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Evaluating the Effectiveness of an Intervention and Teacher Competencies in Enhancing Fine Motor and Graphomotor Skills in Preschool Children of North India

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Abstract

Fine-motor and grapho-motor competencies underpin handwriting readiness, early literacy, and a successful transition to school, yet evidence jointly addressing children's developmental progression, intervention effectiveness, and the teacher and institutional conditions shaping delivery remains scarce in developing-country settings. This study assessed the developmental progression of fine-motor and grapho-motor skills among preschool children, evaluated a structured intervention, and compared preschool teachers' knowledge, instructional strategies, confidence, implementation challenges, and institutional support across government and private preschools in Lucknow district, Uttar Pradesh, India. A quasi-experimental pre-test post-test control-group design was combined with a descriptive teacher survey. Participants were 220 children aged 3 to 6 years (experimental n = 110; control n = 110) and 223 teachers. Children's skills were assessed with the Gilboa Functional Test and teacher competencies with a 20-item questionnaire (overall α = 0.758). Groups were equivalent at baseline ($\chi^2 = 0.065$, $p = .968$). After intervention the experimental group improved substantially in skill scores (18.97 to 22.53; $t = 17.78$, $p < .001$; $d = 1.70$) and skill levels ($t = 6.39$, $p < .001$; $d = 0.61$), whereas the control group changed negligibly ($d = 0.22$). Wilcoxon tests confirmed this: 102 of 110 experimental children improved in score and 30 advanced a developmental band, while no child in either group declined ($Z = -8.809$, $p < .001$, $r = 0.84$). The proportion of experimental children in the normal developmental range rose from 72.7% to 91.8%, and the lowest band was no longer occupied afterwards. School type predicted post-intervention levels and age and gender predicted scores, while socio-economic status ceased to differentiate outcomes once baseline was controlled. Teachers reported comparable knowledge and confidence across sectors, but private-preschool teachers reported significantly greater use of instructional strategies and higher institutional support. Structured, developmentally appropriate intervention enhanced children's skills across demographic groups, yet its translation into practice depended on instructional strategies and institutional support, underscoring the case for embedding motor-skill objectives and targeted teacher development in early-childhood policy.

Statement of significance

Fine-motor delay in preschoolers is a health as well as an educational concern, frequently occurring alongside risks to attention, cognition, and school readiness. This study shows that a structured, low-cost programme can meaningfully improve these skills in a resource-constrained Indian setting, that the children furthest behind gained most, and that the support surrounding teachers, rather than their knowledge alone, determines whether children benefit. The findings point to developmental screening, teacher development, and equity-focused early-childhood policy as immediate priorities.

1. Introduction

Roughly one preschool child in six carries a fine-motor developmental risk. Köppen et al. (2026) arrived at that figure from a cohort of 7,542 children aged three to six, but the more consequential part of their finding was what accompanied the risk. Fine-motor difficulty travelled with gross-motor difficulty, and

with early trouble in basic mathematics, attention, and concentration. Motor delay in the preschool years is rarely a solitary problem, and that is precisely why it deserves attention before school entry rather than after it.

Fine-motor skills are the coordinated work of the hand, fingers, and wrist alongside visual and cognitive processing. They let a child grasp, cut, thread, trace, and eventually write. Current evidence treats them not as peripheral physical accomplishments but as indicators of school readiness and predictors of later achievement (Chandler et al., 2021; Suggate et al., 2023). They also sit on the boundary between education and child health. Fine-motor skill and visual perception mediate the effect of very preterm birth on visual-motor integration before school entry (Dathe et al., 2026), and impaired motor coordination defines developmental coordination disorder, for which structured movement intervention shows meta-analytic benefit (Peng et al., 2026).

Grapho-motor skills are the specialised branch of that ability governing drawing and handwriting. A child must hold and control a writing tool, regulate pressure, orient marks in space, form figures, and keep hand and eye together. Working with 166 preschoolers, Trouli and Linardakis (2022) found grapho-motor performance to be multidimensional and driven mainly by fine-motor precision and integration, with handwriting control the component most affected. This explains a pattern familiar to any preschool teacher: children who struggle here write slowly, produce illegible script, and quietly withdraw from written work. Left alone, those difficulties follow them into the primary years.

What makes grapho-motor competence worth studying is that it carries motor development forward into literacy. Following 363 first-graders, Maurer et al. (2023) showed grapho-motor skill predicting later spelling. The route from movement to writing appears to run through cognitive self-regulation: Khoury-Metanis and Khateb (2023) found executive functions mediating the contribution of fine-motor skill to literacy achievement, while Chandler et al. (2021) reported self-regulation moderating the same link, cushioning children whose motor development lags. Experimental work strengthens the causal reading. In a trial with 205 fourth-graders, Lê et al. (2023) found digital fine-motor training improved literacy, grapho-motor skill, and executive functioning together, not motor skill alone. Newer studies map the affective layer beneath this, with Ghanamah and Eghbaria-Ghanamah (2026) showing self-regulation mediates the link between playfulness and motor learning, and Klingele et al. (2025) finding that children in early school age already hold a grapho-motor self-concept tied to their measured skill.

Because grapho-motor competence is learned rather than simply matured into, the preschool years are a period when structured teaching can change trajectories. Meta-analytic and controlled evidence confirms that motor-focused programmes work, though the benefit shifts with design, dosage, and delivery (Peng et al., 2026; Spanaki et al., 2014). That places the teacher at the centre of the problem, and here the evidence is less reassuring: Bingham and Gerde (2023) found educators conceptualise early writing in quite different ways, and that these conceptions shape the support children actually receive.

Almost all of this evidence comes from well-resourced Western settings. Preschool provision in developing contexts differs sharply in teacher preparation, class size, materials, and institutional backing, and often differs again between government and private providers in the same district. In Uttar Pradesh those differences plausibly shape both children's motor trajectories and the instruction surrounding them, yet integrated evidence is scarce. The present study takes up that gap by examining, within one design, the developmental progression of preschoolers' fine-motor and grapho-motor skills, the effectiveness of a structured intervention, and the competencies and institutional conditions of teachers across government and private preschools in Lucknow district. Children's skills were assessed using the Gilboa Functional Test (GIFT), an instrument within a fast-moving field of early motor assessment (Zhang et al., 2025).

1.1 Research questions

1. How do fine-motor and grapho-motor skills progress among preschool children, and do experimental and control groups differ before and after intervention?
2. Does a structured intervention programme improve preschool children's fine-motor and grapho-motor skills?
3. Do demographic factors, namely school type, gender, age, and socio-economic status, shape post-intervention outcomes once baseline performance is controlled?
4. Do preschool teachers in government and private settings differ in knowledge, instructional strategies, confidence and reflection, implementation challenges, and institutional support related to grapho-motor development?

1.2 Research objectives

1. To assess the developmental progression of fine-motor and grapho-motor skills among preschool children.
2. To evaluate the effectiveness of a structured intervention programme in improving fine-motor and grapho-motor skills among preschool children.
3. To examine preschool teachers' knowledge, instructional strategies, confidence and reflection, implementation challenges, and institutional support related to grapho-motor skill development, and to compare these across government and private preschools.

2. Literature review

2.1 Theoretical foundation

No single theory accounts for grapho-motor development, which grows out of biological maturation, cognitive growth, experience, instruction, and social interaction acting together. This study therefore borrows from several.

Psychomotor theory supplies the base premise: coordinated movement emerges from sensory input, neural processing, and motor output working as one system, so handwriting reflects an internal perceptual-motor process rather than muscle action alone (Ajuriaguerra and Auzias, 1975). Grapho-motor skill is therefore treated here as an integrated outcome, assessed with an instrument sampling several coordinated components. Piaget (1952) explains the cognitive side, with children building knowledge through active engagement and moving through stages of representation; grapho-motor growth follows the same path from scribble to controlled mark, which is why intervention must meet a child's readiness rather than outrun it. Vygotsky (1978) shifts focus to the adult, where scaffolding within the zone of proximal development carries a child until support can be withdrawn, making teacher knowledge, confidence, and materials legitimate objects of study.

Bronfenbrenner widens the lens again. Development occurs through repeated proximal interactions whose quality depends on the institutional layers around them (Bronfenbrenner, 1979; Bronfenbrenner and Morris, 2006), the clearest justification for comparing government and private preschools directly. Developmental readiness theory addresses timing, holding that children need a threshold of maturity before handwriting can be learned efficiently (Gesell, 1940), a position supported by Klingele et al. (2025). Motor-learning and dynamic systems theory explain change itself: practice and feedback move a skill toward automaticity, and because the developing system stays adaptable, altering one component can shift the whole (Thelen and Smith, 1994). That is the premise this study tests.

2.2 Fine-motor development in early childhood

Fine-motor development is now read as an integrative process linking neurological maturation, sensory processing, and visual-motor integration with whatever opportunities a child's surroundings supply. Mapping three decades of research, Zhang et al. (2024) document sustained growth in scholarly interest alongside a shift from clinical assessment toward education and intervention. Two patterns recur: competence grows quickly but unevenly across the preschool years, and it matters beyond the motor domain, since early fine-motor status forecasts a spread of later outcomes. What drives the variation is becoming clearer. Ghorbanzadeh et al. (2025) found motor competence and its link to executive functioning jointly patterned by age, sex, and family socio-economic status. Adversity registers earlier still: studying infants exposed to poverty, Fioroni Ribeiro da Silva et al. (2026) identified access to fine-motor toys and the presence of cohabiting caregivers as protective, while male sex and household crowding were associated with atypical motor patterns. Sinvani, Golos, and Ben Zagmi (2023) reach a compatible conclusion from a cross-sectional study of young children, linking grapho-motor skill to the material and social qualities of the home. Fine-motor development, on this evidence, is biological and contextual at once, which is directly relevant to comparing preschools that differ systematically in resources.

2.3 Grapho-motor skills and school readiness

Grapho-motor skill draws together motor control, visual perception, spatial organisation, proprioceptive feedback, and cognitive planning. Trouli and Linardakis (2022) gave the clearest structural account, showing through path modelling that fine-motor precision and integration influence every major component of grapho-motor performance, with handwriting control and figure reproduction most strongly affected. Readiness frameworks now rank grapho-motor competence alongside cognitive and linguistic readiness, and the bridge into literacy is documented rather than assumed: Maurer et al. (2023) showed grapho-motor skill predicting later spelling, which places handwriting at the meeting point of motor learning and literacy.

More recent work adds a self-referential dimension. Klingele et al. (2025) found children hold a multidimensional grapho-motor self-concept related to their measured skill, implying that early difficulty may carry motivational as well as mechanical consequences. That would explain the disengagement practitioners see long before any formal diagnosis. Grapho-motor skill thus works as a developmental hinge, joining fine-motor maturation to literacy on one side and academic self-perception on the other.

2.4 Fine-motor and grapho-motor skills as predictors of academic outcomes

The claim that early motor skill forecasts academic performance has moved from correlation toward mechanism. At population scale, Köppen et al. (2026) showed fine-motor developmental risk strongly associated with risk in basic mathematics and in attention and concentration. Pagerols et al. (2026), working with academic records for more than nine thousand students, found that once co-occurring conditions were controlled, motor difficulties were most directly linked to lower marks in movement-dependent subjects such as arts and physical education. That result is a useful corrective, since it warns against treating the motor-to-academic link as uniform across the curriculum.

The mechanism looks largely cognitive. Khoury-Metanis and Khateb (2023) found executive functions mediating the contribution of fine-motor skill to literacy achievement, and Suggate et al. (2023) showed fine-motor skill, handwriting, and typing each contributing independently to reading development. Both align with the intervention evidence below, where motor training produced collateral gains in executive functioning and literacy (Lê et al., 2023). Motor skill, on this reading, supports academic achievement rather than driving it, working through the regulatory and transcription processes underneath early literacy. Much of this evidence remains correlational with heterogeneous effect sizes, which is exactly why controlled intervention studies still earn their place.

2.5 Intervention programmes

Structured motor intervention improves fine-motor and grapho-motor skills, though the size of the benefit is conditional. The closest precedent for the present design is Spanaki et al. (2014), whose quasi-experimental study of Greek children found no baseline difference but a significant post-intervention advantage on total grapho-motor score. Occupational-therapy trials agree from other populations: Ratzon et al. (2007) reported gains in writing-readiness from a short programme for first-graders in a low

socio-economic setting, and Ohl et al. (2013) found a ten-week classroom programme improved fine-motor and visual-motor skills in kindergarteners while controls slightly declined.

Recent work specifies when intervention succeeds. Li-Tsang et al. (2023) found a sensorimotor programme improved handwriting more when sessions were spread across a month than compressed into two weeks, making spacing an active ingredient rather than a scheduling detail. Peng et al. (2026), meta-analysing exercise interventions for children with developmental coordination disorder, reported significant gains but found them weakening as duration and session count rose. More is not automatically better. Two mechanisms recur: spillover, with Lê et al. (2023) showing fine-motor training lifting literacy and executive functioning alongside motor skill, and regulation, with Ghanamah and Eghbaria-Ghanamah (2026) finding self-regulation mediates the effect of playful engagement on motor learning. The practical lesson is that embedded, well-spaced practice beats isolated drilling.

2.6 Teacher competencies and institutional support

If intervention works but only under conditions, the adults delivering it become decisive, and the literature keeps finding a gap between what teachers know and what they do. Bingham and Gerde (2023) found substantial variation in how early childhood educators think about early writing, and showed those conceptions shaping the support children received, with narrower definitions producing narrower practice. Measuring teacher knowledge alone is therefore insufficient. What teachers do, and what their setting permits, has to be examined alongside it. Qualitative work in low-resource settings describes teachers scaffolding fine-motor development through improvised use of sand, clay, and paper craft (Oyeyemi et al., 2026), an observation consistent with Bingham and Gerde's (2023) finding that instructional support tracks what teachers understand and what their setting affords. Instructional quality, on this evidence, is constrained by resources without being reducible to them.

The institutional layer around the teacher is the least studied element and the most relevant to a government versus private comparison. Settings investing in professional development, materials, and collaborative practice tend to sustain stronger instruction, while resource-constrained settings struggle to obtain specialised materials and training. That is the fault line this study examines empirically.

2.7 Demographic and contextual moderators

Gender differences favouring girls recur across designs and measures. Bondi et al. (2022) found a female advantage in fine-motor skills among school beginners, Maurer et al. (2023) reported stronger grapho-motor performance in girls in a sample of 363 first-graders, and Kaloyanova (2026), using a visual-motor copying task, observed fewer errors among girls. The convergence across a physiological study, a longitudinal literacy study, and a copying task suggests the effect is not an artefact of any single measurement approach. Age effects are equally consistent, with performance improving across the preschool span as coordination matures (Bondi et al., 2022; Zhang et al., 2024).

Setting and socio-economic status carry the most weight for this study. Following children entering school across urban, small-rural, and village settlements, Gyarmathy (2026) found persistent disparities for children from smaller settlements that ordinary provision did little to close, a settlement-size effect that parallels the school-type contrast examined here. The same conclusion is reached from other directions: Ghorbanzadeh et al. (2025) traced motor competence to family socio-economic status, Fioroni Ribeiro da Silva et al. (2026) linked poverty exposure to atypical motor patterns in infancy, and Sinvani, Golos, and Ben Zagmi (2023) connected grapho-motor skill directly to the material qualities of the home. Together these converge on motor development as shaped by context but not fixed by it, and possibly responsive to targeted provision. That proposition is testable, and this study tests it.

2.8 Assessment of fine-motor and grapho-motor skills

Any intervention finding is only as credible as the instrument used to detect it. Reviewing fine-motor assessment instruments for typically developing preschoolers, Zhang et al. (2025) map a growing but uneven toolkit and call for closer attention to cross-cultural comparability. Refinement is under way on several fronts: Fitjar et al. (2024) developed a method for detailed analysis of letter-formation accuracy and fluency; Sinvani and Gilboa (2023) validated a remote graphomotor examination, extending standardised assessment beyond the clinic; and digital platforms now offer rapid screening of visuomotor precursors (Apicerni et al., 2026; D'Angelo and Caldarelli, 2025). The GIFT used here samples the coordinated components this literature identifies as central.

3. Research gap

Four claims are now well supported. Fine-motor and grapho-motor skills underpin school readiness and forecast later academic and cognitive outcomes, partly through executive and self-regulatory mechanisms (Chandler et al., 2021; Khoury-Metanis and Khateb, 2023; Köppen et al., 2026). Structured intervention improves these skills, subject to dosage, spacing, and mode of engagement (Lê et al., 2023; Li-Tsang et al., 2023; Peng et al., 2026; Spanaki et al., 2014). Teacher competence and institutional support determine whether those potential reaches children, and the two often diverge (Bingham and Gerde, 2023). Demographic and contextual factors pattern outcomes without wholly determining them (Gyarmathy, 2026; Ghorbanzadeh et al., 2025).

What is missing is any study examining these strands simultaneously under controlled conditions, and five gaps follow. Theoretically, existing accounts isolate one mechanism at a time while the position developed above implies they operate jointly. Methodologically, the strongest recent evidence is correlational, with mediational claims resting on observational designs (Khoury-Metanis and Khateb, 2023; Suggate et al., 2023), leaving controlled intervention evidence with quantified effect sizes scarce outside Western samples. Institutionally, the conditions converting teacher knowledge into practice are barely studied, and almost no work compares them across government and private providers in one district despite clear reason to expect divergence (Bronfenbrenner and Morris, 2006; Bingham and Gerde,

2023). In population terms, much evidence comes from primary-school children (Maurer et al., 2023; Ratzon et al., 2007; Ohl et al., 2013), leaving the preschool foundation under-evidenced. Geographically, population-scale evidence originates overwhelmingly in high-resource settings (Köppen et al., 2026; Pagerols et al., 2026; Gyarmathy, 2026), with integrated evidence from North Indian preschool systems largely absent. By testing a structured intervention against a control group while comparing teacher competence and institutional support across sectors in Lucknow district, this study supplies exactly the evidence the field lacks.

4. Hypothesis development and conceptual framework

4.1 Hypothesis development

The hypotheses follow from the relationships established above, and each names a relationship between variables that the analysis then tests.

Intervention and child outcomes. Motor-learning theory holds that repeated, feedback-rich practice moves a skill toward automaticity, and dynamic systems theory predicts that during a period of high adaptability a change in one component can shift the whole developing system (Thelen and Smith, 1994). The empirical record supports both: Spanaki et al. (2014), Ohl et al. (2013), and Ratzon et al. (2007) all report trained groups diverging from equivalent controls. If those findings generalise here, the intervention should differentiate the groups afterwards while leaving them comparable before.

H1. Following the intervention, children in the experimental group attain significantly higher fine-motor and grapho-motor skill levels than children in the control group, with no significant group difference at baseline.

H2. The experimental group shows a significant pre-to-post improvement in fine-motor and grapho-motor skill scores and levels, whereas the control group does not show a practically meaningful change.

Demographic factors and post-intervention performance. Development does not proceed identically for every child. Girls outperform boys across several samples (Bondi et al., 2022; Kaloyanova, 2026; Maurer et al., 2023), performance rises with age as coordination matures (Bondi et al., 2022), and settlement type and socio-economic conditions both pattern outcomes (Fioroni Ribeiro da Silva et al., 2026; Ghorbanzadeh et al., 2025; Gyarmathy, 2026). Bronfenbrenner's account explains why: proximal processes vary in quality with the surrounding context. Once baseline is controlled, these characteristics should still register.

H3. After controlling for baseline performance, child demographic factors (school type, gender, age, socio-economic status) are associated with post-intervention fine-motor and grapho-motor outcomes.

Preschool type and the instructional context. Teachers translate developmental knowledge into daily practice, but only within what their institution allows (Bingham and Gerde, 2023; Oyeyemi et al., 2026).

Applying the bioecological account to the systems around the teacher, government and private preschools differ in preparation, materials, and administrative backing, so their teachers should differ correspondingly.

H4. Teachers in government and private preschools differ significantly in graphomotor-related competencies (knowledge, instructional strategies, confidence and reflection) and contextual conditions (implementation challenges, institutional support and resources).

4.2 Conceptual framework

The framework follows the theoretical base and matches the analyses actually run, carrying one causal claim at the child level with the teacher comparison running alongside rather than feeding into it.

At the child level the independent variable is group membership. The dependent variables are fine-motor and grapho-motor performance, measured as a continuous score and a skill level, before and after the intervention using the GIFT. School type, gender, age, and socio-economic status enter ANCOVA as covariates with baseline controlled. The teacher strand compares knowledge, strategies, confidence, challenges, and institutional support between sectors descriptively, not as a predictor of child outcomes, because the two datasets were not linked.

The framework therefore claims three things: the intervention improves performance from pre-test to post-test (paired t-tests, Wilcoxon signed-rank tests, chi-square), post-intervention performance varies by demographic factors once baseline is adjusted (ANCOVA), and teacher and institutional conditions differ by preschool type (chi-square). Each element maps onto an analysis carried out.

5. Methods

5.1 Research design

A quantitative, quasi-experimental pre-test post-test non-equivalent control-group design was used to evaluate the intervention's effect on children's fine-motor and grapho-motor skills, complemented by a cross-sectional survey of teachers (Campbell and Stanley, 1963; Shadish, Cook, and Campbell, 2002). The design was quasi-experimental because random assignment of individual children within intact preschool classes was not feasible.

5.2 Setting and sampling

A multi-stage purposive procedure was applied. Lucknow district (Uttar Pradesh, India) was selected for its co-existing government (Bal Vatika) and private preschool systems. From its eight blocks, two were purposively chosen using maximum-variation logic to capture the widest urban-rural contrast: Sarojini Nagar (urban) and Mohanlalganj (rural). This stratification was intended to strengthen external validity and aligns with the National Education Policy 2020's emphasis on foundational learning across the

urban-rural divide. Within consenting government Bal Vatikas and private preschools in each stratum, all eligible children were enrolled through total enumeration (Etikan, Musa, and Alkassim, 2016).

5.3 Participants

The sample comprised 220 children aged 3 to 6 years (experimental n = 110; control n = 110; equally split between government and private settings) and 223 teachers (government n = 93; private n = 130). Children with neurological, visual, or hearing impairments were excluded.

5.4 Group allocation

Children were assigned to conditions at the intact-group level rather than individually, to prevent contamination of the control condition by intervention activities. Because individual randomisation was not possible, baseline equivalence was established empirically: a pre-intervention chi-square showed no association between group and skill level ($\chi^2 = 0.065$, $p = .968$), confirming the groups were comparable at the outset. Baseline scores were additionally controlled statistically through ANCOVA.

5.5 Measures

Children's fine-motor and grapho-motor skills were assessed with the Gilboa Functional Test (GIFT), a norm-referenced screening instrument developed and validated for children aged 3 to 6 years on a community sample of 611 children (Gilboa, 2017). The GIFT samples pencil control, line formation, and figure reproduction through tasks drawn from everyday preschool activity, and yields both a continuous skill score and a categorical skill level classified as developmental delay, suspected delay, or normal. Its published psychometrics are sound: content validity was established by an expert panel, test-retest reliability was 0.95 and inter-rater reliability 0.94, and scores correlated significantly with the Beery-VMI ($r = 0.32$), the Beery-MC ($r = 0.33$), the manual dexterity subscale of the Movement Assessment Battery for Children ($r = -0.364$), and the DCDQ'07 ($r = 0.41$). The instrument also discriminated between mainstream and special education preschools ($t = 3.99$, $p < .001$). Its design for the 3 to 6 age band and grounding in familiar classroom tasks suited the present sample.

Teachers' knowledge, instructional strategies, confidence and reflection, implementation challenges, and institutional support were measured with a 20-item questionnaire; internal consistency for the overall instrument was acceptable ($\alpha = 0.758$), with subscale reliabilities reported in Section 6.2.

5.6 Intervention

The experimental group received a structured programme of age-appropriate activities targeting hand strength, dexterity, bilateral coordination, visual-motor integration, tracing, drawing, and prewriting skills, while the control group continued routine preschool instruction. The intervention was implemented over two month and integrated into regular classroom activities rather than delivered as standalone therapy sessions. During this period, participants received e.g., 2 sessions per week, with each session lasting approximately e.g., within 30–40 minutes, resulting in e.g., 16 sessions in total. The programme was delivered by researcher with class teachers who had received prior orientation on the intervention

protocol. To promote consistent implementation, teachers followed a standardized activity guide and maintained session records. Fidelity was monitored through e.g., weekly observations by the researcher, implementation checklists, and periodic review of activity logs to ensure that the planned activities were delivered consistently across participating classrooms.

5.7 Data analysis

Data were analysed in IBM SPSS, with significance set at $p < .05$ and effect sizes reported alongside every significance test.

Distributional properties were examined before analysis, following Kim (2013), who recommends judging normality by absolute skewness and kurtosis rather than formal tests once samples exceed roughly 300, and who identifies absolute skewness above 2 and absolute kurtosis above 7 as indicating substantial non-normality. Kim also notes that Shapiro-Wilk and Kolmogorov-Smirnov become unreliable in large samples because they flag trivial departures. That is precisely the pattern here: Shapiro-Wilk returned significant results across variables, so descriptive indices were given precedence.

Judged against those thresholds, the skill score was well behaved at both time points, with skewness of − 0.457 and − 0.411 and kurtosis of − 0.733 and − 0.687. The skill level variable, a three-point ordinal classification, departed more substantially after the intervention (skewness − 2.329, kurtosis 4.701), exceeding the skewness threshold and reflecting a ceiling effect as most children moved into the highest band.

Analyses followed from these checks. Chi-square tests examined categorical associations between group type and skill level, and between preschool type and teacher variables; chi-square requires no distributional assumptions. Paired-sample t-tests assessed within-group change, with Cohen's d as a magnitude index. Because the skill level variable violated normality, within-group change was additionally examined using Wilcoxon signed-rank tests, with r as the effect-size index, run separately for each condition. ANCOVA examined demographic covariates of post-intervention outcomes while controlling for baseline performance.

5.8 Ethics Statement

Formal approval from an Institutional Ethics Committee was not required for this study according to the policies of the authors' institution. The study involved minimal risk, no personal identifying information was collected, and participation was entirely voluntary. Written informed consent was obtained from the parents or legal guardians of all participating children, and permission was obtained from the participating schools. All data were anonymized prior to analysis. Teacher participation was voluntary and anonymous, and no identifying information was recorded.

6. Results

6.1 Participant characteristics

Table 1
Demographic characteristics of study participants

Participants	Variable	Category	n (%)
Children (N = 220)	Study group	Experimental	110 (50.0)
		Control	110 (50.0)
	School type	Government (Bal Vatika)	110 (50.0)
		Private	110 (50.0)
	Gender	Boys	125 (56.8)
		Girls	95 (43.2)
	Socio-economic status	Lower	32 (14.5)
		Upper-lower	73 (33.2)
		Lower-middle	76 (34.5)
		Upper-middle	39 (17.7)
	Age (years)	3.0-3.5	27 (12.3)
		3.6–3.11	40 (18.2)
		4.0-4.5	46 (20.9)
		4.6–4.11	35 (15.9)
		5.0-5.5	33 (15.0)
		5.6–5.11	39 (17.7)
Teachers (N = 223)	Preschool type	Government	93 (41.7)
		Private	130 (58.3)
	Age (years)	20–29	73 (32.7)
		30–39	57 (25.6)
		40–49	64 (28.7)
		50–59	29 (13.0)
	Qualification	BTC	32 (14.3)
		Other	191 (85.7)
	Experience	Less than 5 years	59 (26.5)
		Between 5–10 years	70 (31.4)
		More than 10 years	94 (42.2)

Participants	Variable	Category	n (%)
	Teaching level	Pre-Nursery	32 (14.3)
		Junior KG	32 (14.3)
		Senior KG	66 (29.6)
		Govt Bal Vatika	93 (41.7)

Children were evenly distributed across conditions and across government and private settings, and the teacher sample spanned both sectors with varying qualifications, experience, and teaching levels.

6.2 Reliability of the teacher questionnaire

Table 2
Reliability of the teacher questionnaire (N = 223)

Scale	Items	Cronbach's α	Spearman-Brown
Knowledge of Graphomotor Skills	6	0.674	n.a.
Strategies	9	0.840	n.a.
Confidence and Reflection	3	0.723	n.a.
Challenges and Support	2	n.a.	0.650
Overall scale	20	0.758	n.a.

The Strategies scale was the most reliable (α = 0.840), followed by Confidence and Reflection (α = 0.723) and Knowledge of Graphomotor Skills (α = 0.674), with the full 20-item instrument returning α = 0.758. Because Cronbach's alpha is not an appropriate index for a two-item scale, reliability for Challenges and Support is reported as the Spearman-Brown coefficient (0.650), which for a two-item measure is algebraically equivalent to standardised alpha and implies an inter-item correlation of approximately 0.48. Two values fall below the conventional 0.70 threshold, which is common for short scales and acceptable in exploratory work, though it warrants caution in interpreting those subscales.

Distributional properties of the three multi-item teacher scales are reported in Table 3.

Table 3
Distributional characteristics of teacher scales (N = 223)

Scale	SD	Skewness	SE	Kurtosis	SE
Knowledge of Graphomotor Skills	0.792	−0.562	0.163	0.111	0.324
Strategies	0.862	−0.450	0.163	−0.340	0.324
Confidence and Reflection	0.850	−0.257	0.163	−0.562	0.324

All values fall well inside the limits identified by Kim (2013), with absolute skewness below 0.6 and absolute kurtosis below 0.6, indicating no substantive departure from normality in the teacher data. Teacher-level comparisons nonetheless used chi-square, which carries no distributional assumptions, so these statistics are reported as evidence of data quality rather than as justification for a parametric test.

6.3 Scale development for teacher constructs

Teacher construct scores were classified into five interpretive levels by dividing each scale's observed range into five equal intervals. Because every scale is scored from a minimum equal to its item count rather than from zero, the bands begin at each scale's true minimum: 6 for Knowledge, 9 for Strategies, and 3 for Confidence and Reflection. Scores below these minima are not attainable, so bands starting at 1 would have been empty by construction.

Table 4
Interpretive level bands for teacher constructs (rebased to scale minima)

Level	Knowledge (6–30)	Strategies (9–45)	Confidence and Reflection (3–15)
Very Low	6–10	9–16	3–5
Low	11–15	17–23	6–7
Moderate	16–20	24–30	8–10
High	21–25	31–37	11–12
Very High	26–30	38–45	13–15

6.4 Distributional characteristics of child outcomes

Descriptive statistics for the four child outcome variables are reported in Table 4, since these determined the choice of test.

Table 5
Distributional characteristics of child outcome variables (N = 220)

Variable	Min	Max	M	SD	Skewness	SE	Kurtosis	SE
Skill score, pre-intervention	1	32	19.06	7.810	−0.457	0.164	−0.733	0.327
Skill level, pre-intervention	1	3	2.65	0.618	−1.601	0.164	1.368	0.327
Skill score, post-intervention	1	35	20.86	7.945	−0.411	0.164	−0.687	0.327
Skill level, post-intervention	1	3	2.79	0.489	−2.329	0.164	4.701	0.327

The two skill score distributions sit well inside the limits set out by Kim (2013), justifying parametric treatment. The skill level distributions do not, and the deviation worsens after the intervention. That

worsening is substantively informative rather than a data problem: skewness moved from − 1.601 to − 2.329 precisely because the programme pushed children into the top band, producing a ceiling. Level-based analyses were therefore supported by non-parametric and categorical procedures, reported below.

6.5 Progression of skills: group comparison

Table 6
Distribution of children across skill levels by group, before and after intervention

Phase	Group	Developmental delay n (%)	Suspected delay n (%)	Normal n (%)	Total
Pre-intervention	Control	8 (7.3)	21 (19.1)	81 (73.6)	110 (100)
	Experimental	9 (8.2)	21 (19.1)	80 (72.7)	110 (100)
	Total	17 (7.7)	42 (19.1)	161 (73.2)	220 (100)
Post-intervention	Control	8 (7.3)	21 (19.1)	81 (73.6)	110 (100)
	Experimental	0 (0.0)	9 (8.2)	101 (91.8)	110 (100)
	Total	8 (3.6)	30 (13.6)	182 (82.7)	220 (100)

Table 7
Chi-square tests of association between group type and skill level

Assessment phase	Pearson χ^2	df	p	Likelihood ratio	Linear-by-linear
Pre-intervention	0.065	2	.968	0.065 (p = .968)	0.048 (p = .827)
Post-intervention	14.998	2	.001	18.230 (p < .001)	14.899 (p < .001)

The two groups began as near-mirror images: 8 versus 9 children in developmental delay, 21 each with suspected delay, and 81 versus 80 in the normal range ($\chi^2 = 0.065$, p = .968).

After the intervention the distributions separate sharply ($\chi^2 = 14.998$, p = .001). The control group did not shift at all, ending with exactly the counts it started with. The experimental group moved from 9 children in developmental delay to none, from 21 with suspected delay to 9, and from 80 in the normal range to 101, lifting the proportion in the normal range from 72.7% to 91.8%. Because two cells carry expected counts slightly below five, the likelihood-ratio statistic (18.230, p < .001) and the linear-by-linear association (14.899, p < .001) are reported alongside Pearson's chi-square; both are significant and the linear-by-linear test is appropriate for the ordinal outcome, so the conclusion is robust. H1 is supported.

6.6 Intervention effectiveness: within-group change

Table 8
Pre-post comparison of fine- and grapho-motor skills, with effect sizes

Group	Variable	Pre M ± SD	Post M ± SD	t	p	d
Control (n = 110)	Skill score	19.15 ± 7.78	19.20 ± 7.75	2.278	.025	0.22
	Skill level	2.66 ± 0.61	2.66 ± 0.61	n.a.	n.a.	n.a.
Experimental (n = 110)	Skill score	18.97 ± 7.87	22.53 ± 7.82	17.781	< .001	1.70
	Skill level	2.65 ± 0.63	2.92 ± 0.28	6.393	< .001	0.61

The control group barely moved, from 19.15 to 19.20. That change reached significance (t = 2.278, p = .025) but the effect was trivial (d = 0.22) and mean skill level did not shift at all. The experimental group improved substantially on both outcomes: skill score rose from 18.97 to 22.53 (t = 17.781, p < .001; d = 1.70) and skill level from 2.65 to 2.92 (t = 6.393, p < .001; d = 0.61).

Because skill level violated normality, these comparisons were repeated using Wilcoxon signed-rank tests, run separately by condition (Table 9).

Table 9
Wilcoxon signed-rank tests of pre-post change, by group

Group	Variable	Improved	Unchanged	Declined	Z	p	r
Control (n = 110)	Skill score	5	105	0	−2.236	.025	0.21
	Skill level	0	110	0	0.000	1.000	0.00
Experimental (n = 110)	Skill score	102	8	0	−8.809	< .001	0.84
	Skill level	30	80	0	−5.477	< .001	0.52

The non-parametric results confirm the parametric ones and sharpen them. Not one child in either group declined on either measure. In the control group five children of 110 improved in score and 105 were unchanged, while skill level was completely static, with all 110 children in the same band before and after (Z = 0.000, p = 1.000). The control group's statistically significant score change therefore rests on five children gaining a single point each, which is why its effect size is only r = 0.21.

The experimental group presents the opposite picture. Of 110 children, 102 improved in skill score (Z = − 8.809, p < .001, r = 0.84) and 30 advanced a full developmental band (Z = − 5.477, p < .001, r = 0.52); every band promotion in the sample occurred in this group. One further detail deserves attention. The post-intervention minimum for experimental skill level was 2 against a pre-intervention minimum of 1, meaning the lowest developmental band was no longer occupied after the programme, while the control minimum remained 1. The children furthest behind at baseline were the ones who moved. H2 is supported.

Spearman rank correlations between pre- and post-intervention measures make the same point from a different angle (Table 10).

Table 10
Spearman rank correlations between pre- and post-intervention measures, by group

Group	Pair	rho	p
Control	Skill score pre and post	.999	< .001
	Skill level pre and post	1.000	n.a.
	Skill score pre and skill level pre	.436	< .001
Experimental	Skill score pre and post	.956	< .001
	Skill level pre and post	.609	< .001
	Skill score pre and skill level pre	.457	< .001

In the control group the pre-post correlations are effectively perfect (.999 for score, 1.000 for level): no child changed rank relative to any other. In the experimental group they fall to .956 and .609. A correlation of .609 on skill level is the signature of genuine reordering, meaning the intervention did not lift every child equally but changed which children stood where. Combined with the emptying of the lowest band, this indicates the programme worked differentially in favour of those who began furthest behind. The moderate score-level correlations within each time point (.436 and .457) also confirm the two outcomes capture related but non-redundant information.

6.7 Demographic covariates of post-intervention outcomes

Two ANCOVAs examined whether school type, gender, age, and socio-economic status predicted post-intervention outcomes, controlling for baseline performance.

Table 11
ANCOVA for post-intervention skill levels

Variable	F	p	Partial η^2	Result
School type	167.381	< .001	0.610	Significant
Gender	0.019	.891	0.000	Not significant
Age	0.170	.973	0.008	Not significant
Socio-economic status	1.197	.315	0.033	Not significant

Table 12
ANCOVA for post-intervention skill scores

Variable	F	p	Partial η²	Result
School type	2.234	.138	0.020	Not significant
Gender	4.403	.038	0.040	Significant
Age	11.041	< .001	0.349	Significant
Socio-economic status	1.608	.192	0.044	Not significant

For skill levels, school type was the only significant covariate ($F = 167.381$, $p < .001$, $\eta^2 = 0.610$), with private-preschool children showing marginally higher levels ($M = 2.95 \pm 0.22$) than government-preschool children ($M = 2.89 \pm 0.32$). For skill scores, gender ($F = 4.403$, $p = .038$, $\eta^2 = 0.040$) and age ($F = 11.041$, $p < .001$, $\eta^2 = 0.349$) were significant: girls scored higher ($M = 24.14 \pm 8.40$) than boys ($M = 21.14 \pm 7.06$), and scores rose across age groups. Socio-economic status predicted neither outcome. H3 is therefore partially supported, with school type driving band attainment and age and gender driving raw scores. Given the ceiling documented in Table 5, the level-based result should be read cautiously, a point developed in Section 7.3.

6.8 Teacher competencies and institutional context

Table 13
Association between preschool type and teacher-related variables

Variable	χ²	df	p	Result
Knowledge of Graphomotor Skills	0.523	3	.914	Not significant
Instructional Strategies	23.193	3	< .001	Significant
Confidence and Reflection	5.304	3	.151	Not significant
Implementation Challenges	2.806	4	.591	Not significant
Institutional Support and Resources	45.774	4	< .001	Significant

Knowledge ($\chi^2 = 0.523$, $p = .914$), confidence and reflection ($\chi^2 = 5.304$, $p = .151$), and perceived implementation challenges ($\chi^2 = 2.806$, $p = .591$) did not differ between sectors. Instructional strategies ($\chi^2 = 23.193$, $p < .001$) and institutional support ($\chi^2 = 45.774$, $p < .001$) did, with private-preschool teachers reporting greater use of graphomotor strategies and higher institutional backing. H4 is partially supported: the sectors are comparable in what teachers know and how confident they feel, but they diverge in what teachers do and what their institutions provide.

7. Discussion

7.1 Principal findings

The study asked three things: whether preschool children's fine-motor and grapho-motor skills respond to structured intervention, whose skills respond and under what conditions, and whether teachers work under comparable circumstances across sectors. The intervention produced a very large gain in the trained group against a control group that scarcely moved, and no child anywhere in the sample went backwards. Demographic factors patterned outcomes selectively, and socio-economic status dropped out altogether once baseline was controlled. Teachers across sectors proved comparable in what they know but markedly unequal in what they do and in the support they receive. What follows interprets these results rather than restating them.

7.2 Interpreting the intervention effect

One detail deserves separate emphasis. Thirty experimental children sat below the normal range at baseline, nine in developmental delay and twenty-one in suspected delay, and every one of them advanced a band. The nine in developmental delay left it entirely, while the corresponding eight children in the control group remained exactly where they started. The only experimental children who did not improve were the eighty already at the top of the scale, who had no room to. The rank correlations capture the same movement: skill level correlated 1.000 from pre to post in the control group but only .609 in the experimental group. That fall reflects convergence rather than reshuffling, since no child overtook another; the lower bands closed on the top one, converting differences into ties. Interventions often benefit those already doing well, widening a distribution rather than lifting its floor, so a result running the other way is worth stating plainly. It also supplies the mechanism behind the socio-economic finding discussed next.

7.3 Demographic patterning of outcomes

The demographic results reward closer reading, because they part company with the literature in instructive ways.

The most consequential divergence concerns socio-economic status. A consistent body of work documents SES gradients in early motor development: Ghorbanzadeh et al. (2025) found family socio-economic status patterning motor competence, Fioroni Ribeiro da Silva et al. (2026) showed poverty exposure predicting atypical motor variation in infancy, and Gyarmathy (2026) documented settlement-based disparities that ordinary schooling did little to close. Against that backdrop, the absence of any SES effect once baseline was controlled is a notable and encouraging null. The most plausible reading is that a well-structured programme works as an equaliser, supplying practice opportunities that more advantaged homes provide anyway. The band data support this directly: all nine children in the lowest band moved out of it, and the rank reordering documented in Table 10 confirms that the gains were concentrated among those starting furthest behind. The equity reading needs replication before it drives policy, but it is consistent with the protective-factor logic in Fioroni Ribeiro da Silva et al. (2026), where access to fine-motor materials rather than family income was the proximal ingredient.

The gender result, girls outscoring boys after the intervention, runs with the female advantage reported by Bondi et al. (2022), Maurer et al. (2023), and Kaloyanova (2026). Two cautions temper it: the effect

was small ($\eta^2 = 0.040$), and gender differences here appear domain-specific rather than general, since Maurer et al. (2023) found girls stronger in grapho-motor skill but boys more accurate in spelling. The result is best read as a modest, task-dependent advantage rather than a broad developmental gap.

The dissociation between skill levels, which responded to school type, and skill scores, which responded to age and gender, is less commonly reported, and the distributional data now allow a firmer explanation than speculation. Skill level is a three-point classification, and after the intervention it was severely ceilinged, with a skewness of − 2.329 and 91.8% of experimental children in the top band. A coarse banded outcome compressed against its ceiling exaggerates group contrasts, because children whose underlying scores overlap substantially can still fall either side of a band boundary. That is the likeliest source of the very large school-type effect on levels ($\eta^2 = 0.610$) sitting beside a non-significant effect on scores ($\eta^2 = 0.020$). Comparable studies using continuous outcomes (Spanaki et al., 2014; Ohl et al., 2013) did not face this artefact. The continuous score should therefore be treated as the primary outcome, with the banded level retained as a descriptive and clinical aid rather than a basis for inferential comparison.

The age gradient on scores is exactly what developmental theory predicts, matching Bondi et al. (2022) and the steep preschool growth curves that make early intervention worth attempting.

7.4 The knowledge-practice gap among teachers

The teacher findings carry a message that neither a pure training account nor a pure resourcing account captures alone. Government and private preschool teachers did not differ in knowledge, confidence, or the challenges they reported, but they differed sharply in the instructional strategies they used and the institutional support behind them. Knowing about graphomotor development did not translate into doing it where materials, time, and administrative backing were thinner.

The pattern is theoretically legible. From a Vygotskian standpoint a teacher's capacity to scaffold depends on the cultural tools available, and from a bioecological standpoint the proximal processes between teacher and child are conditioned by the institutional layers around them (Bronfenbrenner and Morris, 2006). It is consistent too with Bingham and Gerde (2023), who found teachers' conceptions of early writing shaping practice but only within the envelope their settings permit, and with evidence that teachers in low-resource settings improvise with local materials when provision falls short (Oyeyemi et al., 2026). The inference is uncomfortable but clear: professional development alone will not close this gap, because the binding constraint is institutional rather than cognitive.

Because the teacher and child datasets were analysed in parallel rather than linked, this strand describes the instructional conditions rather than testing their causal influence on children's gains. The convergence is nonetheless suggestive. The sector difference in children's post-intervention skill levels mirrors the sector difference in strategies and support, a correspondence a linked multilevel design could test directly.

7.5 Theoretical integration

Taken together the findings support an account of grapho-motor development as multidimensional and ecologically embedded rather than something that simply unfolds with maturation. The intervention results back motor-learning and dynamic-systems accounts of malleable early motor development. The selective demographic effects show that this malleability operates within contextual patterning and can partly override it, most visibly in the disappearance of the socio-economic gradient. The teacher results locate the real constraint in the institutional environment rather than in teacher knowledge. The study therefore pushes school-readiness scholarship past individual child factors toward the joint consideration of child, intervention, and institution within a single design.

8. Implications

8.1 Theoretical implications

By combining child outcomes with teacher-related conditions, the study supports motor-learning and dynamic systems theories empirically and extends school-readiness scholarship toward an ecological account in which intervention, teacher competence, and institutional resources jointly shape grapho-motor development. The knowledge-practice gap gives concrete content to the bioecological claim that proximal processes depend on the systems around them. The disappearance of the socio-economic effect after intervention refines contextual-patterning accounts by showing that structured provision can attenuate background disparities rather than merely reflect them.

8.2 Practical implications

Preschools should build fine-motor and grapho-motor activity into daily routines rather than treating it as an occasional add-on, since the evidence on distributed practice suggests regular embedded activity outperforms concentrated sessions. Teacher development should cover graphomotor milestones, assessment, and evidence-based strategies, but the present findings caution that training alone is not enough. Schools must also ensure steady access to age-appropriate manipulatives and writing tools, since resourcing rather than knowledge was where the sectors diverged.

8.3 Policy implications

Early-childhood curriculum frameworks should incorporate motor-development objectives alongside cognitive and language goals, and authorities should invest in teacher capacity-building and infrastructure, particularly in government preschools where institutional support lagged. The absence of a socio-economic effect after intervention, together with the emptying of the lowest developmental band, suggests scalable structured programmes may work as an equity lever, which bears directly on foundational-learning missions in India and comparable systems.

8.4 Health implications

Fine-motor difficulty occurs alongside attentional, cognitive, and readiness risks at population scale (Köppen et al., 2026) and features in clinically defined vulnerability from very preterm birth (Dathe et al.,

2026) to developmental coordination disorder (Peng et al., 2026). Routine screening of fine-motor and grapho-motor skills in preschool would strengthen early identification, and the responsiveness of these skills to a low-cost classroom programme indicates preschools can act as a first line of developmental support where specialist occupational-therapy services are scarce. Embedding screening within early-childhood systems aligns educational and child-health objectives instead of treating them separately.

9. Limitations

Several limitations bound the interpretation, though none undermines the central findings. The study was confined to selected preschools in one district of Uttar Pradesh, so generalisation beyond comparable North Indian settings should be cautious despite the urban-rural stratification. Outcomes were measured over a short post-intervention window, so nothing can be said about durability. The quasi-experimental design without individual randomisation leaves room for selection effects at group level, mitigated but not removed by demonstrated baseline equivalence and statistical control of baseline scores.

Measurement introduces further bounds. The banded skill-level outcome is coarse and became severely ceilinged after the intervention, which is why the continuous score carries the primary inferential weight. The interpretive banding of teacher constructs began at one rather than each scale's true minimum, and two teacher subscales fell below the conventional reliability threshold. The design was quantitative throughout, omitting classroom observation and teacher voice. Finally, the teacher and child datasets were analysed in parallel rather than linked, so the study describes but does not causally test whether teacher competencies or institutional support condition children's gains.

10. Future research

These limitations map onto a clear agenda. Longitudinal follow-up should test whether the gains persist and translate into handwriting quality, literacy, and school adjustment. Randomised or matched designs would strengthen causal inference where feasible, and full reporting of dosage parameters would let the field test the spacing and intensity effects identified by Li-Tsang et al. (2023) and Peng et al. (2026). The most valuable extension would link teacher and child data through multilevel models, turning the suggestive sector correspondence observed here into a direct test of whether strategies and institutional support moderate intervention effects. Multi-site studies would improve generalisability, and mixed-method designs incorporating classroom observation and teacher interviews would illuminate how these interventions work in resource-constrained settings. A finer-grained outcome measure would also avoid the ceiling encountered here.

11. Conclusion

This study asked whether preschool children's fine-motor and grapho-motor skills can be improved substantially in a low-resource setting, and whether the conditions for delivering that improvement are equitably distributed across the systems serving young children.

The answer to the first question is affirmative and large. A structured, developmentally appropriate programme produced a very large gain in skill scores, moved 30 children up a full developmental band, and emptied the lowest band entirely, while 102 of 110 children improved and not one child in the whole sample declined. Socio-economic status, which patterns motor development so reliably elsewhere, stopped differentiating outcomes once the programme was in place.

The answer to the second question is more sobering. Teachers across government and private preschools were equally knowledgeable and equally confident, but they were not equally equipped or supported, and their practice diverged accordingly.

The contribution of this study is to hold those two findings in one frame. Early grapho-motor development is malleable, the tools for supporting it are simple and classroom-deliverable, and the children furthest behind stand to gain the most. What limits the reach of that opportunity is not what teachers know. It is what their institutions allow them to do.

Declarations

Competing Interests:

The authors declare that they have no competing interests.

Ethics approval and consent to participate:

This study was descriptive in nature and was conducted using administration of a survey; no biological material was collected. Ethical approval for this study was formally waived by the Institutional Ethical Committee (IEC), Babasaheb Bhimrao Ambedkar University (BBAU), Lucknow, Uttar Pradesh, India, as the study involved only a non-invasive survey-based assessment with no clinical intervention. The study was conducted in accordance with the principles of the Declaration of Helsinki and the applicable guidelines and regulations of the committee. Written informed consent was obtained from the parent/legal guardian of all participating preschool children prior to their inclusion in the study.

Clinical trial number

Not applicable

Consent for publish

Participants provided consent for anonymized data to be published for academic and scientific purpose only.

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Author Contribution

Author 1 conceived and designed the study, collected the data, and prepared the manuscript. Author 2 and 3 supervised the research, conducted the statistical analyses, interpreted the findings, and critically revised the manuscript. All the authors read and approved the final version.

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Data Availability

The datasets generated and analysed during the current study are available from the corresponding author upon reasonable request.

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Figures

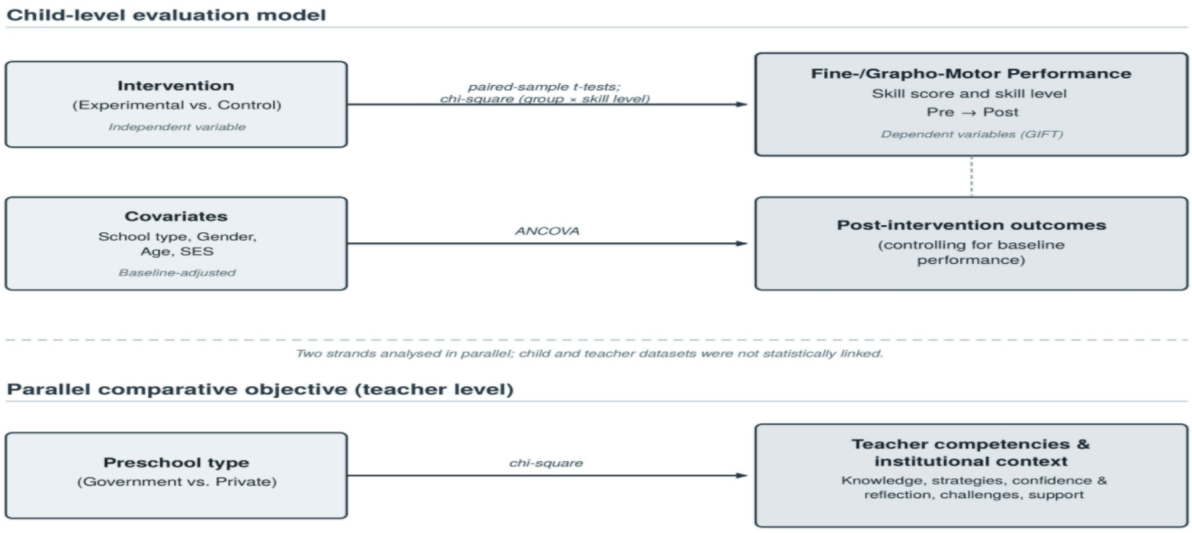


Figure 1

Conceptual framework. The upper panel represents the child-level evaluation: the intervention contrast is tested against pre-to-post fine-motor and grapho-motor performance using paired-sample t-tests and chi-square, and demographic covariates are examined on baseline-adjusted post-intervention outcomes using ANCOVA. The lower panel represents the parallel teacher-level comparison of competencies and institutional context across preschool types using chi-square. The two strands were analysed in parallel and the datasets were not statistically linked.