Eye Movement, Strabismus, Amblyopia and Neuro-Ophthalmology

Factors Associated with Impaired Motor Skills in Strabismic and Anisometropic Children

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Received: May 29, 2020
Accepted: July 30, 2020
Published: August 25, 2020

Citation: Kelly KR, Morale SE, Beauchamp CL, Dao LM, Luu BA, Birch EE. Factors associated with impaired motor skills in strabismic and anisometropic children. *Invest Ophthalmol Vis Sci.* 2020;61(10):43. https://doi.org/10.1167/iovs.61.10.43

Purpose. We evaluated motor skills in children diagnosed with strabismus and anisometropia, with or without amblyopia, and explored factors associated with impairments.

Methods. A total of 143 strabismic and anisometropic children 3 to 13 years of age (96 amblyopic, 47 nonamblyopic) and a group of age-similar 35 control children completed Manual Dexterity, Aiming and Catching, and Balance tasks from the Movement Assessment Battery for Children, Second Edition. Raw scores were converted to standardized scores, and amblyopic and nonamblyopic children were compared to controls. Clinical and sensory factors associated with motor performance were also evaluated.

Results. Overall, amblyopic and nonamblyopic children were three to six times more likely than controls to be at risk for or to have a total motor impairment (≤15th percentile). Although amblyopic children scored lower than controls for the Manual Dexterity, Aiming and Catching, and Balance tasks, nonamblyopic children scored lower on Manual Dexterity only. Factors related to manual dexterity deficits include the presence of amblyopia and binocularity deficits typical of these eye conditions. Aiming, catching, and balance deficits were most pronounced in children with an infantile onset of the eye condition, a history of strabismus, and reduced binocularity.

Conclusions. Amblyopia and strabismus disrupt the development of motor ability in children. These findings highlight the widespread effects of discordant binocular input early in life and the visual acuity and binocularity deficits typical of these eye conditions.

Keywords: amblyopia, strabismus, anisometropia, visuomotor development, binocularity

Amblyopia (lazy eye) is the most common cause of poor vision in one eye among children, affecting 2% to 4% of children in the United States.[1] The most common causes of amblyopia are strabismus (misalignment of the visual axis) and anisometropia (unequal refractive error). The discordant binocular experience due to these pediatric eye conditions not only impairs visual acuity in the affected eye but also results in fellow eye deficits and disrupts the development of binocularity (e.g., decreased stereoacuity, interocular suppression).[1–4] Amblyopia emerges during a critical period of brain maturation and has the potential to affect the performance of real-world tasks that require vision for development, including fine and gross motor skills.

Coordination of the eyes, hands, and body is essential for object manipulation (fine motor skills) and navigating the environment (gross motor skills). Studies investigating motor skills have focused on the effects of strabismus or the role that binocularity plays in development and have shown that normal stereoacuity and fusion are essential to task performance.[5–16] Binocularity is disrupted in amblyopia; yet, only a small number of studies investigating motor skills have focused on the impact of amblyopia specifically, particularly in children. These studies have found that amblyopic children and adults have impaired fine motor skills, such as reaching, grasping, object manipulation, and transferring test answers to a multiple-choice form.[17–25] A limited number of studies have also found gross motor impairments in amblyopic adults and children performing tasks designed to assess postural stability and walking,[26–28] and such impairments can increase the risk of injury.[29] However, these studies had heterogeneous groups with limited age ranges and small sample sizes, thus making it difficult to ascertain factors associated with motor impairments.

We evaluated fine and gross motor skills of children 3 to 13 years of age with a history of strabismus or anisometropia, with or without amblyopia, during binocular viewing using the Movement Assessment Battery for Children, Second Edition (MABC-2). Our goal was to determine the extent to which amblyopia affects the maturation of visuomotor ability and to explore clinical (etiology, age at diagnosis) and sensory (severity of amblyopia, binocularity) factors associated with any deficits.

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TABLE 1. Age Bands and Tasks for the Manual Dexterity, Aiming and Catching, and Balance Subscales

	Age Band			
	3–6 y	7–10 y	11–13 y	Outcome Measure
Manual dexterity				
Unimanual	Post coins, one hand	Place pegs, one hand	Turn pegs, one hand	Latency*
Bimanual	Thread beads	Thread lace	Build triangle	Latency
Drawing trail	Stay inside lines	Stay inside lines	Stay inside lines	Number of errors
Aiming and catching				
Aiming	Throw beanbag anywhere on mat	Throw beanbag in red circle on mat	Throw ball at wall target	Number of successful hits
Catching	Catch beanbag, two hands	Catch ball, two hands	Catch ball, one hand	Number of successful catches†
Balance				
Static balance	Balance, one-leg	One-board balance, one leg	Two-board balance, two legs	Latency‡
Walking	Walk heels raised	Walk heel-to-toe forwards	Walk heel-to-toe backwards	Number of successful steps
Jumping	Jump on mats, two feet	Jump on mats, one foot	Zig-zag jump on mats, one foot	Number of successful jumps§

* Only the preferred hand was used for analysis for all age bands.
† Total catching score (average of left and right hand) used for analysis for age band 11–13 years.
‡ Total static balance score (average of left and right leg) used for analysis for age bands 3–6 years and 7–10 years.
§ Total jumping score (average of left and right leg) used for analysis for age bands 7–10 years and 11–16 years.

METHODS

Participants

Children 3 to 13 years of age diagnosed with strabismus and/or anisometropia ($n = 143$), with or without amblyopia, were referred to the Retina Foundation of the Southwest by pediatric ophthalmologists in the Dallas-Fort Worth area. Amblyopia was defined as an interocular difference in visual acuity of ≥0.2 logMAR, with best-corrected visual acuity (BCVA) in the fellow eye of ≤0.1 logMAR (20/25 or better; 0.3 logMAR [20/40] for ages 3−4 years).[30] Strabismic children were initially diagnosed with esotropia but were aligned with surgery and/or spectacle correction within 6 prism diopters of orthotropia at the time of the test visit. Children with strabismus and anisometropia (i.e., combined mechanism) were included in the strabismus group. Age-similar control children ($n = 35$) who had age-normal visual acuity and stereoacuity and no history of vision disorders were also enrolled. All children were tested with their habitual spectacle correction, if required, which was confirmed by medical record review. No child enrolled in the study was born preterm (<37 weeks gestational age) or had co-existing ocular or systemic disease, congenital infections/malformations, or developmental delay. Medical records were obtained from referring ophthalmologists to extract information about diagnosis, current alignment, cycloplegic refraction, and prior treatment plans. English was the primary language for all children.

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 U.S. Health Insurance Portability and Privacy Act. Informed consent was obtained from a parent or legal guardian, and assent was obtained from children ≥10 years of age prior to testing and after explanation of the study.

Procedure

Vision Assessment. Prior to motor skills testing, children had a vision assessment that included the following:

1. Crowded monocular BCVA using the electronic Early Treatment for Diabetic Retinopathy Study (e-ETDRS) protocol[31,32] (≥7 years of age) or the Amblyopia Treatment Study HOTV protocol[33,34] (<7 years of age) to provide logMAR BCVA.
2. Stereoacuity using the Randot Preschool Stereoacuity and Stereo Butterfly Tests,[35,36] converted to log arcsec for analyses (ranging from 1.3 to 3.3 log arcsec); nil stereoacuity was arbitrarily assigned a value of 4 log arcsec.
3. Extent of suppression scotoma using the Worth 4 Dot (W4D) test at seven different distances, measured as the farthest distance that the child reported four dots and converted to size of suppression scotoma in log degrees (larger numbers represent larger suppression scotomas; no fusion at the shortest distance was assigned a value of 1.2 log deg).[37,38]
4. Depth of suppression using a computerized dichoptic eye chart that determines the non-preferred eye/preferred eye contrast ratio (i.e., balance point) at which the child can overcome interocular suppression and report letters presented to each eye with equal likelihood (Contrast Balance Index, CBI).[2,39]

Movement Assessment Battery for Children, Second Edition. Each child was tested during binocular viewing with the MABC-2[40] (administered by KRK or SEM), a standardized test used to identify children with delay or impairment in motor development that is administered in three age bands (3–6, 7–10, and 11–16 years) and consists of Manual Dexterity, Aiming and Catching, and Balance subscales with eight tasks in total (Table 1). The raw score for each task was converted into a standardized score using look-up tables provided with the MABC-2. Higher standardized scores indicate better performance. To compare a child's motor proficiency with published

Table 2. Group Characteristics

Characteristic	Amblyopic (n = 96)	Nonamblyopic (n = 47)	Control (n = 35)
Sex (female), n (%)	43 (45)	22 (47)	18 (51)
Strabismus, n (%)	53 (55)	33 (70)	n/a
Strabismus only, n (%)	19 (36)	22 (67)	n/a
Strabismus and anisometropia, n (%)	34 (64)	11 (33)	n/a
Right eye affected, n (%)	25 (47)	22 (47)*	n/a
Anisometropia, n (%)	43 (45)	14 (30)	n/a
Hyperopic, n (%)	33 (77)	9 (64)	n/a
Myopic, n (%)	5 (12)	1 (7)	n/a
Astigmatic, n (%)	5 (12)	4 (29)	n/a
Magnitude of anisometropia (D), mean ± SD	3.3 ± 2.0	1.7 ± 0.8	n/a
Right eye affected, n (%)	24 (56)	7 (50)*	n/a
Age (y), mean ± SD (range)	8.2 ± 2.5 (3.8 to 13.1)	7.0 ± 2.6 (3.3 to 13.1)	8.3 ± 2.8 (4.2 to 13.0)
AE† BCVA (logMAR), mean ± SD	0.4 ± 0.3	0.1 ± 0.1	0.0 ± 0.1
Snellen equivalent	20/50 ± 3 lines	20/25 ± 1 lines	20/20 ± 1 lines
Range	0.1 to 1.9	–0.1 to 0.3	–0.1 to 0.1
FE‡ BCVA (logMAR) mean ± SD	0.0 ± 0.1	0.1 ± 0.1	0.0 ± 0.1
Snellen equivalent	20/20 ± 1 lines	20/25 ± 1 lines	20/20 ± 1 lines
Range	–0.1 to 0.2	–0.1 to 0.3	–0.1 to 0.1
Stereoacuity (log arcsec), mean ± SD (range)	3.4 ± 0.8 (1.8 to 4)	3.1 ± 1.0 (1.6 to 4)	1.6 ± 0.2 (1.3 to 2.0)
Extent of suppression (log deg), mean ± SD (range)	0.4 ± 0.4 (–0.2 to 1.2)	0.3 ± 0.6 (–0.2 to 1.2)	−0.2 ± 0.0 (−0.2 to −0.2)
Depth of suppression (CBI), mean ± SD (range)	4.8 ± 3.6 (0.2 to 11.0)	3.0 ± 2.9 (0.2 to 11.0)	n/a

AE, amblyopic eye; FE, fellow eye.

* 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.

† For nonamblyopic children, either the previously amblyopic eye or the right eye if the child was never amblyopic is listed. For normal control children, the right eye is listed.

‡ For children who were never amblyopic and control children, the left eye is listed.

age-matched normative data,[40] standardized scores per task were summed to produce subscale scores and then a Total Motor score, which was converted to a percentile (standard score of 10 = 50th percentile). According to MABC-2 instructions, children scoring ≤5th percentile have a significant total motor impairment, children scoring between 6th and 15th percentile are at risk for impairment, and children scoring ≥16th percentile are typically developed.

Statistical Analyses

Primary Analyses. Our primary goal was to determine the impact of amblyopia on motor performance. An odds ratios (OR) with 95% confidence intervals (CIs) was calculated based on Total Motor percentile scores to determine whether amblyopic or nonamblyopic patients had a higher incidence of being categorized as being at risk or impaired (i.e., ≤15th percentile) compared with controls. We also assessed the difference in standardized scores for the Total Motor score and each subscale (Manual Dexterity, Aiming and Catching, Balance) using a series of independent t-tests to compare amblyopic children and nonamblyopic children to control children (Bonferroni-corrected P = 0.025). For subscales that were significantly different from controls, we assessed performance on each individual task.

Secondary Analyses. To determine factors related to Total Motor and subscale (Manual Dexterity, Aiming and Catching, Balance) performance, we compared clinical and sensory factors among the patient group to controls using independent t-tests for the following:[2]

- Age at diagnosis—infantile, <12 months; late onset, >12 months (Bonferroni-corrected P = 0.025).
- Etiology—strabismus (including combined mechanism); anisometropia (Bonferroni-corrected P = 0.025).
- Severity of current amblyopia—mild, 0.1 to 0.2 logMAR; moderate, 0.3–0.6 logMAR; severe, ≥0.7 logMAR (Bonferroni-corrected P = 0.017)
- Stereoacuity—normal, ≤60 arcsec; reduced, 100 to 800 arcsec; nil, not measurable (Bonferroni-corrected P = 0.017).
- Extent of suppression (W4D)—bifoveal/macular, −0.15 to 0.45 log deg; peripheral/none, 0.60 to 1.2 log deg (Bonferroni-corrected P = 0.025)
- Depth of suppression (CBI)—no suppression, ≤2; suppression, >2 (Bonferroni-corrected P = 0.025).

Results

A total of 178 children were enrolled and completed the visual acuity, stereoacuity, extent of suppression, and MABC-2 tests (96 patients completed the depth of suppression test). These included 96 amblyopic strabismic and/or anisometropic children (amblyopic; 43 females; mean age = 8.2 ± 2.5 years), 47 nonamblyopic strabismic and/or anisometropic children (nonamblyopic; 22 females; mean age 7.0 ± 2.6 years), and 35 normal control children (control; 18 females; mean age 8.3 ± 2.8 years). Control data for the MABC-2 have previously been published.[41] The magnitude of mean ± SD anisometropia was 1.7 ± 0.8 diopters (D) in nonamblyopic anisometropic children and 3.3 ± 2.0 D in amblyopic anisometropic children. The majority of the anisometropic children had hyperopic anisometropia (74%). Amblyopic children did not differ in age from controls (P = 0.85). Nonamblyopic children trended toward being slightly younger than controls, but this trend was not significant

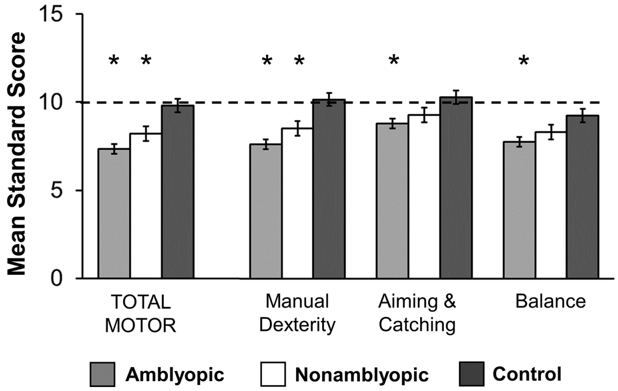

Figure. Mean total motor and subscale standard scores for amblyopic children (*light gray bars*), nonamblyopic children (*white bars*), and control children (*dark gray bars*). Error bars represent ± SEM. Dashed lines represent 50th percentile. *Significantly different from controls (Bonferonni-corrected).

($P = 0.033$). Because scoring on the MABC-2 is standardized based on age, this was not an issue. Descriptive statistics for clinical and sensory information are provided in Table 2.

Total Motor and Subscale Performance

Compared with just 11% (4/35) of controls, 45% (43/96) of amblyopic children and 28% (13/47) of nonamblyopic children were categorized as being at risk for or having a Total Motor impairment (amblyopic, OR = 6.3, 95% CI = 2.1–19.2, $Z = 3.2$, $P = 0.001$; nonamblyopic, OR = 3.0, 95% CI = 0.9–10.1, $Z = 1.7$, $P = 0.08$). Compared with the Total Motor standardized scores for controls (9.8 ± 2.3), the scores were lower for amblyopic (7.4 ± 2.7; $t_{129} = 4.8$, $P < 0.001$) and nonamblyopic (8.2 ± 2.9; $t_{80} = 2.7$, $P = 0.009$) children (Fig.).

Amblyopic children scored lower than controls on the Manual Dexterity (7.6 ± 2.7 vs. 10.2 ± 3.0; $t_{129} = 4.7$, $P < 0.001$), Aiming and Catching (8.8 ± 3.4 vs. 10.3 ± 2.9; $t_{129} = 2.3$, $P = 0.023$), and Balance (7.8 ± 3.1 vs. 9.3 ± 2.4; $t_{129} = 2.6$, $P = 0.012$) subscales (Fig.). Within the Manual Dexterity scale, amblyopic children scored lower than controls for unimanual dexterity (8.2 ± 3.2 vs. 9.8 ± 2.7; $t_{129} = 2.5$, $P = 0.012$), bimanual dexterity (7.9 ± 3.2 vs. 9.7 ± 3.5; $t_{129} = 2.7$, $P = 0.008$), and the drawing trail (7.0 ± 3.9 vs. 9.7 ± 2.9; $t_{129} = 3.7$, $P < 0.001$). Within the Aiming and Catching scale, amblyopic children scored lower than controls for catching (8.1 ± 3.2 vs. 10.1 ± 2.6; $t_{129} = 3.2$, $P = 0.002$) but not aiming (9.3 ± 3.2 vs. 9.9 ± 2.8; $t_{129} = 1.1$, $P = 0.28$). Within the Balance scale, amblyopic children scored lower than controls for static balance (7.9 ± 2.9 vs. 9.2 ± 2.8; $t_{129} = 2.3$, $P = 0.022$) and jumping (9.3 ± 3.5 vs. 10.9 ± 2.1; $t_{129} = 2.6$, $P = 0.010$) and trended toward scoring lower for walking, but this trend was not significant (7.2 ± 4.0 vs. 8.7 ± 3.8; $t_{129} = 2.0$, $P = 0.05$).

Nonamblyopic children scored lower than controls on the Manual Dexterity subscale (8.5 ± 3.0 vs. 10.2 ± 3.0; $t_{80} = 2.5$, $P = 0.014$) but not on the Aiming and Catching (9.3 ± 3.2 vs. 10.3 ± 2.9; $t_{80} = 1.5$, $P = 0.14$) or Balance (8.3 ± 3.1 vs. 9.3 ± 2.4; $t_{80} = 1.5$, $P = 0.14$) subscales (Fig.). Within the Manual Dexterity scale, nonamblyopic children did not differ from controls for unimanual dexterity (9.2 ± 3.1 vs. 9.8 ± 2.7; $t_{80} = 0.9$, $P = 0.39$) or bimanual dexterity (8.8 ± 3.1 vs. 9.7 ± 3.5; $t_{80} = 1.3$, $P = 0.21$), but they did score lower than controls for the drawing trail (7.5 ± 3.8 vs. 9.7 ± 2.9; $t_{80} = 2.8$, $P = 0.006$).

Clinical Factors Associated with Motor Performance

Etiology. (See Table 3.) Strabismic children (n = 86) scored lower than controls for all three subscales of the

Table 3. Factors Affecting Motor Performance

		Subscales, Mean (SD)		
Factor	***n***	**Manual Dexterity**	**Aiming and Catching**	**Balance**
Control	35	10.2 (3.0)	10.3 (2.9)	9.3 (2.4)
Etiology				
Strabismus	86	7.7 (2.7)*	8.7 (3.2)*	7.7 (3.1)*
Anisometropia	57	8.2 (2.9)*	9.3 (3.5)	8.4 (3.1)
Age at onset				
Infantile	27	7.2 (3.1)*	8.2 (3.1)*	7.5 (3.4)*
Late	116	8.1 (2.7)*	9.2 (3.4)	8.1 (3.0)
Severity of amblyopia				
None	47	8.5 (3.0)*	9.3 (3.2)	8.3 (3.1)
Mild	32	7.6 (2.5)*	8.9 (3.8)	8.9 (3.7)
Moderate	48	7.5 (2.9)*	8.9 (3.4)	7.3 (2.9)*
Severe	16	8.0 (2.4)*	8.5 (2.7)	7.1 (1.8)*
Stereoacuity				
Normal	13	9.7 (2.8)	9.9 (3.5)	9.5 (2.6)
Subnormal	38	7.5 (3.0)*	9.6 (3.7)	7.5 (3.1)*
Nil	92	7.8 (2.6)*	8.6 (3.1)*	7.9 (3.1)
Extent of suppression				
Bifoveal–macular fusion	92	8.0 (2.8)*	9.3 (3.4)	8.1 (3.0)
Peripheral–no fusion	51	7.7 (2.8)*	8.4 (3.2)*	7.6 (3.2)*
Depth of suppression				
None	35	8.7 (2.6)	9.1 (3.6)	8.1 (3.0)
Suppression	61	7.3 (2.8)*	8.8 (3.4)	7.9 (3.3)

* Indicates significantly lower scores than controls (Bonferonni-corrected).

MABC-2 (all $P \leq 0.013$). Anisometropic children ($n = 57$) scored lower than controls for Manual Dexterity only ($P = 0.002$). Those with combined mechanism (strabismus and anisometropia) were categorized to the strabismus group. We explored whether children with strabismus alone ($n = 41$) differed from those with strabismus and anisometropia ($n = 45$). No significant differences were found for any of the subscales or the Total Motor score (all $P \geq 0.40$).

Age of Diagnosis. Children with infantile onset ($n = 27$) scored lower than controls for all three subscales (all $P \leq 0.022$). Children with late onset ($n = 116$) scored lower than controls for manual dexterity only ($P < 0.001$).

Sensory Factors Associated with Motor Performance

Severity of Amblyopia. Children with mild amblyopia ($n = 32$) scored lower than controls on Manual Dexterity only ($P < 0.001$). Children with moderate amblyopia ($n = 48$) scored lower than controls on Manual Dexterity ($P < 0.001$) and Balance ($P = 0.001$). Children with severe amblyopia ($n = 16$) scored lower than controls on Manual Dexterity ($P = 0.014$) and Balance ($P = 0.002$). As shown in the primary analysis, nonamblyopic children scored lower than controls on Manual Dexterity only. For children with no amblyopia, there was no difference between those who never had amblyopia ($n = 16$) and those whose amblyopia was successfully treated ($n = 31$; all $P > 0.09$).

Stereoacuity. Children with normal stereoacuity ($n = 13$) scored similar to controls on all three subscales (all $P \geq 0.62$). Children with subnormal stereoacuity ($n = 38$) scored lower than controls on Manual Dexterity ($P < 0.001$) and Balance ($P = 0.007$). Children with nil stereoacuity ($n = 92$) scored lower than controls on Manual Dexterity ($P < 0.001$) and Aiming and Catching ($P = 0.006$).

Extent of Suppression (W4D). Children with bifoveal/macular fusion ($n = 51$) scored lower than controls for Manual Dexterity only ($P < 0.001$). Children with peripheral/no fusion ($n = 38$) scored lower than controls for all three subscales (all $P \leq 0.011$).

Depth of Suppression (CBI). A subset of 96 patients competed the depth of suppression task at their motor skills testing visit. Children with no suppression ($n = 35$) did not score differently than controls on any subscale. Children with suppression ($n = 61$) scored lower than controls on Manual Dexterity ($P < 0.001$) only.

Discussion

Our cohort of children with strabismus or anisometropia was more likely to be at risk for or to have a significant Total Motor impairment than controls, with amblyopia doubling the odds. Total Motor scores incorporate individual subscale scores for the Manual Dexterity, Aiming and Catching, and Balance subscales, on all of which amblyopic children scored low compared with controls. Nonamblyopic children had lower scores for Manual Dexterity only, consistent with amblyopia playing a role to increase risk of motor deficits.

Manual dexterity deficits have been reported previously in children with amblyopia.[20–25] We have also reported lower scores for all manual dexterity tasks in amblyopic children; nonamblyopic children scored lower for the drawing trail only. In the MABC-2 manual dexterity scale, the unilateral (e.g., coins in a slot) and bimanual (e.g., threading beads) tasks are scored by time to completion, whereas the drawing trail task is scored by the number of drawing errors. Webber et al.[23] also described more prominent deficits for timed rather than precise manual dexterity tasks in amblyopic children. Amblyopic children are slower at planning and executing reaching movements, with a less precise grasp than controls. However, compensatory strategies may change with age; younger children (5–7 years old) spend longer than controls in the final approach and rely more on visual feedback to guide movement, whereas older children (7–9 years old) spend longer in the object contact phase and rely more on tactile feedback for grasping.[20,22] During reaching and grasping, amblyopic adults exhibit reduced hand peak velocity and acceleration and prolonged acceleration duration, in addition to making more errors, indicating that manual dexterity deficits persist with age.[17–19,42,43]

Although the presence of amblyopia was a major factor affecting motor skills, we were unable to identify an association between the severity of amblyopia and manual dexterity performance; all categories scored lower than controls. We did, however, find that poor binocularity also played a large role in manual dexterity deficits. Children with reduced or nil stereoacuity, peripheral or no fusion, and suppression scored lower than controls for the Manual Dexterity subscale, whereas those with normal binocularity did not. Previous studies have shown the importance of good binocularity in manual dexterity performance.[18,20,22]

Amblyopic children scored lower than controls on the Aiming and Catching subscale, primarily due to poor catching performance. Previous studies have reported worse catching, but not aiming, for amblyopic and strabismic children, as well as children with deprivation amblyopia.[10,27,41] Aiming may be a less difficult task than catching. Aiming requires visual input for planning the throw and some visual feedback about the position of the arm and hand during the throw.[44] Catching is an interceptive task that requires sophisticated spatiotemporal coordination of the arm and hand motion with target motion to reach the interception point at an appropriate time and configuration for grasping, and then tightening the hand's grip.[45] Control of the grasping movement may be the most important indicator of catching performance,[46] with poorer catching in stereodeficient individuals being due to less hand closure and lower peak closing hand velocity when grasping a ball.[14] In our study, children with reduced or nil stereoacuity and peripheral or no fusion scored lower than controls on the Aiming and Catching subscale, further supporting the importance of binocularity in ball skills.

Amblyopic children in our study also scored lower on the Balance subscale, primarily due to poor static balance (postural stability) and jumping performance. Severity of amblyopia was a factor in poor balance, with moderate and severe amblyopia scoring lower than controls. Previous studies have reported impaired static balance for both amblyopic children and nonamblyopic children with strabismus[27,28]; however, these studies included strabismic children with ≥10 prism diopters, which could have reduced the field of view during balance testing. Our nonamblyopic group included only strabismic children aligned within 6 prism diopters of orthotropia at the time of testing, which may account for the inconsistency among studies. Amblyopic and strabismic children and adults are more cautious than controls when navigating the environment; for example, they take shorter steps during natural walking, reduce their walking velocity, and increase their toe clearance when navigating high obstacles.[9,26] In our study, children with reduced or nil stereoacuity and peripheral or no fusion also scored lower than controls on the Balance subscale, suggesting a large role of binocular vision.

Manual dexterity deficits were pervasive across all factors, with the exception of those with normal stereoacuity and no suppression. Children that were the most impaired on multiple scales were strabismic, had an infantile onset of their eye condition, and had poor binocularity. Children that were the least impaired on multiple scales were anisometropic, had a late onset, and had good binocularity. Strabismus can result in more severe binocularity deficits than anisometropia, even after the eyes are aligned, and especially when the onset is infantile.[47] In our study, strabismic children had poorer stereoacuity (3.7 ± 0.64 vs. 2.7 ± 0.89 log arcsec; $P < 0.001$) and stronger suppression (0.54 ± 0.47 vs. 0.17 ± 0.39 log deg; $P < 0.001$) than those with anisometropia, although affected eye visual acuity was no different between the groups (0.31 ± 0.30 vs. 0.33 ± 0.33; $P = 0.64$). Binocular cues such as vergence and stereopsis provide essential information for distance and location judgments, as well as three-dimensional object properties during motor tasks.[26,48]

Even in stereodeficient individuals, covering one eye affects gait during walking, suggesting that both eyes contribute and that field of view is important during navigation.[26] Use of binocular cues emerges in infancy but continues to develop during early childhood.[49–51] Thus, discordant binocular input during infancy and childhood may disrupt the ability to use these cues during motor development,[22,52] which is evident by our finding of poorer performance with an infantile onset of the eye condition. In our study, children with anisometropia had a later mean age at diagnosis than those with strabismus (4.8 ± 2.4 vs. 2.6 ± 2.0 years; $P < 0.001$). Although better binocularity in anisometropic children likely contributed to the lack of deficits seen for the Aiming and Catching and Balance subscales, the later onset of anisometropia may also play a role.[53] Children with normal stereoacuity and normal depth of suppression in our study did not score lower than controls on any subscale, consistent with earlier studies showing better motor performance in those with recovered binocularity[19,20] and suggesting that binocularity is essential to task performance.

Motor impairments may adversely influence a child's life and may cause difficulties in the classroom, especially in earlier grades when learning requires manipulating objects for counting and vocabulary. For later grades, children with amblyopia and strabismus are slow to transfer answers to a multiple-choice form,[21] which could affect their performance on timed, standardized tests. Motor deficits may also cause difficulties playing sports and navigating the environment in everyday activities, with an increase in the risk of injury and falls.[29] Finally, motor impairments may affect self-esteem and self-perception.[24,25,54] Lower self-perception is evident in amblyopic children, due in part to lower scores for physical competence and peer acceptance related to worse manual dexterity and ball skills.[24,25] Successful treatment of the visual acuity deficits and binocular dysfunction that accompany amblyopia and strabismus may lead to improved motor abilities.[55]

Our study had limitations. It is difficult to tease apart the individual contributions of sensory and clinical factors as they often co-exist to varying degrees (e.g., strabismus, reduced stereoacuity, suppression). In any case, it is clear that a history of discordant binocular input during visual development also impacts the development of motor ability. Finally, we were unable to control for experience with motor skills; however, many of the children in this study participated in physical recreational activities.

Conclusions

Amblyopia and strabismus disrupt the development of motor ability in children. Manual dexterity deficits appear to be secondary to the visual acuity and binocularity deficits typical of these eye conditions. Factors associated with aiming, catching, and balance deficits include an infantile onset of the eye condition, a history of strabismus, and reduced binocularity. These findings highlight the widespread effects of discordant binocular input early in life.

Acknowledgments

Supported by grants from the National Eye Institute (EY022313, EY028224) and by the Knights Templar Eye Foundation.

Preliminary results were presented at the American Association for Pediatric Ophthalmology and Strabismus 2016 annual meeting in Vancouver, British Columbia, Canada.

Disclosure: **K.R. Kelly,** None; **S.E. Morale,** None; **C.L. Beauchamp,** None; **L.M. Dao,** None; **B.A. Luu,** None; **E.E. Birch,** None

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