Temporal Eye–Hand Coordination During Visually Guided Reaching in 7- to 12-Year-Old Children With Strabismus

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Purpose. We recently found slow visually guided reaching in strabismic children, especially in the final approach. Here, we expand on those data by reporting saccade kinematics and temporal eye–hand coordination during visually guided reaching in children treated for strabismus compared with controls.

Methods. Thirty children diagnosed with esotropia, a form of strabismus, 7 to 12 years of age and 32 age-similar control children were enrolled. Eye movements and index finger movements were recorded. While viewing binocularly, children reached out and touched a small dot that appeared randomly in one of four locations along the horizontal meridian (±5° or ±10°). Saccade kinematic measures (latency, accuracy and precision, peak velocity, and frequency of corrective and reach-related saccades) and temporal eye–hand coordination measures (saccade-to-reach planning interval, saccade-to-reach peak velocity interval) were compared. Factors associated with impaired performance were also evaluated.

Results. During visually guided reaching, strabismic children had longer primary saccade latency (strabismic, 195 ± 29 ms vs. control; 175 ± 23 ms; P = 0.004), a 25% decrease in primary saccade precision (0.15 ± 0.06 vs. 0.12 ± 0.03; P = 0.007), a 45% decrease in the final saccade precision (0.16 ± 0.06 vs. 0.11 ± 0.03; P < 0.001), and more reach-related saccades (16 ± 13% of trials vs. 8 ± 6% of trials; P = 0.001) compared with a control group. No measurable stereocuity was related to poor saccade kinematics.

Conclusions. Strabismus impacts saccade kinematics during visually guided reaching in children, with poor binocularity playing a role in performance. Coupled with previous data showing slow reaching in the final approach, the current saccade data suggest that children treated for strabismus have not yet adapted or formed an efficient compensatory strategy during visually guided reaching.

Keywords: eye–hand coordination, strabismus, saccades, reaching, binocularity

Strabismus affects 2% to 4% of children and results in discordant binocular experience when the visual and ocular motor systems are still developing.1,2 Even after surgical or optical intervention to align the eyes, esotropic strabismus (nasalward eye turn) is associated with visual deficits, including amblyopia, binocular dysfunction, and ocular motor deficits that persist into adulthood.3–8 Ocular motor deficits typical of strabismus include fixation instability,6,9,10 decreased vergence,7,11 and abnormal saccade initiation and execution.8,12,13 Most ocular motor studies have focused on adults with strabismus and little is known about ocular motor development in children with treated strabismus. Sensory and ocular motor impairments in strabismus may interfere with other developing systems, such as the motor system, and with the communication between the eyes and the hands, namely, visuomotor integration. Yet, no studies have examined ocular motor impairments in strabismic children in relation to eye–hand coordination.

Eye–hand coordination in three dimensional space is essential for efficient object manipulation, requiring depth perception cues to localize the object, plan the movements, and guide the arm toward the object.14–15 Normal binocular vision during childhood provides important sensory input for optimal development of eye–hand coordination.16–18 The use of binocular cues is immature during childhood,19,20 which could thus be disrupted by discordant binocular experience early in life from strabismus. Children with strabismus and amblyopia have impaired fine motor skills
that rely on eye–hand coordination, such as placing coins into a box, threading beads, and transferring answers to a multiple choice form.\textsuperscript{21–24} Poor performance was associated with binocular dysfunction (decreased/no measurable stereoacuity, suppression), regardless of whether amblyopia was present, indicating normal stereoacuity and fusion are essential to optimal task performance.\textsuperscript{21–23,25–26}

We previously reported that children with treated strabismus are slower at reach execution, especially in the final approach, with greater end point error than their peers with normal vision when asked to touch a dot on a screen.\textsuperscript{27} These findings suggest an inefficient use of visual feedback during online control of reaching in the final approach.\textsuperscript{28–30} During eye–hand coordination tasks, the eyes move first to fixate the target, providing high-resolution information about its physical properties and location, which can facilitate planning and execution of the reach.\textsuperscript{28–30} Given the sensory and ocular motor dysfunction typical of strabismus, information gathered after the saccade regarding a target’s physical properties and location may be suboptimal and could impact the control of the reach in the final approach.

Here, we use a protocol previously established in adults\textsuperscript{12,31,32} to examine visually guided reaching in children 7 to 12 years of age with a history of strabismus. We previously published reach kinematic data from this study as described elsewhere in this article.\textsuperscript{27} As a next step in the current study, we analyze the eye movement data and evaluate temporal eye–hand coordination to determine the extent to which strabismus impacts visuomotor integration, and explore clinical and sensory factors associated with deficits. We hypothesize that children with strabismus will have slower saccades with more corrections made during the reach. Further, we predict that poorer control will be associated with impaired sensory binocular dysfunction (i.e., decreased or no measurable stereoacuity, suppression). The current analyses provide further insight into the role of vision and binocular function in the development of visuomotor integration, which may guide interventions to ameliorate or prevent eye–hand coordination impairments in children with strabismus.

**METHODS**

**Participants**

Children 7 to 12 years of age diagnosed with esotropic strabismus (herein called strabismus) alone or strabismus and anisometropia were referred to the Retina Foundation of the Southwest by Dallas–Fort Worth pediatric ophthalmologists. Strabismic children were aligned with surgery or spectacle correction to less than 12 prism diopters of orthotropia at near at the time of testing. Age-similar control children with age-normal visual acuity and stereoacuity and no history of vision disorders were also enrolled. Testing was completed with the child’s habitual spectacle correction. Diagnosis, current alignment, and prior treatment were extracted from medical records obtained from the child’s referring ophthalmologist. All children spoke English as their primary language. Children who were preterm (<37 weeks gestational age) or had coexisting ocular or systemic disease, congenital infections or malformations, or (neuro)developmental delay were excluded from the study. Only children with arm lengths (shoulder to fingertip) of 50 cm or greater were enrolled.

**Ethics**

The research protocol observed the tenets of the Declaration of Helsinki, was approved by the Institutional Review Board of the University of Texas Southwestern Medical Center and conformed to the requirements of the United States Health Insurance Portability and Privacy Act. Informed consent was obtained from a parent or legal guardian and assent was obtained from children 10 years or more of age before testing and after explanation of the study.

**Procedure**

**Vision Assessment.** A vision assessment was conducted before visually guided reaching, (1) Crowded monocular best-corrected visual acuity with the Electronic Early Treatment Diabetic Retinopathy Study protocol, scored in logMAR.\textsuperscript{30} Amblyopia was defined as an interocular difference of 0.2 or more logMAR, with best-corrected visual acuity in the fellow eye of 0.1 logMAR or less (20/25 or better). (2) Stereoaucuity with the Randot Preschool Stereoaucuity and Stereo Butterfly Tests,\textsuperscript{30} converted to log arcsec (ranging from 1.3 to 3.3 log arcsec). No measurable stereoaucuity was arbitrarily assigned a value of 4 log arcsec. (3) Extent of suppression was quantified with the Worth four-dot fusion test at seven different distances, measured as the farthest distance that four dots are reported, converted to size of suppression scotoma in log degrees.\textsuperscript{35,36}

**Visually Guided Reaching.** A detailed description of the setup and testing protocol can be found in our recent article that reported reach kinematics data from this study.\textsuperscript{27} Briefly, children wore their habitual optical correction with both eyes open, used their self-reported dominant hand, and sat at a table with their head stabilized at a 35-cm viewing distance. The initial hand position required the child to use their index finger and thumb to hold a stick attached to the table at body midline 5 cm from the eyes (Fig. 1). Reach kinematics were recorded with the Leap Motion Controller system (LMC) recorded hand movements.

![Figure 1](image-url)
system (software version 4.0; Leap Motion Inc., San Francisco, CA, USA) placed 10 cm in front of the initial hand position. Eye movements were simultaneously recorded with a 500-Hz high-speed video binocular eye tracker (EyeLink 1000; SR Research, Ontario, Canada) placed behind and above the display monitor 45 cm from the child's eyes. Pilot testing showed this eye tracker position was best to avoid occlusion of the eye tracker by the hand or display monitor.

Separate five-point horizontal calibrations were performed for the index finger (touch each dot as accurately as possible) and the eyes (look at each dot for 4 seconds) during binocular viewing using a 0.3° white dot presented sequentially from left to right at −10°, −5°, 0°, +5°, and +10°. In the experimental trials, the child was instructed to fixate a white cross (1.4°) with a red dot in the middle centered on the screen with both eyes open. Once the cross disappeared, a 0.3° white dot appeared randomly at one of the four locations along the horizontal meridian (±5° or ±10° from fixation). The child was instructed to reach out and touch the dot with the tip of their index finger as quickly and accurately as possible. A total of 40 trials were completed per child, with the first four counting as practice trials (36 experimental trials). Testing time was approximately 15 minutes.

Data Processing

Saccade Kinematics. Eye position data per eye were filtered with a low-pass second-order Butterworth filter and a cutoff frequency of 80 Hz. Filtered data was used to obtain eye velocity using a two-point differentiation method. A custom MATLAB script (MathWorks Inc, Natick, MA, USA) identified primary saccades using a velocity threshold of 30 deg/s. Each trial was inspected visually to confirm that saccades were correctly identified by the custom script and to ensure that both eyes moved together. A primary saccade was the first saccade that occurred within 80 to 1000 ms after target onset in the correct direction, with a gain of 30% or more of the expected amplitude. Corrective saccades were those occurring within 50 to 250 ms after the primary saccade. Reach-related saccades were those occurring more than 250 ms after the primary saccade ended and during the reach. This latency distinction between corrective and reach-related saccades is based on research showing that corrective saccades typically occur with a latency of 250 ms.37,38 To minimize the risk of categorizing a microsaccade as a corrective or reach-related saccade, we only included saccades that were 0.4° or more. Trials were excluded if data was missing (i.e., blink, lost tracking of eye) or noisy during the period from 250 ms before target onset to the end of the primary saccade.

Mean saccade kinematic measures include (1) primary saccade latency: time from target onset to saccade initiation; (2) primary saccade gain: ratio of saccade amplitude to target amplitude, a measure of accuracy; (3) primary saccade precision: variability (i.e., standard deviation) of primary saccade gain; (4) primary saccade peak velocity (PV): maximum eye-velocity attained during saccade; (5) final saccade gain: ratio of final saccade amplitude, which is the sum of the primary, corrective, and reach-related saccade amplitude, to target amplitude; (6) final saccade precision: variability of final saccade gain; (7) frequency of corrective saccades: percentage of trials that included a corrective saccade; and (8) frequency of reach-related saccades: percentage of trials that included a reach-related saccade.

Temporal Eye–Hand Coordination. Details on reach kinematics data processing can be found in our previously published article.27 Using reach kinematics measures in combination with primary saccade latency, we calculated two temporal eye–hand coordination measures: (1) saccade-to-reach planning interval: interval between end of primary saccade and reach initiation, which reflects time available for planning the reaching response after the primary saccade was complete; and (2) saccade-to-reach PV interval: interval between end of the primary saccade and when PV was attained, which reflects amount of time after the eyes were in close vicinity of the target to the end of the initial stage of reach execution.

Statistical Analyses

Primary Analyses. Independent t tests were used to compare strabismic children to control children for all saccade kinematics and temporal eye–hand coordination measures. Effect size was calculated using Cohen's d.

Secondary Analyses. Kruskal-Wallis one-way ANOVAs were conducted to determine clinical and sensory factors related to performance: prior surgery (yes, no); amblyopia present (yes, no); stereocuity measurable (present, not present); extent of suppression scotoma (bifoveal–macular fusion, −0.15 to 0.45 log deg; peripheral–no fusion, 0.60 to 1.2 log deg). Significant ANOVAs were followed with Mann–Whitney U post hoc tests. All tests were corrected for multiple comparisons and P values were adjusted using Holm's sequential Bonferroni procedure, which corrects for type I error as effectively as the traditional Bonferroni method while retaining more statistical power.29 Children with fewer than 14 useable saccade trials (at least 7 useable trials per side, left/right) were excluded from further analysis.

Results

Reach kinematic data from 36 strabismic children and 35 control children for this task have been published.27 Of the children tested, eye movement data were available from 30 strabismic children (female = 20; mean age, 9.7 ± 1.8 years) and 32 control children (female = 18; 9.6 ± 1.8 years). The remaining 6 strabismic children and 3 control children were not included due to having fewer than 14 useable saccade trials because of artefacts, blinks, or poor calibration. Children with strabismus did not differ from controls in age (P = 0.79) or arm length (P = 0.32). (See Table 1 for group characteristics.)

Saccade Kinematics

No interocular differences (strabismus, nonpreferred vs. preferred eyes; control, right vs. left eyes) were found for either group. Therefore, only the preferred eye (left eye for controls) was included in the analysis. See Figure 2 for group comparisons of saccade kinematic measures, and Figure 3 for example eye traces from a typical child with strabismus and a control.

Latency. Strabismic children had longer saccade latency than controls (strabismus, 195 ± 29 ms
FIGURE 2. Violin plots displaying the distribution of saccade kinematic measures for strabismic children compared with controls. For each violin plot, the embedded boxplot represents the interquartile range, the black cross represents the mean, and black horizontal lines represent the median. Strabismic children were similar to controls for primary saccade PV (B), primary saccade gain (C), and final saccade gain (E), but had significantly longer primary saccade latency (A), and decreased primary saccade gain (D) and final saccade gain (F).

Accuracy. No difference between groups was found for primary saccade gain (strabismus, 0.94 ± 0.11 vs. control, 0.95 ± 0.07; \( t_{60} = 0.44; P = 0.67; d = 0.1 \)) or for final gain (strabismus, 1.00 ± 0.06 vs. control, 1.00 ± 0.05; \( t_{60} = 0.54; P = 0.71; d = 0.1 \)).

Precision. Strabismic children had a 25% decrease in primary saccade precision (strabismus, 0.15 ± 0.06 vs. control, 0.12 ± 0.02; \( t_{60} = 3.23; P = 0.002; d = 0.8 \)) and a 45% decrease in final saccade precision (strabismus, 0.16 ± 0.06 vs. control, 0.11 ± 0.03; \( t_{60} = 3.9; P < 0.001; d = 1.0 \)) compared with controls.

PV. No difference between groups was found for PV (strabismus, 324 ± 60 deg/sec vs. control, 330 ± 44 deg/sec; \( t_{60} = 0.41; P = 0.69; d = 0.1 \)).

Corrective and Reach-Related Saccades

No group difference was found for frequency of corrective saccades (strabismus, 37 ± 16% vs. control, 38 ± 18%; \( t_{60} = 0.32; P = 0.75; d = 0.08 \)). However, strabismic children had
more reach-related saccades than controls (strabismus, 16 ± 13% vs. control, 8 ± 6%; $t_{60} = 3.33; P = 0.001; d = 0.85$). (See Fig. 4.)

**Temporal Eye–Hand Coordination**

No group difference was found for the saccade-to-reach planning interval (strabismus, 110 ± 78 ms vs. control, 136 ± 64 ms; $t_{60} = 1.42; P = 0.16; d = 0.36$) or the saccade-to-reach PV interval (strabismus, 311 ± 91 ms vs. control, 330 ± 75 ms; $t_{60} = 0.88; P = 0.38; d = 0.22$). (See Fig. 5 and Fig. 6.)

**Factors Associated With Saccade Kinematics**

We further probed why strabismic children had longer saccade latency, decreased primary and final saccade precision, and more reach-related saccades by considering clinical and sensory factors. Compared with controls, the following factors were related to poor performance for (1) primary saccade latency: nonamblyopic ($U = 91; P < 0.001$), stereoacuity not present ($U = 163; P = 0.002$), bifoveal–macular fusion ($U = 159; P = 0.001$), (2) primary saccade precision: nonamblyopic ($U = 107; P = 0.003$), stereoacuity not present ($U = 109; P < 0.001$), peripheral-no fusion ($U = 56; P = 0.005$), (3) final saccade precision: no surgery ($U = 107; P = 0.001$), stereoacuity not present ($U = 134; P < 0.001$), and (4) reach-related saccades: stereoacuity not present ($U = 119; P < 0.001$), peripheral-no fusion ($U = 58; P = 0.006$). The only factor showing a group difference within the strabismic group was stereoacuity; strabismic children with stereoacuity not present had decreased primary saccade precision and more reach-related saccades than strabismic children with stereoacuity present. (See Table 2.)

Between the ages of 7 and 12 years, a transition occurs from beginning to use information derived from visual feedback to the acquisition of more integrated feedforward-feedback control. For those measures that were impaired in strabismic children compared with controls (saccade latency, saccade precision, reach-related saccades), we compared 7- to 9-year-old children with 10- to 12-year-old children within the strabismic group to determine whether any improvement occurs with age. The only measure that improved with age was primary saccade latency (7–9 years, 205 ± 31 ms vs. 10–12 years, 180 ± 16 ms; $P = 0.015; d = 1.0$). In contrast, final saccade precision was worse in the older age group (7–9 years, 0.14 ± 0.05 ms vs. 10–12 years, 0.18 ± 0.16 ms; $P = 0.015; d = 1.0$).
FIGURE 4. Violin plots displaying the distribution of the percentage of corrective saccades and reach-related saccades for strabismic children compared with controls. For each violin plot, the embedded boxplot represents the interquartile range, the black cross represents the mean, and black horizontal lines represent the median. Strabismic children had a similar frequency of corrective saccades as controls (A), but more reach-related saccades than controls (B).

FIGURE 5. Examples of a typical visually guided reaching trial for a child with strabismus (top) and a control child (bottom). The dotted line indicates primary saccade latency (SL). Included in both examples are the saccade-to-reach planning interval (S-R) and the saccade-to-reach-PV interval (S-PV), and a reach-related saccade (RRS) in the strabismus example only. An asterisk (*) in the strabismus example indicates group mean is significantly different than controls.
Eye–Hand Coordination in Strabismus

FIGURE 6. Violin plots displaying the distribution of the saccade-to-reach planning interval (A) and the saccade-to-reach PV interval (B) for strabismic children compared with controls. For each violin plot, the embedded boxplot represents the interquartile range, the black cross represents the mean, and black horizontal lines represent the median. No group differences were found.

TABLE 2. Factors Affecting Saccade Kinematics in Strabismic Children Compared With Controls

| Factor                  | n  | Primary Saccade Latency (ms) | Primary Saccade Precision | Final Saccade Precision | Reach-Related Saccades (%) |
|-------------------------|----|-----------------------------|---------------------------|-------------------------|----------------------------|
| Control                 | 32 | 175 ± 23                    | 0.12 ± 0.02               | 0.11 ± 0.03             | 7.6 ± 5.7                  |
| Surgery                 |    |                             |                           |                         |                            |
| Yes                     | 14 | 189 ± 13*                   | 0.15 ± 0.05               | 0.15 ± 0.06             | 15.7 ± 12.1                |
| No                      | 16 | 201 ± 37*                   | 0.16 ± 0.05               | 0.16 ± 0.06             | 16.7 ± 14.7                |
| Amblyopia               |    |                             |                           |                         |                            |
| Amblyopic               | 15 | 187 ± 23                    | 0.15 ± 0.06               | 0.15 ± 0.07             | 14.7 ± 10.0                |
| Nonamblyopic            | 15 | 204 ± 31*                   | 0.15 ± 0.03               | 0.16 ± 0.06             | 17.8 ± 16.3                |
| Stereoacuity            |    |                             |                           |                         |                            |
| Not present             | 21 | 198 ± 29*                   | 0.16 ± 0.04*              | 0.17 ± 0.07*            | 21.2 ± 12.5*               |
| Present                 | 9  | 189 ± 29                    | 0.12 ± 0.05               | 0.12 ± 0.04             | 4.7 ± 6.0                  |
| Extent of Suppression   |    |                             |                           |                         |                            |
| Peripheral-no fusion    | 9  | 195 ± 34                    | 0.15 ± 0.03*              | 0.16 ± 0.06*            | 21.4 ± 14.3*               |
| Bifoveal-macular fusion | 21 | 195 ± 27*                   | 0.15 ± 0.05               | 0.15 ± 0.07*            | 14.0 ± 12.6                |

Values are mean ± standard deviation.
*Significantly different than controls.
†Significantly different between categories for strabismic children
‡For nonamblyopic children, the affected eye was either the at-risk or previously amblyopic eye, or the right eye (if the child was never amblyopic)

DISCUSSION

Children treated for strabismus have prolonged saccade onset latency during visually guided reaching while viewing binocularly, consistent with previous studies in strabismic adults.8,12 Longer latencies may point to an immaturity of controlling visual fixation (i.e., disengaging fixation) that occurs before saccade onset.42 Fixation instability, which is a hallmark of strabismus, may impact the timing of saccade initiation.5,9,10 Because saccade latency reflects the time it takes to program the saccade before initiation, prolonged saccade latency could also reflect a delay in sensorimotor transformation. In other words, there may be a delay in processing the visual information about the location and distance of the target, converting that information into a planned motor command (i.e., the saccade), and then executing that motor command. Spatial distortions and positional uncertainty are present in strabismus43,44 and could impact this sensorimotor transformation during visually guided reaching.

Strabismic children initiated reach-related saccades twice as frequently as controls (16% vs. 8% of trials), consistent with strabismic adults (11%–15% of trials).32 Inconsistent with strabismic adults who have more corrective saccades,12 no difference in frequency of corrective saccades (i.e., occurred before reach initiation) was found. For strabismic children, the majority of corrective saccades (92%) occurred before or during the acceleration (initial) phase of the reach. Corrective saccades are common in normal vision and may be prepared at the same time as the primary saccade.38 Strabismic children may be overshooting or undershooting the target, with reach-related saccades being generated to correct the positional error that remained after the primary saccade. This is supported by
our finding of a 25% to 45% decrease in saccade precision, despite a mean saccade gain comparable with controls. The majority of reach-related saccades (82%) in the strabismic group occurring during the deceleration (final) phase of the reach. However, the initial variability in saccades was not rectified by these reach-related saccades, evidenced by the lack of difference between primary (0.15) and final (0.16) saccade precision, which may be impacting the lower touch accuracy found in this group. Again, spatial distortions and positional uncertainty in encoding the visual information could impact the precision of saccades.

Coupled with slower reaching in the final approach, an increase in the incidence of reach-related saccades, especially in the final approach to the target, suggests a reliance on visual feedback that is less efficient during the reach. It is also possible that the increased incidence of reach-related saccades is due to fixation instability, which would increase the variability of the primary saccade.

No group differences in temporal eye–hand coordination measures were found (saccade-to-reach, saccade-to-reach PV intervals). These data are in contrast with those from strabismic adults, who show a longer saccade-to-reach PV interval compared with controls, particularly if their binocular vision was deficient, pointing to a deficit in the planning and initial execution of the reach. Because the saccade-to-reach planning interval and saccade-to-reach PV interval both exclude the final approach of the reach where strabismic children are slowest, no impairment on our temporal eye–hand coordination measures is not surprising and points to inefficient use of visual feedback as the culprit for slower reaching. It may then appear that the delay in saccade initiation (but normal saccade velocity and accuracy), and the slow reach in the final but not initial approach point to a problem with saccades and reaches individually rather than there being a problem with visuomotor integration. Alternatively, despite normal saccade velocity and accuracy, saccade precision was decreased and the incidence of reach-related saccades was increased in strabismic children, suggesting that visuomotor integration is indeed impacted. A reach-related saccade is an extra step that needs to be planned and executed, suggesting that additional information is required after the primary saccade to reach the target properly, and thus changing the coordination pattern.

Coupled with our previously reported reach kinematic data, the current findings suggest that children aged 7 to 12 years treated for strabismus have not yet adapted or formed an efficient compensatory strategy for visually guided reaching while binocularly viewing. Strabismic children take longer to initiate a saccade to a target before reaching, take longer to reach to the target owing to more time spent in the final approach, and produce more reach-related saccades. Strabismic adults also take longer to saccade to the target and produce more reach-related saccades, but, unlike strabismic children, they spend more time in the initial approach, and produce more corrective saccades before the reach. Therefore, the strategy for visually guided reaching in strabismic individuals changes from relying more on visual feedback for online control during childhood to relying more on the visuomotor plan in adulthood. At 7 years of age, children are just learning to use visual feedback for online corrections, the use of this feedback is not yet mastered and may be less efficient in strabismic children. This is evidenced by our finding that final saccade precision was worse by 29% in older strabismic children compared with younger strabismic children, despite a quicker saccade latency. This finding may reflect a speed–accuracy tradeoff. Even with quicker saccades, strabismic children age 10 to 12 years were still slower than controls aged 10 to 12 years (161 ± 15 ms; \( P = 0.002 \)). Our findings point to a change in compensatory strategies that develop with age. It is unknown at what age this switch occurs because there are no data in teenagers with strabismus.

Nonamblyopic children had prolonged saccade latency and decreased primary and final saccade precision, whereas those with amblyopia only exhibited a decreased final saccade precision. Nonamblyopic strabismic adults also show prolonged saccade latency (191 ± 29 ms), whereas amblyopic strabismic adults do not (177 ± 39 ms). This difference may reflect the fact that infantile esotropia (before 12 months of age) is accompanied by poorer binocularity status but typically does not result in amblyopia. In this study, seven of the strabismic children had an early onset of strabismus. However, variance of the saccade amplitude precision in the amblyopic group was large, despite having a similar mean as the nonamblyopic group, and may account for the lack of significance. This may also hold true for extent of suppression; both categories yielded similar mean saccade latencies and precision, but only one category was significantly different from controls (see Table 2). The disconjugacy of saccades in strabismus significantly decreases, but saccade accuracy remains the same after strabismus surgery. In our study, all strabismic children were aligned within 12 prism diopters; thus, the disconjugacy of saccades would have been minimal. Certainly, we found no interocular difference in saccade kinematics, suggesting that saccade disconjugacies are not the cause of the increased latency or the decreased precision.

A longer saccade latency, decreased saccade precision, and more reach-related saccades were related to having no measurable stereoaucity and peripheral–no fusion. Poor binocular status is associated with poor ocular motor function in strabismus, including decreased vergence and abnormal saccade initiation and execution.\(^\text{8,12,13}\) During visuomotor tasks, binocular cues provide vital information about an object’s distance, location, and three-dimensional properties. Good binocularity is important for eye–hand coordination, and the use of binocular cues may be disrupted by strabismus early in life. This finding is supported not only by better performance in strabismic children with better binocularity in our study, but also by end point inaccuracies during reaching and grasping in the strabismic children in our study and children with binocular dysfunctions in a previous study. Previous studies also show better motor performance in those with recovered binocularity, suggesting that binocularity contributes to optimum planning and execution of visually guided reaching.

Our study had potential limitations. It is possible microsaccades were incorrectly categorized as corrective or reach-related saccades. To minimize this risk, we used an inclusion criterion of 0.4° or more amplitude in both eyes. It is challenging to tease apart the individual contributions of clinical and sensory factors because they often coexist, especially with small sample sizes in two of the sensory categories (peripheral–no fusion, \( n = 9 \); stereoaucity present, \( n = 9 \)). However, our data, along with previous studies on eye–hand coordination in strabismus, point to the role that
binocular dysfunction plays in impaired visuomotor ability. Although we were unable to control for experience with eye-hand coordination, our task was a simple reaching task with which all children will have had experience, regardless of enrollment in physical recreational activities.

**Conclusions**

Strabismus impacts saccade kinematics during visually guided reaching in children, with poor binocularity playing a role in performance. There seems to be a reorganization of motor control with age; rather, a switch from a disruption in childhood to a change in planning in adulthood that impacts visually guided reaching in individuals with strabismus, suggestive of a compensatory adaptation of reaching. Understanding this switch and the processes underlying impairments in eye-hand coordination may lead to interventions targeted at preventing or ameliorating slow reaching or slow eye movement latency in strabismic children.

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