Motor skills in children with strabismus

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PURPOSE To assess the extent to which strabismus in children was associated with motor difficulties and to examine which parameters of strabismus were most closely associated with motor development.

METHODS The motor skills of children who were suffering from strabismus, were tested binocularly using the Movement Assessment Battery for Children, Second Edition (MABC-2) and compared with the motor performance of monocularly tested healthy controls without any ophthalmologic disease.

RESULTS A total of 40 children with strabismus (mean, 7.25 ± 3.83 years; 19 females) and 18 controls (mean age, 8.33 ± 5.42 years; 6 females) were tested. According to the MABC-2 test, of the 40, 19 had no motor disability, and 21 were at risk of or already presented significant motor disabilities. Results of the MABC-2 were significantly lower for strabismic children without binocularity compared to those with binocularity ($P = 0.002$). Lack of binocularity was associated with significantly lower performance for static balance ($P = 0.003$) as well as for catching tasks ($P = 0.042$).

CONCLUSIONS Lack of binocularity and stereopsis in children is associated with significant motor skills impairment, in particular for static balance and catching tasks. These results should be confirmed with a larger sample, including older patients, to assess the compensation mechanisms that develop with age and the actual effects of strabismus on overall motor performance. (J AAPOS 2020;24:76.e1-6)

Strabismus, occurring in about 2% of children 4-10 years of age,[1,2] is associated with abnormal binocular vision and stereopsis, because the brain is unable to fuse images from the two eyes. Normal stereopsis is based on three categories of depth cues[3]: light/shadow, perspective, and triangulation. Strabismus is associated with slow reading,[4] as a result of fixation instability,[5] and with difficulties performing visuomotor tasks[6] such as grasping[7] or balance.[8] Balance control associated with gait has been shown to improve after strabismus surgery in patients with onset of strabismus before 1 year of age.[9] Similarly, 3 months after strabismus surgery in esotropic children, a comparable motor performance was found for patients and controls with the exception of ball skills, whereas half of esotropic children had abnormal or borderline results before surgery.[10]

In the case of anisometropic amblyopia, motor performance is significantly worse in 3- and 6-year-old hyperopic children than in age-matched emmetropic children, with deficits in manual dexterity, balance, and ball skills.[11] The present study investigated the extent to which strabismic patients present with similar motor deficits. It also aimed to shed light on which parameters of strabismus, such as the strabismus type, deviation angle, and degree of binocularity, were correlated with the severity of motor deficits.

Subjects and Methods

The research protocol followed the tenets of the Declaration of Helsinki and was approved by the University of Louvain's Human Biomedical Ethics Board. The study cohort included children treated for strabismus at the Cliniques Universitaires Saint-Luc and control children without strabismus or amblyopia. Tests were carried out between February 2019 and December 2019. All participants and their care givers provided informed written consent before participating in the study.

Inclusion criteria were as follows: child age >3 years and <13 years; correct completion of motor and ophthalmological testing; understanding of test instructions; and informed, written consent. Exclusion criteria included premature birth; medication that could affect testing; a history of neurological, vestibular, or

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Submitted October 7, 2019.
Revision accepted January 4, 2020.
Published online March 18, 2020.

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1091-8531/$36.00
https://doi.org/10.1016/j.jaapos.2020.01.005

orthopedic disease; cognitive or developmental impairment; and behavioral disorder. Furthermore, inclusion criteria for strabismic children also included the following condition: that the child has had strabismus, has been cured, where applicable, surgically and/or with spectacles, and amblyopia, if present, has been treated with occlusion therapy. Lastly, controls were required to have no ophthalmological disease as well as stereopsis of at least 60 arcsec and corrected visual acuity of 0 logMAR or better in both eyes.

Procedures

Each participant performed the Movement Assessment Battery for Children, Second Edition (MABC-2), and received an ophthalmologic examination on the same day. Testing conditions and facilities were identical for all children, including the individuals administering the tests.

Movement Testing

MABC-2 is a validated tool[12,13] to identify motor impairments in children between 3 years and 16 years. In this test, children perform 8 tasks, customized for three age ranges and covering 3 "motor areas": manual dexterity, aiming and catching, and static and dynamic balance (Table 1). Strabismic children performed the test binocularly, and controls, monocularly, with one eye patched.

Each MABC-2 testing session lasted for 20-40 minutes. It was confirmed that the child had not taken the test in the previous 6 months, to avoid a test-retest effect. Performance for the eight tasks was scored quantitatively and qualitatively. The results were compared with MABC-2 scores of 3,230 North Belgian and Dutch age-matched healthy children, tested binocularly, to provide standard scores and percentile ranks. The standard scores were computed so that the mean standard score for a healthy population was 10, with a standard deviation of 3. Two-thirds of a healthy population was therefore expected to have a standard score of 7-13. Standard scores were also computed for the three motor areas as well as for the total MABC-2 test, by adding the scores of the relevant tasks and similarly normalizing the results. A North Belgian and Dutch normative population[14] was chosen because of its sociocultural proximity as well as the similarities between the Dutch and Belgian education systems.

Motor results were classified as follows (Table 2): a standard score of ≤4 or a rank at or below the 5th percentile (red traffic light) was considered "significant motor difficulty"; a standard score >7 or a rank above the 16th percentile (green traffic light), "unlikely to have a motor difficulty"; and a standard score between 4 and 7, inclusive (orange traffic light), "at risk."

The 16th percentile corresponds to a standard score of 7, one standard deviation below the mean standard score. The other cut-off, at 2 standard deviations below the mean, is a standard score of 4. This standard score represents a stricter cut off than the 5th percentile, which was chosen as the other percentile cut-off by the MABC-2 test designers.[14] The quantitative scoring was interpreted in light of the qualitative assessment to distinguish between poor performance resulting from motor difficulty and from motivational factors.

Ophthalmologic Testing

Ophthalmologic examination included assessment of binocularity and stereopsis, evaluation of deviation angle, and measure of visual acuity (see eSupplement 1, available at jaapos.org). All tests were administered with the best optical correction.

Fusion tests were performed at distance (5 m) and at near (33 cm) fixation. Central fusion was assessed using the Worth 4-Dot test. If the child's capabilities allowed, peripheral fusion was evaluated using Bagolini glasses. The TNO stereotest (plates II, V, VI) was used at 33 cm to quantify the child's stereoscopy. The deviation angle was measured using the alternate cover test at distance, at near, and at near with a +3 D spherical lens placed in front of the spectacles, in order to relax convergence and identify cases of strabismus associated with abnormal accommodative convergence.

Participant Subgroups

The tested children were classified according to three dimensions: (1) strabismus type, (2) degree of binocularity, and (3) deviation angle. Strabismus type included infantile strabismus (documented prior to 6 months of age), strabismus secondary to reduced visual acuity in one eye, and acquired strabismus (onset after 6 months of age, with or without an accommodative component). Binocularity was classified as absent, with suppression at distance and/or at near, partial without stereopsis, with fusion at distance and at near but no stereopsis, or normal, with fusion at distance and at near and subnormal or full stereopsis. Deviation subgroups included below 12^{Δ}, between 12^{Δ} and 20^{Δ}, and above 20^{Δ}.

Statistical Analysis

The average standard scores for each group were compared 3 by 3 using an ANOVA test, in cases of normal data distribution, and a Kruskal-Wallis test, when normality was not verified. These scores were also compared 2 by 2 using a t test when sample normality was verified and a Mann-Whitney test otherwise, with appropriate Bonferroni correction for multiplicity in both cases. As the sample size was <50 individuals, sample normality was assessed using a Shapiro-Wilk test. A P value of <0.05 was considered significant.

The sample size was chosen based on the sample sizes in similar studies[9,10,15] and the number of available participants with the required criteria. However, a sample size of 40 strabismic participants was sufficient, given that in a one-way ANOVA study (with three groups), a sample of 33 subjects achieves 90% power to detect differences between the means versus the alternative of equal means using an F test with an α of 0.05 significance level, assuming means of 6.1, 8.1, and 11.5. The common standard deviation within a group was assumed to be 3.3.

Results

A total of 66 volunteers, aged 3-12 years, including 48 children treated for strabismus and 18 healthy controls, were tested. Of these, 8 were excluded (5 for developmental delay, behavioral troubles, or prematurity, 2 for inaccurate or incomplete testing, and 1 for vestibular troubles). The

Table 1. Description of Movement Assessment Battery for Children's eight tasks for the three motor areas and the three age categories

	3-6 years	7-10 years	11-16 years
Manual dexterity 1	Post coins	Placing pegs	Turning pegs
Manual dexterity 2	Threading beads	Threading lace	Triangle with nuts and bolts
Manual dexterity 3	Drawing task	Drawing task	Drawing task
Aiming and catching 1	Catching beanbag	Catching with two hands	Catching with one hand
Aiming and catching 2	Throwing beanbag onto mat	Throwing beanbag onto mat	Throwing ball at wall-mounted target
Static and dynamic balance 1	One-leg balance	One-board balance	Two-board balance
Static and dynamic balance 2	Walking heels raised	Walking heel-to-toe forward	Walking toe-to-heel backward
Static and dynamic balance 3	Jumping on mats	Hopping on mats	Zigzag hopping

Table 2. The three levels of motor difficulty, as assessed by the Movement Assessment Battery for Children test, with the associated standard scores, percentile ranks and standard deviations

	Standard score	Percentile rank	Standard deviation	Traffic light
Significant motor difficulty	≤4	≤5th	≥ −2	Red
At risk	>4 and ≤7	>5th and ≤16th	< −2 and ≥ −1	Orange
Unlikely to have a motor difficulty	>7	>16th	< −1	Green

final cohort included 40 strabismic children (mean age, 7.25 ± 3.83 years [standard deviation]; 19 females) and 18 control children (mean age, 8.33 ± 5.42 years; 6 females).

All 58 children performed the MABC-2 test and received an ophthalmologic examination. According to MABC-2, 8 strabismic children had motor difficulties, 13 were at risk of having motor difficulties, and 19 were unlikely to have a motor difficulty. The median standard score of strabismic children for the total movement test was 7, at the upper threshold of the at-risk population (Figure 1); the average standard score was 7.55, lower than the theoretical MABC-2 average standard score of 10.

With regard to strabismus type, 13 participants had infantile strabismus, 6 had secondary strabismus, and 21 had acquired strabismus. There were 21 participants with no binocularity, 13 with partial binocularity, and 6 with normal binocularity. Finally, with regard to deviation subgroup, 29 were below 12^{Δ}, 5 were between 12^{Δ} and 20^{Δ}, and 6 were above 20^{Δ}

Total MABC-2 Scores of Strabismic Children across Subgroups

Children's total MABC-2 test scores were compared for strabismus type, binocularity, and deviation angle. The effect of binocular visual acuity on motor function was further analyzed. Test scores were significantly different for the three binocularity subgroups (P = 0.002), with significantly lower scores for children without binocularity compared with those who had normal binocularity (P = 0.002). There was no significant difference between scores of children with different strabismus types (P = 0.094) or deviation angles (P = 0.107). Total test scores of children with sensory strabismus were not significantly different from those of children with infantile or acquired strabismus (P = 0.200). In addition, total test scores were not significantly correlated (R = 0.080) with binocular visual acuities.

Mean standard scores for the groups without binocularity (mean, 6.1) and with partial binocularity (mean, 8.1) were significantly lower (P <0.001 and P = 0.048, resp.) than the mean standard score of 10 expected for a healthy population (Figure 1). The mean and median standard scores of the with-binocularity subgroup corresponded to a level unlikely to have a motor difficulty, whereas the without-binocularity subgroup was at risk of motor difficulty.

Motor Area Scores of strabismic Children across Binocularity Groups

Standard scores for the binocularity subgroups were compared for the three motor areas. For the balance area, they significantly differed between groups (P = 0.002), with lower scores for the without-binocularity subgroup compared with the normal-binocularity subgroup (P = 0.002). Standard scores for the other motor areas did not differ significantly between binocularity subgroups.

Focus was directed to whether the difference between binocularity subgroups was significant for the three tasks that comprised the balance area (Figure 2A). Results showed that they were significantly different for the first balance task (P = 0.005), as well as for the second task (P = 0.006), which assess static and dynamic balance, respectively. Additionally, standard scores of the group without binocularity were significantly lower than those of the group with normal binocularity for the first balance task (P = 0.003).

In addition, standard scores of the three binocularity subgroups were compared for the catching and aiming task (Figure 2B). They were significantly different for the catching task (P = 0.042), but not for the aiming task (P = 0.348).

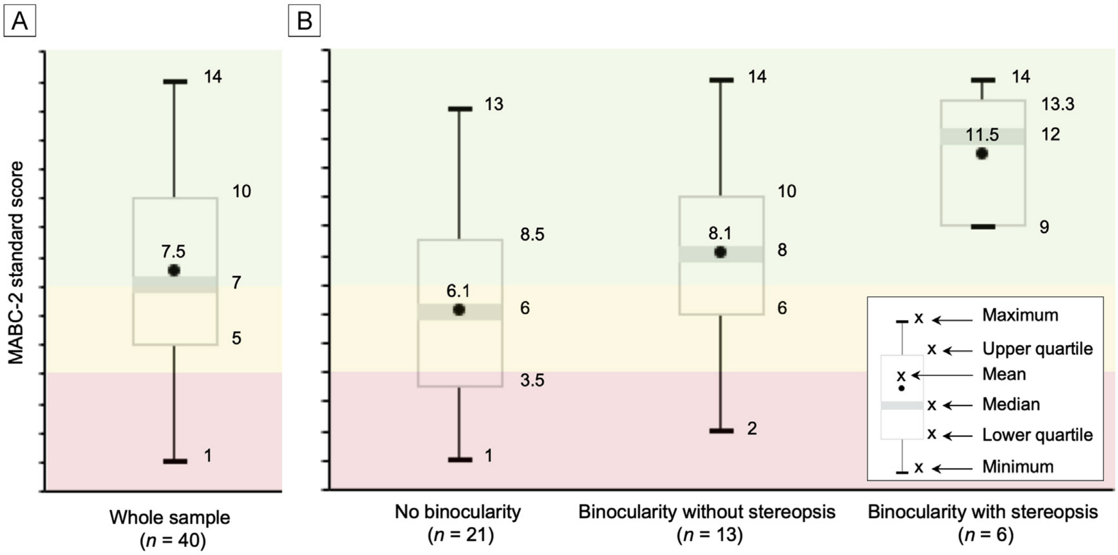

FIG 1. Distribution of total Movement Assessment Battery for Children test standard scores. A, Whole sample of strabismic children. B, Three strabismic groups: no binocularity, partial binocularity, and normal binocularity.

Standard Scores Compared with Scores of Monocularly Tested Controls

Motor performance of the monocularly tested controls was compared to the results of the North Belgian and Dutch controls, who performed the tasks in binocular viewing conditions. Results for the catching task ($P = 0.001$), as well as for the second manual dexterity task ($P = 0.017$) were significantly lower for the monocularly tested controls. There was no statistically significant difference for the other motor tasks.

Moreover, motor performance of the monocularly tested controls was also compared to the results of strabismic children without binocularity. Results of the strabismic children were significantly lower ($P = 0.032$) than those of monocularly tested controls in the static and dynamic balance area (Figure 3). The factor explaining the difference in motor performance between monocularly tested children and strabismic children without binocularity may be binocular vision development.

Discussion

This study confirmed that lack of binocularity in children is associated with significant motor skills impairment, in particular for static balance and catching tasks. In line with these results, mean and median standard scores of children without binocularity were in the "at risk" zone for total test score, as well as for the static balance and catching tasks. This study also showed that the extent of motor deficiency was neither correlated with the strabismus type nor with the deviation angle, even though the quality of binocularity may be linked to some extent with the degree of misalignment.

With regard to the relationship between degree of binocularity and strabismus type, in infantile strabismus, it is expected that no binocular vision, or at best, a significantly altered binocularity, will develop. However, it may happen that a child with infantile strabismus and a small deviation angle develops a partial binocularity.[16] On the other hand, a child with acquired strabismus and a large angle may not be able to develop normal binocularity, depending on the onset age of strabismus. Lastly, children with secondary strabismus and severe amblyopia generally do not develop a binocular vision.[17] On the other hand, the deviation angle and degree of binocularity do not have a linear relationship, as a result of variations among individuals. In effect, development of binocularity with stereopsis requires the absence of deviation for most children but may succeed in children with a horizontal deviation of up to 8^{Δ}.[16] The lack of a significant relationship between the deviation angle and standard scores should, however, be confirmed with a larger sample of children with midrange (12^{Δ}-20^{Δ}) and large angles ($>20^{\Delta}$).

This study showed that standard scores for the catching task were significantly correlated with degree of binocularity. This finding is in line with previous studies,[10,18] which confirmed that binocular information and depth perception were key for dynamic motor tasks such as catching a ball. The correlation, however, was not significant for the aiming task, which accords with the finding that greater accuracy was obtained when aiming monocularly with the dominant eye rather than with the fellow eye or binocularly with both eyes.[19] Without relying on the binocular disparity between eyes, depth can be perceived based on perspective, light, and shadows. In addition, it has been demonstrated, in reach-to-touch movements, that strabismic patients, using either both eyes or the nonamblyopic eye, had reach latency and accuracy comparable to visually normal controls.[20] However, they compensated for their visual

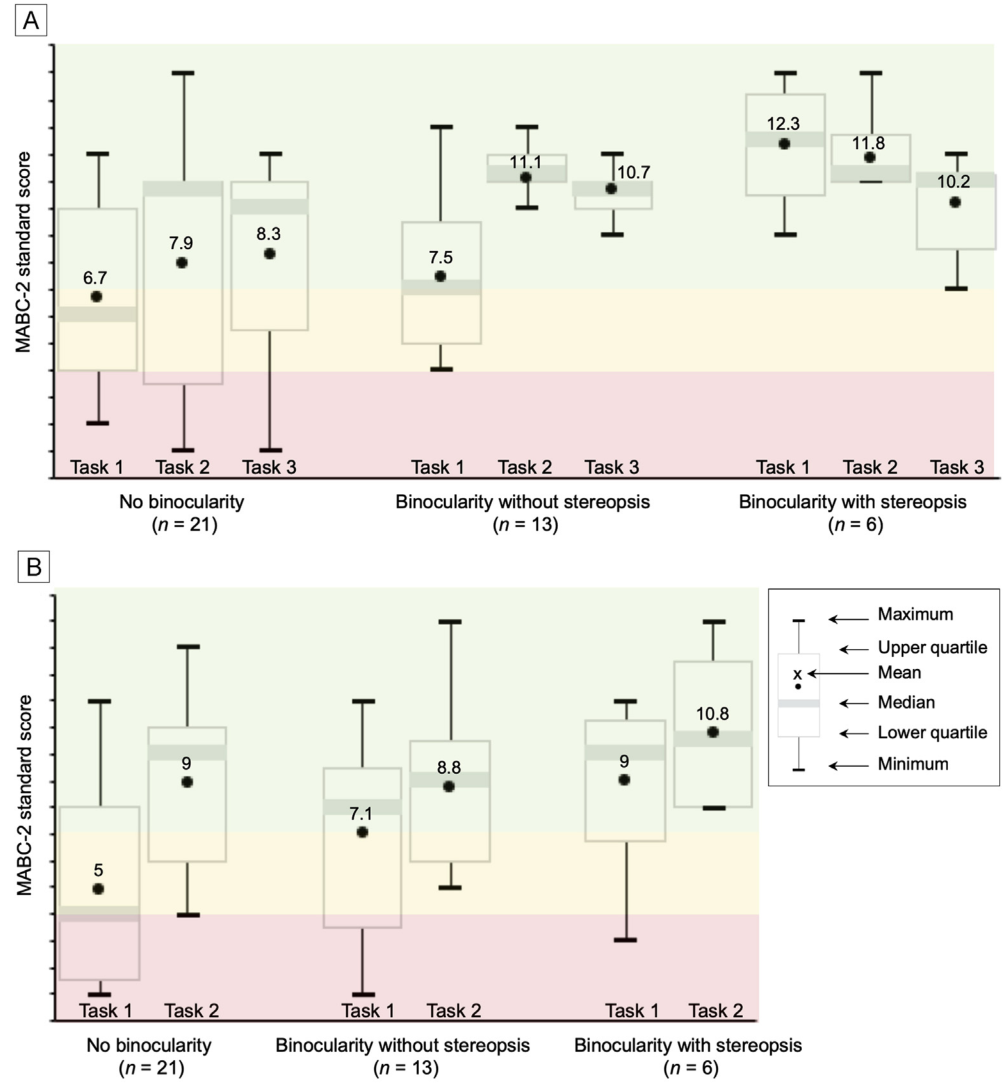

FIG 2. Distribution of Movement Assessment Battery for Children test standard scores for the balance (A), and aiming and catching tasks (B) for strabismic children depending on their level of binocularity.

deficit by developing an alternative motor strategy with a reduced reach peak speed acceleration and a prolonged acceleration phase.

A significant correlation between participants' performance during the static balance task and the binocularity level was shown In agreement with this finding, it was demonstrated that even a subtle binocularity anomaly might lead to postural instability.[21] Performance during the dynamic balance tasks was not significantly correlated with the binocularity level. This can be understood by taking into account previous findings that strabismic children partially compensate for their visual deficits by using proprioceptive input to a greater extent than age-matched controls.[22]

Scores for the MABC-2 manual dexterity tasks were not significantly correlated with the binocularity level. In contrast to this finding, Webber and Wood[23] found that children with amblyopia, particularly those with strabismus, presented deficits for fine motor skills, especially when the tasks required speed and dexterity. A potential explanation for these differences may be a result of the three MABC-2 tasks requiring less speed and dexterity than the Bruininks-Oseretsky test administered by Webber and Wood.[23] The choice of MABC-2 allowed for a quick and reliable evaluation, which was pivotal to retain children's attention.

Future studies should assess more precisely motor skills such as manual dexterity. Furthermore, the results of the present study should be confirmed with a larger sample of children, including a larger number of children with median and large deviation angles. Assessing older children could illustrate a timeline for development of further compensation mechanisms in the proprioceptive, vestibular, or visual domains. This could allow for assessment

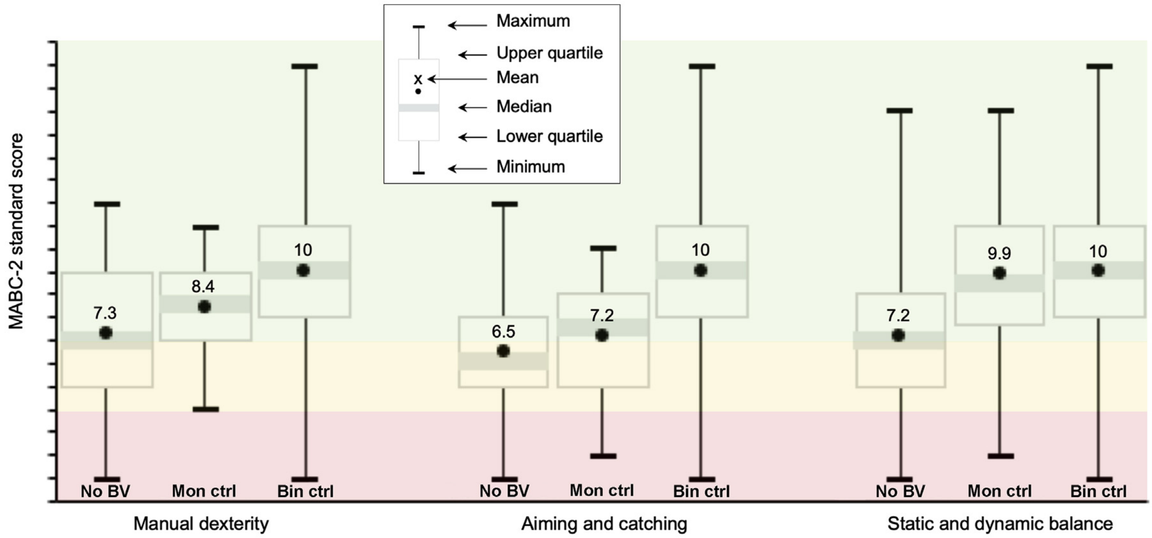

FIG 3. Distribution of Movement Assessment Battery for Children test standard scores for the manual dexterity, aiming, catching, and balance tasks for strabismic children without binocular vision (*No BV*) and for the monocularly (*Mon ctrl*) as well as binocularly tested controls (*Bin ctrl*).

of the actual effects of strabismus on overall motor performance.

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