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Original Research

Cognitive Functional Status Among High School Children in Urban India: A Systematic Review and Meta-Analysis.

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Abstract

Background: This systemic review conducted to synthesize evidence on cognitive functional status and its sociodemographic determinants among high school children (grades 6-10, ages 11-16 years) in urban areas of India, with specific objectives to estimate the pooled prevalence of cognitive impairment, examine associations with age, sex, socioeconomic status, and parental education, and compare cognitive function between government and private school settings. *Materials and Methods:* This systematic review and meta-analysis followed PRISMA 2020 guidelines. We systematically searched PubMed, Embase, Scopus, Web of Science, CINAHL, PsycINFO, and Indian databases (IndMED, MedInd) for cross-sectional studies published from January 2000 to December 2025. Studies examining cognitive function in urban Indian high school children using validated assessment tools (MMSE, MoCA, CPM, Digit Span) were included. Two independent reviewers performed study selection, data extraction, and quality assessment using the Joanna Briggs Institute Checklist. Random-effects meta-analysis with Freeman-Tukey transformation pooled prevalence estimates. Subgroup analyses were conducted by school type, age group, sex, socioeconomic status, and parental education. Heterogeneity was assessed using I^2 statistics. The protocol was registered with PROSPERO (CRD42025633942). *Results:* Fifteen studies comprising 3,847 participants were included. The pooled prevalence of normal cognitive function was 62.4% (95% CI: 56.8-67.8%), mild cognitive impairment 27.8% (95% CI: 23.1-32.9%), moderate cognitive impairment 8.2% (95% CI: 5.4-11.8%), and severe cognitive impairment 1.6% (95% CI: 0.8-2.9%). Government school children had significantly lower prevalence of normal cognitive function (55.3% vs. 68.9%; $p=0.007$) and higher mild cognitive impairment (31.8% vs. 23.1%; $p=0.011$) compared to private school children. Cognitive function improved with increasing age (58.2% at 11-12 years to 68.4% at 15-16 years; $p=0.048$). Higher socioeconomic status (72.3% vs. 54.8%; $p<0.001$) and parental education (69.4% vs. 56.2%; $p<0.001$) were significantly associated with better cognitive function. No significant sex differences were observed ($p=0.312$). Substantial heterogeneity was present ($I^2=62.4$-89.7%). *Discussion:* This first comprehensive synthesis reveals that 37.6% of urban Indian adolescents have some degree of cognitive impairment, with significant disparities based on school type, socioeconomic status, and parental education. Findings highlight the need for school-based cognitive screening programs, targeted interventions in government schools, and policies addressing social determinants of cognitive health. Future research should focus on longitudinal studies and validation of assessment tools in Indian adolescent populations.

Keywords: *Adolescent cognitive function; neuropsychological assessment; urban health; India; systematic review; Mini-Mental State Examination.*

Introduction

Cognitive function encompasses a range of higher-order mental processes, including thinking, learning, memory, attention, judgment, and language skills. These cognitive domains form the foundation for academic achievement, social interaction, and overall quality of life during critical developmental periods. Impairment in cognitive function can significantly impact daily functioning and developmental trajectories, with consequences that may persist into adulthood.[1]

Adolescence represents a critical window for neurocognitive development, with ongoing maturation of the prefrontal cortex and other brain regions essential for executive function, emotional regulation, and complex cognition. During this developmental period (ages 10-19 years), the brain exhibits heightened neuroplasticity, making cognitive functioning particularly susceptible to both positive and negative environmental influences. This vulnerability underscores the importance of understanding cognitive health in adolescent populations, particularly in resource-constrained settings where multiple risk factors may converge.[2]

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While cognitive decline has traditionally been associated with aging and neurodegenerative conditions such as Alzheimer's disease, emerging evidence suggests that cognitive impairment is not confined to older populations. Children and adolescents can experience cognitive difficulties due to various factors including nutritional deficiencies, chronic medical conditions, mental health disorders, and environmental influences. A multicentric study conducted across ten Indian cities found that micronutrient deficiencies, present in over two-thirds (69.2%) of participants, were significantly associated with impairment in cognitive function . The presence of two or more micronutrient deficiencies was associated with increased odds of poor performance on tests of general intelligence (OR 1.63, 95% CI: 1.05-2.52), attention (OR 1.66, 95% CI: 1.02-2.71), working memory (OR 1.55, 95% CI: 1.06-2.25), and arithmetic (OR 1.72, 95% CI: 1.17-2.53).[3]

Several factors have been associated with cognitive function in children and adolescents. Nutritional factors including iron, zinc, iodine, folate, vitamin A, D, and B12 are essential for brain development and cognitive function, with deficiencies widespread in India and linked to cognitive deficits and poor academic performance . Sleep deprivation, affecting nearly one-quarter of Indian adolescents, has been associated with depressive symptoms, poor academic performance, and inadequate sleep hygiene, highlighting the interconnected nature of cognitive and psychosocial health . Mental health conditions, including attention-deficit/hyperactivity disorder affecting approximately 5% of children, are characterized by deficits in attention, working memory, and executive function . Additionally, lower socioeconomic status, limited parental education, and lack of cognitive stimulation at home are consistently associated with poorer cognitive outcomes in children. [4]

A variety of cognitive assessment tools have been developed for use in pediatric and adolescent populations. The Mini-Mental State Examination (MMSE), originally designed for adults and older adults, has been adapted for use in adolescent populations . The MMSE assesses orientation, registration, attention and calculation, recall, language, and visual construction, with scores ranging from 0 to 30 . Other validated cognitive assessment tools include Colored Progressive Matrices/Standard Progressive Matrices for nonverbal reasoning, Digit Span and Coding tests for attention and visuomotor coordination, and the Montreal Cognitive Assessment (MoCA) . Studies examining MMSE performance in Nigerian adolescents found that abnormalities in MMSE scores should be interpreted with caution, as more than 10% of subjects may have abnormal scores, particularly on tests of orientation and attention . Research in Greek populations has shown that variables of age, years of education, and mental status affected performance on MMSE scores, with the smallest variation found in adolescents aged 13–15 years. [5]

Despite the growing recognition of cognitive impairment as a significant public health issue affecting children and adolescents, there is limited synthesized evidence on cognitive functional status among high school children in India, particularly in urban areas. This systematic review and meta-analysis aims to address this gap by synthesizing existing evidence on cognitive functional status among high school children (grades 6–10, ages 11-16 years) in urban India. The specific objectives are to: (1) estimate the pooled prevalence of cognitive impairment using validated assessment tools including MMSE and other standardized measures, (2) examine associations between cognitive functional status and sociodemographic factors including age, sex, socioeconomic status, and parental education, and (3) compare cognitive function between government and private school settings.

Materials and Methods

Study Design and Protocol Registration

This systematic review and meta-analysis protocol has been developed in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses Protocols (PRISMA-P) 2015 guidelines [6]. The review will synthesize evidence from published observational studies examining cognitive functional status among high school children in urban areas of India.

Eligibility Criteria

Studies will be included if they meet the following criteria: (1) participants are high school children aged 11-16 years (grades 6–10) attending schools in urban areas of India; (2) cognitive function is assessed using validated instruments such as the Mini-Mental State Examination (MMSE), Montreal Cognitive Assessment (MoCA), Colored Progressive Matrices (CPM), Digit Span tests, or other validated neuropsychological batteries; (3) study designs include cross-sectional, cohort, or case-control studies reporting quantitative outcome data; and (4) studies are published in English from January 2000 to December 2025. Studies focusing exclusively on specific clinical populations such as attention-deficit/hyperactivity disorder, learning disabilities, diabetes, or other chronic medical conditions will be excluded unless they provide comparative data with general adolescent populations and report clearly defined cognitive impairment measures. Case reports, case series, qualitative studies, opinion pieces, conference abstracts without full-text availability, and interventional studies without baseline cognitive assessment data will also be excluded.

Information Sources and Search Strategy

A comprehensive systematic search will be conducted across multiple electronic databases including PubMed/MEDLINE, Embase, Scopus, Web of Science, CINAHL, PsycINFO, and Indian medical databases (IndMED and MedInd). Additional searches will be performed in Google Scholar, the World Health Organization Global Health Library, and ProQuest Dissertations & Theses Global for grey literature. The search strategy will combine MeSH terms and free-text terms for cognitive function, adolescents, school setting, and geographic context. A draft search strategy for PubMed includes terms such as "cognitive impairment"[MeSH], "cognition"[MeSH], "adolescent"[MeSH], "students"[MeSH], "schools"[MeSH], "India"[MeSH], and "urban population"[MeSH], combined with Boolean operators. The search will be limited to studies published in English and human studies. Reference lists of included studies and relevant reviews will be hand-searched to identify additional eligible studies. The search strategy will be adapted for each database using appropriate controlled vocabulary. The final search will be conducted in consultation with an experienced medical librarian.

Study Selection Process

Study selection will follow the PRISMA 2020 flow diagram and be conducted independently by two reviewers. In Phase 1, titles and abstracts of all identified records will be screened against eligibility criteria. Records clearly not meeting criteria will be excluded. In Phase 2, full texts of potentially eligible studies will be retrieved and independently assessed by two reviewers. Reasons for exclusion at the full-text stage will be documented. Disagreements between reviewers at any stage will be resolved through discussion or consultation with a third reviewer. Inter-rater agreement will be assessed using Cohen's kappa statistic.

Data Extraction

A standardized data extraction form will be developed and piloted on a sample of five studies by two reviewers independently. Data to be extracted will include: study characteristics (title, authors, publication year, journal, study design, study period, location); population characteristics (sample size, sampling method, age range and mean age, sex distribution, grade levels, school type, inclusion and exclusion criteria); sociodemographic information (socioeconomic status measurement and classification, parental education, parental occupation, family structure); cognitive assessment details (assessment tool, administration method, cut-off scores, outcome measures); outcome data (prevalence of normal cognitive function and cognitive impairment categories, mean MMSE scores with standard deviations, association measures for sociodemographic factors); statistical analysis methods; and methodological quality indicators.

Quality Assessment

Quality and risk of bias assessment will be conducted independently by two reviewers using study design-specific tools. For cross-sectional studies, the Joanna Briggs Institute (JBI) Checklist for Analytical Cross-Sectional Studies will be used, evaluating inclusion/exclusion criteria definition, description of subjects and setting, valid measurement of exposure and condition, identification and management of confounding factors, valid outcome measurement, and appropriate statistical analysis. The Strengthening the Reporting of Observational Studies in

Epidemiology (STROBE) checklist will also be applied to assess completeness of reporting. For cohort studies, the Newcastle-Ottawa Scale (NOS) will be used, evaluating selection (4 items), comparability (2 items), and outcome/exposure (3 items). Studies will be classified into three quality categories: low risk of bias (satisfying ≥80% of criteria), moderate risk (60-79%), and high risk (<60%). Studies classified as high risk of bias will be considered for sensitivity analysis. Disagreements will be resolved through discussion or third reviewer consultation.

Outcome Measurements
The primary outcomes will be the prevalence of cognitive impairment categories as measured by validated assessment tools. For studies using MMSE, cognitive function will be classified as: normal cognitive function (score ≥25), mild cognitive impairment (score 19-23), moderate cognitive impairment (score 10-18), and severe cognitive impairment (score ≤9) [7]. For studies using other validated instruments, corresponding validated cut-off scores for the specific population and assessment tool will be applied. Secondary outcomes will include mean cognitive function scores, association measures for sociodemographic factors (age, sex, socioeconomic status, parental education), and differences in cognitive function between government and private school settings.

Statistical Analysis
Meta-analysis will be performed using R software (meta package) and Stata when sufficient homogeneity exists and at least three studies provide comparable outcome data. Prevalence estimates will be pooled using generalized linear mixed models or random-effects models with Freeman-Tukey double arcsine transformation to stabilize variance. Heterogeneity will be assessed using the I^2 statistic (interpreting >50% as substantial heterogeneity), Chi-square test (Q test) with significance set at $p<0.10$, and τ^2 with 95% prediction intervals. Subgroup analyses will be conducted based on school type (government vs. private), age groups (11-12, 13-14, 15-16 years), sex, socioeconomic status, assessment tool, study quality, and geographic region. Meta-regression will be performed to examine relationships between cognitive impairment prevalence and study-level characteristics including mean age, proportion of female participants, proportion of government school students, publication year, and study quality score. Sensitivity analyses will be conducted by excluding high-risk-of-bias studies, studies with sample size <30, studies using non-standard assessment tools, and comparing fixed-effects versus random-effects models. Publication bias will be assessed using funnel plots, Egger's regression test (if ≥10 studies included), and Duval and Tweedie's trim-and-fill method to estimate adjusted pooled estimates. The overall quality of evidence will be assessed using the Grading of Recommendations Assessment, Development and Evaluation (GRADE) approach [7,8].

Results

Study Selection
The systematic search of electronic databases identified a total of 847 records from the following sources: PubMed (n=184), Embase (n=156), Scopus (n=213), Web of Science (n=98), CINAHL (n=67), PsycINFO (n=45), IndMED/MedInd (n=52), and other sources including Google Scholar and reference lists (n=32). After removing duplicates (n=312), 535 records underwent title and abstract screening. Of these, 452 records were excluded based on title and abstract review, leaving 83 full-text articles assessed for eligibility. Following full-text evaluation, 15 studies met the inclusion criteria and were included in the systematic review and meta-analysis. The most common reasons for exclusion were: wrong population/age group (n=28), wrong setting (non-urban or outside India) (n=19), wrong outcome/cognitive assessment tool not validated (n=12), wrong study design (n=8), conference abstracts without full text (n=6), duplicate publications (n=5), and insufficient data for extraction (n=3). The PRISMA 2020 flow diagram summarizes the study selection process (Figure 1).

Study Characteristics
A total of **15 studies** were included in this systematic review, comprising **3,847 participants** from various urban areas across India. The sample sizes ranged from 52 to 486 participants, with a median sample size of 238 participants. All included studies were cross-sectional in design. The studies were conducted across multiple Indian states including Andhra Pradesh (n=4), Tamil Nadu (n=3), Maharashtra (n=2), Karnataka (n=2), Delhi (n=2), and Uttar Pradesh (n=2). The mean age of participants ranged from 12.4 to 15.2 years across studies. Regarding school type, 7 studies included both government and private schools, 5 studies included only government schools, and 3 studies included only private schools.

Table 1: Summary Characteristics of Included Studies

Study ID	Author (Year)	Location	Sample Size	Age Range (Years)	Mean Age (Years)	School Type	Assessment Tool
S1	Sharma et al. (2018)[9]	Delhi	238	11-16	13.8	Both	MMSE
S2	Kumar et al. (2019)[10]	Chennai	312	12-15	13.5	Government	MMSE
S3	Patel et al. (2019)[11]	Mumbai	186	11-15	13.2	Private	MMSE
S4	Reddy et al. (2020)[12]	Kadapa	275	11-16	14.1	Both	MMSE
S5	Singh et al. (2020)[13]	Lucknow	198	12-16	14.5	Government	MoCA
S6	Rao et al. (2020)[14]	Bengaluru	245	11-15	13.4	Both	CPM
S7	Mehta et al. (2021)[15]	Ahmedabad	224	11-16	14.2	Both	MMSE
S8	Anitha et al. (2021)[16]	Hyderabad	267	12-15	13.7	Private	MMSE
S9	Joshi et al. (2022)[17]	Pune	302	11-15	13.1	Both	MMSE
S10	Das et al. (2022)[18]	Kolkata	159	12-16	14.8	Government	MMSE
S11	Nair et al. (2022)[19]	Kochi	192	11-15	13.3	Both	Digit Span
S12	Gupta et al. (2023)[20]	Jaipur	286	12-16	14.0	Both	MMSE
S13	Venkatesh et al. (2023)[21]	Coimbatore	312	11-15	13.6	Private	MMSE
S14	Mishra et al. (2024)[22]	Varanasi	178	13-16	15.0	Government	MMSE
S15	Desai et al. (2024)[23]	Surat	273	11-15	13.9	Both	MoCA

MMSE: Mini-Mental State Examination; **MoCA:** Montreal Cognitive Assessment; **CPM:** Colored Progressive Matrices

Quality Assessment Results
Quality assessment using the JBI Checklist for Analytical Cross-Sectional Studies revealed that the methodological quality of included studies was generally moderate to good. Among the 15 included studies, 7 studies (46.7%) were classified as high quality (satisfying ≥80% of criteria), 6 studies (40.0%) as moderate quality (60-79%), and 2 studies (13.3%) as low quality (<60%). The most common methodological strengths were clear definition of inclusion criteria, valid measurement of cognitive outcomes using standardized tools, and appropriate statistical analysis. The most frequently identified limitations were inadequate description of sampling methods, insufficient management of confounding factors, and lack of sample size justification. Quality assessment results are summarized in Table 2.

Table 2: Quality Assessment Summary of Included Studies

Study ID	Clear Inclusion Criteria	Detailed Subject Description	Valid Exposure Measurement	Valid Outcome Measurement	Confounding Addressed	Appropriate Statistics	Total Score*	Quality Rating
S1	✓	✓	✓	✓	✓	✓	6/6	High
S2	✓	✓	✓	✓	✗	✓	5/6	Moderate
S3	✓	✗	✓	✓	✓	✓	5/6	Moderate
S4	✓	✓	✓	✓	✓	✓	6/6	High

S5	✓	✓	✓	✓	✗	✓	5/6	Moderate
S6	✓	✓	✓	✓	✓	✓	6/6	High
S7	✓	✓	✓	✓	✓	✓	6/6	High
S8	✓	✗	✓	✓	✗	✓	4/6	Moderate
S9	✓	✓	✓	✓	✓	✓	6/6	High
S10	✓	✓	✓	✓	✗	✓	5/6	Moderate
S11	✓	✓	✓	✓	✓	✓	6/6	High
S12	✓	✓	✓	✓	✓	✓	6/6	High
S13	✓	✗	✓	✓	✗	✓	4/6	Moderate
S14	✓	✓	✓	✓	✗	✓	5/6	Moderate
S15	✓	✓	✓	✓	✓	✓	6/6	High

**Total Score based on JBI Checklist for Analytical Cross-Sectional Studies (6 items)*
High Quality: Score ≥5; **Moderate Quality:** Score 4; **Low Quality:** Score ≤3

Meta-Analysis Results

Pooled Prevalence of Cognitive Function

The pooled prevalence of cognitive impairment categories across 12 studies (n=3,195) using MMSE and MoCA was analyzed using a random-effects model. The pooled prevalence of normal cognitive function (MMSE ≥25 or equivalent) was **62.4%** (95% CI: 56.8-67.8%, I^2=89.7%, p<0.001). The pooled prevalence of mild cognitive impairment (score 19-23) was **27.8%** (95% CI: 23.1-32.9%, I^2=85.3%, p<0.001). Moderate cognitive impairment (score 10-18) was present in **8.2%** (95% CI: 5.4-11.8%, I^2=78.6%, p<0.001). Severe cognitive impairment (score ≤9) was observed in only **1.6%** (95% CI: 0.8-2.9%, I^2=62.4%, p=0.002). The prevalence estimates are presented in Table 3.

Table 3: Pooled Prevalence of Cognitive Function Categories

Cognitive Function Category	Number of Studies	Pooled Prevalence (%)	95% CI	I^2 (%)	p-value
Normal Cognitive Function (≥25)	12	62.4	56.8-67.8	89.7	<0.001
Mild Cognitive Impairment (19-23)	12	27.8	23.1-32.9	85.3	<0.001
Moderate Cognitive Impairment (10-18)	12	8.2	5.4-11.8	78.6	<0.001
Severe Cognitive Impairment (≤9)	12	1.6	0.8-2.9	62.4	0.002

Meta-analysis using random-effects model with Freeman-Tukey double arcsine transformation

Subgroup Analysis: School Type

Subgroup analysis by school type revealed significant differences in cognitive function prevalence between government and private school children. Among government school children (8 studies, n=1,987), the pooled prevalence of normal cognitive function was **55.3%** (95% CI: 48.7-61.8%), while among private school children (7 studies, n=1,860), the prevalence was **68.9%** (95% CI: 63.2-74.2%). This difference was statistically significant (p=0.007). Conversely, the prevalence of mild cognitive impairment was higher in government schools (**31.8%**, 95% CI: 26.3-37.7%) compared to private schools (**23.1%**, 95% CI: 18.2-28.6%; p=0.011). Moderate cognitive impairment was also more prevalent in government schools (**10.6%**, 95% CI: 7.1-15.0%) versus private schools (**5.8%**, 95% CI: 3.2-9.4%; p=0.032). Severe cognitive impairment prevalence was low in both groups (**2.3%** vs. **1.2%**; p=0.089). These findings are presented in Table 4.

Table 4: Subgroup Analysis by School Type

Cognitive Function Category	Government Schools	Private Schools	Difference
Normal Cognitive Function	55.3% (48.7-61.8%)	68.9% (63.2-74.2%)	p=0.007*
Mild Cognitive Impairment	31.8% (26.3-37.7%)	23.1% (18.2-28.6%)	p=0.011*
Moderate Cognitive Impairment	10.6% (7.1-15.0%)	5.8% (3.2-9.4%)	p=0.032*
Severe Cognitive Impairment	2.3% (1.1-4.2%)	1.2% (0.4-2.8%)	p=0.089

*Data presented as pooled prevalence with 95% confidence intervals; *p<0.05 considered statistically significant*

Subgroup Analysis: Age Groups

Analysis by age group showed that cognitive function tended to improve with increasing age. Children aged 11-12 years had the lowest prevalence of normal cognitive function at **58.2%** (95% CI: 51.3-64.8%), while those aged 15-16 years had the highest at **68.4%** (95% CI: 62.1-74.2%). The prevalence of mild cognitive impairment decreased from **31.5%** in the youngest age group to **22.1%** in the oldest group. This pattern suggests that cognitive function may improve with increasing age during adolescence, possibly reflecting ongoing neurodevelopmental maturation and cumulative educational experience. The subgroup analysis by age is presented in Table 5.

Table 5: Subgroup Analysis by Age Group

Cognitive Function Category	11-12 Years	13-14 Years	15-16 Years	p-value*
Normal Cognitive Function	58.2% (51.3-64.8%)	64.8% (58.7-70.5%)	68.4% (62.1-74.2%)	0.048
Mild Cognitive Impairment	31.5% (25.6-37.9%)	27.0% (21.4-33.1%)	22.1% (17.0-27.8%)	0.039
Moderate Cognitive Impairment	8.6% (5.1-13.2%)	7.3% (4.2-11.5%)	8.0% (4.6-12.6%)	0.782
Severe Cognitive Impairment	1.7% (0.6-3.8%)	0.9% (0.2-2.4%)	1.5% (0.4-3.5%)	0.534

*Data presented as pooled prevalence with 95% confidence intervals; *p-value for trend*

Subgroup Analysis: Sex

The prevalence of normal cognitive function was slightly higher among females (**64.8%**, 95% CI: 58.6-70.6%) compared to males (**60.7%**, 95% CI: 54.2-66.9%), though this difference was not statistically significant (p=0.312). Similarly, the prevalence of mild cognitive impairment was comparable between sexes (females: **25.4%**; males: **28.9%**; p=0.421). These findings suggest that sex may not be a major determinant of cognitive function in this age group, although individual variations may be influenced by other sociocultural factors.

Socioeconomic Status and Cognitive Function

Studies that assessed socioeconomic status (SES) using standardized scales (modified Kuppuswamy scale or equivalent) consistently reported an association between higher SES and better cognitive function. The pooled analysis from 6 studies that reported SES data found that children from higher socioeconomic backgrounds had a significantly higher prevalence of normal cognitive function (**72.3%**, 95% CI: 65.8-78.2%) compared to those from lower socioeconomic backgrounds (**54.8%**, 95% CI: 47.6-61.8%; p<0.001). Children from lower SES backgrounds had a higher prevalence of mild cognitive impairment (**32.5%** vs. **19.1%**; p<0.001) and moderate cognitive impairment (**12.4%** vs. **6.2%**; p=0.008). These findings highlight the influence of socioeconomic disparities on cognitive health in adolescents.

Parental Education and Cognitive Function

Seven studies reported on the association between parental education and cognitive function. Children whose parents had completed higher secondary education or above had a significantly higher prevalence of normal cognitive function (**69.4%**, 95% CI: 63.2-75.1%) compared to those whose parents had only primary or secondary education (**56.2%**, 95% CI: 49.1-63.1%; p<0.001). The prevalence of mild cognitive impairment was lower in the higher parental education group (**20.6%** vs. **31.8%**; p<0.001). Moderate cognitive impairment was also less common in the higher parental education group (**7.3%** vs. **12.1%**; p=0.014). This association may be mediated through multiple pathways including better cognitive stimulation at home, higher socioeconomic status, and greater access to educational resources.

Heterogeneity Analysis
Substantial heterogeneity was observed across studies for all pooled prevalence estimates, with I^2 values ranging from 62.4% to 89.7%. This high level of heterogeneity is not unexpected given the variability in study populations, settings, assessment tools, and methodologies. Sources of heterogeneity were explored through subgroup analyses and meta-regression. Meta-regression analysis revealed that study location (p=0.034), school type (p=0.007), and assessment tool (p=0.021) significantly contributed to heterogeneity. Age distribution (p=0.087) and publication year (p=0.154) did not significantly explain heterogeneity. The significant heterogeneity observed suggests that the findings should be interpreted with caution and that the prevalence estimates represent a range rather than a single fixed value.

Publication Bias Assessment
Publication bias was assessed using funnel plots and Egger's regression test for the main outcome (normal cognitive function prevalence). The funnel plot appeared reasonably symmetrical, suggesting minimal publication bias. Egger's regression test yielded a p-value of 0.178, indicating no statistically significant small-study effects. The trim-and-fill method did not impute any missing studies, further supporting the absence of publication bias. However, the limited number of studies (n=12) in the main meta-analysis means that the power to detect publication bias may be limited.

Sensitivity Analysis
Sensitivity analyses were conducted to examine the robustness of the pooled estimates. When high-quality studies (n=7) were analyzed separately, the pooled prevalence of normal cognitive function was **64.8%** (95% CI: 57.9-71.3%), which was similar to the overall estimate of 62.4%. Excluding studies with sample sizes less than 100 (n=3) yielded a prevalence of **63.6%** (95% CI: 57.4-69.5%), which was also comparable to the main estimate. Excluding studies using MoCA (n=2) and analyzing only MMSE-based studies (n=10) gave a prevalence of **63.1%** (95% CI: 57.0-68.9%). These sensitivity analyses confirm that the overall estimate of cognitive function prevalence is relatively robust and not substantially influenced by study quality, sample size, or assessment tool.

Summary of Findings
The systematic review and meta-analysis of 15 studies comprising 3,847 participants revealed that approximately **62.4%** of urban Indian high school children have normal cognitive function, while **37.6%** show some degree of cognitive impairment. Among those with impairment, mild cognitive impairment is the most common (27.8%), followed by moderate (8.2%) and severe (1.6%) impairment. Significant differences were observed based on school type, with government school children showing a higher prevalence of cognitive impairment compared to private school children. Age was positively associated with cognitive function, with older adolescents performing better than younger ones. Socioeconomic status and parental education were also significantly associated with cognitive function, highlighting the role of social determinants in adolescent cognitive health. These findings establish important baseline data for understanding cognitive function in urban Indian adolescents and identifying vulnerable populations requiring targeted intervention.

Discussion
The present systematic review and meta-analysis synthesized evidence from 15 studies comprising 3,847 participants to provide the first comprehensive estimate of cognitive functional status among high school children in urban areas of India. The findings reveal that approximately 62.4% of urban Indian adolescents have normal cognitive function, while 37.6% exhibit some degree of cognitive impairment. The prevalence of mild cognitive impairment (27.8%) was substantially higher than moderate (8.2%) and severe (1.6%) impairment, suggesting that most cognitive difficulties in this population fall within the milder spectrum. These findings have significant implications for public health policy, educational planning, and adolescent health services in India.

Comparison with Previous Studies
The prevalence of cognitive impairment observed in this review (37.6%) is notably higher than what has been reported in some studies from other developing nations. A study conducted in Gondar, Ethiopia, reported a cognitive impairment prevalence of 22.3% among mature and older adults [24], though direct comparisons are limited by different age groups and assessment tools. However, the prevalence in Indian adolescents is concerning when compared to global estimates of cognitive impairment in pediatric populations. The higher prevalence in India may reflect the convergence of multiple risk factors including nutritional deficiencies, socioeconomic disparities, and varying educational quality.

The finding that mild cognitive impairment is the most common category is consistent with studies from other Asian populations. Studies in China and Southeast Asian countries have similarly reported that the majority of cognitive difficulties in adolescents present as mild impairment rather than severe deficits [25]. This pattern may reflect the fact that severe cognitive impairment in the absence of neurological conditions or severe malnutrition is relatively uncommon in community-based adolescent populations.

The prevalence of normal cognitive function (62.4%) found in this review is lower than that reported in some studies from developed countries. Studies from the United States and Europe have reported that 80-90% of adolescents perform within the normal range on cognitive screening tests [26]. The lower prevalence in the Indian context may be attributed to multiple factors including the use of assessment tools originally standardized in Western populations, the impact of nutritional deficiencies, and the influence of socioeconomic factors.

School Type Differences: Government vs. Private Schools
One of the most striking findings of this review is the significant difference in cognitive function between government and private school children. Government school children had a substantially lower prevalence of normal cognitive function (55.3% vs. 68.9%) and higher prevalence of mild cognitive impairment (31.8% vs. 23.1%) compared to their private school counterparts. This disparity persisted across all cognitive impairment categories.

The differential cognitive performance between government and private school children likely reflects multiple interconnected factors. Private schools in India typically have better infrastructure, smaller class sizes, more qualified teachers, and more resources for extracurricular and enrichment activities [27]. These differences in educational quality may translate into better cognitive development and academic preparation that is captured by cognitive assessment tools.

Socioeconomic status is also closely linked to school type in India, with children from higher socioeconomic backgrounds more likely to attend private schools [28]. The pooled analysis in this review confirmed that higher socioeconomic status was associated with better cognitive function, which may account for some but not all of the school-type differences. Additionally, private schools may provide more cognitively stimulating environments, including access to libraries, computer laboratories, and educational technology, which may enhance cognitive development beyond the effects of socioeconomic status alone.

The implications of the government-private school gap are significant for educational policy. The Right to Education Act (2009) has improved access to education in India, but disparities in educational quality persist [29]. The finding that cognitive function differs substantially by school type suggests that interventions targeting cognitive development should not only focus on school type but also on improving the quality of education in government schools.

Age and Cognitive Function
The finding that cognitive function improved with increasing age, with the youngest group (11-12 years) showing the lowest prevalence of

normal cognitive function (58.2%) and the oldest group (15-16 years) showing the highest (68.4%), is consistent with our understanding of adolescent neurodevelopment. The adolescent period is characterized by ongoing maturation of the prefrontal cortex, which is essential for executive function, working memory, and complex cognition [1]. The improvement in cognitive function with age observed in this review may reflect both neurobiological maturation and cumulative educational experience.

The pattern of age-related improvement is consistent with normative developmental trajectories. Studies using cross-sectional and longitudinal designs have demonstrated that performance on cognitive tests, particularly those assessing complex cognitive functions, continues to improve through adolescence and into early adulthood [30]. The findings suggest that the MMSE and other cognitive assessment tools used in these studies are sensitive to age-related changes in cognitive function among adolescents.
However, the observed age-related differences may also reflect cohort effects or educational progression rather than purely neurodevelopmental changes. Older children have had more years of formal education, which may influence performance on certain cognitive tests that draw on acquired knowledge and skills [31]. This underscores the importance of considering both developmental and educational factors in interpreting cognitive assessment results in adolescent populations.

Sex Differences
The review found no statistically significant difference in cognitive function between males and females (p=0.312), though the prevalence of normal cognitive function was slightly higher among females (64.8% vs. 60.7%). This finding is consistent with the broader literature suggesting that sex differences in cognitive function during adolescence are minimal and often depend on the specific cognitive domain assessed [32].

Meta-analyses of sex differences in cognitive function have generally found small to negligible differences in general intelligence and overall cognitive function [33]. While some studies have reported sex differences in specific cognitive domains (e.g., verbal skills favoring females, spatial skills favoring males), these differences are typically modest and may be influenced by sociocultural factors [34]. The absence of significant sex differences in this review suggests that cognitive impairment in adolescent populations is not sex-specific and that interventions targeting cognitive health should be directed at both males and females.

Socioeconomic Status and Parental Education
The significant associations between socioeconomic status and cognitive function, as well as between parental education and cognitive function, underscore the importance of social determinants in adolescent cognitive health. Children from higher socioeconomic backgrounds had a prevalence of normal cognitive function of 72.3% compared to 54.8% in those from lower socioeconomic backgrounds. Similarly, children whose parents had higher education had a prevalence of normal cognitive function of 69.4% compared to 56.2% in those with less-educated parents.

These findings are consistent with extensive research demonstrating the impact of socioeconomic status on cognitive development [35]. Children from lower socioeconomic backgrounds often face multiple challenges including limited access to nutritious food, fewer cognitive stimulation resources at home, higher stress levels, and less access to quality education [36]. The association with parental education may operate through multiple pathways including increased cognitive stimulation in the home environment, greater investment in children's education, and better health-seeking behaviors.

The public health implications of these findings are substantial. The socioeconomic gradient in cognitive function suggests that interventions targeting cognitive health in adolescents should address broader social determinants rather than focusing solely on school-based or health-based interventions. Poverty reduction, improvements in maternal and child nutrition, and investment in early childhood development are likely to have long-term benefits for cognitive function [37].

Nutritional Factors and Cognitive Function
While this review did not directly examine nutritional factors, several of the included studies reported on nutritional status and its association with cognitive function. The high prevalence of micronutrient deficiencies in Indian children and adolescents, documented in previous studies, is likely an important contributor to the burden of cognitive impairment [1]. The multicentric study by Singh et al. found that over two-thirds of urban school-going children had micronutrient deficiencies, and the presence of two or more deficiencies was associated with poor performance on tests of general intelligence, attention, working memory, and arithmetic [1].

Iron, zinc, iodine, vitamin A, D, and B12 deficiencies are widespread in India and have well-established effects on cognitive function [38]. These nutrients are essential for various aspects of brain development and function, including myelination, neurotransmitter synthesis, and synaptic plasticity. The high prevalence of cognitive impairment observed in this review may partly reflect the burden of these nutritional deficiencies.

The relationship between nutrition and cognitive function in adolescents is particularly important given the ongoing brain development during this period. Adolescence is characterized by significant brain reorganization and continued synaptic pruning, which may be vulnerable to nutritional deficiencies [39]. Addressing nutritional deficiencies in adolescents through supplementation programs and dietary interventions could potentially improve cognitive function and reduce the prevalence of cognitive impairment.

Sleep and Cognitive Function
Sleep deprivation, which affects nearly one-quarter of Indian adolescents, has been associated with depressive symptoms, poor academic performance, and inadequate sleep hygiene [2]. The review findings suggest that sleep may be an important but understudied determinant of cognitive function in Indian adolescents. The associations between sleep and cognitive function are well-established, with sleep deprivation affecting attention, working memory, executive function, and learning [40].

The pattern of cognitive function observed in this review, with a high prevalence of mild cognitive impairment, may partly reflect the impact of sleep deprivation. Studies have shown that even modest sleep deprivation can impair cognitive performance in adolescents, and the effects may accumulate over time [41]. The finding that cognitive function improves with age may partly reflect changes in sleep patterns and sleep hygiene as adolescents mature.

Given the prevalence of sleep deprivation in Indian adolescents, interventions targeting sleep hygiene in schools may be an important strategy for improving cognitive function. Educational programs promoting healthy sleep habits, later school start times, and reduced screen time before bed could potentially improve cognitive outcomes in this population.

Mental Health and Cognitive Function
The association between mental health conditions and cognitive impairment is well-established, with conditions such as attention-deficit/hyperactivity disorder (ADHD), depression, and anxiety affecting cognitive function [3]. While the present review did not focus specifically on mental health, the high prevalence of mild cognitive impairment observed may partly reflect undiagnosed or untreated mental health conditions.

ADHD, which affects approximately 5% of children in India, is characterized by deficits in attention, working memory, and executive function [42]. Depression and anxiety can also impair cognitive function through effects on attention, processing speed, and memory [43]. The high burden of cognitive impairment in Indian adolescents may be associated with underdiagnosis and undertreatment of these conditions, particularly in government schools where mental health services may be limited.

The review findings highlight the need for integrated mental health and cognitive screening programs in schools. Early identification of cognitive difficulties and underlying mental health conditions could enable early intervention and potentially improve long-term outcomes [44]. This is particularly important in government schools, where the prevalence of cognitive impairment was higher and mental health services may be less accessible.

Assessment Tools and Methodological Considerations

The use of different cognitive assessment tools across studies (MMSE, MoCA, CPM, Digit Span) is both a strength and limitation of the literature. The most commonly used tool was the MMSE (10 studies), which is widely validated and has established cut-offs for cognitive impairment. However, the MMSE was originally developed for use in adult and elderly populations, and its applicability to adolescents has been questioned [4]. Studies examining MMSE performance in Nigerian adolescents found that abnormalities in MMSE scores should be interpreted with caution, as more than 10% of subjects may have abnormal scores, particularly on tests of orientation and attention [4].

The use of tools originally developed for adult populations raises important questions about the validity of cognitive impairment classifications in adolescents. Normative data for cognitive assessment tools in Indian adolescents are limited, and the cut-offs used to define cognitive impairment may not be appropriate for this age group [45]. The high prevalence of cognitive impairment observed in this review may partly reflect the use of adult-based cut-offs rather than adolescent-specific norms.

The Montreal Cognitive Assessment (MoCA) and Colored Progressive Matrices (CPM) have been validated in adolescent populations and may be more appropriate for this age group [46]. However, the limited number of studies using these tools in Indian adolescents restricts the analysis of tool-specific differences. Future research should focus on validating cognitive assessment tools in Indian adolescent populations and establishing age-appropriate normative data.

Clinical and Public Health Implications

The findings of this review have several important clinical and public health implications. First, the high prevalence of cognitive impairment (37.6%) among urban Indian adolescents suggests that cognitive screening should be integrated into school health programs. Early identification of cognitive difficulties could enable timely intervention, including referral to mental health professionals, educational support, and nutritional rehabilitation.

Second, the significant disparity between government and private school children highlights the need for targeted interventions in government schools. Improving the quality of education, enhancing cognitive stimulation, and addressing nutritional deficiencies in government schools could help reduce the cognitive function gap and improve outcomes for disadvantaged children. This is particularly important given the large number of children attending government schools in India.

Third, the association between socioeconomic status, parental education, and cognitive function suggests that addressing social determinants is essential for improving adolescent cognitive health. Policies targeting poverty reduction, improving maternal and child nutrition, and increasing access to quality education are likely to have beneficial effects on cognitive function. The findings support the importance of early childhood interventions and cross-sectoral approaches to improving cognitive outcomes.

Fourth, the potential role of mental health in cognitive impairment suggests that integrated mental health services in schools are needed. Screening for cognitive difficulties should be accompanied by mental health screening, and school-based mental health services should be strengthened to support children with both cognitive and mental health difficulties.

Fifth, the findings suggest that public health interventions targeting cognitive health in adolescents should be multifaceted. Nutritional interventions (iron, zinc, B12, vitamin D supplementation, improved dietary quality), educational interventions (improving school quality, cognitive stimulation programs), and mental health interventions (school-based mental health services, stress reduction programs) should be considered as part of a comprehensive approach to improving cognitive function in adolescents [47].

Strengths and Limitations

Strengths

This systematic review and meta-analysis has several important strengths. First, it is the first comprehensive synthesis of cognitive function in urban Indian adolescents, providing essential baseline data for public health planning. The review followed PRISMA-P guidelines, was registered with PROSPERO, and used systematic search methods to identify studies from multiple databases.

Second, the large number of participants (3,847 across 15 studies) provides robust estimates of cognitive function prevalence in this population. The use of meta-analysis and subgroup analyses allowed for the exploration of sources of heterogeneity and the identification of factors associated with cognitive function.

Third, the quality assessment of included studies using validated tools (JBI Checklist, NOS, STROBE) provided a systematic evaluation of methodological quality and allowed for sensitivity analyses to examine the robustness of findings.

Fourth, the subgroup analyses by school type, age, sex, socioeconomic status, and parental education provided important insights into the determinants of cognitive function in this population.

Limitations

Several limitations should be acknowledged. First, the heterogeneity across studies was substantial (I^2 62-90%), indicating considerable variability in study design, population, and methods. While subgroup analyses and meta-regression explored some sources of heterogeneity, other factors such as cultural differences, environmental factors, and sampling strategies may have contributed to the observed variability.

Second, the cross-sectional nature of all included studies limits causal inference. Associations between sociodemographic factors and cognitive function may be bidirectional or confounded by other factors. Longitudinal studies are needed to examine the temporal relationships between risk factors and cognitive function in this population.

Third, the use of different cognitive assessment tools (MMSE, MoCA, CPM, Digit Span) across studies complicates direct comparison of prevalence estimates. The MMSE, while widely used, was originally developed for adult populations and may not be optimally sensitive to cognitive changes in adolescents.

Fourth, the limited number of studies from some regions of India restricts geographic generalizability. Studies were concentrated in a few states (Andhra Pradesh, Tamil Nadu, Maharashtra, Karnataka, Delhi), and findings may not be representative of all urban areas in India.

Fifth, the inclusion of only English-language studies may have introduced language bias, although Indian databases (IndMED, MedInd) were included to minimize this.

Sixth, publication bias remains a concern, though the funnel plot and Egger's test did not suggest significant small-study effects.

Future Research Directions

The findings of this review identify several important directions for future research. First, longitudinal studies are needed to examine developmental trajectories of cognitive function in Indian adolescents. Understanding how cognitive function changes over time, the predictors of cognitive improvement or decline, and the effects of interventions on cognitive outcomes are important research priorities.

Second, future research should focus on validating cognitive assessment tools in Indian adolescents and establishing age-appropriate normative data. The use of tools validated in adult populations may overestimate the prevalence of cognitive impairment in adolescents, and the development of Indian adolescent-specific norms is needed.

Third, the mechanisms linking nutritional factors, socioeconomic status, and cognitive function should be explored further. Studies using biomarkers, neuroimaging, and detailed assessments of cognitive function could provide insights into the biological and social pathways underlying cognitive impairment in adolescents.

Fourth, research on interventions to improve cognitive function in adolescents is needed. Randomized controlled trials of nutritional interventions, educational interventions, and mental health interventions could provide evidence to guide policy and practice.

Fifth, studies comparing different cognitive assessment tools in the same population are needed to determine which tools are most appropriate for adolescent populations and which cut-offs for cognitive impairment are most clinically meaningful.

Conclusion
This systematic review and meta-analysis provides the first comprehensive estimate of cognitive functional status in urban Indian high school children. The findings reveal that 37.6% of this population exhibit some degree of cognitive impairment, with mild impairment being the most common category. Significant disparities exist between government and private school children, with government school children having a higher prevalence of cognitive impairment across all categories. Socioeconomic status, parental education, and age were also significantly associated with cognitive function.

The high prevalence of cognitive impairment in urban Indian adolescents represents a significant public health concern with important implications for educational outcomes, mental health, and long-term well-being. The findings underscore the need for comprehensive approaches to improving adolescent cognitive health, including nutritional interventions, educational improvements, school-based screening programs, and mental health services.

Future research should focus on longitudinal studies, validation of assessment tools in adolescent populations, and intervention trials to identify effective strategies for improving cognitive function in this population. The establishment of baseline prevalence data through this review provides an important foundation for monitoring adolescent cognitive health and evaluating the impact of public health interventions in India.

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