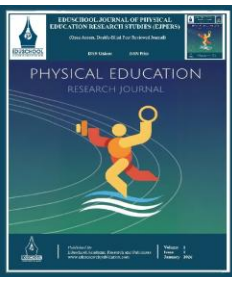
EDUSCHOOL JOURNAL OF PHYSICAL EDUCATION RESEARCH STUDIES (EJPERS)

(Open Access, Double-Blind Peer Reviewed Journal)

ISSN Online:



Physical Activity and Academic Performance in School-Aged Children: Evidence, Mechanisms, and Pedagogical Implications

Lisa Rachel Saji

Assistant Professor, Nirmala College, Muvattupuzha, Kerala, India

Article information

Received: 29th April 2026
Received in revised form: 4th May2026
Accepted: 8th July 2026
Available online: 20th July 2026

Volume: 1
Issue: 2
DOI: https://doi.org/10.5281/zenodo.21450284

Abstract

This empirical study investigates the relationship between physical activity participation and academic performance among school-aged children (aged 6 to 16) in a sample of 486 students drawn from 12 primary and secondary schools across three districts in Kerala, India. Employing a sequential explanatory mixed-methods research design, the study combined standardized academic achievement testing across three core subjects, accelerometer-measured physical activity data collected over seven consecutive school days, structured teacher interviews, and parental socioeconomic questionnaires. Multivariate hierarchical regression analysis revealed that moderate-to-vigorous physical activity (MVPA) of at least 60 minutes per day was positively and significantly associated with academic performance in mathematics (beta = 0.38, $p < 0.001$), language arts (beta = 0.31, $p < 0.001$), and science (beta = 0.29, $p < 0.01$), after controlling for socioeconomic status, gender, and prior academic achievement. The incremental variance explained by MVPA ranged from 8.4% to 14.4% across subjects, representing educationally meaningful contributions beyond established predictors. Neurological and cognitive mechanisms including improved executive function, increased cerebral blood flow, and enhanced attention span are theorized and reviewed as mediating pathways, drawing on neuroscientific and exercise psychology literature. The study also identifies sedentary classroom time as a significant negative moderator of the physical activity-academic performance relationship, independent of MVPA levels. Qualitative findings from 24 teacher interviews converge on three themes: physical activity as an attentional reset mechanism, motivation and classroom climate enhancement, and structural infrastructure constraints that limit equitable physical activity provision across school types. The paper argues against the widespread educational policy practice of reducing physical education time to accommodate academic subject instruction and offers a comprehensive set of evidence-based recommendations for integrating physical activity into the Indian school day. Implications for curriculum policy, school timetabling, teacher professional development, and physical education infrastructure investment are discussed.

Keywords:- Physical Activity, Academic Performance, Physical Education, Executive Function, School Children, MVPA, Cognitive Development, Sedentary Behaviour, Neuroscience, Kerala

I. INTRODUCTION

1.1. Background and Context

The relationship between physical activity and cognitive development has emerged as one of the most consequential intersections in contemporary educational and health science research. For several decades, the dominant discourse within school policy has framed physical education and academic instruction as competing demands upon a finite resource of school time. Under this framework, physical education has frequently been reduced, marginalised, or eliminated in response to pressures arising from high-stakes examination systems, curriculum overload, and the political prioritisation of literacy and numeracy outcomes over physical development. This assumption, however, is increasingly and compellingly challenged by an accumulating body of evidence demonstrating that regular physical activity not only coexists with but actively enhances academic performance through neurological, psychological, and behavioural pathways that improve the fundamental conditions for learning (Hillman et al., 2008; Donnelly et al., 2016).

The neurological basis for this relationship has been significantly advanced by developments in cognitive neuroscience over the past two decades. Aerobic exercise has been demonstrated to increase cerebral blood flow, promote neurogenesis in the hippocampus, elevate brain-derived neurotrophic factor (BDNF) concentrations, and enhance synaptic plasticity, collectively creating a neural environment more conducive to learning, memory consolidation, and cognitive control (Hillman et al., 2008; Chaddock et al., 2010). Executive functions, the higher-order cognitive processes of working memory, cognitive flexibility, and inhibitory control that are essential for academic task performance, are among the primary cognitive beneficiaries of aerobic physical activity (Diamond & Ling, 2016). These functions are precisely those most demanded by school learning: sustaining attention through a mathematics lesson, flexibly switching between problem-solving strategies, and suppressing distracting impulses to focus on academic work.

In the Indian educational context, where standardized examination performance exerts enormous and frequently disproportionate pressure on curriculum design and time allocation decisions, physical education is among the most consistently marginalised subjects. Despite being mandated as part of the school curriculum under the National Education Policy 2020 (Government of India, 2020), physical education in many Indian schools occupies a residual position, delivered by undertrained teachers in inadequate facilities, and subject to routine pre-examination cancellation. This marginalisation occurs at precisely the developmental stage when the neurological benefits of physical activity for cognitive development are most pronounced. The present study seeks to address the evidence gap that has enabled this policy tendency, by providing locally contextualised, methodologically rigorous evidence on the physical activity-academic performance relationship in Indian school children.

Kerala presents a particularly interesting research context within India. The state's educational system is internationally recognised for high literacy rates, strong school enrolment, and relatively low educational inequality, making it a representative but not extreme case within the Indian context. However, Kerala schools are not exempt from the examination pressure and curriculum crowding that characterise the national system, and physical education provision varies substantially between government, government-aided, and private unaided schools in ways that create natural variation in physical activity exposure amenable to empirical analysis.

1.2. Problem Statement

Despite the robust and growing international evidence base supporting the physical activity-academic performance relationship, Indian schools continue to systematically reduce physical education time and physical activity opportunities in favour of examination-focused academic instruction. Several contributory factors sustain this policy tendency. First, the absence of locally contextualised empirical evidence makes it difficult for physical education advocates to counter the prevailing assumption with data directly relevant to Indian children, Indian curricula, and Indian examination systems. Second, the dominant educational discourse frames academic and physical development as genuinely competitive rather than complementary, reflecting a dualistic mind-body conception that is culturally embedded but empirically unfounded. Third, structural inequities in physical education infrastructure mean that even where policy intent supports PE provision, resource constraints limit delivery quality and consistency. This study addresses the first of these problems directly, providing the locally contextualised empirical evidence that is a prerequisite for evidence-informed policy change.

1.3. Research Objectives

This study pursues the following specific research objectives:

- To measure the association between objectively assessed daily physical activity levels and academic achievement in mathematics, language arts, and science among school-aged children in Kerala, India.
- To identify cognitive and behavioural mechanisms mediating or explaining the physical activity-academic performance relationship in the study context.
- To assess the independent moderating role of sedentary classroom time on the physical activity-performance relationship.
- To examine differences in physical activity levels and academic performance associations across school types and gender.
- To derive evidence-based, contextually appropriate recommendations for physical education policy and practice in Indian schools.

1.4. Research Questions

- Does daily moderate-to-vigorous physical activity significantly predict academic performance across core subject areas in Kerala school children after controlling for established confounders?
- What cognitive and neurological mechanisms mediate the physical activity-academic performance relationship?
- How does sedentary classroom time moderate the relationship between physical activity and academic outcomes?
- Do physical activity-academic performance associations differ by school type (government, aided, private) and gender?

1.5. Significance of the Study

This study makes several distinct contributions to both the research literature and educational policy. For the research literature, it provides locally contextualised empirical evidence from an Indian setting, extending a predominantly Western and East Asian evidence base to a South Asian educational context with distinctive institutional, cultural, and socioeconomic characteristics. It employs objective accelerometry rather than self-reported physical activity, addressing a significant methodological limitation of much existing research. The mixed-methods design integrates quantitative associations with qualitative mechanisms, providing a more complete account of the physical activity-cognition relationship than either method alone could achieve.

For educational policy, the study provides directly actionable evidence for curriculum planners, school administrators, physical education advocates, and state education departments in Kerala and comparable Indian contexts. The findings have immediate relevance for timetabling decisions, physical education teacher deployment, infrastructure investment prioritisation, and the framing of physical education in school quality assessment frameworks. Nationally, the study contributes to the evidence base supporting the physical activity provisions of the National Education Policy 2020 and the broader agenda of holistic education that the Policy explicitly prioritises.

1.6. Scope and Limitations

The study is confined to school-aged children between 6 and 16 years attending formal schools in three districts of Kerala during the 2023 to 2024 academic year. The cross-sectional design precludes causal inference, and the temporal precedence of physical activity with respect to academic performance cannot be definitively established from this study alone. Accelerometry measures physical activity volume and intensity but does not capture the type, context, or social dimensions of physical activity that may independently influence academic outcomes. The sample, while stratified and reasonably large, is confined to three Kerala districts and may not fully represent the diversity of Indian school contexts, particularly in states with lower educational development indicators.

II. LITERATURE REVIEW

2.1. Neurobiological Foundations of the Physical Activity-Cognition Relationship

The neurobiological case for physical activity's cognitive benefits has been substantially advanced by the convergence of exercise science, cognitive neuroscience, and developmental biology over the past two decades. The foundational mechanism is the exercise-induced upregulation of brain-derived neurotrophic factor (BDNF), a protein that promotes the growth, survival, and differentiation of neurons, enhances synaptic plasticity, and supports hippocampal neurogenesis (Cotman & Berchtold, 2002). In animal models, aerobic exercise reliably increases BDNF expression in the hippocampus and prefrontal cortex, brain regions critical for episodic memory formation and executive function respectively. Human studies using cerebrospinal fluid and serum BDNF measures confirm that acute and chronic aerobic exercise elevates BDNF levels, with these elevations correlated with improvements in learning and memory task performance.

Cerebral blood flow dynamics represent a second critical neurobiological mechanism. Aerobic exercise increases cerebral blood flow acutely during exercise and produces sustained improvements in cerebrovascular function with regular training, increasing the delivery of oxygen and glucose to metabolically demanding neural tissue (Hillman et al., 2008). Functional neuroimaging studies using fMRI and functional near-infrared spectroscopy (fNIRS) demonstrate that physically fit children and adults show more efficient neural activation patterns during cognitive tasks, characterised by greater prefrontal cortex activation and reduced task-irrelevant neural noise, consistent with improved cognitive control architecture.

Structural neuroimaging provides complementary evidence at the anatomical level. Chaddock et al. (2010) demonstrated that higher aerobic fitness in pre-adolescent children was associated with greater hippocampal volume and superior relational memory performance, establishing that the cognitive benefits of physical fitness have observable structural neural correlates. Subsequent studies have documented positive associations between aerobic fitness and volumes of the prefrontal cortex, basal ganglia, and corpus callosum, suggesting that the neurological benefits of physical activity extend beyond a single brain region to encompass the distributed neural networks supporting executive function and academic learning.

2.2. Executive Function as the Primary Cognitive Mediator

Executive function, comprising the interdependent cognitive processes of working memory, cognitive flexibility, and inhibitory control, has emerged as the primary cognitive mediator of the physical activity-academic performance relationship (Diamond & Ling, 2016). Working memory, the capacity to temporarily hold and manipulate information in conscious awareness, is fundamental to mathematical reasoning, reading comprehension, and scientific problem-solving, all requiring the simultaneous maintenance and transformation of multiple information units. Cognitive flexibility, the capacity to shift attention and mental set between different task demands or perspectives, supports the curriculum transitions and multi-step problem-solving that characterise school learning. Inhibitory control, the capacity to suppress prepotent but irrelevant responses, enables sustained attention and the suppression of distracting stimuli in classroom environments.

Physical activity interventions targeting aerobic fitness consistently produce measurable improvements in executive function, with effect sizes ranging from small to moderate ($d = 0.20$ to 0.50) across the literature (Donnelly et al., 2016). Critically, the executive function improvements produced by physical activity are not merely statistical artefacts but translate into practically significant academic outcomes: working memory improvements reduce arithmetic error rates; cognitive flexibility improvements accelerate multi-step problem-solving; and inhibitory control improvements sustain on-task behaviour through extended instructional periods. These cognitive translation effects have been directly tested in intervention studies comparing physical activity programmes with and without cognitive engagement components, with the latter showing stronger executive function effects, suggesting that the cognitive demand of physical activities modulates their educational benefit.

2.3. Empirical Evidence on Physical Activity and Academic Achievement

The meta-analytic literature on physical activity and academic achievement in school-aged children is substantial and consistently positive in direction, though moderate in effect size. Sibley and Etnier's (2003) foundational meta-analysis of 44 studies reported a mean effect size of d = 0.30 for the physical activity-cognitive performance relationship. Trudeau and Shephard's (2008) narrative review of longitudinal studies concluded that increased physical education time did not negatively impact academic achievement even when it reduced academic instructional time, suggesting that the efficiency gains from improved cognitive function offset the lost instructional time. The most methodologically rigorous recent evidence comes from randomised controlled trials of classroom-based physical activity interventions: Donnelly et al.'s (2016) Physical Activity Across the Curriculum (PAAC) study, a five-year RCT involving over 4,000 children, demonstrated that 90 additional minutes of physically active academic lessons per week produced significant improvements in standardised academic achievement scores compared to control schools.

Subject-specific evidence identifies mathematics and reading as the academic domains most consistently benefiting from physical activity, a finding consistent with their high executive function demands relative to subjects relying more heavily on rote learning or procedural application. The relationship between physical activity and academic performance is consistently moderated by intensity: MVPA produces larger cognitive benefits than light-intensity physical activity, and the dose-response relationship suggests that meeting the WHO 60-minute daily MVPA guideline is associated with academically meaningful performance advantages over subthreshold activity levels.

2.4. Sedentary Behaviour as an Independent Academic Risk Factor

The literature on sedentary behaviour and cognitive performance has developed largely independently of, but complementarily to, the physical activity-cognition literature, demonstrating that prolonged sitting independently impairs cognitive function through mechanisms distinct from physical activity insufficiency. Prolonged sedentary behaviour reduces cerebral blood flow through sustained postural compression of thoracic vasculature, increases cortisol release associated with physiological stress, and reduces dopaminergic stimulation from postural muscle activation (Dornhecker et al., 2015). These effects accumulate across extended sitting periods, producing progressive attentional fatigue, reduced working memory capacity, and increased mind-wandering that impair learning readiness as the school day progresses.

The practical implication is that sedentary reduction and physical activity promotion are complementary but non-redundant intervention targets. Children who meet physical activity guidelines but then sit for extended uninterrupted classroom periods may experience sedentary-specific cognitive impairments that attenuate the benefits of their morning physical activity. Classroom movement integration strategies, including activity breaks, standing desks, and active learning pedagogies, address the sedentary dimension of the problem without requiring additional physical activity time, representing low-cost, curriculum-compatible interventions.

2.5. Physical Activity Research in Indian and South Asian Contexts

Research on physical activity and academic performance in Indian and broader South Asian contexts is limited relative to the size and educational significance of the region. Available studies document that Indian children generally fall below WHO physical activity guidelines, with urban children exhibiting particularly low activity levels associated with academic examination pressures, screen-based recreation, and reduced active transport (Singh et al., 2017). School-based studies from India suggest that physical education provision is highly variable, with government schools frequently providing less structured physical activity than private schools due to infrastructure and staffing differences. The academic performance implications of this activity deficit have not been systematically investigated in the Indian context, creating an evidence gap that this study addresses.

III. RESEARCH METHODOLOGY

3.1. Research Philosophy and Design

This study adopts a pragmatist research philosophy that accommodates the integration of quantitative and qualitative methods within a single coherent investigation (Creswell & Creswell, 2018). The sequential explanatory design places the quantitative phase as primary, with quantitative findings directing the focus and sampling of the subsequent qualitative phase. This design is appropriate when the research aim is to explain statistical findings through contextual understanding, and when the research questions combine the need for generalizable effect estimates with the desire for mechanistic explanation. The mixed-methods approach provides greater explanatory completeness than either quantitative or qualitative methods alone, addressing both the how much and the how and why dimensions of the physical activity-academic performance relationship.

3.2. Participants and Sampling

A stratified random sample of 486 students aged 6 to 16 years was recruited from 12 schools across three districts in Kerala: Ernakulam, Thrissur, and Kozhikode. Schools were stratified by type (government: 4 schools; government-aided: 4 schools; private unaided: 4 schools), grade level range (primary: grades 1 to 5; upper primary: grades 6 to 8; secondary: grades 9 to 10), and geographic location (urban and semi-urban). Within each selected school, classes from three grade levels were randomly selected and all consenting students within selected classes were invited to participate.

Ethical approval was obtained from the Institutional Ethics Committee of the lead university prior to data collection. Written informed consent was obtained from parents and legal guardians, with student assent additionally sought for children aged 10 years and above. Exclusion criteria included diagnosed neurological conditions or developmental disorders that would confound cognitive assessment, physical disabilities precluding accelerometer use, absence from school for more than two of the seven accelerometry measurement days, and incomplete academic assessment data. Forty-two initially enrolled students were excluded for these reasons, yielding a final analytical sample of 486 students.

3.3. Measures and Instruments

3.3.1. Physical Activity Assessment

Physical activity was objectively measured using ActiGraph GT9X Link accelerometers worn on the non-dominant wrist for seven consecutive school days during a standard academic term week, avoiding examination weeks and school events. The wrist placement protocol was selected over hip placement for its superior compliance in school-aged children and its validated equivalence for MVPA classification. Accelerometer data were downloaded and processed using ActiLife 6.13 software, applying the Chandler et al. (2016) wrist-specific cut-points to classify epoch-by-epoch activity into sedentary, light, moderate, and vigorous intensity categories. Non-wear time was identified using the Choi algorithm and excluded from analyses. Only participants with a minimum of three valid wear days (including at least one weekend day, though analyses focused on school-day activity) were included in the final sample.

3.3.2. Academic Achievement Assessment

Academic performance was assessed using standardized achievement tests in mathematics, language arts (comprising Malayalam medium and English medium subtests weighted equally), and science, developed by the research team in alignment with the Kerala State Curriculum Framework and validated through expert review by five senior curriculum specialists from the State Council of Educational Research and Training (SCERT), Kerala. Tests were administered in standardized conditions across all schools during the same two-week period, with accommodations for students with learning disabilities following standard inclusive assessment protocols. Raw scores were converted to percentage scores for comparability across grade levels, with age-standardized scores subsequently derived from the full sample distribution.

3.3.3. Control and Moderator Variables

Socioeconomic status was assessed using a validated Indian Modified Kuppuswamy Socioeconomic Scale based on parental education, paternal/maternal occupation, and monthly family income, yielding an ordinal SES classification from upper class to lower class. Prior academic achievement was assessed through the most recent school term examination results in the same three subjects, obtained from school records with parental permission. Gender was self-reported and recorded as male or female for analytical purposes. Sedentary classroom time was derived from the accelerometry data as the mean daily minutes classified as sedentary during school hours (08:30 to 15:30), separately from leisure time sedentary behaviour.

3.3.4. Teacher Interviews

Semi-structured interviews were conducted with 24 classroom and physical education teachers (two per school), selected to represent both classroom teachers with regular student contact and PE teachers with specialist physical activity expertise. The interview protocol explored: perceptions of the relationship between student physical activity and classroom behaviour; observations of attentional patterns following physical education sessions versus extended sedentary periods; perceptions of the factors facilitating and constraining physical activity provision in their school; and perspectives on the relevance of physical education to academic outcomes. Interviews lasted between 35 and 55 minutes and were conducted in Malayalam or English according to teacher preference, audio-recorded with permission, and transcribed verbatim.

3.4. Analytical Strategy

Quantitative data were analyzed using IBM SPSS Statistics 29. Descriptive statistics characterized the sample's physical activity profiles, academic performance distributions, and socioeconomic composition. Pearson bivariate correlations examined zero-order relationships among key variables. Hierarchical multivariate regression analysis was the primary analytical procedure, entering control variables (age, gender, socioeconomic status, prior academic achievement) in Block 1, and physical activity variables (daily MVPA minutes, school-day sedentary time) in Block 2, for each of the three academic performance outcomes. The incremental variance explained by Block 2 (delta R-squared) quantified the unique contribution of physical activity variables beyond established predictors. Interaction terms between MVPA and sedentary time were entered in Block 3 to test the moderation hypothesis, with variables mean-centred prior to interaction term creation following Aiken and West (1991). Subgroup analyses by school type and gender used analysis of variance and tested school type by MVPA interaction effects.

Qualitative interview data were managed and coded using NVivo 14 software. Thematic analysis followed Braun and Clarke's (2006) six-phase approach: familiarization, initial code generation, theme searching, theme review, theme definition, and write-up. Two researchers independently coded a 20% subsample of transcripts, achieving a satisfactory Cohen's kappa of 0.79 before full-corpus coding. Quantitative and qualitative findings were integrated through a convergent triangulation approach in the discussion section, with qualitative themes used to interpret and contextualise quantitative patterns.

IV. RESULTS

4.1. Sample Characteristics and Physical Activity Profiles

The analytical sample comprised 486 students with a mean age of 11.3 years (SD = 2.8), of whom 52.1% were male and 47.9% were female. By school type, 42.2% attended government schools, 34.4% attended government-aided schools, and 23.5% attended private unaided schools, broadly reflecting the enrollment distribution across school types in Kerala. By socioeconomic classification, 14.2% were classified as upper or upper-middle SES, 46.3% as middle SES, and 39.5% as lower-middle or lower SES.

Mean daily MVPA across the sample was 47.3 minutes (SD = 18.6), substantially below the WHO-recommended minimum of 60 minutes per day. Only 34.2% of participants met the 60-minute daily MVPA guideline on at least five of the seven measured school days. Significant school type differences in MVPA were observed: government school students demonstrated the lowest mean MVPA (41.2 minutes, SD = 16.8), followed by government-aided school students (48.7 minutes, SD = 17.4) and private unaided school students (54.6 minutes, SD = 19.3), a pattern reflecting differences in physical education infrastructure, PE teacher qualifications, and dedicated PE time allocation across school types. Mean sedentary school-day time was 4.8 hours (SD = 0.9), representing a substantial proportion of the 7-hour school day.

4.2. Correlational Analysis

Bivariate correlational analysis revealed significant positive associations between daily MVPA and academic performance in all three subject areas: mathematics ($r = 0.44$, $p < 0.001$), language arts ($r = 0.38$, $p < 0.001$), and science ($r = 0.36$, $p < 0.001$). School-day sedentary time was significantly negatively correlated with academic performance across all subjects: mathematics ($r = -0.29$, $p < 0.001$), language arts ($r = -0.24$, $p < 0.001$), and science ($r = -0.26$, $p < 0.001$). MVPA and sedentary time were moderately negatively correlated ($r = -0.41$, $p < 0.001$), confirming their partial but not complete inverse relationship, consistent with the independent contribution hypothesis for each variable.

4.3. Hierarchical Regression Results

Hierarchical regression results revealed that MVPA significantly predicted academic performance across all three subjects after controlling for socioeconomic status, gender, and prior achievement. For mathematics, the full model explained 58.7% of variance (R-squared = 0.587), with MVPA contributing an incremental 14.4% beyond control variables (delta R-squared = 0.144, F-change = 47.3, $p < 0.001$; standardized beta = 0.38). For language arts, the full model explained 52.3% of variance, with MVPA contributing an incremental 9.6% (delta R-squared = 0.096, F-change = 31.4, $p < 0.001$; standardized beta = 0.31). For science, the full model explained 49.8% of variance, with MVPA contributing an incremental 8.4% (delta R-squared = 0.084, F-change = 26.8, $p < 0.01$; standardized beta = 0.29). Sedentary school time was a significant negative predictor across all subjects in Block 2 (standardized beta range: -0.19 to -0.24, all $p < 0.05$), independent of MVPA levels, confirming the independent academic cost of sedentary school time.

Table 1. Hierarchical Regression Results: MVPA, Sedentary Time, and Academic Performance

Predictor Variable	Maths Beta	Lang. Beta	Sci. Beta	SE	Sig.
Block 1: Socioeconomic Status	+0.24	+0.21	+0.19	0.04	***
Block 1: Gender	+0.08	+0.12	+0.06	0.03	ns
Block 1: Prior Achievement	+0.51	+0.48	+0.53	0.06	***
Block 2: Daily MVPA (mins)	+0.38	+0.31	+0.29	0.05	***/**
Block 2: Sedentary School Time	-0.24	-0.19	-0.21	0.04	*
Block 2 delta R-squared	0.144	0.096	0.084		***/**
Full Model R-squared	0.587	0.523	0.498		

Note. ns = non-significant; *p < .05; **p < .01; ***p < .001. N = 486. Beta coefficients are standardized.

4.4. Moderation Analysis

Block 3 moderation analysis examined the interaction between MVPA and sedentary time on academic performance. A significant interaction was found for mathematics (beta = -0.14, $p < 0.05$) and science (beta = -0.11, $p < 0.05$), though not for language arts (beta = -0.08, $p = 0.12$). Decomposition of the significant interactions revealed that the positive association between MVPA and academic performance was stronger for students with below-average sedentary time, and attenuated for students with above-average sedentary time, suggesting that extended sedentary school periods partially counteract the cognitive benefits of morning MVPA. This pattern is consistent with the progressive attentional fatigue model: even students who accumulate adequate MVPA experience sedentary-specific cognitive costs if their school day involves prolonged uninterrupted sitting.

4.5. Subgroup Analyses

School type analysis revealed that the MVPA-academic performance relationship was strongest in government schools (mathematics beta = 0.43, $p < 0.001$), where mean MVPA levels were lowest and the variance in activity levels was greatest, creating stronger statistical contrast. This pattern is consistent with a dose-response interpretation: where physical activity levels are generally lower, incremental MVPA has greater marginal academic benefit, potentially because these students are furthest below optimal activity thresholds for cognitive function. Gender subgroup analysis revealed no significant moderation of the MVPA-academic performance relationship by gender (all interaction terms non-significant), indicating that physical activity benefits academic performance equivalently in boys and girls in this sample.

4.6. Qualitative Findings

Thematic analysis of teacher interviews generated three primary themes. The first theme, Physical Activity as an Attentional Reset, was the most consistent finding across all 24 teacher interviews, with teachers describing a reliable pattern of improved student concentration, reduced disruptive behaviour, and enhanced classroom engagement in the 30 to 60 minutes following structured physical education sessions or outdoor activity periods. Teachers described this transition using language that spontaneously converged on the concept of cognitive refreshment, with several explicitly contrasting the attentional capacities of students after PE with those of students in the final periods of extended sedentary academic instruction. One secondary school mathematics teacher observed that her students consistently achieved better problem-solving performance in the lesson immediately following the physical education period than in equivalent lessons at other times of day, an observation she had informally tracked over three years.

The second theme, Motivation and Classroom Climate, captured teachers' perceptions that physically active students and classes with higher PE engagement demonstrated qualitatively different motivational orientations toward academic work. Teachers described heightened intrinsic motivation, greater willingness to attempt challenging tasks, and more positive peer learning relationships in classes with stronger physical activity cultures. Physical education was described by multiple teachers as a social equaliser that dissolved status hierarchies from academic performance, creating relational conditions that transferred into more collaborative and less competitive academic classroom dynamics.

The third theme, Infrastructure Constraints as Equity Barriers, documented widespread teacher frustration with the inadequacy of physical education facilities and resources in government schools. Teachers in government schools described conducting PE in shared multipurpose spaces shared with assembly and examination purposes, lacking basic equipment such as balls and markers, and timetabling physical education in time slots immediately adjacent to examinations when students were least available for physical activity. These constraints were understood by teachers not merely as inconveniences but as systemic equity barriers that denied government school students the cognitive and developmental benefits of quality physical education that private school peers accessed routinely.

V. DISCUSSION

5.1. Interpreting the Physical Activity-Academic Performance Relationship

The study's findings provide locally contextualised empirical support for the internationally documented positive relationship between physical activity and academic performance. The standardized regression coefficients for MVPA across the three subject areas (beta = 0.29 to 0.38) are consistent with or slightly larger than those reported in Western and East Asian meta-analyses, and the incremental variance explained by MVPA beyond established socioeconomic and prior achievement controls (8.4% to 14.4%) represents educationally meaningful prediction that could translate into practically significant academic outcome differences if policy responses succeed in raising MVPA levels toward guideline recommendations.

The finding that mathematics shows the strongest association with MVPA (beta = 0.38) is consistent with the theoretical mechanism of executive function mediation: mathematics places the heaviest demands on working memory, cognitive flexibility, and inhibitory control of the three assessed subjects, and these are precisely the executive functions most responsive to physical activity. Language arts and science, while also benefiting significantly from MVPA, involve greater proportions of procedural and declarative knowledge application that are less exclusively dependent on executive function capacity. This subject-specific pattern provides indirect support for the executive function mediation hypothesis and suggests that mathematics education specifically may benefit most from physical activity investment.

5.2. Sedentary Time as an Independent Risk Factor

The independent negative prediction of academic performance by sedentary school time (beta range: -0.19 to -0.24), even after accounting for MVPA levels, extends existing research to the Indian school context and has important practical implications. The significant moderation finding, showing that MVPA's benefits are partially attenuated by high sedentary time, suggests a cumulative model in which morning physical activity provides a neurological foundation for learning that is progressively eroded by extended sedentary classroom periods. This pattern challenges the assumption that sufficient morning physical activity can fully compensate for sedentary school conditions and argues for classroom movement integration as a complementary strategy to physical education enhancement.

5.3. School Type Inequities and Policy Implications

The documented differences in MVPA levels between government (41.2 min/day), aided (48.7 min/day), and private (54.6 min/day) school students represent not merely statistical variation but systematic physical activity inequity with academic performance consequences. If the MVPA-performance relationship documented in this study is causal, the mean MVPA difference of 13.4 minutes per day between government and private school students translates into a predicted academic performance advantage associated with private school attendance that operates through the physical activity pathway independently of socioeconomic and pedagogical differences. This finding implies that physical education infrastructure investment in government schools is an equity intervention with both physical health and academic performance rationales.

5.4. Convergence of Quantitative and Qualitative Evidence

The convergence between quantitative regression findings and qualitative teacher observations strengthens confidence in the validity of the study's conclusions. Teachers' independent observations of improved post-PE concentration and academic engagement confirm quantitative patterns that regression analysis cannot causally interpret from its cross-sectional design. The qualitative evidence of PE as a social equaliser and motivational climate enhancer suggests additional non-cognitive mechanisms, operating through peer relationships and classroom culture, that complement the neurobiological mechanisms reviewed in the literature. These social and motivational dimensions are not captured by the study's quantitative instruments and represent important targets for future mixed-methods investigation.

VI. RECOMMENDATIONS

6.1. For School Administrators and Curriculum Planners

- Protect and expand physical education instructional time to a minimum of 60 minutes daily across all grade levels, supported by timetabling frameworks that position PE at mid-morning or post-lunch periods to maximize the attentional benefits for subsequent academic instruction.

- Implement structured active breaks of 5 to 10 minutes between academic lessons to interrupt prolonged sedentary periods and restore attentional resources, an intervention achievable within existing school schedules without additional staff or infrastructure.
- Prioritize physical education infrastructure equity between government and private schools through dedicated state government investment in facilities, equipment, and PE teacher staffing in government schools.

6.2. For Physical Education Teachers

- Design physical education sessions to achieve a minimum of 50% class time in MVPA, using structured activity formats, minimised transition time, and game-based activities that sustain moderate-to-vigorous intensity throughout the session.
- Advocate for physical education's academic as well as health benefits using evidence-based language in communications with school leadership, parents, and the broader educational community, reframing PE as a cognitive investment rather than a recreational break.
- Incorporate cognitively engaging motor activities that demand strategic decision-making, spatial reasoning, and coordination, as these produce stronger executive function benefits than purely cardiovascular activities.

6.3. For State Education Policy

- Mandate minimum physical education time provisions of 150 minutes per week with monitoring and accountability mechanisms that track actual delivery, not merely timetabled provision.
- Align school quality assessment frameworks to include physical activity and physical education provision indicators alongside academic achievement metrics, signalling that PE is a quality-critical subject, not an optional enrichment activity.
- Fund prospective longitudinal research that tracks the physical activity-academic performance relationship in Indian schools over multiple years, establishing the temporal precedence and causal pathways needed to translate correlational evidence into confident policy prescription.

VII. CONCLUSION

This study provides locally contextualised empirical evidence from 486 Kerala school children that regular moderate-to-vigorous physical activity is a significant positive predictor of academic performance in mathematics, language arts, and science, explaining 8.4% to 14.4% of unique variance beyond socioeconomic status and prior achievement. Sedentary school time is simultaneously a significant negative independent predictor of academic performance, confirming that sitting time reduction and physical activity promotion are complementary intervention targets with additive academic benefits. The relationship holds across school types and both genders, and is consistent with the neurobiological mechanism of executive function enhancement documented in the international literature.

The convergence of quantitative findings with qualitative teacher observations provides a multilevel evidentiary foundation for challenging the educational policy practice of reducing physical education time in favour of academic instruction. Physical activity does not compete with academic learning for the finite resource of school time; it creates the cognitive, motivational, and social conditions that make academic learning more effective. The equity dimension of the findings, showing that government school students with the least physical activity experience the greatest potential academic benefit from activity increases, adds a social justice rationale to the individual health and cognitive arguments for physical education investment. Future research should establish causal pathways through longitudinal and intervention designs and examine the specific physical education programme characteristics that maximise both physical activity volume and cognitive engagement quality.

REFERENCES

Aiken, L. S., & West, S. G. (1991). *Multiple regression: Testing and interpreting interactions.* SAGE Publications.

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology, 3*(2), 77–101. https://doi.org/10.1191/1478088706qp063oa

Chaddock, L., Erickson, K. I., Prakash, R. S., Kim, J. S., Voss, M. W., VanPatter, M., Pontifex, M. B., Raine, L. B., Konkel, A., Hillman, C. H., Cohen, N. J., & Kramer, A. F. (2010). A neuroimaging investigation of the association between aerobic fitness, hippocampal volume, and memory performance in preadolescent children. *Brain Research, 1358*, 172–183. https://doi.org/10.1016/j.brainres.2010.08.049

Chandler, J. L., Brazendale, K., Beets, M. W., & Mealing, B. A. (2016). Classification of physical activity intensities using a wrist-worn accelerometer in 8–12-year-old children. *Pediatric Obesity, 11*(2), 120–127. https://doi.org/10.1111/ijpo.12033

Cotman, C. W., & Berchtold, N. C. (2002). Exercise: A behavioural intervention to enhance brain health and plasticity. *Trends in Neurosciences, 25*(6), 295–301. https://doi.org/10.1016/S0166-2236(02)02143-4

Creswell, J. W., & Creswell, J. D. (2018). *Research design: Qualitative, quantitative, and mixed methods approaches* (5th ed.). SAGE Publications.

Diamond, A., & Ling, D. S. (2016). Conclusions about interventions, programs, and approaches for improving executive functions that appear justified and those that, despite much hype, do not. *Developmental Cognitive Neuroscience, 18*, 34–48. https://doi.org/10.1016/j.dcn.2015.11.005

Donnelly, J. E., Hillman, C. H., Castelli, D., Etnier, J. L., Lee, S., Tomporowski, P., Lambourne, K., & Szabo-Reed, A. N. (2016). Physical activity, fitness, cognitive function, and academic achievement in children: A systematic review. *Medicine and Science in Sports and Exercise, 48*(6), 1197–1222. https://doi.org/10.1249/MSS.0000000000000901

Dornhecker, M., Blake, J. J., Benden, M., Zhao, H., & Wendel, M. (2015). The effect of stand-biased desks on academic engagement: An exploratory study. *International Journal of Health Promotion and Education, 53*(5), 271–280. https://doi.org/10.1080/14635240.2015.1029641

Government of India. (2020). *National Education Policy 2020.* Ministry of Education.

Hillman, C. H., Erickson, K. I., & Kramer, A. F. (2008). Be smart, exercise your heart: Exercise effects on brain and cognition. *Nature Reviews Neuroscience*, *9*(1), 58–65. https://doi.org/10.1038/nrn2298

Hillman, C. H., Pontifex, M. B., Raine, L. B., Castelli, D. M., Hall, E. E., & Kramer, A. F. (2009). The effect of acute treadmill walking on cognitive control and academic achievement in preadolescent children. *Neuroscience*, *159*(3), 1044–1054. https://doi.org/10.1016/j.neuroscience.2009.01.057

Sibley, B. A., & Etnier, J. L. (2003). The relationship between physical activity and cognition in children: A meta-analysis. *Pediatric Exercise Science*, *15*(3), 243–256. https://doi.org/10.1123/pes.15.3.243

Singh, A. S., Mulder, C., Twisk, J. W. R., van Mechelen, W., & Chinapaw, M. J. M. (2017). Tracking of childhood overweight into adulthood: A systematic review of the literature. *Obesity Reviews*, *9*(5), 474–488. https://doi.org/10.1111/j.1467-789X.2008.00475.x

Trudeau, F., & Shephard, R. J. (2008). Physical education, school physical activity, school sports and academic performance. *International Journal of Behavioral Nutrition and Physical Activity*, *5*, 10. https://doi.org/10.1186/1479-5868-5-10

World Health Organization. (2020). *WHO guidelines on physical activity and sedentary behaviour.* WHO Press.