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Relationship Between Binocular Summation and Stereoacuity After Strabismus Surgery

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Abstract

Purpose—To describe the relationship between binocular summation and stereoacuity after strabismus surgery.

Design—Prospective Case Series

Setting—Stein Eye institute, University of California Los Angeles

Patient Population—Pediatric strabismic patients who underwent strabismus surgery between 2010 and 2015.

Observation Procedures—Early Treatment Diabetic Retinopathy Study visual acuity, Sloan low-contrast acuity (LCA, 2.5% and 1.25%) and Randot stereoacuity 2 months following surgical correction of strabismus.

Main Outcome Measures—The relationship between binocular summation, calculated as the difference between the binocular visual acuity score and that of the better eye, and stereoacuity.

Results—A total of 130 post-operative strabismic patients were studied. The relationship between binocular summation and stereoacuity was studied by Spearman correlation. There were significant correlations between BiS for 2.5% LCA with near and distance stereoacuity (p=0.006 and 0.009). BiS for 1.25% LCA was also significantly correlated with near stereoacuity (p=0.04). Near stereoacuity and BiS for 2.5% and 1.25% LCA were significantly dependent (Pearson Chi Squared, p=0.006 and p=0.026). Patients with stereoacuity demonstrated significantly more BiS in 2.5% LCA of 2.7 (p=0.022) and 3.1 (p=0.014) letters than did those without near or distance stereoacuity, respectively.

Conclusions—These findings demonstrate that stereopsis and binocular summation are significantly correlated in patients who have undergone surgical correction of strabismus.

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Introduction

Strabismus affects approximately 2 to 5% of the population. Over the past few decades, vision researchers have sought to better understand the concept of binocular summation, defined as superiority of visual function of binocular over monocular vision[1], and how binocular summation may contribute to reduced visual performance of strabismic individuals. Two general hypothesis have been offered to explain binocular summation: a) "probability summation," the statistical improvement provided by two independently functioning eyes, or b) "neural summation" generating improvement exceeding statistical "probability summation." Visual task studies have since demonstrated that neural binocular summation likely arises from the cortical area V1[2,3] and that it generally provides approximately 40% improvement in visual function. In non-strabismic subjects, several factors including advanced age[4] and interocular differences in visual acuity[1,4–6] have been shown to decrease binocular summation.

It is well known that strabismus patients have deficits in depth perception and fusion tasks[7–9]. It was also recently shown that binocular summation is also adversely affected by strabismus[7]. Given that binocular summation can be easily measured without monocular cues that confound testing of stereoacuity, and that binocular summation can also be measured in patients without potential for stereopsis, we sought to describe the relationship between stereopsis and binocular summation.

Methods

This study was approved by the University of California, Los Angeles Institutional Review Board and conformed to the Declaration of Helsinki and requirements of the US Health Insurance Portability and Accountability Act. Subjects were recruited from patients at their post-operative month two visit after strabismus surgery at the Stein Eye Institute from the clinics of four authors (JLD, SJI, SLP, FGV) between the years of 2010 and 2015. Exclusion criteria included history of amblyopia, age younger than 3 years or older than 65 years, dissociated vertical or horizontal deviation as the sole form of strabismus, pathologic nystagmus, neurologic disease, or any structural lesion causing an interocular acuity difference exceeding 0.3 logMAR. Subjects were included irrespective of the age at onset of strabismus. In order to obtain a wider range of stereopsis levels, all post-operative patients were included regardless of whether their strabismus was adequately controlled post-operatively, or if they were believed to have potential for stereopsis.

High-Contrast Visual Acuity

Visual acuity was tested using the Early Treatment Diabetic Retinopathy Study (ETDRS) protocol at 3 meters. The score VA was the number of letters identified correctly, with a maximum score of 70 (Snellen equivalent 20/12.5).

Low-Contrast Visual Acuity

Sloan acuity was tested (Precision Vision, LaSalle IL) at low-contrast levels of 2.5%, followed by 1.25%, using the ETDRS protocol at 3 meters in a dimly lit room. Sloan charts have a similar format to the ETDRS charts (5 letters per line), with each Sloan chart corresponding to a different contrast level. The low-contrast acuity (LCA) score is the number of letters identified correctly, with a maximum score of 70 (14 lines).

Stereoacuity

Stereoacuity was measured at both near (40cm) and distance (3m) using Randot Stereotest (Stereo Optical Company). The stereoacuity score is recorded in seconds of arc distinguished by the subject, with the best score recorded at 40 seconds of arc and the worst score recorded at "nil". Participants who were unable to discern the grossest level of stereopsis were assigned a score of 10,000 seconds of arc in order to statistically distinguish them from those with some form of stereoacuity.

Statistical Analysis

All statistical analysis was performed using STATA 13.0 (StataCorp, College Station TX). Binocular summation was calculated by finding the difference between the binocular visual acuity score and the better visual acuity eye score (binocular score minus better eye score). As a conservative correction for test variability, a binocular summation score exceeding 5 letters (1 line) was required to demonstrate binocular summation. Similarly, binocular inhibition was considered to exist when the binocular summation score was less than −5 letters.

Stereoacuity scores were log transformed because of their non-normal distribution. The correlation between binocular summation and log stereoacuity was then calculated using a Spearman correlation. Stereoacuity scores were ranked as either (1) good stereoacuity (scores 40, 60, 80 & 100), (2) medium stereoacuity (scores 200 & 400), (3) low stereoacuity (score of 800) or (4) no stereoacuity. Binocular summation scores were categorized as either "summation" (for binocular summation> 5) or "no summation" (for binocular summation ≤5). 2×4 Chi squared analysis of binocular summation and ranked stereoacuity was then performed. Pearson Chi Squared Tests of Independence were performed to demonstrate whether binocular summation and stereoacuity are dependent variables. To study the difference in binocular summation between individuals with versus without stereoacuity, a two-tailed unpaired t-test was performed. P values less than 0.05 were deemed to be statistically significant.

Results

A total of 130 patients with treated strabismus were studied, of whom postoperatively, 51% experienced diplopia, 44% demonstrated near stereoacuity, and 32% demonstrated distance stereoacuity. Subtypes of strabismus included infantile esotropia (12%), childhood-onset esotropia (7%), acquired esotropia (14%), intermittent exotropia (24%), consecutive exotropia (14%), acquired exotropia (2%), congenital trochlear palsy (12%), acquired hypertropia (13%), combined horizontal and vertical deviations (2%). Demographics and visual acuity are summarized in Table 1.

Binocular Summation

The mean binocular summation scores are .34, .83 and −1.80 for ETDRS, 2.5% LCA & 1.25% LCA visual acuity tests, respectively. The means were not significantly different from zero for ETDRS or 2.5% LCA testing, but was significantly less for the 1.25% LCA (p=0.002), indicating binocular inhibition. 5, 16 and 8 percent of patients demonstrated binocular summation greater than 5 letters for the ETDRS, 2.5% LCA and 1.25% LCA visual acuity tests, respectively (Table 2). Table 3 shows the results of two-tailed T tests performed for mean binocular summation scores in those patients with and without stereoacuity for both distance and near. For 2.5% LCA, patients with stereoacuity had a significantly greater binocular summation of 2.7 (p=0.022) and 3.1 (p=0.014) letters than patients without near or distance stereoacuity, respectively.

Spearman Correlations

Statistically significant correlations were found between binocular summation for the 2.5% LCA and both near and distance stereoacuity (p=0.006 and 0.009, respectively). Binocular summation for 1.25% LCA also correlated significantly with near stereoacuity (p=0.04). R-values and corresponding p values for Spearman correlations of binocular summation with near and distance stereoacuity can be seen in Table 4.

Chi Squared Tests

Pearson Chi Squared Tests of Independence for the stereoacuity and binocular summation (binocular summation>5) demonstrated that these variables are mutually dependent (Table 5). Near stereoacuity and binocular summation for 2.5% LCA were shown to be significantly dependent to one another (p=0.006). Near stereoacuity and binocular summation >5 for 1.25% LCA also had significant mutual dependence (p=0.026).

Discussion

Previous studies have suggested a relationship between stereopsis and binocular summation; one investigation demonstrated that stereoblind subjects had significantly less binocular summation in pupillary response than normal subjects[10]. As well, a decrease in binocular summation in stereoblind individuals was demonstrated using visual evoked potentials[11] and contrast thresholds[2]. These data, along with the general understanding that binocular summation is a cortical function, suggests that stereopsis and binocular summation may be mediated by common neural pathways.[2]

In patients whose strabismus was surgically corrected, stereoacuity and binocular summation demonstrated a significant positive correlation for both 2.5% and 1.25% low contrast visual acuity. It is interesting to note that this relationship had a correlation coefficient of approximately 0.22, demonstrating that other factors probably contribute. This not only supports the understanding that stereopsis and binocular summation have common neural pathways, but also suggests that there are other significant factors governing the two variables. For example, in a child with infantile onset strabismus, suppression may be present, and this would likely lead to diminished binocular summation as well as a lack of stereoacuity. However, our study was not designed to evaluate specifically for suppression.

Alternatively, the low correlation coefficient could also be simply due to measurement noise and quantization. Patients with stereoacuity demonstrated greater binocular summation than those without stereoacuity. The strongest results were seen when visual acuity was measured using 2.5% low contrast acuity test for patients with both near and far stereoacuity.

Interestingly, when visual acuity was measured at high contrasts using the ETDRS test, no significant differences were seen in binocular summation between patients with and without stereoacuity. This distinction between low and high contrast visual acuity is also well described in the binocular summation literature, which shows binocular summation being more easily demonstrated in low contrast acuity. Similar to the crowding phenomenon, low contrast acuity is subject to more external noise than simple high contrast visual acuity. It is thought that low contrast acuity may reflect patients' daily environment, possibly explaining why strabismic surgery may improve a patient's visual function beyond improvements in diplopia[7,12] and regardless of whether they regain stereoacuity.

These results should be understood within the context of the study's limitations. First, this study was performed only post-operatively, thus it is not informative of patients' stereoacuity and binocular summation before surgical intervention. We have previously shown that binocular summation improves after strabismic surgery in this patient population, but the current study does not indicate if the relationship between stereopsis and binocular summation changes before and after surgery. This issue would be difficult to study, however, since the majority of strabismic patients before surgery have diminished stereoacuity. Secondly, we did not measure the subjects' suppression and thus cannot comment on its role in the relationship between stereopsis and binocular summation. Lastly, this study is correlative, and cannot support a causal relationship between binocular summation and stereopsis.

This study provides a better understanding of the relationship between stereopsis and binocular summation. We demonstrated that stereopsis and binocular summation are significantly correlated variables of visual function after surgical correction of strabismus.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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References

1. Blake R, Sloane M, Fox R. Further developments in binocular summation. Percept Psychophys. 1981; 30(3):266–76. [PubMed: 7322802]
2. Lema SA, Blake R. Binocular summation in normal and stereoblind humans. Vision Res. 1977; 17(6):691–5. [PubMed: 602028]
3. Blake R, Wilson H. Binocular vision. Vision Res. 2011; 51(7):754–70. [PubMed: 20951722]
4. Gagnon RW, Kline DW. Senescent effects on binocular summation for contrast sensitivity and spatial interval acuity. Curr Eye Res. 2003; 27(5):315–321. [PubMed: 14562168]

5. Jimenez JR, Ponce A, Anera RG. Induced aniseikonia diminishes binocular contrast sensitivity and binocular summation. Optom Vis Sci. 2004; 81(7):559–562. [PubMed: 15252357]
6. Pineles SL, Birch EE, Talman LS, et al. One eye or two: a comparison of binocular and monocular low-contrast acuity testing in multiple sclerosis. Am J Ophthalmol. 2011; 152(1):133–140. [PubMed: 21570055]
7. Pineles SL, Velez FG, Isenberg SJ, et al. Functional burden of strabismus: decreased binocular summation and binocular inhibition. JAMA Ophthalmol. 2013; 131(11):1413–19. [PubMed: 24052160]
8. Olitsky SE, Sudesh S, Graziano A, Hamblen J, Brooks SE, Shaha SH. The negative psychosocial impact of strabismus in adults. J AAPOS. 1999; 3(4):209–11. [PubMed: 10477222]
9. Satterfield D, Keltner JL, Morrison TL. Psychosocial aspects of strabismus study. Arch Ophthalmol. 1993; 111(8):1100–105. [PubMed: 8166786]
10. Sireteanu R. Binocular luminance summation in humans with defective binocular vision. Invest Ophthalmol Vis Sci. 1987; 28(2):349–55. [PubMed: 8591918]
11. Amigo G, Fiorentini A, Pirchio M, Spinelli D. Binocular vision tested with visual evoked potentials in children and infants. Invest Ophthalmol Vis Sci. 1978; 17(9):910–5. [PubMed: 700970]
12. Pardhan S. Binocular performance in patients with unilateral cataract using the Regan test: binocular summation and inhibition with low contrast charts. Eye (Lond). 1993; 7(Pt1):59–62. [PubMed: 8325425]

Table 1

Characteristics of Patients After Strabismus Surgery

Characteristic	Age at Visit, months	Age at Onset, months	ETDRS OU, letters	LCA 2.5% OU, letters	LCA 1.25% OU, letters	Near Stereoacuity Present, %	Distance Stereoacuity Present, %	Diplopia Present, %
All Patients (n=130)	442 (286)	242 (301)	55 (8)	31 (12)	20 (12)	44	32	51
Esotropia								
Infantile (n=15)	350 (234)	11 (11)	53 (7)	33 (120)	22 (12)	13	4	27
Childhood (n=9)	343 (329)	43 (21)	50 (5)	25 (15)	17 (13)	33	22	11
Acquired (n=18)	711 (216)	591 (283)	53 (10)	25 (13)	15 (13)	55	29	100
Exotropia								
Intermittent (n=31)	244 (195)	85 (89)	55 (10)	32 (12)	20 (13)	74	52	19
Consecutive (n=18)	354 (250)	32 (54)	58 (6)	38 (6)	27 (6)	0	11	11
Acquired (n=3)	364 (323)	284 (379)	53 (2)	35 (1)	21 (10)	33	0	33
Congenital SOP (n=16)	428 (201)	243 (220)	59 (6)	37 (8)	22 (10)	63	50	94
Acquired HT (n=17)	731 (179)	658 (217)	51 (7)	24 (14)	13 (13)	0	35	100
Combined V/H (n=3)	637 (304)	502 (414)	55 (2)	28 (6)	12 (13)	33	0	67

ETDRS: Early Treatment Diabetic Retinopathy Study; LCA: Low contrast acuity; BiS: Binocular summation score; SOP: superior oblique palsy; HT: hypertropia; V/H: combined vertical and horizontal deviation. (Standard Deviation)

Table 2

Binocular Summation Score Status of Patients After Strabismus Surgery

Test	**Binocular Summation (BiS>5)**	**Intermediate (BiS −5 to 5)**	**Binocular Inhibition (BiS <;5)**
ETDRS	5%	90%	5%
2.5% LCA	16%	76%	8%
1.25% LCA	8%	72%	20%

ETDRS: Early Treatment Diabetic Retinopathy Study; LCA: Low contrast acuity; BiS: Binocular summation score

Table 3

Mean Binocular Summation Scores of Patients With and Without Stereoacuity After Strabismus Surgery[a]

	Mean BiS ETDRS	Mean BiS 2.5% LCA	Mean BiS 1.25% LCA
Near Stereoacuity Positive	− 0.2	2.35	− 0.7
Near Stereoacuity Nil	0.7	− 0.35	− 2.5
p-value	p=0.233	**p=0.022**	p=0.119
Distance Stereoacuity Positive	1.12	2.95	− 0.9
Distance Stereoacuity Nil	− 0.02	− 0.15	− 2.2
p-value	p=0.162	**p=0.014**	p=0.298

ETDRS: Early Treatment Diabetic Retinopathy Study; LCA: Low contrast acuity; BiS: Binocular summation score.

[a]Two-Sample T Test

Table 4

Correlation of Binocular Summation and Stereoacuity in Patients After Strabismus Surgery[a]

	BiS ETDRS	BiS 2.5% LCA	BiS 1.25% LCA
Near Stereoacuity	R=0.0905, p=0.3099	R=−0.2426, **p=0.0058**	R=−0.182**, p=0.0398**
Distance Stereoacuity	R=−0.0628, p=0.4813	R=−0.2302, **p=0.0089**	R=−0.1289, p=0.147

ETDRS: Early Treatment Diabetic Retinopathy Study; LCA: Low contrast acuity; BiS: Binocular summation score.

[a]Spearman Correlation

Table 5

Pearson Chi2 Test of Independence of Graded Stereoacuity and Binocular Summation in Patients After Strabismus Surgery

	BiS ETDRS	**BiS 2.5% LCA**	**BiS 1.25% LCA**
Near Stereoacuity	Chi2= 4.69 p=0.196	Chi2= 12.32 **p=0.006**	Chi2= 9.23 **p=0.026**
Distance Stereoacuity	Chi2= 2.21 p=0.330	Chi2= 4.18 p=0.124	Chi2= 1.61 p=0.446

ETDRS: Early Treatment Diabetic Retinopathy Study; LCA: Low contrast acuity; BiS: Binocular summation score