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Original Article

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Developmental Patterns of Visual Perception, Motor Coordination and Visual-motor Integration in Typically Developing Children in West Bengal, India: A Cross-sectional Study

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ABSTRACT

Introduction: Visual-Motor Integration (VMI) reflects the coordinated functioning of perceptual and motor systems and is fundamental for academic and everyday activities. Developmental data especially from non Western populations remain limited.

Aim: To examine age-related developmental trajectories of Visual Perception (VP), Motor Coordination (MC), and VMI in typically developing Indian children aged 7-15 years, and to analyse associated gender differences.

Materials and Methods: This cross-sectional study examined VP, MC, and VMI in 224 typically developing Indian children aged 7-15 years from West Bengal using the Beery-Buktenica developmental test of VMI, Sixth Edition. The study was conducted with the approval of MAHER Doctoral and Ethical Committee. Age effects were analysed using One-way Analysis of Variance (ANOVA) and gender differences using independent-samples t-tests.

Results: Age had a statistically significant effect on VP, MC, and VMI (p-value <0.001), with moderate-to-large effect sizes. VP showed a general age-related increase, whereas MC and VMI exhibited non linear developmental patterns with peak performance in middle childhood and greater variability during adolescence. No significant gender differences were observed.

Conclusion: Visual-motor and perceptual-motor skills continue to change dynamically across school age, with particularly sensitive transitions during early adolescence. These findings extend existing developmental models to a non Western population and highlight the importance of age-sensitive interpretation of VMI-related performance.

Keywords: Age, Child development, Developmental patterns, Gender, Motor skills, Psychomotor performance

INTRODUCTION

Visuo Motor Integration (VMI) refers to the ability to translate visual information into coordinated motor output and is important for activities such as handwriting, drawing, reading, and object manipulation [1-5]. VMI performance involves coordinated functioning of VP, motor control, and higher-order planning processes mediated by distributed cortical networks [6-9]. Previous research reports age-associated differences in VP, MC, and their integration across childhood and adolescence [5,10-12]. While basic perceptual and motor components generally improve with age, integrated visuomotor performance may show variability across developmental stages [7,13]. These variations have been discussed in relation to differences in maturation and experience during school age [7,14]. Systematic reviews indicate that age is a major factor associated with VMI performance, whereas gender differences are often small or inconsistent [2,3,6,12,15,16].

Most available reference data for VMI are derived primarily from Western populations, particularly normative information reported in the Beery-Buktenica test manual and related developmental studies [10-12]. Evidence from large non Western samples remains limited, especially across the developmental period spanning middle childhood and early adolescence [2,6,11]. In addition, relatively few investigations have simultaneously examined VP, MC, and their integration within the same cohort of typically developing children despite their interdependent role in perceptual-motor functioning [9,12,14]. Given the cultural, educational, and environmental diversity that may shape perceptual-motor development, there is a clear need for developmental data from non Western populations. India, representing one of the world's largest and most heterogeneous child populations, remains underrepresented in the international literature on visual-motor development. Examining developmental patterns in this context is essential for testing the generalisability of existing neurodevelopmental models and for improving the interpretation of perceptual-motor assessments across cultures. Cross-cultural research indicates that environmental exposure and educational practices significantly influence perceptual-motor development, highlighting the need for population-specific normative data [11,12].

Accordingly, the present study, examined age- and sex-related differences in VP, MC, and VMI in typically developing Indian children aged 7-15 years, adopting a developmental-neuropsychological framework. This study is a part of a larger research work on sensory processing, VMI and academic performance of children with SLD.

MATERIALS AND METHODS

This study was conducted in mainstream schools located in urban and semi-urban regions of West Bengal, India, between January 2025 and June 2025. Approval for the study was obtained from the Doctoral Committee and Ethical Committee of MAHER (MAHER/IEC/PhD/143) and the study adhered to the ethical principles of the Declaration of Helsinki (2013 revision). Written informed consent was obtained from parents/guardians, and assent was obtained from the participating children prior to assessment.

Inclusion criteria: Typically developing children aged 7-15 years enrolled in regular mainstream education. Children were eligible if they had normal or corrected-to-normal vision and hearing and were able to understand instructions in Bengali or English.

Exclusion criteria: A history of neurological disorders (e.g., epilepsy, cerebral palsy), intellectual disability, diagnosed autism spectrum disorder, attention-deficit/hyperactivity disorder, specific learning disorder, uncorrected visual or auditory impairment, or major psychiatric illness. Eligibility was verified through school medical records, parent-report health screening forms, and teacher confirmation.

Sample size estimation: Sample size estimation was conducted using a priori power analysis for one-way ANOVA (fixed effects, omnibus test). Assuming a moderate effect size (f = 0.25), significance level $\alpha = 0.05$, power $(1-\beta) = 0.80$, and nine age groups, the required minimum total sample size was N = 180 (Cohen J, 1988 [13]).

The study included 224 children, with group sizes ranging from 23 to 26 participants across age groups, ensuring a balanced design and providing power exceeding the minimum requirement

Socio-economic and educational context: Participants were recruited from English- and Bengali-medium schools and the majority of children belonged to middle socio-economic status. Schools from both urban (Kolkata metropolitan region) and semi-urban areas (Ishapur, Kacharapara) were included to enhance representativeness. Group testing was conducted in classrooms with 8-12 students per session under standardised conditions.

Measures

The VMI, VP, and MC were assessed using the Beery-Buktenica Developmental Test of Visual–Motor Integration, Sixth Edition (Beery VMI-6) (Beery KE and Beery NE, 2010 [10]).

The assessment was administered individually in a standardised paper-and-pencil format and scored in accordance with the guidelines provided in the test manual.

The instrument comprises three subtests:

1. **Visual-Motor Integration (VMI):** This subtest requires participants to copy a sequence of increasingly complex geometric forms, thereby assessing the integration of visual perceptual processing with fine motor execution.
2. **Visual Perception (VP):** This subtest involves visual discrimination and matching tasks, designed to evaluate perceptual processing with minimal motor demands.
3. **Motor Coordination (MC):** This subtest requires participants to trace geometric forms within specified boundaries under timed conditions, assessing fine motor control and precision.

The VP subtest employs a multiple-choice format that minimises motor demands, while the MC subtest consists of a timed tracing task evaluating fine motor control. Higher scores in each test indicate better performance with the maximum possible score is 30 and minimum is zero. The Beery VMI-6 demonstrates strong reliability (internal consistency coefficients >0.80) and established construct validity.

Procedure

Assessments were conducted in quiet, well-lit classrooms during regular school hours. Standardised instructions from the test manual were administered in the child's preferred language (Bengali or English). All assessments were conducted by a trained occupational therapist experienced in standardised test administration. Each assessment session lasted approximately 30-45 minutes.

STATISTICAL ANALYSIS

Data were analysed statistically. Normality of distribution was assessed using the Shapiro–Wilk test, and homogeneity of variances was examined using Levene's test. One-way ANOVA was performed to evaluate age-related differences, followed by Tukey's post-hoc tests for pairwise comparisons. Independent-samples t-tests were used to examine gender differences. Effect sizes were reported using eta squared (η^2) for ANOVA and Cohen's d for t-tests. Statistical significance was set at p-value <0.05.

RESULTS

[Table/Fig-1] depicts the demographic characteristics of the participants of the study. The study included 224 children, with a fairly balanced gender distribution. Boys constituted 53.1% (n=119) of the sample, while girls made up 46.9% (n=105), indicating only a slight male predominance. The participants represented a wide age range from 7 to 15 years with the distribution reflecting a strong representation of children in middle childhood and early adolescence, which is developmentally important for visual-motor skills. With respect to school grade, children from Grades 1 through nine were almost evenly represented. Each grade contributed roughly 10-12% of the total sample, ensuring that no single academic level disproportionately influenced the findings.

Variables		n (%)
Gender	Male	119 (53.1)
	Female	105 (46.9)
Age wise distribution		
Age (years)	7	24 (10.7)
	8	23 (10.3)
	9	25 (11.2)
	10	25 (11.2)
	11	26 (11.6)
	12	25 (11.2)
	13	26 (11.6)
	14	24 (10.7)
	15	26 (11.6)
Grade wise distribution		
Grade	1st	24 (10.7)
	2nd	23 (10.3)
	3rd	25 (11.2)
	4th	25 (11.2)
	5th	26 (11.6)
	6th	25 (11.2)
	7th	26 (11.6)
	8th	24 (10.7)
	9th	26 (11.6)

[Table/Fig-1]: Demographic characteristics of the participants (N=224).

[Table/Fig-2] summarises the independent-samples t-test results comparing gender differences in VP, MC, and VMI. There was no significant difference in VP scores between males 26.28±4.06 and females 26.96±3.03, t(222)=-1.41, p-value=0.16. Similarly, MC scores did not differ significantly between males 23.48±6.11 and females 24.83±5.06, t(222)=-1.79, p-value=0.08. For VMI, no significant gender difference was observed (t(222)=-0.12, p-value= 0.90), with males 22.19±6.05 and females 22.30±6.27 performing comparably. These results indicate that gender does not significantly influence performance in any of the three measured domains in this sample.

Gender		N	Mean±SD	Std. Error Mean	t-test (df=222)	SIG
VP	Male	119	26.28±4.06	0.37	-1.41	0.16
	Female	105	26.96±3.03	0.30		
MC	Male	119	23.48±6.11	0.56	-1.79	0.08
	Female	105	24.83±5.06	0.49		
VMI	Male	119	22.19±6.05	0.55	-0.12	0.90
	Female	105	22.30±6.27	0.61		

[Table/Fig-2]: Genderwise analysis of Visual Perception (VP), Motor Coordination (MC) and Visual Motor Integration (VMI) (N=224).

[Table/Fig-3] illustrate mean±standard deviation values for VP, MC, and VMI across age groups (7-15 years). A clear developmental pattern was observed: VP scores increased steadily with age, peaking at 12 years 29.28±1.10 before fluctuating slightly in later years, suggesting progressive maturation of perceptual abilities. MC scores improved until around 11 years 28.44±0.95 but showed a decline by 15 years 17.86±5.36, reflecting a non linear developmental pattern possibly associated with physical or neurological transitions during adolescence. VMI performance peaked at 9 years 25.96±2.12 and 11 years 26.23±2.23, indicating optimal integration of visual and motor processes in middle childhood. A lower mean VMI score was observed in the 8-year group; however, this difference was not statistically significant in post-hoc comparisons, suggesting that it likely reflects sampling variability rather than a true developmental decline. A decline after 12 years 19.36±9.69 suggests developmental variability and potential influences of cognitive or physiological transitions.

Age (in years)	Visual Perception (VP)	Motor Coordination (MC)	Visual-Motor Integration (VMI)
	Mean±SD	Mean±SD	Mean±SD
7 (n=24)	25.25±3.93	20.75±6.03	20.54±5.23
8 (n=23)	24.57±5.51	21.11±4.74	16.13±5.94
9 (n=25)	25.16±1.82	25.16±3.01	25.96±2.12
10 (n=25)	25.00±4.63	26.60±2.25	23.40±4.32
11 (n=26)	28.15±1.41	28.44±0.95	26.23±2.23
12 (n=25)	29.28±1.10	26.48±5.45	19.36±9.69
13 (n=26)	26.73±3.66	26.85±4.70	24.17±5.93
14 (n=24)	27.96±2.07	23.10±6.08	23.90±4.57
15 (n=26)	27.23±3.50	17.86±5.36	19.60±4.07

[Table/Fig-3]: Mean and standard deviation of Visual Perception (VP), Motor Coordination (MC) and Visual Motor Integration (VMI) across the age group (N=224).

[Table/Fig-4] presents the One-way ANOVA results examining age-related differences across the three domains. The results revealed significant differences across age groups for all three variables (p-value<0.001). For VP, a moderate effect size (η^2=0.23) indicates that 23% of variance in scores is explained by age-related factors. MC showed a large effect (η^2=0.35), suggesting that age strongly influences motor development. VMI demonstrated a moderate-to-large effect (η^2=0.27), confirming that age substantially contributes to VMI performance variations.

Variables	Mean±SD	F-value	Df	p-value	η^2
Visual Perception (VP)	26.62±3.66	6.09	8,215	<0.001	0.23
Motor Coordination (MC)	24.09±5.67	14.62	8,215	<0.001	0.35
Visual-Motor Integration (VMI)	22.21±6.13	9.99	8,215	<0.001	0.27

[Table/Fig-4]: Analysis of variance showing mean difference across age group for Visual Perception (VP), Motor Coordination (MC) and Visual Motor Integration (VMI) (N=224).
Note: $\eta^2 = SS_{effect}/SS_{Total}$

Post-hoc comparisons [Table/Fig-5] indicated that significant differences in MC and VP were primarily observed between younger children (7-8 years) and middle childhood groups (9-12 years). For VMI, significant pairwise differences were noted between eight years and 9-11 years and between middle childhood and selected adolescent groups (13-15 years), reflecting age-associated variability across developmental stages.

Domain	Age group comparison	Mean difference	p-value
Visual Perception (VP)	7 vs 12 years	-4.03	0.001
	8 vs 11 years	-3.59	0.008
	9 vs 11 years	-2.99	0.045
	9 vs 12 years	-4.12	0.001
	10 vs 11 years	-3.15	0.027
	10 vs 12 years	-4.28	<0.001
Motor Coordination (MC)	7 vs 9 years	-4.41	0.028
	7 vs 10 years	-5.85	0.001
	7 vs 11 years	-7.69	<0.001
	7 vs 12 years	-5.73	0.001
	7 vs 13 years	-6.10	<0.001
	8 vs 10 years	-5.49	0.002
	8 vs 11 years	-7.33	<0.001
	8 vs 12 years	-5.37	0.003
	9 vs 15 years	7.29	<0.001
	10 vs 15 years	8.73	<0.001
	11 vs 15 years	10.58	<0.001
Visual-Motor Integration (VMI)	7 vs 9 years	-5.42	0.013
	7 vs 11 years	-5.69	0.006
	8 vs 9 years	-9.83	<0.001
	8 vs 10 years	-7.27	<0.001
	8 vs 11 years	-10.10	<0.001
	9 vs 12 years	6.60	0.001
	9 vs 15 years	6.36	0.001
	11 vs 12 years	-6.87	<0.001
	11 vs 15 years	-6.63	<0.001
	12 vs 13 years	-4.81	0.039

[Table/Fig-5]: Post-hoc comparisons of significant data pairs.

DISCUSSION

The present study examined age-associated differences in VP, MC, and VMI among typically developing children aged 7-15 years. In accordance with the study objectives, age demonstrated a significant influence across all three domains, whereas no significant gender differences were observed. These findings indicate that variation in perceptual–motor performance across school age is more strongly related to developmental stage than to sex [5,12,17]. These findings are consistent with earlier studies reporting age-related improvements in VMI and its association with academic performance across school years [3,7]. In addition, prior work has shown minimal gender differences in fine motor performance when relevant covariates are controlled [1].

The significant age effects observed across VP, MC, and VMI are consistent with developmental literature describing progressive refinement of perceptual-motor abilities during childhood [5,17,18]. The moderate-to-large effect sizes suggest that age accounts for a meaningful proportion of variability in performance in these domains. From a neurodevelopmental perspective, these changes likely reflect continued maturation and increasing efficiency of distributed cortical-subcortical networks involving parietal, cerebellar, and frontal regions that support visual analysis, motor planning, and online sensorimotor integration [4,6]. As these networks become more integrated and specialised, children show increasing precision and efficiency in visually guided actions. This pattern is supported by neurodevelopmental evidence demonstrating close links between motor and cognitive maturation [4,6] along with progressive cortical development across childhood and adolescence [9].

The variability observed around 11-12 years may also relate to differences in biological maturation, as pubertal onset occurs at varying ages and often earlier in girls than boys [2,6]. Although pubertal status was not assessed in the present study, such heterogeneity in neuromotor and executive development may contribute to fluctuations in perceptual-motor performance during this transitional period [9,16]. Similar variability during this developmental phase has been reported in prior literature, which characterises adolescence as a period of heightened neurodevelopmental change and performance heterogeneity [16]. Cultural and educational factors may further influence performance; Indian school environments, for example, emphasise early handwriting practice, copy-based learning, and prolonged fine-motor classroom tasks, which may affect visuomotor proficiency differently from Western educational contexts [1,13]. Despite these contextual differences, the overall age-associated pattern observed in this study, a gradual improvement in VP with non linear visuomotor performance, appears broadly comparable to trends reported in Western normative studies [5,17,18]. However, caution is required when directly comparing absolute performance levels across populations, and population-specific reference data remain important [1,17]. Cross-cultural research has also demonstrated variability in perceptual-motor performance across different populations, highlighting the influence of contextual and environmental factors [17,18].

The VP showed a gradual increase across age groups with relative stabilisation during later childhood. This pattern is compatible with models proposing that perceptual discrimination and spatial processing improve with accumulated visual experience and academic exposure [1,6]. MC and VMI demonstrated non linear patterns, with comparatively higher performance during middle childhood and greater variability in early adolescence. Similar age-associated variations have been reported in previous studies [8,11]. As the present study used a cross-sectional design, these findings should be interpreted as age-associated differences rather than direct developmental change. The variability observed in adolescence may reflect heterogeneity in maturation rate and experience [2]. Non linear patterns in MC and related functions have similarly been reported, indicating that developmental trajectories are not uniform across age groups [12]. A lower mean VMI score was observed in the 8-year group; however, this difference was not statistically significant in post-hoc comparisons. This suggests that the observation most likely represents sampling variation rather than a distinct developmental transition [17]. The pattern of VMI performance supports the view that VMI reflects coordinated functioning of perceptual and motor processes rather than a single isolated skill [1,16]. Greater variability observed during early adolescence further indicates that integration efficiency differs across individuals during this period [9].

A notable pattern observed in the present study was the decline in MC and VMI scores at 14 and 15 years when compared to 13 years. This non linear trend may be understood within a neuro-developmental framework. Early adolescence is characterised by ongoing reorganisation of neural systems, including synaptic pruning and increased specialisation within fronto-parietal and cerebellar networks involved in visuomotor processing [6,8]. During this transitional phase, temporary fluctuations in performance may occur before stabilisation in later adolescence [8,17]. In addition, pubertal changes such as rapid physical growth, alterations in body proportions, and hormonal influences may disrupt previously established MC, leading to a transient reduction in efficiency [18].

The larger standard deviations observed in certain age groups, particularly at 12 years for VMI and at 14 years for MC, likely reflect developmental heterogeneity, as children of the same chronological age may differ in biological maturation and neuromotor development [9,16]. This variability further supports the interpretation that the observed decline in performance at 14-15 years is not indicative of regression but reflects transitional developmental processes. Psychosocial factors such as variations in motivation, attentional engagement, and academic demands during adolescence may also contribute to performance differences [18].

It is also important to note that the cross-sectional design of the study limits causal interpretation, and the observed differences represent between-group variability rather than within-individual developmental decline. Similar non linear trajectories in MC and VMI have been reported in prior literature [9,16], indicating that such fluctuations are characteristic of adolescence rather than contradictory to developmental progression.

No significant gender differences were found across any of the measured domains. This finding was consistent with research indicating minimal sex-related differences in integrated perceptual-motor tasks when children have comparable learning environments [12,17]. Finally, the study provides data from an Indian school-based sample, addressing the limited availability of normative developmental information from non Western populations. While the overall patterns were comparable to previously reported trends, performance interpretation should consider contextual educational and environmental factors [1,17].

The present study extends current knowledge by providing data from an underrepresented Indian sample and overall, the findings of the present study are broadly consistent with existing literature on perceptual–motor development, developmental and neuropsychological literature, supporting the role of age as a primary determinant of perceptual-motor performance [3,7,12]. The convergence of findings across studies strengthens the evidence for age-related maturation as a key determinant of visuomotor performance, while also highlighting the need for culturally contextualised normative frameworks.

Limitation(s)

Certain limitations should be considered when interpreting these findings. The sample was obtained from schools within a single geographic region, which may limit generalisability to children from other cultural or educational settings. The study design examined differences across age groups and therefore does not permit conclusions regarding individual developmental change or causality. In addition, performance was assessed using standardised test norms that may not fully reflect population-specific variations, and group administration within school settings may have influenced performance variability. In addition, relevant developmental factors such as pubertal status, cognitive abilities, and detailed environmental exposures were not assessed, which may partly account for variability in perceptual-motor performance across age groups.

Future research should include longitudinal studies to examine individual changes in VP, MC, and VMI over time. Studies involving geographically and socio-economically diverse samples would help clarify contextual influences on perceptual–motor performance. Further research may also explore whether structured training programs are associated with improvements in visuomotor performance in school-age children. Future studies may also incorporate neurodevelopmental and contextual variables, including pubertal status and educational practices, to better understand sources of variability in perceptual-motor development.

CONCLUSION(S)

This study examined age-related differences in VP, MC, and VMI among typically developing children aged 7-15 years. Age was significantly associated with performance across all three domains, whereas no significant gender differences were observed. Performance was generally higher during middle childhood, with greater variability in early adolescence, indicating that perceptual-motor performance should be interpreted in relation to developmental stage rather than gender. The findings provide age-related reference information from an Indian school-based sample for educational and clinical assessment contexts. These findings are consistent with existing developmental literature while extending evidence to a non Western population, highlighting the importance of context-specific interpretation of perceptual–motor assessments.

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