one sequence proved significant with $p = 0.0034$ when comparing the uncrossed contourless test being administered first or last. We feel that we could have anticipated this result because the contourless tests appear to require an innate ability which is influenced by the experience gained in the other tests where form and disparity aid in appreciating stereopsis.

CONCLUSIONS

With the simple though highly sophisticated stereoscopic tests available today, the optometrist can gain valuable information concerning a patient's visual system. What makes this even more attractive, is the short time it takes to carry out these tests and the fact that they can be used from an early age. The ideal would be to use the three tests in conjunction with each other and in the uncrossed as well as the crossed disparity modes. We feel that we have shown that each of these tests assesses a different and special stereoscopic quality. The recognition of objects in front of the plane of regard and behind the plane of regard provides us with information about the function of specialized cortical cells and their pathways in the brain through the optic chiasma and the corpus callosum. Such findings may well throw new light on the etiology of stereoblindness and strabismus and help in identifying and localizing some pathological brain conditions.

We have shown that there are sufficient differences in performances on the three types of stereoscopic tests used in this study to justify the routine testing of both crossed and uncrossed disparity stereopsis as well as evaluating the three types of target presentation which have been described. In this respect it would be useful if an instrument could be designed and manufactured which would provide for the same number of targets and the same target shapes for the three different tests.The stereo/time index which we formulated in our study links stereoacuity to speed of performance. This index may prove useful in correlating academic,intellectual and sporting performance functions where space/time plays a role. A doctoral study is at present being conducted by the senior author of this paper to investigate these possibilities.

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