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Direct and Indirect Pathways of Stunting and Its Determinants of Cognitive Function Among Children Aged 5-9 Years in Amhara Region, Ethiopia: A Structural Equation Modelling

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Direct and Indirect Pathways of Stunting and Its Determinants of Cognitive Function Among Children Aged 5-9 Years in Amhara Region, Ethiopia: A Structural Equation Modelling

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Abstract

Background: Childhood stunting has been associated with impaired neurological development and poorer cognitive performance. However, the pathways linking stunting and contextual- and individual-level determinants to cognitive function, including the indirect pathways through stunting, remain poorly understood. This study examined the direct and indirect pathways linking stunting to cognitive function and its determinants in children aged 5-9 years in Amhara Region, Ethiopia.

Methods: A community-based cross-sectional study was conducted among 809 children aged 5–9 years from June to October 2025 using a multistage sampling technique. Data were collected using an interviewer-administered questionnaire. Cognitive function was assessed using the Raven's Coloured Progressive Matrices. Structural equation modelling (SEM) was used to assess the direct and indirect effects of stunting and its mediating pathways. Model fit was assessed using the chi-square, root mean square error of approximation (RMSEA), comparative fit index (CFI), Tucker-Lewis's index (TLI), and standardized root mean square residual (SRMR). Statistical significance was determined at $p < 0.05$ with 95% confidence intervals.

Result: Stunting (β = -2.71, 95% CI: -3.34, -2.07), living in an open-defecation-free kebele (β = 1.22, 95% CI: 0.54, 1.91), maternal occupation as government employee or agriculture work (β = 1.56, 95% CI: 1.05, 2.07), medium or high family wealth index (β = 0.79, 95% CI: 0.27, 1.34), older child age (β = 0.69, 95% CI: 0.15, 1.23), and living in households with livestock's (β = 1.56, 95% CI: 1.03, 2.12) had direct effects on cognitive function. Stunting mediated the effects of, open-defecation-free kebele, maternal stature, and maternal common mental disorder, dietary diversity and meal frequency on cognitive function.

Conclusion and recommendation: Stunting was directly associated with poorer cognitive function. Socioeconomic, nutritional, sanitation, and maternal factors showed direct or indirect associations with cognitive function through stunting. Thus, integrated, multisectoral interventions addressing stunting and its underlying nutritional, socioeconomic, sanitation, and maternal determinants are essential to promote optimal cognitive development among children aged 5-9 years.

Keywords: Cognitive function; stunting; children 5-9 years; Amhara Region; Ethiopia

Introduction

Stunting is defined as a height-for-age z-score below -2 standard deviations from the WHO Child Growth Reference median[1]. Stunting among school-age children is associated with impaired cognitive development, poorer educational outcomes, reduced adult earnings and productivity, and increased risk of chronic diseases later in life, particularly when followed by excessive weight gain [2-4]. These consequences will impact the quality of human resources in the future because cognitive disorders may accompany stunting[4]. Globally, 23.2% (150.2 million) of children under five were stunted in 2024, mainly in low- and middle-income countries[5]. This burden of stunting often persists beyond under-five, affecting children aged 5-9 years. In Ethiopia, stunting remains a major public health concern, with studies reporting a substantial burden among school-aged children [6, 7].

Middle childhood (ages 5–9) is a critical period of growth during which children undergo major advancements in cognitive function[3]. Developing strong cognitive skills like problem-solving, memory, and executive reasoning during this stage is crucial, as these abilities form the foundation for academic success, social competence, and lifelong achievement [8].o evaluate these foundational abilities in young learners, cognitive function was assessed using Raven's Coloured Progressive Matrices (RCPM)—a nonverbal measure of fluid intelligence and abstract reasoning designed to minimize language and formal schooling biases[9]. However, cognitive development during middle childhood is a dynamic process influenced by various environmental, social, and biological factors. Among these, childhood stunting represents a critical biological insult that can impair underlying neurological development and significantly hinder long-term cognitive outcomes [2-4].

In Ethiopia, evidence indicates that children who experienced early-life stunting had substantially lower cognitive achievement at age eight [8]. Another study found that stunted children performed worse on nonverbal reasoning and school-readiness assessments than their non-stunted peers [10, 11]. Moreover, cognitive function is influenced by multiple interconnected factors, including socioeconomic conditions, family environment, child stimulation, and maternal characteristics [2, 3, 8, 10]. Poor nutrition during critical periods of development may further impair brain structure and function[2, 8]. However, stunting frequently co-occurs with poverty, inadequate cognitive stimulation, and adverse living conditions, which may independently influence cognitive function

[8, 12-14]. These interrelated factors can complicate the interpretation of the association between stunting and cognitive function.

Despite the established association between stunting and cognitive function, evidence among children aged 5-9 years in Ethiopia, particularly in the study region where stunting remains prevalent, is limited. Previous studies have mainly focused on the direct association between stunting and cognitive performance, with less attention given to the pathways through which child, maternal, household, socioeconomic, and community factors may influence cognitive function directly and indirectly through stunting [10, 12, 13, 15]. Moreover, these existing studies have predominantly relied on conventional regression approaches, with limited application of advanced statistical approaches like structural equation modelling (SEM) to investigate the complex interrelationships among contextual and individual-level determinants, stunting, and cognitive function. This highlights critical gaps in both empirical evidence and analytical approaches. Furthermore, although middle childhood is an important period of continued brain and cognitive development, nutrition research has traditionally focused on children under five years of age.

Therefore, this study aimed to examine the direct and indirect pathways linking stunting and its determinants to cognitive function among children aged 5-9 years. Structural equation modelling (SEM) with path analysis was used to assess the relationships among contextual, household/family, and child-level factors, stunting, and cognitive function within a socio-ecological framework[16]. This approach enabled the identification of both direct effects and indirect pathways through stunting, thereby providing a more comprehensive understanding of the mechanisms linking multiple determinants to cognitive function. The findings may provide evidence to inform context-specific strategies for preventing stunting and promoting optimal cognitive development during middle childhood.

Method and materials

Study area and setting: The study was conducted in the North Gojjam and South Gondar administrative zones of the Amhara Region, northwestern Ethiopia. North Gojjam Zone comprises ten districts and had an estimated population of 1,561,460 in 2025, with Bahir Dar serving as its administrative centre. South Gondar Zone consists of fourteen districts and had an estimated

population of 2,702,398 in 2025, with Debre Tabor as its administrative centre. Data were collected from 29 June 2025 to 02 October 2025.

Study design and population: A community-based cross-sectional study was conducted. The source population comprised all children aged 5-9 years residing in two zonal administrations. The study population comprised all children aged 5-9 years residing in selected kebeles.

Sample size calculation: The sample size was initially calculated using the single-population-proportion formula, assuming a 76.8% prevalence of good cognitive function[12], a 95% confidence level, and a 5% margin of error (n = 274). Factoring in a design effect of 1.5 and a 10% non-response rate, the required minimum sample size was 457. However, to ensure adequate statistical power for secondary multivariable regression models and detailed subgroup comparisons across age categories within the broader doctoral project, a final target sample of 835 parent-child pairs (children aged 5–9 years) was ultimately recruited.

Sampling technique and procedure: A multistage sampling technique was employed. First, five districts (two from North Gojjam and three from South Gondar) were selected using a simple random sampling technique (SRS). Second, 16 kebeles were selected from the five selected districts using SRS. Third, eligible children were selected from the selected kebeles using a systematic sampling technique (SyRS). The sample size was allocated to each selected kebele using probability proportional to size (PPS), based on the estimated number of children aged 5-9 years obtained from the census. Before data collection, a house-to-house census was conducted with the support of health extension workers to identify all eligible children. The sampling interval (k) was calculated by dividing the total number of eligible children in the selected kebeles (12,441) by the required sample size (835), yielding ($k = 14.9 \approx 15$). Using Microsoft Excel, a random starting number between 1 and 15 was generated (household 9), after which every 15^{th} household with an eligible child was systematically selected. In households with more than one eligible child, a single child was selected using a simple random lottery method (**Figure 1**).

Figure 1: Sampling technique scheme for assessing the direct and indirect pathways of stunting and its determinants on cognitive function among children aged 5–9 years in North Gojjam and South Gondar Zones, Amhara Region, Ethiopia, 2025.

Inclusion and Exclusion Procedure: Children aged 5-9 years who had been permanent residents of the selected kebeles for at least six months were eligible. Children with mental, hearing, or

visual impairments, as well as those whose parents or caregivers did not provide consent, were excluded.

Variables: Cognitive function was the outcome variable. Independent variables were community, household/family, and child-level factors.

Data collection tool and procedure: Data were collected via an interviewer-administered semi-structured questionnaire adapted from EDHS and other relevant literature [12, 13, 17, 18] using the Kobo Toolbox. Community-level data were collected through interviews with kebele leaders or health extension workers. The Minimum Dietary Diversity Score (MDDS) was assessed based on ten food groups[19] Household food insecurity was assessed using the Food Insecurity Experience Scale Survey Module (FIES-SM). Food insecurity status was determined by summing responses to the eight items and categorizing households into two levels: food secure (scores 0–3) and food insecure (scores 4-8) [20]. Child hygiene was assessed by spot check of hands, clothing, face, and hair. Each item ((hands, clothing, face, and hair) scored 0 (dirty) or 1 (clean). Scores were summed (0-4) and categorized: 0=Very poor, 1=Poor, 2=Fair, 3=Good, 4=Excellent [21]. Household water sources were classified as improved (piped, boreholes, protected wells/springs, rainwater, and packaged/delivered water) or unimproved (rivers and unprotected springs)[22].

Children's cognitive function was assessed using the Raven's Coloured Progressive Matrices (RCPM). The test comprises 36 items divided equally into three sets (A, Ab, and B) of 12 items each. The assessment was conducted individually in a quiet room, and the test procedure was explained clearly to each child. Each child was provided with an RCPM booklet and corresponding answer sheet and was instructed to identify the missing piece that correctly completed each visual pattern from the available response options. A total raw score (ranging from 0 to 36) was calculated by summing the correct responses, with higher scores reflecting greater cognitive ability[9]. In the structural equation model, the RCPM total score was treated as a continuous observed endogenous variable.

Anthropometric measurements: child height was measured to the nearest 0.1 cm using a portable board, with children standing without shoes and with heels, buttocks, and shoulders aligned. Weight was measured to the nearest 0.1 kg using a beam balance. Children's age in months was obtained from parents. Stunting was defined as a height-for-age z-score (HAZ) below -2 standard

deviations from the WHO growth reference [1]. Height-for-age Z-scores were calculated using WHO AnthroPlus software[23]. Maternal nutritional status was assessed using body mass index (BMI, kg/m²) and classified as: chronic energy deficiency (BMI <18.5 kg/m²), normal weight (18.5–24.9 kg/m²), overweight (25.0–29.9 kg/m²), and obesity (≥30.0 kg/m²)[24]. Maternal height was also assessed, with values below 150 cm classified as short stature[18]. Child birth size was assessed based on the parent's report of whether the child was very large, larger than average, average, smaller than average, or very small at birth, as per the EDHS questionnaire [17].

The wealth index was constructed using Principal Component Analysis (PCA) based on household assets (e.g., television, bicycle), housing materials, and water/sanitation facilities. Each item was scored 0 (absent) or 1 (present). Household scores were assigned to members, ranked, and divided into quintiles (20% each). Rural and urban households were assessed separately and then combined[25]. Women's decision-making autonomy was assessed using three items: (1) her own health care, (2) major household purchases, and (3) visits to family/relatives. For each, she received a score of 1 if she decided alone or jointly, and 0 otherwise. An aggregate score was created; women were classified as autonomous if they participated in decision-making across all three domains, and non-autonomous if not[25].

Maternal/caregiver mental health assessment was conducted using the World Health Organisation (WHO) Self-Reporting Questionnaire (SRQ-20). This 20-item tool evaluates depressive, anxiety, panic, and somatic symptoms experienced in the past four weeks, with each item scored as 1 for presence or 0 for absence of symptoms. The total score ranges from 0 to 20, with scores above 8 indicating mental distress[26-28].

Operational Definitions: Social support service was considered available if the kebele had the Productive Safety Net Programme (PSNP) or non-governmental organizations (NGOs) working on food security or disaster response. A kebele was open defecation-free (ODF) if it had a verified health extension worker certification of less than two years.

Quality improvement: Data collectors and supervisors received three days of training on the study objectives, the tools, interviewing techniques, and anthropometric measurements. The questionnaire was translated into Amharic (local language) and pre-tested on 5% of the sample. Necessary revisions were made based on the pre-test findings before the actual data collection. Anthropometric training covered proper positioning, equipment calibration, and measurement

standardisation. Each child's height and weight were measured twice, and the average of the two measurements was recorded. The weighing scale was calibrated after every five measurements using a standard 5-kg weight. Cognitive function was assessed by trained psychologists using standardised methods and instruments. Uniform instructions were provided to all participants to minimise variability during the assessment. Supervisors reviewed completed questionnaires daily to provide immediate feedback, while the overall data collection process was supervised by the principal investigator. Finally, the data were cleaned, coded, and exported to Stata version 17 for analysis.

Data processing and analysis: The data were analyzed using STATA version 17 statistical software. Height-for-age Z-scores (HAZ) were calculated with WHO AnthroPlus version 1.0.1 [23]. Descriptive statistics were used to summarize the characteristics of the study participants. The mean cognitive function scores of stunted and non-stunted children were compared using an independent two-sample t-test.

Structural equation modelling (SEM) with path analysis was used to assess the direct and indirect relationships between contextual and individual-level factors and children's cognitive function, with stunting specified as a potential mediator. Guided by the socioecological framework, the model specified a hierarchical pathway in which contextual factors influenced household/family factors, which subsequently influenced individual-level factors and cognitive function, with stunting potentially mediating these relationships. Overall model fit was assessed using the chi-square (χ^2) test, Tucker–Lewis index (TLI), comparative fit index (CFI), root mean square error of approximation (RMSEA), and standardized root mean square residual (SRMR). TLI and CFI values ≥ 0.90, RMSEA <0.08, and SRMR <0.08 were considered indicative of acceptable model fit [29]. Mediation analysis was conducted to estimate the indirect effects of predictors on cognitive function through stunting. Direct, indirect, and total effects were estimated directly from the fitted structural equation model. Statistical significance was assessed using 95% confidence intervals and a p-value <0.05.

Ethical considerations: Ethical approval was obtained from the Institutional Review Board of Bahir Dar University, College of Medicine and Health Sciences (Protocol No. 4026/2025). Permission to conduct the study was also obtained from the Amhara Public Health Institute. Informed consent was obtained from the parents or legal guardians of all child participants

involved in the study. All methods were performed in accordance with the Declaration of Helsinki[30].

Result

Child-level characteristics

A total of 809 children aged 5-9 years were included in the final analysis, yielding a 96.9% response rate. Of these, 55.75% were male, and 69.22% were aged 5-7 years. Most children were singletons (97.53%) and had a medium or large birth size (90.98%). Regarding dietary practices, 71.45% had inadequate minimum dietary diversity, while 79.11% consumed at least three meals per day. Approximately one in ten children (10.26%) was classified as thin, and 38.32% were stunted (**Table 1**).

Table 1:Child-related characteristics among children aged 5-9 years in North Gojjam and South Gondar Zones, Amhara Region, northwest Ethiopia, 2025 (n = 809).

Household/family level characteristics

Most households had a medium and above family size (86.5%), and 90.4% used an improved water source. Only 23.1% of mothers/caregivers reported having decision-making autonomy. The majority (97.2%) of households were classified as food secure. The majority of respondents were married (94.8%), and 54.3% were housewives. Among fathers, 71.6% were farmers, and 37.9% were unable to read and write. Common mental disorders were identified in 23.5% of mothers (**Table 2).**

Table 2: Household/family-related characteristics among children aged 5-9 years in the North Gojjam and South Gondar zones, Amhara Region, northwest Ethiopia, 2025 (n = 809).

Community-level factors

The information obtained at the kebele level was linked to individual children based on their kebele of residence. More than half of the children (56.0%) lived in rural areas. Most kebeles were located within 10 km of the nearest health facility (95.4%). Social support systems were reported in only 10.4% of kebeles, while open defecation was practiced in 80.2% (**Table 3**).

Table 3: Community household/family-related characteristics among children aged 5-9 years in the North Gojjam and South Gondar zones, Amhara Region, northwest Ethiopia, 2025 (n = 809).

Distribution of cognitive function among children 5-9 years

Cognitive function was assessed on a continuous scale, meaning higher scores represented better cognitive performance. The kernel density plot showed that the overall Raven's Coloured Progressive Matrices (RCPM) cognitive function scores were approximately normally distributed, with a mean (SD) of 26.90 (±4.13). Scores were higher among non-stunted than stunted children, with a slightly right-skewed distribution among non-stunted children and a left-shifted distribution among stunted children. Non-stunted children achieved significantly higher mean cognitive scores than stunted children (28.16 [95% CI: 27.79, 28.53] versus 24.88 [95% CI: 24.55, 25.26]; mean difference = 3.29, 95% CI: 2.75 to 3.83, $p < 0.001$) (**Figure 2**).

Figure 2: Kernel density distribution of Raven's Coloured Progressive Matrices cognitive scores by stunting status among children aged 5–9 years in Gojjam and South Gondar Zones, Amhara Region, northwestern Ethiopia, 2025 (n=809*)*

Structural equation model fit indices

The model showed an excellent fit to the observed RCPM data. The chi-square test was nonsignificant ($\chi^2 = 23{,}086$, $p = 0.146$), indicating significant model fit. The RMSEA was 0.021, with a CFI of 0.991 and TLI of 0.97.5, further supporting the model excellent fit (**Table 4**).

Table 4: Model fit indices for the structural equation model.

Direct, indirect and total effects of factors associated with cognitive function among children aged 5-9 years

Stunting was negatively associated with children's cognitive function (β = -2.71, 95% CI: -3.34, -2.07), while higher cognitive function was observed among children living in ODF kebeles (β = 1.22, 95% CI: 0.54, 1.90), children of government-employed or agricultural mothers (β = 1.56, 95% CI: 1.05, 2.07), children from middle- or high-wealth households (β = 0.79, 95% CI: 0.27, 1.31), children aged 8-9 years (β = 0.69, 95% CI: 0.15, 1.23), and children living in households with animals (β = 1.56, 95% CI: 1.00, 2.12) (**Table 5**;**Figure 3**).

Table 5: Direct, indirect, and total effects of factors associated with cognitive function among children aged 5–9 years in North Gojjam and South Gondar Zones, Amhara Region, Northwest Ethiopia, 2025 (n=809)

Figure 3: Path analysis of direct and indirect factors associated with cognitive function of children aged 5-9 years in North Gojjam and South Gondar Zone, Amhara Region, northwest Ethiopia, 2025 (n=809)

Significant indirect associations with cognitive function were observed through stunting-related pathways. Adequate dietary diversity score (DDS) (β = 0.55, 95% CI: 0.34, 0.76) and consuming at least three meals per day (β = 0.36, 95% CI: 0.16, 0.56) were positively associated with cognitive function through stunting. Living in an ODF kebele also showed an indirect association with cognitive function through pathways involving stunting, maternal common mental disorders (CMDs), DDS, and meal frequency (β = 0.57, 95% CI: 0.32, 0.83). Maternal CMDs were associated with cognitive function through indirect pathways involving stunting, DDS, and meal frequency (β = 0.96, 95% CI: 0.67, 1.25) (**Table 5**; **Figure 3**).

Table 5: Direct, indirect, and total effects of factors associated with cognitive function among children aged 5–9 years in North Gojjam and South Gondar Zones, Amhara Region, Northwest Ethiopia, 2025 (n=809)

Figure 3: Path analysis of direct and indirect factors associated with cognitive function of children aged 5-9 years in North Gojjam and South Gondar Zone, Amhara Region, northwest Ethiopia, 2025 (n=809)

The decomposition of effects showed distinct patterns across determinants. The associations of stunting, maternal occupation, household wealth, and living with animals with cognitive function were entirely direct, whereas the effects of maternal CMDs and maternal height were entirely indirect. For residence in an ODF kebele, both direct and indirect pathways contributed to the total association, accounting for 68% and 32% of the total effect, respectively (**Table 5**).

Table 5: Direct, indirect, and total effects of factors associated with cognitive function among children aged 5–9 years in North Gojjam and South Gondar Zones, Amhara Region, Northwest Ethiopia, 2025 (n=809)

Discussion

The present study examined the direct and indirect pathways linking stunting and its determinants to cognitive function among children aged 5-9 years in the North Gojjam and South Gondar zones of the Amhara Region, Ethiopia. Children achieved a mean RCPM that was higher than scores reported in previous studies from southern and southeastern Ethiopia [12, 13]. Differences in study populations and settings may partly explain this variation. Unlike earlier school-based studies, the present community-based study captured children with diverse educational, socioeconomic, and environmental backgrounds, potentially providing a broader representation of children's cognitive performance in the study area.

The findings in our study indicate that children's cognitive function is shaped by an interplay of nutritional, socioeconomic, environmental, and maternal factors. Stunting emerged as the strongest adverse factor and was directly associated with lower cognitive function. This finding is consistent with studies conducted in Ethiopia, Nigeria, and Cambodia [12, 13, 31-33]. Stunting reflects chronic nutritional deprivation during critical periods of growth and development and is associated with structural and functional changes in the developing brain, including impaired myelination, reduced synaptic connectivity, and altered neurodevelopmental processes. Beyond biological effects, stunting may also influence children's ability to engage with their learning environment and can be accompanied by reduced stimulation and developmental opportunities, which together may contribute to poorer cognitive outcomes [33, 34].

Household socioeconomic circumstances were also important determinants of cognitive function. Children whose mothers were engaged in government employment or agricultural occupations demonstrated better cognitive performance than those whose mothers were not employed. Similar associations have been reported elsewhere [35, 36]. Maternal employment may improve access to economic resources that support child nutrition, health care, education, and learning materials. In agrarian settings, engagement in productive agriculture may also strengthen household food security and dietary adequacy, creating conditions that support children's cognitive development [35, 37]. Similarly, children from better-off households achieved higher cognitive scores,

reinforcing evidence that economic resources facilitate access to health services, improved living conditions, educational opportunities, and cognitively stimulating environments [13, 35, 37].

The positive association between residence in ODF kebeles and cognitive function highlights the importance of community-level environmental conditions. Similar findings have been reported from Indonesia [14]. Improved sanitation may reduce children's exposure to enteric pathogens, recurrent infections, and environmental enteric dysfunction, thereby supporting both physical growth and neurological development. In addition, ODF environments may provide safer and healthier conditions that promote children's participation in play, learning, and social interaction, all of which are important for cognitive development [14, 38].

Age-related differences in cognitive performance observed in this study are consistent with established developmental trajectories. Older children achieved higher cognitive scores than younger children, likely reflecting ongoing brain maturation as well as greater cumulative exposure to learning opportunities, schooling, and cognitively stimulating experiences [9, 39, 40]. The development of executive function, reasoning ability, and visuospatial processing continues throughout middle childhood, contributing to progressive improvements in cognitive test performance with increasing age.

An unexpected finding was the positive association between living with animals and cognitive function. While some studies have documented developmental benefits associated with children's interactions with domestic animals, including opportunities for exploration, observation, responsibility, and social-emotional development[41-43]. This finding contrasts with literature from low-resource settings linking close human-animal cohabitation to increased exposure to environmental contamination and zoonotic infections [44, 45]. Livestock ownership may also serve as a marker of household assets, economic stability, and access to animal-source foods, which could partially explain the observed positive association [46]. Given the contrasting evidence, this relationship warrants further investigation to better understand the circumstances under which animal ownership benefits or compromises child cogtive developmet.

The pathway analysis further demonstrated that several determinants influenced cognitive function indirectly through stunting. Adequate dietary diversity and higher meal frequency were positively associated with cognitive function through their effects on reducing stunting. These findings support evidence that adequate dietary intake provides essential nutrients required for healthy

linear growth and brain development [47-49]. Similarly, residence in ODF kebeles contributed indirectly to better cognitive outcomes through pathways involving reduced stunting and improved maternal mental health, illustrating the interconnected nature of environmental, nutritional, and psychosocial influences on child development [38, 45, 50, 51].

Maternal factors also played an important role in shaping children's cognitive function through indirect mechanisms. Maternal common mental disorders influenced cognitive outcomes through pathways involving stunting, dietary diversity, and meal frequency, highlighting the importance of maternal wellbeing for child development. Poor maternal mental health may affect caregiving quality, feeding practices, emotional responsiveness, and health-seeking behaviours, thereby influencing both nutritional status and cognitive development. Similarly, maternal height exerted an indirect influence through stunting and maternal mental health pathways. Maternal stature reflects cumulative nutritional and socioeconomic experiences across generations and has long been recognized as an important predictor of child growth and development [52-54].Together, these findings underscore the intergenerational nature of child cognitive development and the importance of addressing maternal, nutritional, environmental, and socioeconomic determinants simultaneously.

Strengths and limitation of the study

The strengths of this study include the use of structural equation modelling to examine the direct and indirect pathways linking nutritional, socioeconomic, environmental, and maternal factors to children's cognitive function. The use of Raven’s Coloured Progressive Matrices (RCPM), a nonverbal assessment of cognitive ability, was also appropriate for children with varying levels of formal schooling. However, the cross-sectional design limits causal inference and does not establish the temporal sequence of the observed associations. Furthermore, single-point measurements of stunting and cognitive function could not capture changes in children's nutritional status and cognitive development over time. Self-reported variables may also be subject to recall and reporting biases. Genetic factors, which were not measured in this study, may also have confounded the observed associations with cognitive function.

Conclusion and recommendation

This study demonstrates that cognitive function among children aged 5-9 years in North Gojjam and South Gondar Zone, Amhara Region, northwest Ethiopia, is shaped by a complex web of direct and indirect socio-ecological determinants. Structural equation modelling showed that stunting, cohabitation with animals, open-defecation practices, maternal employment, household wealth, and child age had significant direct effects on cognitive function. In addition, dietary diversity, meal frequency, community sanitation, maternal height, and maternal CMD had significant indirect effects on cognitive function through stunting. Integrated interventions should prioritize stunting prevention, improved dietary diversity and meal frequency, community sanitation, maternal mental health support, and measures to address household socioeconomic disadvantages. Longitudinal studies are needed to clarify the temporal relationships among stunting, its determinants, and children's cognitive function.

Declaration

Ethics approval and consent to participate: Ethical approval was obtained from the Ethical Review Board of Bahir Dar University, College of Medicine and Health Sciences (Protocol No. 4026/2025). Permission to conduct the study was also obtained from the Amhara Public Health Institute. Informed consent was obtained from the parents or legal guardians of all child participants involved in the study. All methods were performed in accordance with the Declaration of Helsinki.

Consent for publication: Not applicable because the manuscript does not include, images, or videos relating to individual participants

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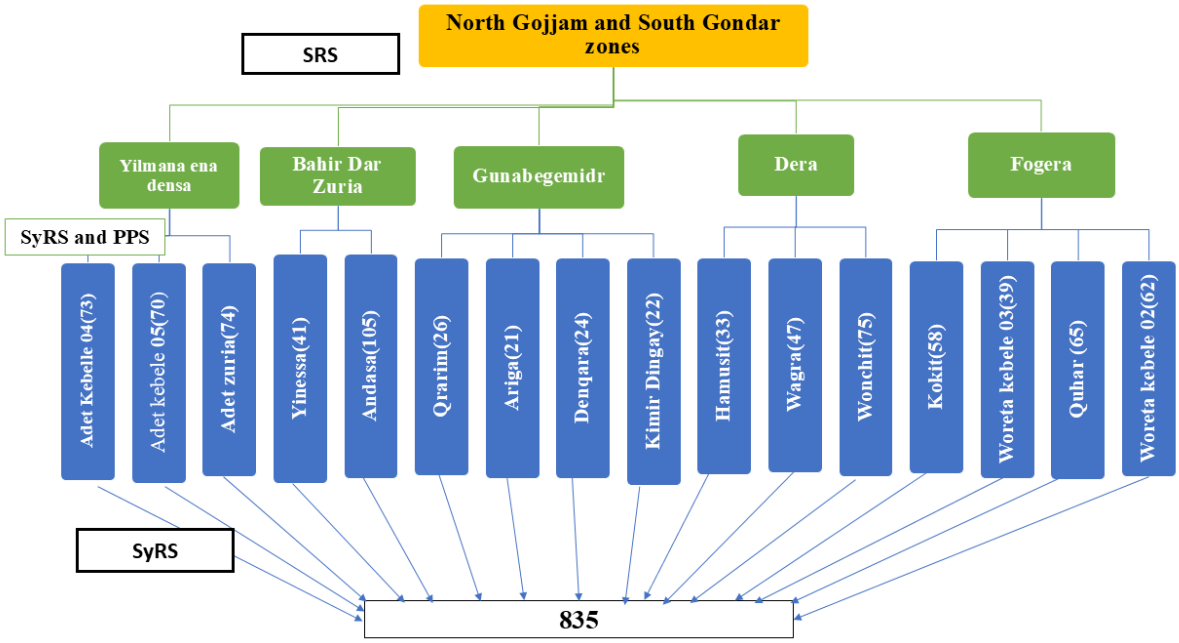
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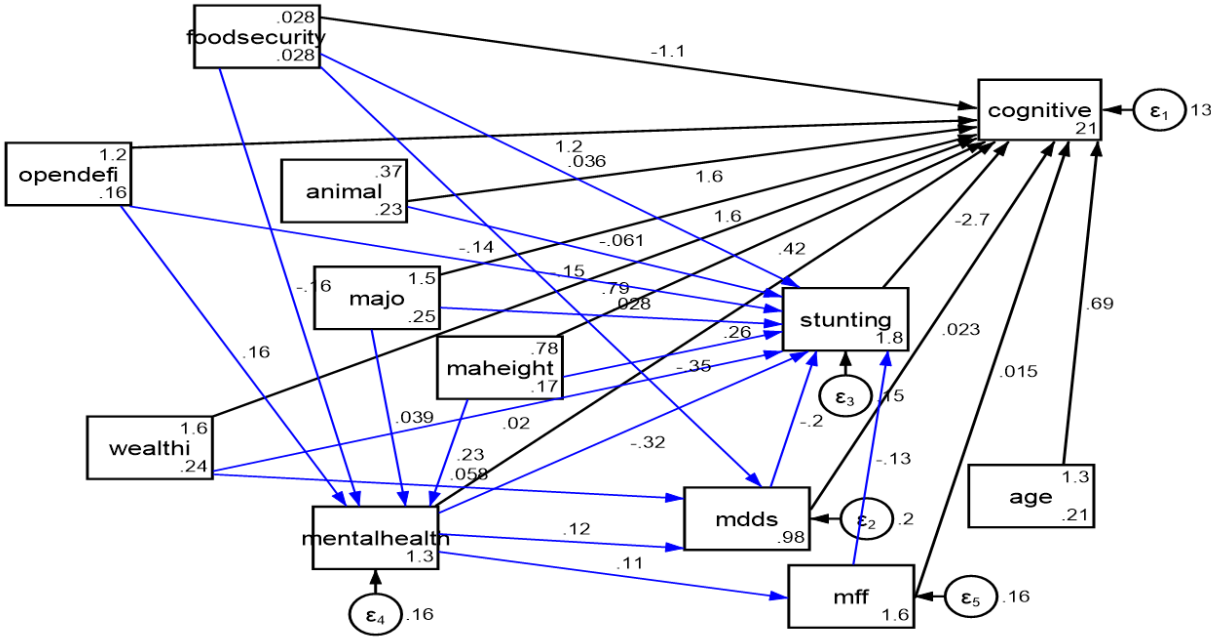
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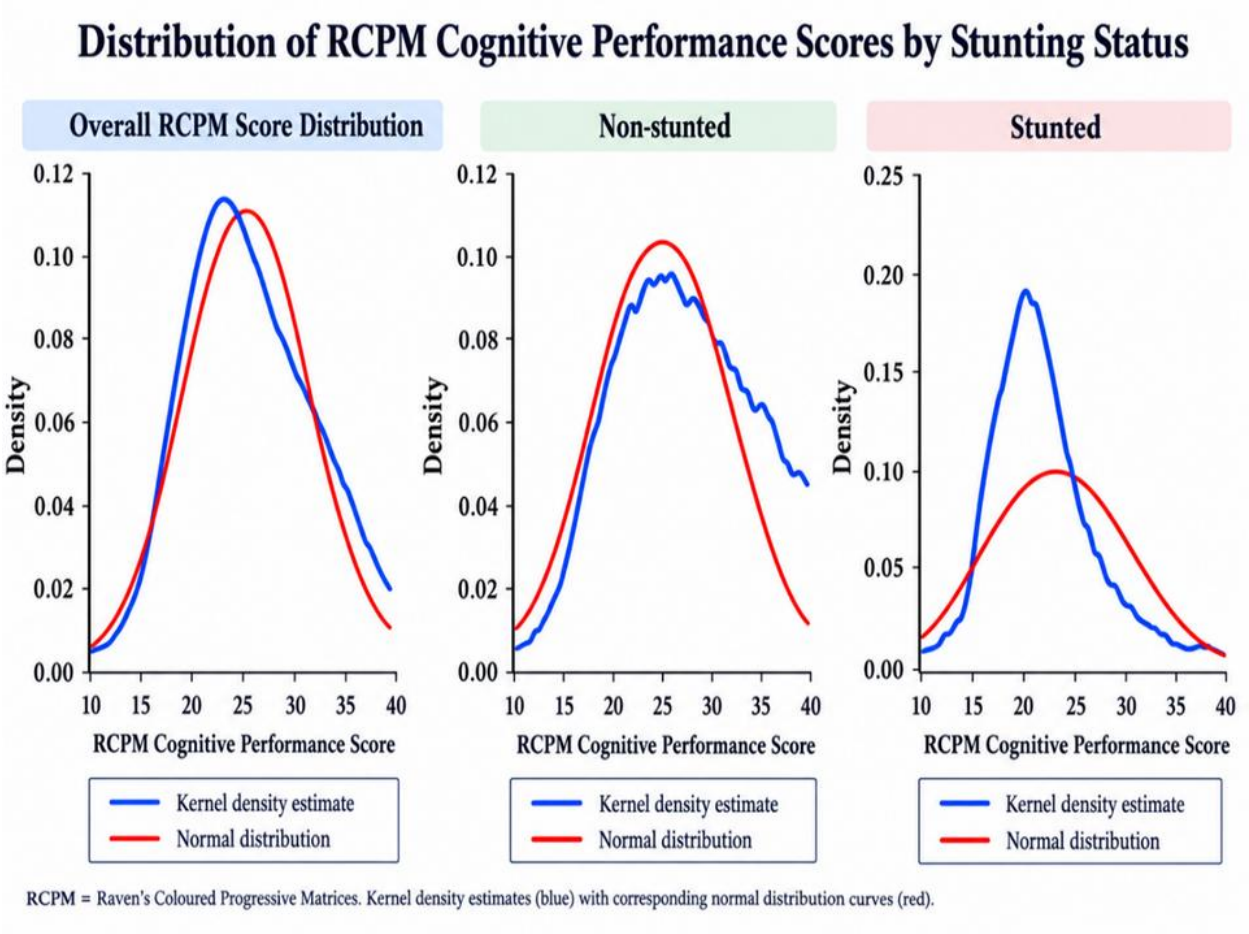
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SRS
North Gojjam and South Gondar zones
Yilmana ena densa
Bahir Dar Zuria
Gunabegemidr
Dera
Fogera
SyRS and PPS
Adet Kebelle 04(73)
Adet kebele 05(70)
Adet zuria(74)
Yinessa(41)
Andasa(105)
Qrarim(26)
Ariga(21)
Denqara(24)
Kimir Dingay(22)
Hamusit(33)
Wagra(47)
Wonchit(75)
Kokit(58)
Woreta kebele 03(39)
Quhar (65)
Woreta kebele 02(62)
SyRS
835



Key: *opendefi, open-defecation-free kebele; foodsecurity, household food security; animal, living in the same room with animals;wealthi,wealth index;mentalhealth, maternal common mental disorder; mff, meal frequency per day; maheight, maternal height; majo, maternal occupation; mdds, minimum dietary diversity score. Black arrows indicate direct associations, whereas blue arrows indicate indirect associations*


Distribution of RCPM Cognitive Performance Scores by Stunting Status
Overall RCPM Score Distribution
Non-stunted
Stunted
Density
RCPM Cognitive Performance Score
Kernel density estimate
Normal distribution
RCPM = Raven's Coloured Progressive Matrices. Kernel density estimates (blue) with corresponding normal distribution curves (red).

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