Stereopsis and unilateral brain disease

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Performance on a random-letter stereoscopic task has been reported to be affected by right but not left cerebral disease. Subsequent studies employing a conventional stereoacuity test have challenged these results and proposed that dementia may be the primary determinant of impaired stereopsis in patients with brain disease. The latter investigators have failed to distinguish between local and global stereopsis. The present study confirms the original findings, rules out dementia as a potential artifact, and attempts to reconcile the conflicting series of reports.

Key words: brain disease, cerebral cortex—right, dementia, random-pattern stereograms, vision tests—stereopsis, visual perception

In 1969 Carmon and Bechtoldt reported that patients with disease of the right cerebral hemisphere frequently performed defectively on a random-letter stereogram task (similar to the random-dot stereograms of Julesz), whereas patients with left hemisphere disease generally performed at a normal level. These findings were confirmed on a second sample of patients with unilateral brain disease by Benton and Hécaen. Subsequently, Durnford and Kimura found a left visual field superiority for the recognition of tachistoscopically presented random-dot stereoscopic forms in normal subjects. These results collectively support the inference drawn by Carmon and Bechtoldt that the right hemisphere is relatively dominant for stereopsis when there are no monocular form and depth cues.

Two recent studies employing the Titmus Test of stereoacuity have challenged this view. This multiple-choice task containing monocular form cues assesses level of stereoacuity within the range of 40 to 800 sec arc when viewed at the standard distance. Rothstein and Sacks reported that the stereoacuity of 8 patients with cerebral disease invading the right parietal lobe ranged from 50 sec of arc to gross stereopsis whereas neither of two patients with left parietal lobe damage showed any evidence of stereopsis. All 10 controls had 40 sec of arc stereoacuity. Upon this evidence they concluded that “involvement of the left parietal lobe appears to be related to a greater impairment of stereopsis than damage to the right parietal lobe.”

In a study by Lehmann and Wälchli, each Titmus Test target was briefly exposed to each subject four times. Frequency of errors rather than stereoscopic thresholds were recorded. The performance of patients with right hemisphere lesions did not significantly differ from those with left hemisphere lesions. However, patients judged to be intellectually normal performed better than patients described as intellectually impaired due to “disturbances of memory, orientation, arithmetic, logic, self criticism, activity and vigilance.” The authors concluded that “patient subgroups with different location of..."
brain lesions cannot be distinguished by employing graded task difficulties in depth perception (disparities) and, furthermore, "in our opinion, there is no reason to assume that the use of Julesz stereograms would basically change the result."

To account for the findings of the Carmon-Bechtoldt and Benton-Hecaen studies, Lehmann and Wälchli suggested there may have been an artifact in patient selection resulting in right hemisphere patients being more demented than left hemisphere patients. An alternative explanation, which would render the cited data as being generally consistent, assumes that there is a basic difference between tests of stereoscopic acuity and the Random-letter Test of Bechtoldt and that in this difference lies the source of differential hemispheric involvement in performance on this special type of stereoscopic task.

Certain procedural aspects of the two original studies have apparently been overlooked in the later studies. For example, in the Carmon-Bechtoldt study, all the patients demonstrated some degree of stereopsis prior to testing. Also, the smallest disparity of the stereotargets was 15.5 min of arc, which is above the disparity range sampled by the Titmus Test. More importantly, the degree of retinal disparity was not related to performance in any patient group, whereas matrix density (the number of stimulus elements in the display) had a significant and consistent effect in all groups. Similar results were reported by Benton and Hecaen, who selected their subjects on the basis of normal performance on the Keystone test, a conventional stereoacuity measure (slide DB6D of Test 7 from the Keystone Home Training Series). Both of the original studies found that matrix densities in the middle range (40% to 60%) were more easily identified than those at 100% matrix density by all patient groups. The 10% level of density was of intermediate difficulty. Thus the stereoscopic impairment observed among right-hemisphere-damaged patients occurred in the context of stereoacuity sufficiently keen to detect the depth effect. The evidence that performance was primarily determined by stimulus factors other than the degree of disparity supports the concept that the perception of random-letter stereoscopic targets involves distinctive visuoperceptive processes which are not assessed by conventional tests of stereoacuity.

The role of acquired general intellectual impairment (i.e., dementia) as a determinant of performance on either the stereoacuity or random-letter stereoscopic tests has not yet been adequately evaluated. The purpose of the present study was to retest the validity of the hypothesis of right hemisphere dominance for the perception of random-letter stereograms, to re-evaluate the effect of side of lesion on stereoacuity measures, and to assess the effect of acquired intellectual impairment on both types of performance.

Methods

Subjects. Patients were selected from the neurology and neurosurgery services of University of Iowa Hospitals and the Iowa City Veterans Administration Hospital. Qualifications for selection included age between 16 and 69 years and an unequivocal diagnosis of unilateral brain disease supported by at least one radiographic test (brain scan, computerized tomography, angiography) or the neurosurgeon's operative report. Additionally, each patient had to meet the following behavior and history criteria: right-handed as assessed by the Neurosensory Center Handedness Questionnaire, corrected (or uncorrected) near visual acuity better than 20/70 in each eye as assessed by the Bausch & Lomb Modified Orthorater, binocular single vision as assessed by screening stereoslides in the Realist Stereoviewer, no evidence of psychosis or history of psychiatric disease requiring hospitalization; no history or evidence of mental deficiency dating back to childhood and at least an eighth grade education. Patients with a history of ophthalmologic disorders sufficient to prevent the normal acquisition of stereopsis and patients with current ophthalmologic signs which would degrade or eliminate stereoacuity (e.g., ophthalmoplegia, diplopia) were not accepted for study. Cases were consecutively collected until there were 30 patients each in the right-hemisphere-damaged group (RH group) and left-hemisphere-damaged group (LH group).

For the LH group, the mean age was 47.6 years, and the mean educational level was 11.9
From arteriovenous malformations and aneurysms; neoplastic lesions refer to any tumor invading or compressing a cerebral hemisphere; traumatic lesions refer to the surgeon’s observation of a contused and/or lacerated brain with or without local edema; atrophic lesions refer to lobectomies, cortical excisions, focal cortical atrophy, or complete surgical removal of a tumor.

**Stereoscopic measures.** Patients viewed the demonstration stereogram of the Titmus Test\(^{11}\) and were asked to indicate the apparent spatial location of the wings of the fly by pinching them. In the few cases where the effect was not seen, the patients concurrently reported a history of an ophthalmologic disorder which would preclude the normal development of stereopsis and hence were excluded from the study. The testing followed the procedures in the accompanying instructions, using the prescribed viewing distance of 40.6 cm. Responses were made by pointing or naming the circle in each target which appeared in front of the others. Scores of 3 or less on the Titmus Test (stereoacuity $\geq 200$ sec of arc) were considered evidence of inadequate (defective) stereoacuity, since this corresponded most closely with the prescribed acuity criterion on the Keystone Test.\(^{10}\)

The Keystone and Random-letter tests were presented in a Realist Stereoviewer (Model 2062) mounted on a stand which could be adjusted for different viewing heights but precluded horizontal or vertical rotations. Illumination was held constant at approximately 3.5 ft-cd. Proper focus and ocular alignment were obtained with two preliminary slides. For the Keystone near-stereoacuity test (a slide consisting of 12 rows with five geometric figures in each) patients were asked to indicate which figure in each row appeared in front of the others. Scores of 8 or less (stereoacuity $\geq 216$ sec of arc) were considered evidence of inadequate stereoacuity. This slide also provided a test of ocular suppression. Patients were excluded if they reported strong ocular rivalry, visual suppression, or diplopic images and were unable to appreciate any stereoscopic effect on the Keystone slide despite readjustment efforts.

The Random-letter Test was introduced with the aid of a physical model depicting the anomalous square target and the letters carried with it, projecting out from one of the four quadrants. Testing was preceded by four demonstration slides.
(with 60% density and 46.5 min of arc disparity). Subjects were asked to identify the quadrant in which the square (the stereotarget) appeared by naming or pointing to its position on a chart placed below the stereoscope. The test consists of 24 stereoslides presented in a fixed order. Each slide contains a computer-generated 35 mm random-letter stereogram composing a square field of 23.3 degrees of arc with a smaller stereotarget square of 5 degrees of arc. The task employs two disparity levels, 15.5 and 46.5 min of arc, and three levels of matrix density, 10%, 40%, and 100%. Each disparity-density combination appeared in each of the four quadrants. Viewing time was restricted to 45 seconds per slide. A score below 16 was considered an impaired performance in accordance with the preset criterion.4-10 When there was a difference of more than 3 errors between either pair of homologous quadrants, the slides were reversed and presented again. The precaution was taken to control for an impaired performance occurring as a consequence of visual inattention, but in no case did this procedure result in raising a defective score to a passing score (or vice versa).

**Tests of intellectual functioning.** Separate subtests from the Wechsler Adult Intelligence Scale were selected for each unilaterally brain-damaged group in order to circumvent the confounding effects of focal lesions on measures of general intellectual functioning. Many LH patients were severely aphasic, thus precluding the use of verbal measures, and some RH patients suffered from constructional apraxia and visuoperceptive defects, thus rendering inappropriate any related tasks as indices of general intellectual functioning in these patients. Because it has generally been found that the mean Wechsler Performance IQ of LH patients closely approximates the mean Verbal IQ of RH patients,14 the measure of general intellectual functioning for LH patients was derived13 from the Block Design and Picture Arrangement subtests from the Performance Scale, whereas for RH patients the Arithmetic Reasoning and Similarities subtests from the Verbal Scale were employed. Each obtained IQ15 was compared with the patient's expected IQ based on his educational level. Since a previous study had found that 97% of control patients show discrepancies of less than 18 IQ points between obtained and expected scores,16 this empirical criterion was adopted to classify patients as to the presence or absence of general intellectual impairment. Additionally, LH patients were given the Visual Naming and Aural Comprehension subtests of the Multilingual Aphasia Examination15 to assess expressive and receptive aphasic disorders.

**Results**

**Group performance levels.** The distribution of scores for the two unilaterally brain-damaged groups were relatively homogeneous with the exception of the performance of RH patients on the Random-letter Test as shown in Fig. 1. On the basis of the raw scores from these tests, the statistical assumption of constant variance and covariance was rejected by Box's test (p < 0.0001). Therefore raw scores were converted to decimal percent correct scores and transformed into radian arc sin values. The transformed scores satisfied the statistical assumption (p = 0.124). An over-all analysis of variance for repeated measures yielded a main effect for groups (p = 0.013), a main effect for tests (p = 0.0004), and an interaction between groups and tests (p = 0.0055). Comparable results were obtained with raw score values.

The level of performance on the three stereoscopic tests did not differ for LH patients (p = 0.760), but there was a significant difference among performance levels for RH patients (p = 0.0002). Application of Tukey's test to the three mean scores for RH patients disclosed one difference that was significant beyond the 0.05 level: RH patients performed significantly worse on the Random-letter Test than they did on the Keystone Test (p < 0.01). There was only one significant between-group difference among the three tests: RH patients performed significantly worse on the Random-letter Test than did LH patients (p < 0.05). Thus it was essentially this interaction effect of a differentially poorer performance by RH patients on the Random-letter Test that accounted for the main effects for both groups and tests by the over-all analysis of variance.

**Analysis of defective performances.** Differences in the frequency of failing performances as defined by the predetermined criteria were assessed by Fisher's exact test employing one-tailed probabilities. Defective Titmus Test performances were encoun-
Table I. Differences in performance patterns* on tests of stereoacuity and the random-letter test

<table>
<thead>
<tr>
<th>Group</th>
<th>A = Titmus Test; B = Random-letter Test</th>
<th>A = Keystone Test; B = Random-letter Test</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A+/B+</td>
<td>A+/B−</td>
</tr>
<tr>
<td>LH</td>
<td>27 2 0 1 28 0 2</td>
<td></td>
</tr>
<tr>
<td>RH</td>
<td>18 10 1 1 19 7 4</td>
<td></td>
</tr>
</tbody>
</table>

*+ = pass; − = fail.

Table II. General intellectual impairment in relation to stereoscopic test performances

<table>
<thead>
<tr>
<th>Group</th>
<th>Titmus Test</th>
<th>Keystone Test</th>
<th>Random-letter Test</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pass</td>
<td>Fail</td>
<td>Pass</td>
</tr>
<tr>
<td>LH:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Normal</td>
<td>21 0</td>
<td>20 1</td>
<td>20 1</td>
</tr>
<tr>
<td>Demented</td>
<td>8 1</td>
<td>8 1</td>
<td>8 1</td>
</tr>
<tr>
<td>RH:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Normal</td>
<td>24 2</td>
<td>23 3</td>
<td>19 7</td>
</tr>
<tr>
<td>Demented</td>
<td>4 0</td>
<td>3 1</td>
<td>0 4</td>
</tr>
</tbody>
</table>

tered in one LH patient (3%) and in two RH patients (7%) (p = 0.500); defective Keystone Test performances were observed in two LH patients (7%) compared to four RH patients (13%) (p = 0.671); however, 11 RH patients (37%) versus two LH patients (7%) failed the Random-letter Test (p = 0.005). The LH group contained 18 aphasic patients (60%), yet for each test one failing performance was accounted for by a nonaphasic patient, suggesting that test performance was not related to the presence of aphasia.

Since a demonstrable impairment in stereoacuity may be a sufficient cause for failure on the Random-letter Test, it is of critical importance to examine the data for evidence of dissociated performances, i.e., instances of a passing performance on a stereoacuity test accompanied by a failing performance on the Random-letter Test. The distributions of the various performance patterns for each hemispheric group appear in Table I. The left side of this table shows the obtained distributions of performance patterns when the Titmus Test served as the criterion for adequate stereoacuity. A chi-square analysis indicated a significant difference between the two distributions (p = 0.043). Of particular interest is the fact that among LH patients with adequate stereoacuity, only two of the 29 cases (7%) showed the dissociation compared with 10 of 28 cases (36%) in the RH group (p = 0.006). More clear-cut results obtained when the Keystone Test served as the criterion for stereoacuity (right side of Table I). There was a distinct difference between the performance patterns of the two groups (p = 0.009). No LH patient who passed the Keystone Test failed the Random-letter Test, but seven of 26 (27%) RH patients showed this predicted dissociation in performance (p = 0.0009) and four of these patients (57%) had scores of 9 on the Titmus Test.

The relationships between general intellectual impairment and performance on the three stereoscopic tests within the two patient groups are presented in Table II. Nine LH patients (30%) and four RH patients (13%) showed significant intellectual impairment, but the difference in frequency between the two groups was not significant (p = 0.209). When Fisher's exact test was applied to the distributions in Table II, it was found that among LH patients no significant relationship existed between intellectual impairment and performance on the Titmus Test (p = 0.300), Keystone Test (p = 0.954), or the Random-letter Test (p = 0.954). Simi-
larly, in RH patients, no relationship with dementia was found for either the Titmus Test ($p = 0.747$) or the Keystone Test ($p = 0.925$). However, there was a statistical relationship between intellectual impairment and Random-letter Test performance for this group ($p = 0.012$). All four RH patients showing intellectual defect failed the Random-letter Test, although these cases accounted for only 36% of such failures. Similar results were obtained when the analysis was restricted to those RH patients with adequate stereoacuity as assessed by the Keystone Test: all three cases with intellectual impairment failed the Random-letter Test along with four of 19 nonimpaired RH patients ($p = 0.013$). The mean IQ of the LH group was 98.3, which was not significantly different from the mean IQ of 102.7 for the RH group ($p = 0.258$). When the intellectually impaired patients were excluded from the comparison, LH patients obtained a mean IQ of 106.0 and RH patients obtained a mean IQ of 106.1.

Discussion

The results confirm the discovery of Carmon and Bechtoldt $^1$ and replicate the findings of Benton and Hecaen. $^4$ It would be difficult to deny that within the right hemisphere there exists a mechanism which is intimately involved in the stereoscopic resolution of random-pattern stereograms. This mechanism, whatever its nature be, can evidently be selectively impaired by lesions in the right cerebral hemisphere without necessarily affecting stereopsis (stereoacuity) per se. Although inadequate stereoacuity, as defined by a predetermined criterion for the Keystone Test, was always associated with impaired Random-letter Test performance, as would be expected, there was no demonstrable relation between the side of the cerebral lesion and defective stereoacuity. Furthermore, supplanting the clinical concept of dementia with objective and validated measures of intellectual impairment, one must consider fallacious the speculation of Lehmann and Wälchli $^7$ that impairment in performance on the Random-letter Test in the original two studies $^1$ was the result of biased sampling or merely a reflection of "dementia." Despite the higher frequency of general intellectual impairment in LH patients (60% of whom were clinically and psychometrically aphasic), when defective stereoacuity according to the Keystone Test criterion was eliminated as a cause for impairment, only RH patients showed the specific predicted effect, and the majority of these (57%) were not "demented."

How do these results bear on our concepts of stereopsis? Julesz $^3$ speaks of two forms of stereopsis, local and global. Local stereopsis is the point-by-point matching of disparate stimulus elements in the two half-images with the assignment of a depth value for each. The process is presumed to occur at the level of the visual cortex by disparity-detecting neurons. $^6$ This binocular feature-disparity-matching process is presumed to be mediated in area 17 in cats $^{17}$ and in area 18 in monkeys. $^{18}$ Indirect evidence for the existence of such neurons in human subjects comes from psychophysical experiments employing afterimage effects to induce stereopsis. $^{19-21}$ In man these effects have been shown to exist within a range of disparities up to 16 min of arc. $^{21}$

Global stereopsis might be considered merely an explanatory concept; that is, it is invoked to account for phenomena that cannot be explained by local stereopsis mechanisms alone. For example, in terms of random-dot stereograms, local stereopsis could provide information for identifying disparities between stimulus units within the stereotarget (submatrix). But consider that for any one stimulus unit in the submatrix of one half-image, there are many corresponding units in the other half-image, each with different disparity values and directions (crossed or uncrossed). $^{16}$ In fact, this is what human subjects report when less than 80% of the dots in the submatrix are coded for disparity; that is, they report seeing some dots in front of the background plane, some behind it, and some at the same level, but they do not see a surface with a recognizable form. $^{22}$ (A few subjects in this experiment oc-
occasionally reported seeing individual letter elements in depth but could not make out the form of the target. This was counted as an error.) Also, global stereopsis can be obtained with stimulus units composed of vernier cues equal to or below the normal threshold of vernier acuity. Global stereopsis with random-letter stereograms can be produced with brightness patterns alone, in the absence of form disparity, and also in the presence of form rivalry. These facts do not fit the concept of local stereopsis (either central or peripheral) as a retinotopic matching of corresponding stimulus elements. Thus one function assigned to global stereopsis is the recognition of disparate but correlated brightness patterns that consequently allows for a uniform matching of disparate elements.

Qualitative perceptual differences also emphasize the need to distinguish local from global stereopsis. With global stereopsis one perceives a global form, or surface, with anomalous edge contours (neither of which are available under monocular inspection), as opposed to individual stimulus units appearing in depth. With the use of stabilized retinal images, random-dot stereograms can be pulled apart up to about 120 min of arc before diplopia occurs, whereas for solid-line stimuli (as might be used in conventional stereoscopic tests) this limit for fusion is about 65 min of arc. However, once these “break-away” points are reached, one need only return to a separation of 42 min of arc for fusion to occur with line stimuli, whereas random-dot stimuli require returning to within Panum’s area (6 min of arc). These perceptual and functional differences argue for the existence and uniqueness of global stereopsis.

Gulick and Lawson suggest that the contribution of global stereopsis to random-pattern stereopsis may be the ability to abstract from the binocular input the form of the target contained within these special stereograms. In one investigation they demonstrated the perception of a global form (a translucent square surface with sharp anomalous edge contours) in the absence of a brightness-pattern disparity or form-pattern (texture) disparity and on the basis of interposition cues alone. Regarding these anomalous edge contours which accompany global stereopsis and define the form of the matrix target, Coren has suggested that they are due to the same mechanism which results in the perception of anomalous forms and contours under monocular conditions. Although additional investigations are needed to determine the validity of this hypothesis, the current evidence is compatible with the concept that global stereopsis may result from cooperation between the mechanisms of local stereopsis in the visual cortex of both hemispheres and certain right hemisphere visuoperceptive mechanisms.

In summary, having excluded general intellectual impairment as an explanation for the findings in the Carmon-Bechtoldt and Benton-Hecaen studies, the present investigation confirms the hypothesis that the right hemisphere is dominant for global stereopsis but not local stereopsis. The additional mechanism(s) needed to achieve global stereopsis, while working with stereoscopic mechanisms, may not be of a strictly stereoscopic but of a more general visuoperceptive nature, perhaps those involved in utilizing subtle cues to achieve form recognition. Furthermore, this same right hemisphere mechanism may be operable under monocular as well as stereoscopic binocular vision. The fact that some right hemisphere lesions severely affect global stereopsis without destroying local stereopsis provides presumptive evidence of the anatomic and functional independence of these two capacities.

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