· Clinical Research ·

Visual motor integration, visual perception and motor coordination in children with horizontal strabismus

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Abstract
● **AIM:** To compare visual motor integration (VMI) in non-amblyopic children with and without horizontal strabismus.
● **METHODS:** VMI, visual perception, and motor coordination were evaluated in non-amblyopic children aged 6 to 17 years old using the Beery-Buktenica Developmental Test of Visual-Motor Integration (Beery-VMI), together with its supplementary Developmental Tests of Visual Perception and Motor Coordination.
● **RESULTS:** Forty-five non-amblyopic children with horizontal strabismus (23 males, 22 females; mean age: 126.0±33mo) and 45 children without strabismus (22 males, 23 females; mean age: 126.2±34mo) were enrolled. Children with horizontal strabismus exhibited significantly lower mean Beery-VMI scores (P<0.001), visual perception scores (P<0.001), and motor coordination scores (P<0.001) compared with controls, even after adjustment for confounding variables including sex, age, regular sports participation, number of siblings, and stereopsis.
● **CONCLUSION:** Non-amblyopic children with horizontal strabismus demonstrate significantly poorer performance in Beery-VMI, visual perception, and motor coordination compared with children without strabismus.

● **KEYWORDS:** strabismus; psychomotor performance; visual perception; child development; developmental disabilities
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INTRODUCTION

Strabismus is an ocular misalignment in which the eyes do not meet at the same point of fixation[1-3]. It has both physical and psychological consequences, which are particularly concerning when strabismus is present from childhood. When strabismus develops during the critical visual maturation period, it can lead to amblyopia. In addition, failure of sensory fusion compromises depth and disparity discrimination, resulting in a loss of stereopsis; consequently, binocular function may be impaired even in the absence of amblyopia[4]. Beyond these functional deficits, these children may experience self-esteem issues[5-6] and face difficulties in seeking employment in adulthood[7-8]. Horizontal strabismus, in which the visual axes are deviated in the horizontal plane, comprises more than 80% of strabismus cases[9-11]. To avoid visual confusion from different images viewed by each eye, these children tend to suppress the image from the squinting eye, resulting in reduction of visual information received[12]. Additional adaptations, including abnormal retinal correspondence and compensatory head posture, may also occur. This monocular state may significantly affect a child's hand-eye coordination[13-14].

Visual motor integration (VMI) is the degree of ability to perceive visual input, process the information, and coordinate a motor response, essentially testing hand-eye coordination[15]. Development of motor functions is an essential part of a child's growth, with the fastest growth occurring during early childhood. During this period, adequate stimulation allows the brain and motor skills to grow and mature in line with developmental milestones[16]. Normal motor development during childhood has been postulated to serve as a precursor to the maturation of other aspects of motor skills[17]. Studies show that poor VMI is associated with poor academic achievement[18-20] and may predict poor school performance[21-24]. Therefore, VMI may act as a proxy for predicting a child's school readiness. The Beery-Buktenica Developmental Test of Visual-Motor Integration (Beery-VMI test) is one of the most commonly used measurements of VMI[25] with a reported reliability of 0.92[26] and internal consistency scores ranging from 0.82 to 0.87[27].

To date, the relationship between strabismus and VMI remains poorly defined. The lack of awareness and information on this may deprive children with strabismus from receiving services which might modify their development, thus hindering them from achieving their highest potential. This study aims to fill this gap by comparing the VMI of children with and without horizontal strabismus, in the hope that this will open avenues to explore potential approaches of management.

PARTICIPANTS AND METHODS

Ethical Approval The study obtained ethical approval from the Human Research Ethics Committee of Universiti Sains Malaysia (USM/JEPeM/2007037) and was conducted according to the principles of the Declaration of Helsinki for Human Research. Informed and written consent were obtained from subjects and their parents.

This cross-sectional study included 90 children aged 6 to 17 years old who attended the Paediatric Ophthalmology Clinic of Hospital Pakar Universiti Sains Malaysia from October 2020 to September 2021.

Inclusion criteria included all children aged 6 to 17 years old with and without horizontal strabismus with a best corrected vision in both eyes of better than 6/9 attending the Paediatric Ophthalmology Clinic of Hospital Universiti Sains Malaysia. Horizontal strabismus was defined as a prism cover test measuring ≥12 prism diopters in the horizontal meridian. The group of non-strabismic children were all orthophoric. Children with neurological disorders, cranial nerves palsies, orthopaedic disease, vestibular disease, cognitive or behavioural disorders, and those who were born preterm were excluded.

Ocular Assessment Data collected included patient age in months, gender, favourite sport activities (defined as sports performed 3 or more times per week and categorized into team sports, individual sports, or no regular sport participation), number of siblings, medical history, and ocular history. All subjects underwent a full ophthalmological assessment by a single ophthalmologist. Type of strabismus was determined using the prism cover test by the same investigator. Visual acuity was tested using a Snellen Chart at 6-meter distance. In children with glasses, visual acuity was documented while wearing glasses.

Stereopsis was evaluated using the Titmus stereoacuity test. This test has 3 parts; the fly, the animal, and the circle. We utilized the fly portion with the subjects wearing polarized glasses and holding the test booklet at reading distance in a well-lit room. This portion of the test consists of an image of a housefly, the wings of which appear to be elevated if the stereopsis is at least 3000s. Subjects were asked to "pinch" the tip of the wing between thumb and forefinger and the position of their fingers was observed. Subjects with poor stereopsis tend to touch the wing rather than "pinching" the wing; the latter action involves the fingers being placed above the plane of the picture due to the three-dimensional characteristic of the image. Stereopsis was documented as present or absent based on a cut-off point of 3000s.

Visual Motor Integration Assessment The Beery-VMI test was administered, including its two supplementary tests; the visual perception (VP) test and motor coordination (MC) test. The Beery-VMI is a test that assesses the level of integration between visual input and motor output by assessing the ability to copy and imitate forms and shapes given. It consists of 30 items which the subjects are asked to copy. A raw score of 1 to 30 is given.

The VP test consists of 30 items. The first three items require subjects to identify parts of their own bodies, picture outlines and parts of a picture respectively. The remaining 27 items are based on matching a given shape to its duplicate among a list of options of different size and orientation. Similarly, a raw score of one to 30 is given.

For the MC test, the first three items, designed for very young children, require the subject to climb on a chair, hold a pencil and hold a paper. The remaining 27 items require subjects to trace a shape without going outside double-lined paths. A raw score of one to 30 is then given. To ensure that participants understood the tasks and to minimize any effect of unfamiliarity on performance, an example shape tracing was demonstrated on one item prior to testing.

The raw score from the three tests is then converted into the standardized score based on the tables provided within the Beery-VMI Administration, Scoring and Teaching Manual (fifth edition). This provides age-standardized scores for the Beery-VMI, VP and MC tests. The Beery-VMI score evaluation was done by a single occupational therapist.

Sample Size Sample size was determined using G Power Software 2010, assuming an effect size of 0.6 and power of 0.80. Accordingly, 45 participants were recruited for each group, with groups matched for age and gender, yielding a total sample of 90 subjects.

Statistical Analysis Statistical analyses were performed

Table 1 Demographic and clinical characteristics of children with horizontal strabismus

Variables	Children with horizontal strabismus (*n*=45)	Children without strabismus (*n*=45)	Mean difference (95%CI)	*P*
Gender				
Male (%)	23 (51)	22 (49)		0.835[a]
Female (%)	22 (49)	23 (51)		
Age in months, mean±SD	126.0±33	126.2±34	0.2 (-14, 14.4)	0.972[b]
Favourite sports (%)				
None	26 (58)	23 (52)		0.668[c]
Team sport	12 (27)	11 (24)		
Individual sport	7 (15)	11 (24)		
Number of siblings, mean±SD	3.5±1.8	2.7±1.3	0.8 (-1.4, -0.1)	0.019[b,d]
Presence of stereopsis (%)	14 (31)	45 (100)		<0.001[a]

[a]Pearson Chi-square test was applied; [b]Independent *t*-test was applied; [c]Fisher exact test was applied; [d]*P*<0.05 is statistically significant. CI: Confidence interval; SD: Standard deviation.

Table 2 Comparison of Beery-VMI, visual perception and motor coordination score between children with horizontal strabismus and children without strabismus Mean (95%CI)

Variables	Model	Mean score (*n*=45)		Mean difference (95% CI)	*F* (*df*)	*P*
		Children with horizontal strabismus adjusted	Children without horizontal strabismus adjusted			
Beery-VMI score	Unadjusted mean	82.4 (76.2, 88.5)	105.0 (98.8, 111.1)	22.6 (13.9, 31.3)		<0.001[a]
	Model 1	82.4 (76.3, 88.5)	105.0 (98.9, 111.1)	22.6 (13.9, 31.2)	27.0 (1, 85)	<0.001
	Model 2	82.2 (75.9, 88.4)	105.2 (98.9, 111.4)	23.0 (14.0, 32.0)	25.9 (1, 84)	<0.001
	Model 3	80.3 (72.6, 88.0)	107.1 (99.4, 114.7)	26.7 (14.0, 39.5)	17.5 (1, 84)	<0.001
	Model 4	80.1 (72.3, 87.9)	107.3 (99.5, 115.1)	27.2 (14.2, 40.1)	17.4 (1, 83)	<0.001
Visual perception score	Unadjusted mean	81.7 (76.9, 86.5)	100.9 (96.1, 105.7)	19.2 (12.3, 26.0)		<0.001[a]
	Model 1	81.7 (77.0, 86.4)	100.9 (96.2, 105,5)	19.2 (12.6, 25.7)	33.4 (1, 85)	<0.001
	Model 2	81.4 (76.7, 86.2)	101.1 (96.4, 105.9)	19.7 (12.8, 26.6)	32.6 (1, 84)	<0.001
	Model 3	83.5 (77.7, 89.4)	99.0 (93.2, 104.9)	15.5 (5.8, 25.2)	10.1 (1, 84)	0.002
	Model 4	83.3 (77.4, 89.2)	99.3 (93.3, 105.2)	16.0 (6.1, 25.8)	10.4 (1, 83)	0.002
Motor coordination score	Unadjusted mean	83.1 (77.6, 88.6)	102.2 (96.7, 107.8)	19.2 (11.3, 27.0)		<0.001[a]
	Model 1	83.2 (78.0, 88.4)	102.1 (96.9, 107.3)	18.9 (11.6, 26.3)	26.2 (1, 85)	<0.001
	Model 2	82.6 (77.3, 87.9)	102.7 (97.4, 108.0)	20.5 (12.4, 27.7)	27.4 (1, 84)	<0.001
	Model 3	81.5 (75.0, 88.0)	103.8 (97.3, 110.4)	22.3 (11.5, 33.2)	16.8 (1, 84)	<0.001
	Model 4	81.0 (74.4, 87.6)	104.3 (97.7, 110.9)	23.3 (12.3, 34.3)	17.8 (1, 83)	<0.001

Model 1 adjusted for gender, age, favourite sport activities; Model 2 adjusted for gender, age, favourite sport activities, number of siblings; Model 3 adjusted for gender, age, favourite sport activities, presence of stereopsis; Model 4 adjusted for gender, age, favourite sport activities, number of siblings and presence of stereopsis. CI: Confidence interval; *df*: Degree of freedom. [a]Independent *t*-test was applied.

using IBM SPSS Statistics for Windows, Version 27.0 (IBM Corp, Armonk, NY, USA). A Chi-square test and fisher exact test were used to determine the statistical differences in categorical variables between children with horizontal strabismus and children without horizontal strabismus. An independent *t*-test was used to determine the mean differences in numerical variables between these two groups of children. An independent *t*-test was also performed to determine the differences in the mean score of Beery-VMI, visual perception, and motor coordination between the groups. Adjustment for confounding factors was performed using one way analysis of covariance.

RESULTS

A total of 90 children were included in this study, 45 (50.0%) with horizontal strabismus and 45 (50.0%) children without strabismus. Their mean age was 126.0mo. Comparing children with horizontal strabismus and children without strabismus, there were no statistically significant differences in age, gender, and favourite sport activities between the groups (Table 1). However, there were statistically significant differences in the number of siblings (*P*=0.019) and the presence of stereopsis (*P*<0.001) between the groups.

We found significant differences in the mean Berry-VMI score between children with horizontal strabismus and children without strabismus (*P*<0.001). Similarly, the VP score and MC score in children with strabismus was significantly lower than in children without strabismus (*P*<0.001). These differences persisted even after adjustment for age, gender, favourite sport activities, number of siblings, and the presence of stereopsis (Table 2).

Table 3 Summary of literature regarding motor skills in children with strabismus

Name	Country/region	Year	Sample size	Study	Result	Conclusion
Current study	Malaysia	2026	90	Cross-sectional	*P*<0.001	Non-amblyopic children with horizontal strabismus have poorer VMI, VP and MC compared to children without strabismus
Ibrahimi *et al*[15]	Mexico	2021	146	Cross-sectional	*P*<0.050	Strabismic children with amblyopia have lower VP than non-amblyopic children with strabismus. Amblyopia does not affect VMI and MC in strabismus
Vagge *et al*[4]	Italy	2021	47	Cross-sectional	*P*<0.001	Motor skills are reduced in children with strabismus
Yeh *et al*[64]	Taiwan, China	2021	40	Cross-sectional	95%CI 88.78%, 100%	Children with strabismus and abnormal stereopsis have impaired fine motor competency
Hemptine *et al*[63]	Belgium	2020	40	Cross-sectional	*P*=0.002	Lack of stereopsis is associated with significant motor skill impairment
Niechwiej-Szwedo *et al*[35]	Canada	2014	41	Cross-sectional	*P*<0.001	Strabismic amblyopic patients have longer saccade latency

VP: Visual perception; VMI: Visual motor integration; MC: Motor coordination; CI: Confidence interval.

DISCUSSION

VMI is the ability to receive visual input and coordinate a motor response. It is an important skill in children, having been linked to better school performance and readiness[28]. VMI is a proxy for motor skills, as Bonifacci[29] observed that children aged 6 to 10 years old with different VMI have different gross motor abilities. Visual impairment is known to affect motor skills[30-32]. However, strabismus, with its attendant visual consequences, has only rarely been the focus of studies evaluating motor function. Our study demonstrated that non-amblyopic children with horizontal strabismus have significantly poorer Beery-VMI, VP, and MC scores than children without strabismus, even after adjustment for potential cofounding factors.

A child with strabismus usually uses only one eye to see at any one time, placing them in a monocular state[33]. The reduced information received by the brain while only using one eye may explain the poorer VMI performance we observed in strabismic children, as partial obscuration of vision has been associated with poorer motor integration[34]. Among a cohort of children with strabismus, of whom approximately 40% were amblyopic, Vagge *et al*[4] observed a reduction in motor skills. Likewise, Niechwiej-Szwedo *et al*[35] observed similar impairments in eye-hand coordination among a cohort of adults with and without strabismic amblyopia. The findings of other studies assessing motor skills in strabismic children are highlighted in Table 3. Subjects with monocular vision not only have problems in depth perception but may also have difficulty in activities not requiring depth perception, such as reading, watching television, and judging object size[36-37]. We postulate that this phenomenon may explain the lower VP score we observed in strabismic subjects, as this test required subjects to match geometrical shapes of differing size and orientation.

MC score is evaluated by asking subjects to trace a guided path without going out of the bordered path[26]. Our findings that the motor coordination score in children with horizontal strabismus was significantly lower than in children without strabismus are in keeping with the results of Caputo *et al*[38]. They postulated that poor motor coordination may not be due to lack of binocularity, but rather lack of simultaneous perception. These conclusions were derived from observations that children aged 4 years old and older with surgically corrected strabismus showed improvement in motor coordination despite absence of improved binocularity. The poorer motor coordination performance we noted in our test group may also be related to the impaired form perception, motion processing and oculomotor behaviour associated with monocularity[39].

Among preschool children, girls seem to perform better in fine motor skills, while boys do better at gross motor skills[40-41]. This difference has been attributed to earlier neuromuscular maturation in girls, including finer hand dexterity and coordination during early childhood. Gender was thus included as a confounder in our analysis, although as children mature, the differences in fine motor skills between boys and girls seem to normalize[42]. We also adjusted for subjects' favourite sports due to reported differences in fine and gross motor skill between children involved in team sports and children involved in individual sports[43].

Presence of siblings has been noted to allow more cooperative play and imitation learning[44]. As there was a statistically significant intergroup difference in the number of siblings per subject (*P*=0.019), our multivariate analysis adjusted for this. Likewise, we adjusted for stereopsis, as lack of stereopsis may negatively affect VMI[45-46]. Although Ibrahimi *et al*[15] failed to document a significant difference of Beery-VMI score between children with stereopsis and without stereopsis, our study observed that adjustment for the presence of stereopsis had the most impact on the change in mean intergroup differences for all scores.

Strabismus is an important cause of reduced visual function and quality of life in children[47-49]. The prevalence of strabismus among preschool and school-going children ranges from 1% to 5%, although among children born preterm, this figure is higher[2,50-53]. The pathophysiology of strabismus is complex, and existing studies may only scratch the tip of the iceberg regarding the impact of this condition in a child's life[54]. Early intervention can be life changing for children with strabismus[55-57]. Unfortunately, despite its benefits, there are still many barriers to the accessibility of strabismus treatment[58-62]. These barriers may be slowly eroded by improving public awareness, particularly of the consequences of untreated strabismus[61].

Our study highlights the fact that children with horizontal strabismus have poorer VMI development than children without strabismus, even in the absence of amblyopia. Optometrists and ophthalmologists evaluating strabismic children may be unaware of the magnitude and consequences of this impact, as most studies on motor impairment in this group have only emerged in recent years[15,35,63-64]. This may be detrimental to a child's overall health and development. Various authors have hypothesized that VMI is a skill developed in a certain part of the brain of a growing child, and that failure to exercise it may compromise brain development[26,65]. Impairment in VMI due to strabismus may serve as an indication for strabismus surgery in children.

Horizontal strabismus is the most common form of strabismus and accounts for most of the disease burden[9]. Our findings of impaired VMI in children with horizontal strabismus may thus be extrapolated to strabismic children in general. A strength of our study is that we only recruited children without amblyopia, thus avoiding the effect of poor vision in the squinting eye on VMI. This is in contrast to other studies evaluating motor development in strabismic subjects, all of which included subjects with a history of amblyopia[4,35,64,66]. This non-amblyopic focus remains crucial, as the primary visual deficit in strabismus has been shown to independently affect motor learning mechanisms[66]. Also, our use of a test which converts raw score into standardized scores based on subjects' age allowed us to eliminate the potential effects of age on the VMI performance. Last but not least, our adjustment for multiple potential confounding factors demonstrates that visual motor skills are significantly compromised in strabismic children regardless of the presence of stereopsis, suggesting that the underlying mechanisms affecting VMI may involve more than depth perception. Early evidence has suggested that strabismus surgery may lead to significant post-operative improvements in visuomotor skills and sensorimotor integration[67]. We thus plan to build on our research by evaluating the effect of treatment such as strabismus surgery and occupational therapy interventions on VMI in children with strabismus.

One limitation of our study is that resource constraints dictated the necessity of assessing stereopsis using the Titmus stereoacuity test, which measures only local stereopsis and may be affected by monocular cues. A random-dot stereotest would provide a more robust evaluation of global stereopsis[68]. Stereopsis assessment is integral to strabismus management, even after surgery, as training to improve binocular visual perception has been shown to improve strabismus control[69]. Second, refractive error was not incorporated into the analysis. Recent studies have demonstrated that type of refractive error may have influence upon stereopsis, even in the presence of refractive correction[70].

In conclusion, children aged 6 to 17 years old with horizontal strabismus showed lower mean Beery-VMI score, visual perception score and motor coordination score than children without strabismus. These findings prompt consideration of VMI as an additional parameter when considering indications for intervention in strabismus. Children with horizontal strabismus should be referred to an occupational therapist for assessment of VMI.

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