Factors Influencing Stereoacuity Outcomes in Adults With Acquired Strabismus

SHERRY L. FAWCETT, PHD, DAVID R. STAGER, SR, MD, AND JOOST FELIUS, PHD

• PURPOSE: **Functional improvements of binocular vision after strabismus surgery in adults are common but not well understood. In a prospective study, factors associated with stereoacuity outcome in patients with strabismus acquired following binocular vision maturation were investigated.**

• DESIGN: **Prospective data collection.**

• METHODS: **Twenty-three patients aged 14 to 85 years with acquired strabismus were enrolled. Random dot stereoacuity was quantified using a battery of tests including the Randot Preschool Stereoacuity test, the Randot (version 2) shapes test, and the Randot Butterfly test.**

• RESULTS: **Ninety-six percent of patients achieved measurable stereoacuity following successful eye realignment. Better median stereoacuity is achieved in patients with the following characteristics: ≤12 months of constant strabismus (60 vs 400 seconds of arc with >12 months' strabismus, $P < .001$); a presurgical capacity for fine to moderate stereopsis (60 vs 400 seconds of arc with coarse or no measurable stereopsis, $P < .005$); a presurgical capacity for macular fusion (60 vs 400 seconds of arc with no measurable macular fusion capacity, $P < .001$); and postsurgical orthotropia (100 seconds of arc) or intermittent orthotropia (100 seconds of arc vs 2000 seconds of arc with 5 to 8 prism diopters (PD) of postsurgical residual strabismus, $P < .05$).**

• CONCLUSION: **Surgical correction of acquired strabismus is associated with recovery of stereopsis. Factors associated with stereoacuity outcomes include duration of strabismus and presurgical binocular vision capacity. A postsurgical correction of orthotropia or intermittent orthotropia supports better stereoacuity than a larger residual angle of strabismus subtending up to 8 PD of deviation. (Am J Ophthalmol 2004;138:931–935. © 2004 by Elsevier Inc. All rights reserved.)**

Accepted for publication July 13, 2004.

From the Retina Foundation of the Southwest, Dallas (S.L.F., J.F.); and Department of Ophthalmology, University of Texas Southwestern Medical Center, Dallas, Texas (S.L.F., D.R.S., J.F.).

Inquiries to Sherry Fawcett, PhD, Retina Foundation of the Southwest, 9900 N. Central Expressway, Suite 400, Dallas, TX 75231; fax: (214) 363-4538; e-mail: fawcett@retinafoundation.org.

GOOD SENSORY OUTCOMES ARE REPORTED IN adults treated for acquired strabismus.[1–9] Nonetheless, predictive factors for binocular vision outcomes in this population are poorly understood. Although some studies suggest that retinal correspondence, duration of strabismus, age of onset, number of surgical procedures, and type of deviation are good predictors of postoperative binocularity,[1–4] other studies report invariable postoperative binocularity.[5–9] Unfortunately, postoperative binocular sensory function is frequently reported as a noncontinuous variable and may be assessed with an assortment of possible tests. This makes it nearly impossible to correlate clinical factors with good versus coarse versus no binocular vision outcomes because no quantitative data are available or all patients present with the same categoric outcome. The aim of this study is to quantify binocular vision outcomes in patients undergoing treatment for acquired strabismus and to identify factors that may play a role in the restoration of binocular vision. We examined the influence of duration and type of constant strabismus, presurgical capacity for binocular vision, and postsurgical residual angle of strabismus on long-term stereoacuity.

DESIGN AND METHODS

• PATIENTS: Twenty-three consecutive patients with acquired strabismus between ages 14 and 85 years (mean age 47 years) were enrolled. Participants were referred from the clinical practice of one of the authors (D.R.S.) for participation in an ongoing prospective study of binocular vision outcomes among adults with strabismus. At enrollment, all had constant strabismus ranging from 12 to 45 prism diopters (PD), esotropia (ET), or 4 to 65 PD exotropia (XT) with or without a vertical component of 6 to 25 PD hypertropia (HT) in the primary position at near.

The inclusion criterion for patient selection was the presence of a constant eye misalignment with onset at or after age 9 years. Intermittent eye misalignment was present in some patients before age 9 years. Study exclusion criteria included any measurable stereopsis or sensory fusion before treatment (for example, patients failed the

0002-9394/04/$30.00
doi:10.1016/j.ajo.2004.07.030

TABLE 1. Pre- and Postsurgical Characteristics and Stereopsis of Adult Strabismus Patients

ID No.	Age at Treatment (yr)	Duration of strabismus	Etiology	Presurgical Deviation	Presurgical Binocularity* (Stereo)	Presurgical Binocularity* (M Fusion)	Postsurgical Stereopsis (sec of arc)
1	66	2 mo	Head trauma	35ET	400	Yes	60
2	32	3 mo	Unknown	4XT 10LhypoT	250	Yes	40
3	29	3 mo	Graves	10XT 16LhypoT	40	No	40
4	16	4 mo	Head trauma	35XT 6RhypoT	3000	Yes	40
5	47	< 6 mo	CN palsy	6XT 10RhypoT	3000	Yes	100
6	50	< 6 mo	Graves	8XT 25LhypoT	100	No	100
7	52	< 6 mo	CN6 palsy	12ET	40	Yes	60
8	14	4–7 mo	Childhood E(T)	14ET	100	Yes	60
9	33	6–9 mo	Unknown	25XT	800	Yes	100
10	30	< 12 mo	LASIK	20ET	200	Yes	40
11	27	13 mo	Childhood X(T)	20XT 25RhypoT	250	No	200
12	85	16 mo	Head trauma	20ET	2000	No	500
13	43	18 mo	Childhood acc ET	45ET	3000	No	2000
14	74	18 mo	Heat stroke	18LhypoT	400	No	250
15	36	13–18 mo	Childhood X(T)	65XT 6RhypoT	3000	Yes	200
16	76	26 mo	Unknown	18LhypoT	3000	No	2000
17	53	24–36 mo	Childhood X(T)	45XT	3000	No	100
18	63	32 mo	Graves	14XT 25LhypoT	3000	No	400
19	38	36 mo	Eye trauma	25XT	3000	No	400
20	30	6 yr	Trauma	6XT 25RhypoT	400	No	400
21	84	8–10 yr	Childhood X(T)	45XT	Nil	No	400
22	48	10–12 yr	Eye trauma	40ET	Nil	No	2000
23	65	54 yr	Childhood X(T)	55XT	Nil	No	Nil

E(T) = intermittent esotropia; ET = esotropia; hypoT = hypotropia; m fusion = macular fusion (pass/fail the Worth's 4-dot test at 3 m); nil = no measurable stereopsis; stereo = sec of arc; XT = exotropia.

Double line separates patients with ≤12 months constant strabismus from patients with >12 months constant strabismus.

*Presurgical binocularity (stereopsis and macular fusion) measured with angle of strabismus neutralized with loose prisms.

Titmus fly and the Worth's 4-dot tests at near), a difference in best-corrected visual acuity between the eyes greater than two Snellen lines (0.2 logMAR), an onset of constant eye misalignment before age 9 years, a childhood history of amblyopia or occlusion therapy, failed surgical eye realignment (> 8 PD of horizontal or > 4 PD of vertical residual strabismus), and a neurologic component resulting in an inability to complete the test protocol. Written informed consent was obtained before testing from all participants and the parents of minors when applicable. This research was approved by the Institutional Review Board of the University of Texas Southwestern Medical Center, Dallas, Texas, and followed the guidelines of the Declaration of Helsinki.

• **OBSERVATION PROCEDURES AND MAIN OUTCOME MEASURES:** Random dot stereoacuity was quantified pre- and postoperatively from 2000 to 40 seconds of arc using a battery of tests including the Randot Preschool Stereoacuity test (Stereo Optical Co. Inc., Chicago, Illinois), the Randot (version 2) shapes test (Stereo Optical Co., Inc.) and the Randot Butterfly test (Stereo Optical Co. Inc.). If random dot stereoacuity was not measurable with these tests, the Titmus fly (Stereo Optical Co., Inc.) was used to assess the presence or absence of coarse stereopsis. Macular sensory fusion was measured preoperatively using the Worth's 4-dot test at 3 m. All tests were administered in random order by one of the authors (S.L.F.).

Measurements of stereopsis and macular sensory fusion were completed before eye muscle surgery to confirm constant strabismus. The measurements were then repeated with the angle of strabismus neutralized with loose prisms to evaluate the patient's capacity for achieving binocularity following successful eye realignment. Eye alignment was measured using the simultaneous prism and cover test. Postoperative measurements of stereoacuity outcome and eye alignment were completed between 1 and 3 years postsurgery at the same appointment. Patients were tested with their best refractive corrections.

• **DATA ANALYSIS:** For the purpose of statistical analysis alone, the absence of measurable stereopsis was coded arbitrarily as 10,000 seconds of arc. The assignment of this

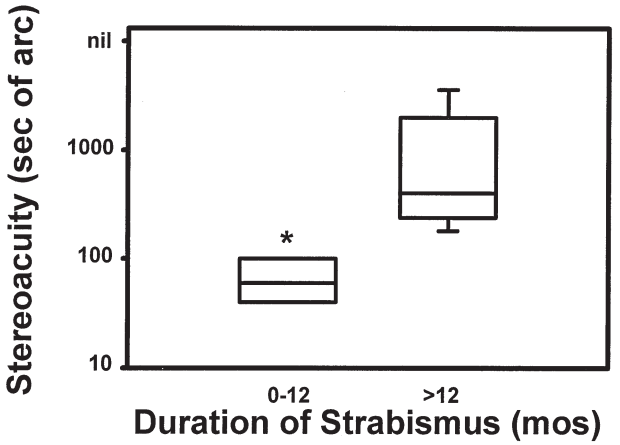

FIGURE 1. Median stereoacuity as a function of duration of constant strabismus. The median value is shown as a horizontal line. Boxes indicate the interquartile intervals (25th and 75th percentile). Error bars indicate the 10th and 90th percentile. Asterisk indicates statistically significant differences, $P < .001$.

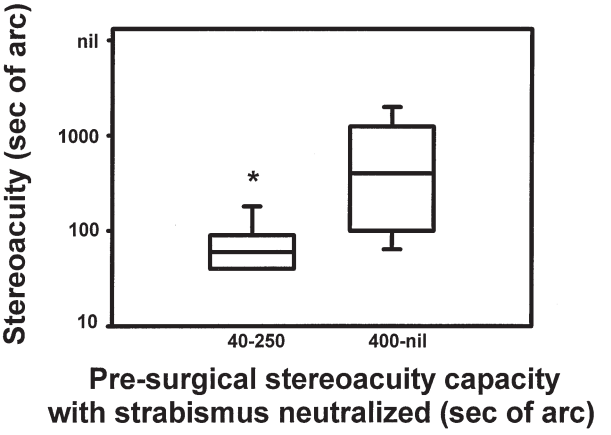

FIGURE 2. Median stereoacuity as a function of presurgical stereoacuity capacity (with angle of strabismus neutralized with loose prisms). The median value is shown as a horizontal line. Boxes indicate the interquartile intervals (25th and 75th percentile). Error bars indicate the 10th and 90th percentile. Asterisk indicates statistically significant differences, $P < .005$.

value has no bearing on the result of nonparametric analyses performed on ordinal data. Duration of constant strabismus was divided into two categories, 12 or fewer months and greater than 12 months. Duration of constant eye misalignment was determined from patient's self-report and from the medical records of the referring ophthalmologist. Because some patients had a known range of age onset only, the consideration of duration as a continuous variable was inappropriate. Presurgical type of strabismus was divided into three categories: ET, XT, and HT. Patients with a combination of horizontal and vertical misalignments were included in the HT group. Presurgical capacity for stereopsis with strabismus neutralized with prisms was divided into two categories: fine to moderate random dot stereoacuity (40 to 250 seconds of arc) and coarse random dot stereoacuity to no measurable stereopsis (400 to nil). Presurgical capacity for macular sensory fusion was divided into two categories: macular sensory fusion (a positive Worth's 4-dot response at 3 m) and no macular sensory fusion (a negative response on the Worth's 4-dot test at 3 m). Postsurgical residual angle of horizontal strabismus was divided into four categories: orthotropia, intermittent (variable) orthotropia, 1 to 4 PD, and 5 to 8 PD.

RESULTS

NINETY-SIX PERCENT OF PATIENTS (22/23) DEMONSTRATED recovery of some stereopsis following successful eye realignment. This data are summarized in Table 1.

Duration of constant strabismus was significantly associated with median stereoacuity outcome following successful treatment. The median stereoacuity of patients with a duration of constant strabismus ≤12 months was 60 seconds of arc, compared with 400 seconds of arc in patients with duration greater than 12 months (Mann-Whitney's rank sum test, T = 56.5, $P = .001$). As shown in Figure 1, the 10 patients who had constant strabismus ≤12 months' duration achieved significantly better median stereoacuity than the 13 patients who had constant strabismus >12 months' duration.

Presurgical type of strabismus was not associated with median stereoacuity outcome. Median stereoacuity values derived following successful eye realignment were not influenced by whether the patient had ET (N = 7, 60 seconds of arc), XT (N = 5, 400 seconds of arc), or HT with or without a horizontal strabismus component before surgery (N = 11, 200 seconds of arc; Kruskal-Wallis' one-way analysis of variance on ranks, H = 1.33, $P = .51$).

A presurgical capacity for fine to moderate stereoacuity (250 seconds of arc or better) was found to be associated with better median stereoacuity outcomes than a presurgical capacity for coarse or no measurable stereoacuity. As summarized in Figure 2, the seven patients who demonstrated the capacity for fine to moderate stereopsis before successful eye realignment with their angle of strabismus neutralized with loose prisms achieved significantly better median stereoacuity following successful treatment (60 seconds of arc) than the 16 patients who had coarse or no presurgical capacity for stereopsis (400 seconds of arc, Mann-Whitney's rank sum test, T = 41.5, $P = .005$).

Similarly, presurgical capacity for macular sensory fusion was found to be associated with better median stereoacuity following successful treatment than no presurgical macular sensory fusion capacity. The nine patients who exhibited the capacity for macular sensory fusion before treatment achieved significantly better median stereoacuity (60 seconds of arc) than the 14 patients who showed no capacity

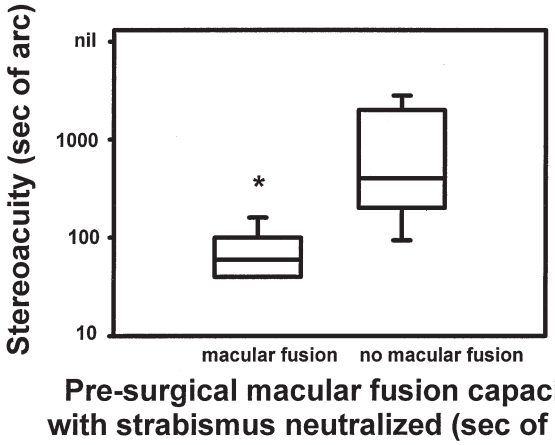

FIGURE 3. Median stereoacuity as a function of presurgical macular sensory fusion capacity (with angle of strabismus neutralized with loose prisms). The median value is shown as a horizontal line. Boxes indicate the interquartile intervals (25th and 75th percentile). Error bars indicate the 10th and 90th percentile. Asterisks indicate statistically significant differences, $P < .001$.

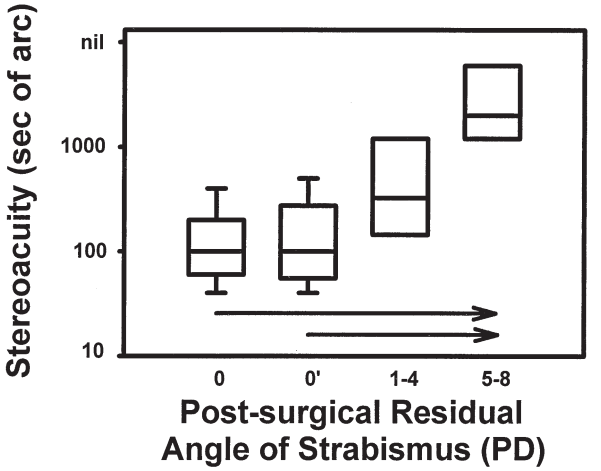

FIGURE 4. Median stereoacuity as a function of postsurgical residual angle of strabismus. The median value is shown as a horizontal line. Boxes indicate the interquartile intervals (25th and 75th percentile). Error bars indicate the 10th and 90th percentile. Arrows indicate statistically significant differences, $P < .05$.

for macular sensory fusion before treatment (400 seconds of arc, Mann-Whitney's rank sum test, T = 57, $P = .001$). These data are summarized in Figure 3.

Postsurgical residual angle of strabismus (10 patients with orthotropia, five patients with intermittent orthotropia, four patients with 1 to 4 PD and four patients with 5 to 8 PD) was also found to be associated with stereoacuity outcome (Kruskal-Wallis' one-way analysis of variance on ranks, H = 8.77, $P = .03$). As summarized in Figure 4, patients with orthotropia and patients with intermittent orthotropia both achieved median stereoacuity of 100 seconds of arc, significantly better than patients with 5 to 8 PD of residual strabismus (2000 seconds of arc; Dunn's method, $P < .05$).

DISCUSSION

IN THE PRESENT STUDY, NEARLY ALL (95.6%) PATIENTS with acquired constant strabismus achieved some recovery of stereopsis following successful eye realignment. The level of functional stereopsis acquired following successful treatment was found to be associated with duration of constant strabismus, the patient's presurgical capacity for binocular vision, and the residual angle of strabismus following treatment.

Just as in children with late onset accommodative strabismus,[10–12] duration of constant strabismus plays an important role in stereoacuity outcomes in patients whose onset of anomalous binocular vision occurs following binocular vision maturation. Patients with 12 months or less constant eye misalignment achieve significantly better random dot stereoacuity than patients with a longer period of eye misalignment. Early alignment of strabismus offers the best opportunity for the complete restoration of normal stereopsis, reducing the incidence thereby of less than perfect stereopsis (monofixation syndrome). These results suggest that the critical period of susceptibility for restoration of stereopsis may be a floating interval. In children with accommodative esotropia, a critical interval of 3 months is indicated.[10,11] Similarly, the data from this study suggest that a critical interval of susceptibility for restoration of stereopsis exists in adults. In adults, the critical interval of susceptibility may extend past 3 months because at least two patients with constant strabismus for a duration longer than 3 months (No. 8 and No. 10 in Table 1) recovered macular fusion. No patients recovered macular fusion following a period of 12 months' constant eye misalignment. As with any restoration of function following injury, we can always expect some individual variation in the ability of a biologic system to recover; whereas some individuals may have a shorter critical interval for restoration, other individuals may have a longer critical interval. Research is under way to determine the length of this critical interval of susceptibility in adults and to characterize critical periods of susceptibility for other measures of binocularity, which may have different underlying mechanisms.

Presurgical capacity for binocular vision (fine to moderate vs coarse or no stereopsis and a presence vs an absence of macular sensory fusion) is highly predictive of stereoacuity outcome following successful treatment. Presurgical measurement of the capacity for binocular visual function may indirectly benefit the patient, because it may encourage the patient and the physician to schedule surgery promptly, thereby reducing the duration of constant eye

misalignment. Coarse or no measurable presurgical capacity for binocular vision did not preclude the development of good stereopsis after surgery. As such, all patients with strabismus onset following the critical period of development should be offered eye muscle surgery.

The postsurgical residual angle of strabismus is associated with stereoacuity outcome. Patients with greater than 5 PD of residual deviation exhibit worse stereoacuity than patients with orthotropia or with intermittent orthotropia. This observation is in agreement with the recent finding that the maximum horizontal deviation that will support true stereopsis is 4 PD.[13]

Eye misalignment can have adverse psychologic,[14] social,[15–18] and functional effects on patients. It has been shown that realigning the eyes in adults leads to improvements of quality of life and social and economic benefits.[15–18] Good sensory outcomes have also been reported,[1–9] but the effects of strabismus surgery on visual function are not completely established. A better understanding of sensory outcomes, such as stereopsis studied here or other sensory aspects (for example, diplopia[19]), will facilitate better patient (and physician) education, which in turn may lead to more prompt treatment of the strabismus problem.[20]

ACKNOWLEDGEMENT

This research was conducted at the Retina Foundation of the Southwest.

REFERENCES

1. Scott WE, Kutschke PJ, Lee WR. 20th annual Frank Costenbader lecture—adult strabismus. J Pediatr Ophthalmol Strabismus 1995;32:348–352.
2. Hertle RW. Clinical characteristics of surgically treated adult strabismus. J Pediatr Ophthalmol Strabismus 1998;35:138–145.
3. Eustis HS, Parks MM. Acquired monofixation syndrome. J Pediatr Ophthalmol Strabismus 1989;26:169–172.
4. Umazume F, Ohtsuki H, Hasebe S. Predictors of postoperative binocularity in adult strabismus. Jpn J Opthalmol 1997; 41:414–421.
5. Kushner BJ. Postoperative binocularity in adults with long standing strabismus: is surgery cosmetic only? Am Orthoptic J 1990;40:64–67.
6. Kushner BJ, Morton GV. Postoperative binocularity in adults with longstanding strabismus. Ophthalmology 1992;99:316–319.
7. Lal G, Holmes JM. Postoperative stereoacuity following realignment for chronic acquired strabismus in adults. J AAPOS 2002;6:233–237.
8. Ball A, Drummond GT, Pearce WG. Unexpected stereoacuity following surgical correction of long-standing horizontal strabismus. Can J Ophthalmol 1993;28:217–220.
9. Mets MB, Beauchamp C, Haldi BA. Binocularity following surgical correction of strabismus in adults. Trans Am Ophthalmol Soc 2003;101:201–208.
10. Fawcett S, Leffler J, Birch EE. Factors influencing stereoacuity in accommodative esotropia. J AAPOS 2000;4:15–20.
11. Fawcett SL, Birch EE. Risk factors for abnormal binocular vision after successful alignment of accommodative esotropia. J AAPOS 2003;7:256–262.
12. Birch EE. Binocular sensory outcomes in accommodative ET. J AAPOS 2003;7:369–373.
13. Leske DA, Holmes JM. Maximum angle of horizontal strabismus consistent with true stereopsis. J AAPOS 2004;8:28–34.
14. Lipton EL. A study of the psychological effects of strabismus. Psychoanal Study Child 1970;25:146–174.
15. Burke JP, Leach CM, Davis H. Psychosocial implications of strabismus surgery in adults. J Pediatr Ophthalmol Strabismus 1997;34:159–164.
16. Satterfield D, Keltner JL, Morrison, TL. Psychosocial aspects of strabismus study. Arch Ophthalmol 1993;111:1100–1105.
17. Olitsky SE, Sudesh S, Graziano A, Hamblen J, Brooks SE, Shaha SH. The negative psychosocial impact of strabismus in adults. J AAPOS 1999;3:209–211.
18. Coats DK, Paysse EA. Impact of large angle horizontal strabismus on ability to obtain employment. Ophthalmology 2000;107:367–369.
19. Kushner BJ. Intractable diplopia after strabismus surgery. Arch Ophthalmol 2002;120:1498–1504.
20. Coats DK, Stager DR Sr, Beauchamp GR, et al. Reasons for delay of surgical intervention in adult strabismus. Arch Ophthalmol. Forthcoming.

Biosketch

Sherry Fawcett has a PH.D in Psychology from the University of Calgary, Alberta Canada. As an Associate Research Scientist at the Retina Foundation of the Southwest and an Adjunct Assistant Professor at the University of Texas Southwestern Medical School, she directs the Mary Crowley Binocular Vision Disorders Laboratory and the Crystal Charity Ball Vision Evaluation Program, both at the Retina Foundation of the Southwest.