Stereoacuity Degradation by Experimental and Real Monocular and Binocular Amblyopia

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Fourteen normal adult volunteers with normal binocular single vision and normal stereoacuity submitted to monocular and binocular degradation of their stereoacuity by cycloplegia and fogging with spherical lenses. Stereoacuity (SA) was reduced as soon as visual acuity (VA), both monocular and binocular, was reduced. There was a marked similarity in the degree of SA reduction produced by monocular and binocular amblyopia. The degree of SA reduction was slightly more marked with monocular decrements than with binocular at VAs between 20/25 and 20/50. Significant intersubject variation was noted. The majority of subjects maintained gross SA at 20/200 monocular or binocular. One subject was reduced to gross stereopsis at 20/30 monocular and 20/50 binocular VAs. Two subjects were able to retain 40 sec of SA until vision was degraded to 20/50. Conversely, 40 sec of SA was not achieved by any subject at monocular or binocular vision less than 20/40 (test for malingering). Thirteen patients with real monocular and binocular organic or functional amblyopia were then compared with the experimental group. On the whole, patients scored somewhat better than normals but their scores fell within the range of responses found in the normal group. Invest Ophthalmol Vis Sci 26:917–923, 1985

Stereopsis is that unique quality of binocular vision that enables us to perceive depth in visual space. It arises from horizontal retinal image disparity between the two foveas or other corresponding retinal points: differeing amounts of such disparity give rise to differing sensations of depth. Just as visual acuity (VA) is graded in terms of minimum angular resolution of two distinct points, stereopsis can be graded (stereoacuity, SA) in terms of the smallest horizontal retinal disparity of images that gives rise to a sensation of depth.

Various abnormalities of the visual system, monocular and binocular, degrade stereopsis. Little data exists concerning the relationship between VA and SA. The present study attempts to clarify this relationship by answering these questions: (1) What effect does a decrement in VA (amblyopia)* have on SA in known normal individuals? (2) Is SA more sensitive to monocular decrements in VA (amblyopia)* or is it more sensitive to binocular decrements in VA? (3) What is the range of VA compatible with normal SA?

Previous references in the literature contain little precise information regarding the relationship between VA and SA. In 1942, Verhoeff[1] described a novel method of measuring SA using a device with deliberately misleading monocular clues; in a discussion of the new technique, the comment was made that several patients with "defective vision" could pass his test, but neither VAs nor SAs were stated. Colenbrander[2] constructed his own SA apparatus and, using himself as a subject, measured his SA after adding an "overcorrection" of up to +2.50D over one and then both eyes; he then measured his VA. He concluded that "stereoscopic vision ceased at a visual acuity of 1/10," but that "above a VA of 1/10 stereoscopic vision kept pace with the former." Significantly, Colenbrander felt that SA decreased more on "overcorrection" of both eyes than on one eye.

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* The term "amblyopia" is used in its broadest sense—a "blunting" of vision, a mild to moderate decrease in VA, organic or functional ("Dimness of vision; partial loss of sight" . . . Stedman's Medical Dictionary, 24th ed, Baltimore, Williams and Wilkins, 1982, p. 49).

Finally, he referred to a colleague who stated, as a result of examining aviators, "Poor VA is generally accompanied by diminished stereoscopic vision, but no regular correlation is to be found."

Burian[3] stated that SA in a normal observer decreased approximately in the same ratio as does the VA, but that VA can be normal without any stereopsis, or VA can be poor with good SA. Stigmar,[4] in an article on the effect of "blurred visual stimuli" on SA, referred to Frey who concluded that sharp retinal images were not a prerequisite for the perception of stereopsis; and to Ogle,[5] who stated that retinal images, if not blurred too much, "may result in only a small decrease in stereoscopic acuity from that with a sharp imagery." Stigmar himself concluded that visual stimuli could be blurred to some extent without appreciable effect on stereoacuity.

Minimal normal SAs for adults have been established by several investigators, including Parks,[6] Ogle,[7] and Scott and Mash,[8] as 40″ disparity. The latter added that 'achieving 40″ requires bifixation, adequate VA, and no manifest deviation.' Adequate VA was not defined, but all of their patients had 20/20 best-corrected VA.

40″ actually represents two standard deviations from the mean in Ogle's work ($\bar{x} = 20''$). Parks found a mean of 24″ in his normal patients. Subsequently, Romano et al[9] studied development of normal SA in children, finding that beyond age 9, normal Titmus Stereotest (TST) SA was 40″; below that age, 40″ could not reliably be expected. Normal limits for various ages were established.

There followed several papers on the use of stereopsis in amblyopia screening and additional data relating VA and SA. Simons and Reinecke[10] noted that all of their patients passing the TST at 100″ or better had no greater than one line of difference in VA, and VA of 20/30 or better in the worse eye. Patients with two lines or more of difference in VA, or monocular VA as poor as 20/300, were able to pass at levels up to 140″ on the TST. The same authors[11] describing the use of the Random-dot E stereogram (RDE) for amblyopia screening, found that those patients who passed that test at 1 m (252″ disparity) had one line or less of difference in VA, 20/25 or better in the worse eye, or were intermittent exotropes. Furthermore, no patient (with one exception) with more than two lines of difference in VA between eyes or 20/40 in the worse eye passed the RDE at all, indicating that the SA in these cases was worse than the 500″ disparity level at the usual testing difference. Simons,[12] in a still later article on normal SAs in children, commented that VA was found to be significantly correlated with SA in all studies in which both were measured, but that the relationship was only approximate. Importantly, he also speculated that bilaterally symmetric decrements in VA might have less effect on SA than on monocular decrements in VA.

The most direct data concerning SA and VA came from Levy and Glick[13] who studied subjects with normal VA, normal binocular vision, and normal stereoacuity. They monocularly degraded VA and measured TST SA at each decrement, finding a proportionate decrease in SA with decreases in monocular VA. When monocular VA had reached 20/200, mean stereoacuity was 160″, a level they felt was attainable on monocular clues alone. Although they did not specifically state the worst monocular VA compatible with 40″ stereoacuity, interpretation of their data showed this level to be 20/40. At the initiation of this study, theirs was the only such paper relating the effects of degraded VA on TST SA in adults free of other ocular abnormalities.

A study prior to Levy and Glick's does exist. Ong and Burley,[14] by adding ±2.0D lenses incrementally over the dominant eye, measured SA with the Howard–Dolman apparatus after inducing anisometropia in adults free of other ocular diseases. They expressed their results in terms of average error in rod alignment (implying decreased SA) and found greatest average errors with greatest induced anisometropia. However, the anisometropic VA was not measured in the experiment.

The present study was therefore undertaken to expand upon previous work regarding VA and SA.

Materials and Methods

Experiments on Normals

Fourteen normal, healthy adult volunteers aged 23 yr and older, and free of ocular disease, participated in this portion of the study. Informed consent was obtained prior to undertaking the examinations. The requirements were: (1) best-corrected Snellen VA of 20/20, distance and near, each eye; (2) no shift of either eye on cover test, distance and near; (3) fusion response at near on Worth Four-dot; (4) normal or atypical-1 response to 4-diopter base-out prism test; (5) 40″ stereoacuity on TST with near correction if needed; (6) no history of strabismus or amblyopia. We recognized the limitations of the cover test in detecting small manifest deviations[15] that might also go unrecognized by Worth testing at near,[16] and therefore required the 4-diopter prism test to aid in proving bifoveal fixation.[17]

These volunteers then underwent binocular cycloplegia with either Mydriacyl 1% or Cyclogyl 1%, one drop in each eye three times, separated by 5 min (Cyclogyl was the preferred drug and used in most cases; Mydriacyl was used only when prolonged cycloplegia was undesirable for occupational reasons). However, if Mydriacyl proved inadequate and the subject agreed to Cyclogyl, the latter was then used. In all cases, adequate cycloplegia was attained. Approximately 30 min after the last drop, testing was begun. The cycloplegic refraction was obtained and 20/20 Snellen acuity verified. Trial frames were placed on the subject, with Titmus polarizers in place. The controls then participated in the two consecutive experiments.

The polarizers were constructed by dismantling a pair of Titmus glasses. The right polarizer was removed and a circular disc, the same diameter as the optical portion of a trial lens, was cut from its center with a small mark at the 90° meridian. The disc was then glued at the edges to a plano trial lens, carefully aligning the 90° mark on the disc with the handle on the trial lens. The handle was etched with an "R". The identical procedure was used to produce a left trial lens polarizer. These trial lens polarizers obviated the need for simultaneous use of trial frames and conventional Titmus glasses.

A pilot experiment was performed on several subjects prior to formal testing. The purpose of the pilot experiment was to determine, among other things, the reproducibility of responses to the TST. With only an occasional exception, the subjects obtained the same level on the TST on repeated trials. On those occasions where the subject varied, not more than one step variation in the TST was found (ie, circles #5, circles #4).

Experiment 1: With polarized trial frames in place, near VA at 33 cm was measured monocularly in both eyes without correction, using a reduced Snellen near card. Based on the cycloplegic refraction, either plus or minus lenses as appropriate were added to produce a near acuity of 20/20 in one eye and 20/200 in the other eye. The 20/20 acuity was kept constant in one eye while the correction in the other eye was changed incrementally to produce graded improvement in the acuity of the subnormal eye (until 20/20 had been reached). At each step of monocularly decreased VA, from 20/200 to 20/20, the best TST score was recorded.

Experiment 2: The correction in the trial frames was changed as necessary to produce 20/200 near Va in both eyes. The correction was then symmetrically altered to produce equal increases in near VA in both eyes, in steps from 20/200 to 20/20. At each step the best TST course was recorded.

Careful attention was paid to testing distance for both near acuity and stereoacuity. To eliminate test performance on monocular clues, subjects were questioned as objectively as possible as to whether they perceived the circle as "elevated," "depressed," or "crooked." Further, the best SA recorded for each level of visual acuity was that noted by the subject to be depressed with the test book inverted. If none of the nine circles could be correctly identified in this way, the stereofly was used, and if perceived correctly, the SA was recorded at 3000″.

During testing the examiner did not tell the subject whether any response was correct or incorrect. He was careful not to give any clues in this regard to minimize any learning factor.

Each subject was observed by the examiner as the trial lens frame was changed at each step to make sure that any phorias which might have been present did not decompensate into a manifest tropia, especially with large decrements in SA. If there was any suspicion of a tropic state, cover testing was performed. No subject demonstrated such a change from phoria to tropia during the testing.

Clinical Comparison and Validation

The charts of 13 patients seen in the University of Florida Eye Clinic between September 1981 and May 1982 were reviewed. Each of these patients had had complete eye exams and was selected for this study because he/she met the following criteria: (1) subnormal Snellen VA in one or both eyes with best correction (ie, functional or organic amblyopia was present); (2) at least 9 years old; (3) no shift on cover test (two exceptions); (4) fusion at near with Worth Four-dot test; (5) no history of strabismus (except as mentioned later) or eye muscle surgery.

The 4Δ test was not recorded for all of these patients. The TST circles test was used to measure SA at near wearing conventional Titmus glasses and best near correction if needed. The SA recorded in the chart was assumed to have been verified by inversion of the test book. This is done routinely in our clinic, where SA is poorer than 100″, and could have been attained on monocular clues.

Results

Experiment 1

The data from the first experiment on normals are contained in Table 1. The best SA attained at each level of monocularly degraded VA is recorded, and the arithmetic mean has been calculated. There is a "statistically significant" relationship between monocularly degraded vision and SA ($P = 0.02$). Stereoacuity began to decrease immediately as monocular VA declined in most cases. The mean data are plotted in Figure 1 with a dashed curve. This curve has a steep initial portion in which very small monocular

Table 1. Experimental monocular amblyopia vs stereocuity data for all subjects

Control number	*20/20*	*20/25*	*20/30*	*20/40*	*20/50*	*20/70*	*20/100*	*20/200*
1	40″	50″	100″	400″	800″	3000″	3000″	3000″
2	40	40	80		80	200		3000
3	40	50		80		200	800	3000
4	40		60	100	100			3000
5	40			40		100		140
6	40	50		60		80	140	400
7	40	80	3000	3000	3000	3000	3000	none
8	40	50	60	80	140	3000	3000	none
9	40	40	100	400	3000	3000		3000
10	40	40	80	100	140	200	400	3000
11	40	100	200		800		3000	none
12	40	60	140	140	400	3000	3000	3000
13	40	40	60	60	100	400	3000	none
14	40	60	60	80	80	200	400	400
N	14	12	11	12	11	12	10	10
Mean	40	55	358	378	790	1365	2067	2267

Note. Vacant data sites resulting from an inability to experimentally adjust VA to the desired level in several normal subjects.

decrements in visual acuity caused large decreases in mean SA. For example, the mean SA at 20/25 monocularly was 55″, while at 20/30 monocularly mean SA had fallen to 358″. Between 20/40 and 20/50 monocularly the mean SA decreased from 378″ to 790″. At the 20/50 monocular level, mean SA had reached the level of the No. 1 Titmus circle, 800″. Thereafter on the curve, mean SA was worse than this level approaching the poorest measurable level, the Stereofly (3000″). Note: The flattening of the curve includes an artifactitious ceiling effect because several patients were unable to demonstrate any steropsis at that point (20/200).

Closer inspection of the data in Table 1 revealed several other interesting findings. The first was that

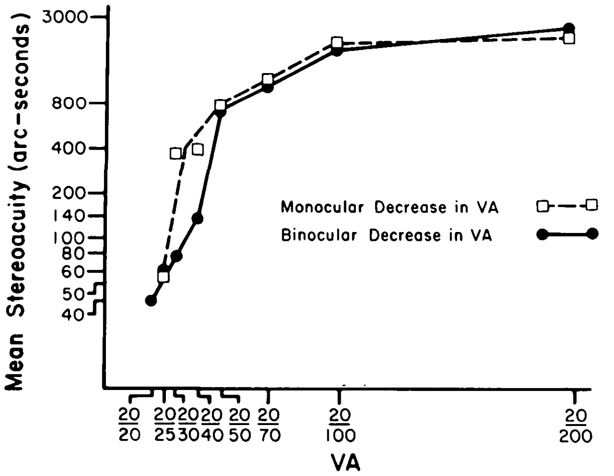

Fig. 1. Stereoacuity vs Snellen visual acuity. Relationship between monocular and binocular amblyopia and stereoacuity (mean values). *P* equals 0.02 for both monocular and binocular amblyopia. Note that between 20/25 and 20/50 stereoacuity decreases more rapidly with monocular amblyopia than binocular.

for each level of monocularly degraded VA there was considerable intersubject variation of best SAs, with smaller variations at better VAs, as might be expected. This variation might be explained by the second observation; for any given subject there appeared to be differing "sensitivities" of SA to monocular decrements in VA. As an example, subject 8 showed an evenly graded change in SA with monocular acuity, reaching 3000″ at 20/70, while subject 7 showed a precipitous change, reaching 3000″ at 20/30. Conversely, subject 5 retained an SA of 140″ at 20/200 monocularly. With the exception of one subject (also subject 5), no subject was able to achieve 40″ of SA with a monocular VA of 20/30 or worse. Subject 5 had 40″ of SA at 20/40 monocular VA but not at 20/50.

Experiment 2

The data are presented in Table 2 and Figure 1, and for each level of binocularly decreased VA the arithmetic mean has been calculated. There is a "statistically significant" relationship between binocularly degraded vision and SA ($P = 0.02$). In almost all cases, SAs began to decrease as soon as VA decreased. However, comparison of these means with those of experiment 1 from 20/25 to 20/50 revealed a very interesting finding: the mean SAs at 20/25 were virtually identical in the two experiments. Monocularly decreased at 20/30 and 20/40, the means were 358″ and 378″, respectively. Binocularly decreased at 20/30 and 20/40, the means were 78″ and 136″.

Thus, SAs were significantly better when the VA had been binocularly degraded rather than monocularly degraded. At 20/50 and worse, the monocular

Table 2. Experimental binocular amblyopia vs stereoacuity

Control number	*20/20*	*20/25*	*20/30*	*20/40*	*20/50*	*20/70*	*20/100*	*20/200*
1	40″	40″	40″	40″	80″	800″	3000″	none
2	40	50	50	50	100	3000	3000	3000″
3	40	50	80	80	80	140	400	3000
4	40		100	140		400	3000	none
5	40			40		200	400	3000
6	40	80	100		400	800		3000
7	40	140	140	400	3000	3000	3000	none
8	40	40	50	60	100	400	3000	none
9	40	80	80	200		400		3000
10	40	50	60	100	400	3000	3000	none
11	40	80	100	400	3000	3000	3000	3000
12	40	60	80	100	100	200	400	3000
13	40	40	60	100	200	400	3000	3000
14	40	60	80	60	80	100	100	140
N	14	12	13	13	11	14	12	9
Mean	40	70	78	136	685	1131	2108	2682

Note. Vacant data sites resulting from an inability to experimentally adjust VA to the desired level in several normal subjects.

and binocular mean SAs were again virtually identical. The mean SA had decreased to 685″ at 20/50 and 1131″ at 20/70, indicating that in this binocular acuity range, mean SA had fallen to the level of the No. 1 circle, 800″. Worse than this VA range, the mean SA approached 3000″, or the level of the Stereofly.

The mean SAs from experiment 2 are graphed in Figure 1, represented by the solid line. Comparison of this curve with the curve from monocular data immediately reveals the difference noted above. This difference was, however, significant only with a *P* value of about 0.10. The initial slope of the binocular curve was not as steep as the monocular curve, indicating between mean SA scores with slightly worse binocular acuity than comparable monocular VAs.

As in the first experiment, the best SAs at each level of binocularly degraded VA in experiment 2 showed a similar variation from subject to subject (the variations for both experiments are graphed in Fig. 2). This appeared to be accounted for in the same way by different "sensitivities" among subjects. However, it is noteworthy that, given the different "sensitivities," most subjects in experiment 2 showed a shift in their "sensitivity" to allow better SAs for a given VA than in experiment 1. For example, subject 8 (mentioned previously) achieved 3000″ at 20/70 monocularly, but decreased to 3000″ only at 20/100 binocularly. Subject 7, with a monocular VA of 20/30 achieved 3000″, but decreased to 3000″ in experiment 2 only when the binocular decrement in VA had reached 20/50.

Experiment 2 was always performed after experimen 1 and the question has been raised as to whether the better SA seen for binocular degradation in experiment 2 might be the result of a learning factor. We cannot absolutely rule this out but it is unlikely for several reasons: We minimized the learning experience by not informing each subject of whether his answers were correct or incorrect (see Materials and Methods). Also, the test was performed from poorest SA to best SA, and that sequence minimizes the exposures to the test materials. Finally, on the average, SA under binocular degradation was better than SA under monocular degradation only for a segment of VAs, from 20/25 to 20/50, not for the whole curve, which should have been the case if learning was a factor.

A normal SA of 40″ was retained by two subjects when binocular acuity was 20/40, but at 20/50 no subject saw 40″. The VA threshold of 20/40 or better

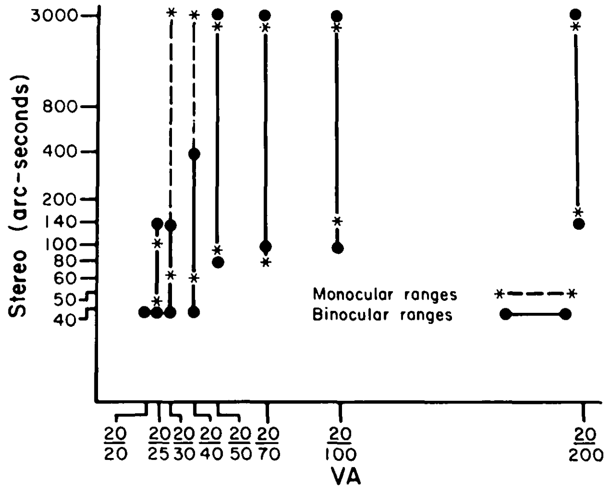

Fig. 2. Stereoacuity vs Snellen visual acuity. Relationship between monocular and binocular amblyopia and stereoacuity (ranges).

Table 3. Real functional and organic amblyopia vs stereoacuity

Patient number	*Diagnosis*	*OD*	*OS*	*Titmus*
1*	X(T), macular scar OS	20/20	20/60	80″
2	Anisometropic / Meridional amblyope OS	20/20	20/100	3000″
3	Meridional amblyope OU	20/25	20/30	50″
4	Anisometropic amblyope OD	20/30	20/20	40″
5	Early Best's disease OS	20/15	20/25	40″
6	Resolving papillitis OD	20/60	20/20	80″
7†	Meridional amblyope OS	20/20	20/30	100″
8	Anisometropic amblyope OS	20/20	20/40	400″
9‡	High hyperope (s̄c)	20/40	20/30	80″
10	Meridional amblyope OU	20/30	20/30	80″
11§	Accommodative ET Anisometropic amblyope OS	20/20	20/40	40″
12	Anisometropic / Meridional amblyope OD	20/30	20/20	40″
13‖	S/P PKP OD several years ago	20/30	20/20	40″

* Orthotropic when Titmus scores recorded.
† Tested with animals only.
‡ +5.50 OU, with 20/20′ OU and Titmus of 40″ c̄c.
§ Orthotropic at near c̄c.
‖ VA OD 20/20 prior to keratoplasty.

for the achievement of 40″ was identical in both experiments.

Clinical Study

In the final portion of this study, patients seen in our Eye Clinic with subnormal VA in one or both eyes were studied. The details of these 13 patients are given in Table 3. With two exceptions, all of these patients had no known abnormalities of binocular vision; the two patients who did have abnormalities had subnormal VA, which was not ascribed to strabismic amblyopia. The other patients largely were ametropic amblyopes, or had another identifiable cause for their subnormal VA. Most of the patients (10/13) had monocularly decreased VA.

Comparisons of these patients' SA scores with the mean SA scores of the appropriate control groups (ie, monocularly vs binocularly degraded VA) revealed that patients 2, 3, 8, 9, and 10 all scored either on the mean or very close. The remaining patients attained SA scores better than the mean SA scores predicted from the appropriate control group. As examples, patients 4, 11, 12, and 13 had monocular VAs of 20/30 or 20/40, and all had SAs of 40″. The mean SAs from the control groups with monocularly degraded VA were 358″ at 20/30 and 378″ at 20/40. However, all of these patients' SA scores fell within the range of responses found in the controls.

Discussion

The data collected in this study confirmed the opinions expressed previously in the literature, and confirmed the data from the previous studies, which suggested that VA and SA are indeed related, and are independent of other ocular abnormalities known to affect either. Most importantly, we have demonstrated a fundamental difference in the SA/VA relationship under conditions of monocularly vs binocularly degraded VA. In our normal subjects, with known normal VA, normal binocular vision, and normal SAs: (1) Performance on the Titmus test (ie, best SA) was definitely proportionate to the Snellen VA. (2) Mean SA deteriorated more rapidly between 20/25 and 20/50 with monocular decrements in VA than with binocular decrements in VA. (3) Between 20/50 and 20/200, mean SA appeared equally degraded by monocular and binocular decrements in VA. (4) There was significant variation from subject to subject in Titmus scores at comparable levels of degraded VA, suggesting differing "sensitivities" in the SA/VA relationship. Despite differing "sensitivities," however, each subject, almost without exception, showed better SA at each VA level with binocularly as opposed to monocularly decreased VA. (5) A monocular or binocular decrement in VA to 20/50 in all patients was required to reduce best SA beyond 40″. (6) Mean SAs and ranges for each level of monocularly or binocularly degraded VA (amblyopia) have been established for normals. (7) Data from study patients suggest that our mean control data may have relevance in predicting Titmus SA based on the level of VA in clinical situations.

Following completion of this study, another study[17] was published that essentially confirms our findings in the experimental monocular and binocular amblyopia groups. That study did not, however, compare their results to results in real clinical situations.

Key words: stereoacuity, amblyopia, binocular vision

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