

Ecology of Food and Nutrition

ISSN: 0367-0244 (Print) 1543-5237 (Online) Journal homepage: www.tandfonline.com/journals/gefn20

Association of Chronic Malnutrition, and Not Anemia, with Cognitive Development in Ethiopian Schoolchildren: A Cross-Sectional Study

Befikadu Tariku Gutema, Muluken Bekele Sorrie, Sifray Batire, Tadiwos Hailu Zewdie, Bruno Levecke, Amina Abubakar, Stefaan De Henauw & Souheila Abbeddou

To cite this article: Befikadu Tariku Gutema, Muluken Bekele Sorrie, Sifray Batire, Tadiwos Hailu Zewdie, Bruno Levecke, Amina Abubakar, Stefaan De Henauw & Souheila Abbeddou (2024) Association of Chronic Malnutrition, and Not Anemia, with Cognitive Development in Ethiopian Schoolchildren: A Cross-Sectional Study, Ecology of Food and Nutrition, 63:6, 647-668, DOI: 10.1080/03670244.2024.2426104

To link to this article: https://doi.org/10.1080/03670244.2024.2426104

Published online: 08 Nov 2024.

Submit your article to this journal

Article views: 214

View related articles

View Crossmark data

Full Terms & Conditions of access and use can be found at
https://www.tandfonline.com/action/journalInformation?journalCode=gefn20

ECOLOGY OF FOOD AND NUTRITION
2024, VOL. 63, NO. 6, 647–668
https://doi.org/10.1080/03670244.2024.2426104

Routledge
Taylor & Francis Group

Check for updates

Association of Chronic Malnutrition, and Not Anemia, with Cognitive Development in Ethiopian Schoolchildren: A Cross-Sectional Study

Befikadu Tariku Gutema[a,b], Muluken Bekele Sorrie[a], Sifray Batire[c], Tadiwos Hailu Zewdie[d], Bruno Levecke[e], Amina Abubakar[f], Stefaan De Henauw[b], and Souheila Abbeddou[b]

[a]School of Public Health, College of Medicine and Health Sciences, Arba Minch University, Arba Minch, Ethiopia; [b]Department of Public Health and Primary Care, Faculty of Medicine and Health Sciences, Ghent University, Ghent, Belgium; [c]Department of Medical laboratory, College of Medicine and Health Sciences, Arba Minch University, Arba Minch, Ethiopia; [d]School of Medicine, College of Medicine and Health Sciences, Arba Minch University, Arba Minch, Ethiopia; [e]Department of Translational Physiology, Infectiology and Public Health, Faculty of Veterinary Medicine, Ghent University, Merelbeke, Belgium; [f]Kenya Medical Research Institute (KMRI)–Wellcome Trust Research Programme, Centre for Geographic Medicine Research (Coast), Kenya Medical Research Institute, Kilifi, Kenya

ABSTRACT

This study assesses the associations between nutritional status and cognitive development of schoolchildren. A unit increase in height-for-age Z-score was associated with 0.12 SD, 0.08 SD and 0.12 SD increase in standardized digit span, Raven's colored progressive metrics, and performance index of visual search task, respectively. A unit increase in body-mass-index-for-age Z-score was associated with 0.11 SD increase in standardized digit span. Hemoglobin concentration was not associated with any of the cognitive outcomes. Chronic malnutrition was associated with cognitive development in schoolchildren while thinness and hemoglobin concentrations were associated with selected or no cognitive outcomes, respectively.

KEYWORDS

Cognition; nutritional status; Schoolchildren

Introduction

The development of the brain starts in the womb, accelerates during pregnancy and early childhood, and continues to mature during school age (Huitt and Hummel 2003; Shonkoff, Phillips, National Research Council, and Institute of Medicine 2000). In low-income countries, early life malnutrition and repeated infections impair the cognitive development of the children, prevent them from attaining their developmental potential and can lead to long-term detrimental effects on their schooling and productivity. It is estimated that nutritional and health insults in early life contribute to the loss of more than 20% income in adulthood (Berkman et al. 2002; Grantham-McGregor et al. 2007; Weiss et al. 2010). Nearly 200 million under five

CONTACT Befikadu Tariku Gutema befikadutariku.gutema@ugent.be; befikadutariku2@gmail.com School of Public Health, College of Medicine and Health Sciences, Arba Minch University, Arba Minch, Ethiopia

© 2024 Taylor & Francis Group, LLC

children do not fulfill their developmental potential (Grantham-McGregor et al. 2007) and about 60 million out of 260 million school-age children 6–17 years old were out of school in 2018 (UNESCO Institute for Statistics 2019a, 2019b).

Child cognitive development is complex and has multiple influencing factors. Malnutrition leads to alteration in structure and function of brain tissues in children (Barrett, Radke-Yarrow, and Klein 1982; Holden 2007; Udani 1992). Research on the relationship between anemia and cognition in school age children is limited but most of the findings show that cognitive development outcomes including intelligence quotient (IQ), language, and educational performance are associated with hemoglobin concentrations (Al-Mekhlafi et al. 2011; Arcanjo, Arcanjo, and Santos 2016; Halterman et al. 2001; Sungthong, Mo-Suwan, and Chongsuvivatwong 2002). School-age children who have low hemoglobin concentrations (Best et al. 2010; Hamid et al. 2011; Perignon et al. 2014), or were stunted (height-for-age Z-score < −2 standard deviations (SD)) performed poorer in cognitive tests including the National Institute of Mental Health and Neurosciences (NIMHANS) neuropsychological battery for children, Raven's colored progressive matrices (RCPM), block design, picture completion, and grade scores for language, mathematics and sciences (Kar, Rao, and Chandramouli 2008; Perignon et al. 2014). Iron supplementation improves cognition among school age children with anemia (Falkingham et al. 2010; Low et al. 2013). Reports have shown that stunting can occur during school age and is associated with cognitive development (Crookston et al. 2014; Georgiadis 2017). Additionally, school age might serve as critical period for recovery from earlier nutritional insults such as stunting (Lundeen et al. 2014).

Anemia is a serious public health problem in schoolchildren (WHO 2015). Systematic reviews and meta-analyses of studies that were conducted in Ethiopia found that 23% of school age children were anemic (Tezera et al. 2018). Similarly around 23% and 18% of school age children in Ethiopia were stunted and wasted (weight-for-height Z-score < −2 SD), respectively (Assemie et al. 2020; Hailegebriel 2020). In 2017, a community-based cross-sectional study in the area of Arba Minch Health and Demographic Health Site (HDSS) indicated that the prevalence of anemia, stunting and wasting among schoolchildren were 37.3%, 41.9% and 8.0%, respectively (Tariku et al. 2018, 2019). These figures show that the nutritional insults that affect the development of the child continue during school-age in Ethiopia. This cross-sectional study aims to assess the association between hemoglobin concentration, height-for-age (HAZ) and body-mass-index-for-age Z-scores (BMIAZ) as independent variables and cognitive development as the dependent variable among schoolchildren at Arba Minch HDSS in Southern Ethiopia.

Materials and methods

Study area and population

This cross-sectional study was conducted in Arba Minch HDSS and provided baseline data for a larger intervention study entitled "The effects of intermittent iron and vitamin A supplementation on nutritional status and development of schoolchildren in Arba Minch HDSS, Southern Ethiopia." Arba Minch HDSS covers tow districts (Arba Minch Zuria and Gach Baba) in the Gamo Zone, Southern Ethiopia. Arba Minch, the administrative town of Gamo Zone, is located at 505 km south from the capital Addis Ababa. In these districts, there are 31 kebeles (the smallest administrative unit in Ethiopia) and 71 public primary schools. Arba Minch HDSS covers 9 kebeles and 22 public primary schools located in lowland (below 1800 m altitude), midland (1800–2400 m), and highland (above 2400 m). A total number of 11,432 pupils (45.4% female) attended the HDSS schools during the academic year 2018/2019.

Study design and sampling technique

An institutional-based cross-sectional study was conducted in Arba Minch HDSS. Baseline data was collected for the intervention study evaluating the effects of intermittent iron and vitamin A supplementation on nutritional status and development of schoolchildren in the Arba Minch HDSS. The intervention was a 2×2 factorial design. Sample size was calculated based on an effect size of 0.30 SD in the hemoglobin concentration ($N = 504$) (Gutema et al. 2024). Baseline data collection was done in two surveys due to an interruption in our intervention caused by the restrictive measures implanted during COVID-19. The national measures in response to the COVID-19 pandemic included closing the schools in March 2020. Consequently, the intervention was interrupted and has been reconducted again during the following academic year. The first baseline data were collected during October 2019, and the second between November and December 2020. The study involved children 7–10 years of age from nine public primary schools in Arba Minch HDSS. The second-survey data were dropped if the child participated in the two consecutive surveys.

One school from each kebele in the HDSS Arba Minch was included in this study. For harmonizing the selection of the schools, the center of the kebele was identified (geographically) and the nearest school to the center of each kebele was included in the study. Immediately after the end of the school registration (September), rosters of grade 1–4 were collected from each school. These rosters include both the name and the age of the enrolled pupil. Children who were below 7 and above 10 years of age

were excluded from the roster. Subsequently, sequential number was given for each school. Using Excel, random numbers were selected and the corresponding children were included if they met all the inclusion criteria.

Data collection and measures

Parents of the children who were randomly selected from the school roster were contacted. Children whose parents consented were invited, one at a time, to a classroom designated for the purpose of the study by the school, screened for eligibility and were given a unique ID. In general, five distinct study teams collected data both at the school and at the homes of the children. The first team of study investigators gave a brief explanation to the child who also was asked for a simplified consent. Consenting pupils underwent a set of assessments including physical examination and anthropometric measurements (weight and height). The pupils provided information on their food intake, hygiene and recent history of illness. The child was then sent to the second team to provide a venous blood and stool sample. Thereafter, the child was sent to the third team for the assessment of cognitive development indicators. At the community, two teams made home visits within two weeks after the baseline assessment to collect data from one of the parents on demographics and socio-economics of the child, their parents and their households. Additionally, data on household food security, food intake and morbidity were collected. The second team administered the strengths and difficulties questionnaire (SDQ) and the home observation for measurement of the environment (HOME) inventory. In the following paragraphs we will provide more details on how the different parameters are measured.

Cognitive development

Table 1 summarizes the cognitive development domains assessed to explore the association between nutritional status and cognitive development in the schoolchildren of this study. Cognitive development of the children was assessed using digit span (forward and backward), visual search using cancellation task, and RCPM tests. Digit span test assesses the working memory (Richardson 2007; Stebbins 2007; Weiss et al. 2010). The assessor reads the digits out at the rate of one per second. The child repeats the numbers in the same order (forward) and in the reverse order (backward). There is no time limit for individuals to respond. Testing ceases when the child fails to accurately report three trials of the same sequence length or when the maximal list length is reached (nine digits for forward and eight digits for backward). Errors as well as the maximal length the child recall are recorded. Visual search using cancellation task is used to assess the attention of the child with their ability of selectivity and motor coordination (Deng et al. 2019; Pradhan and Nagendra 2008). For that, the assessor

Table 1. Summary of the cognitive development domains assessed to explore the association between nutritional status and cognitive development in schoolchildren.

Test	Description
Digit span (forward and backward)	• Working memory refers to the ability to retain information temporarily and use it in the execution of cognitive tasks. • The digit span test is designed to evaluate an individual's working memory. In the forward digit span, the child repeats a sequence of numbers as spoken by the examiner, while in the backward digit span, the child repeats the numbers in the reverse order. Digit span forward primarily taps short-term auditory memory while digits span backward measures the child's ability to manipulate verbal information within temporary storage.
Raven's colored progressive matrices (RCPM)	• Fluid and crystallized intelligence are components of general intelligence. Crystallized intelligence pertains to one's ability to understand language and apply skills, knowledge, and experience. Fluid intelligence involves the ability to deal with new problems through creativity and flexibility. • RCPM instrument test is used to assess abstract reasoning, which aligns with fluid intelligence. The tool is recognized for its culture-fairness or neutrality, requiring minimal verbal instruction. Research supports its reliability across various ethnic groups.
Visual search using cancellation task	• The attention and concentration domain include the ability to maintain focus on a specific stimulus over time (sustained attention) and to do so amidst competing stimuli (selective attention). • The cancellation task, a form of visual search, involves a pattern of symbols interspersed with target symbols. Participants are instructed to cross out (cancel) all the target symbols. The task includes visual search to identify the targets and then either cancel or circle them.

presented to the child pictures (sketch) of men and women, some complete and others with missing parts. The child is instructed to mark those women with full "body" parts. The examiner records the time taken to complete the search, the number of commissions and omissions. Fluid intelligence is the ability to deal with new problems with creativity and flexibility (Cattell 1963; Ellis, Hoskin, and Ratnasingam 2018). The RCPM test is used to assess mental ability associated with abstract reasoning, commonly named fluid intelligence (Bilker et al. 2012). The test consists of 3 parts (A, AB and B), 12 problems each. The questions are formed in a geometric pattern with a section missing. Based on the pattern, the child shall choose the missing cell from the alternatives. A score is given to each set and total score is calculated from all the sections with a minimum score of zero and a maximum of 36.

Weight and height

Weight and height were measured in duplicate in all children at baseline (Cogill 2003). Height was measured to the nearest 0.1 cm using a child/adult portable height-length measuring board (ShorrBoard® –WEIGH AND MEASURE, LLC, MD), and weight was assessed using digital floor scale (Model 869, Seca, Hamburg, Germany) with 100 g precision. If height measurements differed by >0.5 cm or weight measurements differed by >0.1 kg, a third measurement was completed and the average of the two closest values was used in the analysis.

Recent illness history and hygienic practices

Recent illness history and hygienic practices of the children were collected directly from the child using an adapted questionnaire. In addition, physical examination of (i) the child eye for vitamin A deficiency, trachoma and paleness, (ii) thyroid gland, and (iii) skin for assessing scabies were carried out by trained public health personnel. Hygienic practices of the child were defined based on observation of the child's hand (cleanness and trimmed nails).

Hemoglobin and parasitic infections

A venous blood sample was collected for onsite analyses of hemoglobin concentration (Hemocue HB 301, HemoCue® AB, Ängelholm, Sweden) and a rapid diagnostic test (RDT) for malaria parasites based on Histidine-rich protein II (SD BIOLINE Malaria Ag P.F/Pan, Standard Diagnostics, INC., Kyonggi-do, Korea). Stool samples were collected at the schools, stored at 8°C in the field until shipping to the laboratory of the College of Medicine and Health Sciences, Arba Minch University (AMU). The stools were prepared and analyzed immediately upon reception in duplicate using the Kato-Katz method (WHO 2019) to detect *Ascaris lumbricoides*, *Trichuris trichiura*, Hookworms (*Necator americanus* or *Ancylostoma duodenale*), and *Schistosomiasis mansoni*, *Enterobius vermicularis*, *Hymenolepis nana* and *Taenia saginata*.

Strengths and difficulties questionnaire and HOME scale

A 25 item SDQ was used to assess child's emotions, concentration, and their behavior with other children and adults with three possibilities for each item (not true, somewhat true, or certainly true). The response is marked as 0 for "*not true*," 1 for "*somewhat true*" and 2 for "*certainly true*" for negative questions, and 2 for "*not true*," 1 for "*somewhat true*" and 0 for "*certainly true*" for affirmative questions (Goodman 1997). Child's stimulation in their home environment is an important modifying factor in the child cognitive development. HOME scale was used for this assessment including reported and observed parents encouragement to the child, praise the child gets, support provided by the parents, sphere of friends and relatives, and environment of work and play. Specifically, it included the praise the child gets, parental encouragement and support to read, participation of the child in conversations, their keeping the hygiene of their environment and keeping properly their items, availability and proper use of television, visiting places and persons, parents have time to the child, and status of the household (Totsika and Sylva 2004).

Demographic and socio-economic, food security, and dietary intake

Adapted questionnaires were used to collect demographic and socio-economic data of the children, their parents and their households' characteristics. For determining the wealth index, household characteristics (drinking water supply, sanitation facilities, wall material, flooring material, roofing material, number of rooms for living and lighting source), asset (house ownership, agricultural land, separate cooking place, bicycle, animal drawn cart, radio, television, refrigerator, cell phone, table, chair, mattress) and possession of farm animals (cow, cattle, donkey, goat, sheep, chicken, beehives) were included (Central Statistical Agency CSA of Ethiopia, and ICF 2016). Household food security was assessed using Household Food Insecurity Access Scale (Coates, Swindale, and Bilinsky 2007; Gebreyesus et al. 2015). Dietary intake data were obtained from mothers/parents using adapted food frequency questionnaire during the month preceding the enrollment and includes more than 75 food items.

All data collection questionnaires were originally developed in English and translated to Amharic by native research assistants. All data were collected digitally and managed using REDCap electronic data capture tools hosted at the Ghent University (Harris et al. 2009, 2019), offline using the REDCap Mobile App (Harris et al. 2021). Cognitive data were collected on paper and were doubled entered using the same program.

Data quality

Data were collected by trained staffs and research assistants from the health center and the college of medicine and health sciences of Arba Minch, respectively. Several trainings were organized separately for each of the teams involved in the data collection. Refreshment trainings were also organized in October 2020 before resuming the data collection post-COVID restrictions. All the cognitive assessment tests were pre-tested in 10 school-age children from neighboring schools after training was provided to the data collectors. Anthropometric measurements were additionally standardized, and retraining was done when necessary. A difference in measurement of height (>0.5 cm) and weight (>0.1 kg), and hence a third measurement was necessary in 9 (0.99%) and 16 cases (1.77%), respectively. Technical error of measurement (TEM) was calculated during training of the data collectors for anthropometric measurements and the measurement training was repeated until both intra- and inter-observer variabilities were within the acceptable range (<0.05) (Ulijaszek and Kerr 1999). Training was provided for laboratory technicians involved in the stool examination and quality control was also performed on sub-sample for the kato-Katz method. Disagreements on duplicate readings were reported in nine (0.99%), 30 (3.31%), 25 (2.76%)

and 19 (2.10%) cases for *Ascaris lumbricoides*, *Trichuris trichiura*, Hookworms and *Schistosomiasis mansoni*, respectively. Quality control reexamination for *Ascaris lumbricoides*, *Trichuris trichiura*, Hookworms and *Schistosomiasis mansoni* was made by a senior parasitologist on 5.0% of the whole sample. All quality control reexamination for *Ascaris lumbricoides*, *Trichuris trichiura* and Hookworms met the criteria. Only 6 out of 45 slides (13.3%) tested for *Schistosomiasis mansoni* did not meet the quality control criteria (two were false negative and four were false positive).

Ethical considerations

Ethical clearance was obtained from Commission on Medical Ethics of Ghent University (EC/2019/1289) and National Research Ethics Review Committee of Ministry of Science and Higher Education Ethiopia (P.S. M/14.1/505/20). Subsequently, it has been registered at clinicaltrials.gov (reference number: NCT04137354). Formal letters were submitted to the district administration, district health and education office, kebeles office and schools to get their permission to conduct the study. The directors of the selected schools were contacted for authorization. Sensitization workshops were organized to explain the study objectives and methods for the school directors, the teachers and the parents. Every potentially eligible pupil ensured the presence of at least one parent (either the father, mother, or legal guardian) at the sensitization workshop. Children were enrolled only if their parents and themselves provided consent to participate in the study. Personal identifiers of subjects were used by the investigators for the subsequent field activities but not shared with third party.

All children were treated with albendazole (Aldaz 400 mg Tablet, Bayberry Pharmaceuticals Pvt Ltd) for intestinal worms according to the guideline of Ministry of Health of Ethiopia for all participated children (Negussu et al. 2017; WHO 2011b, 2017). Children diagnosed with schistosomiasis and *Taenia saginata*, or trachoma were treated with Praziquantel (40 mg/kg Praziquantel 600 mg, Leben Laboratories (India) Pvt. Ltd.), or tetracycline eye ointment (5 g Tetracycline Hydrochloride Ophthalmic Ointment USP 1%, Galentic Pharma (India) Pvt. Ltd), respectively. Children diagnosed with another illness (malaria, severe anemia, and sign and symptom of vitamin A deficiency, such as night blindness and bitot spot) were referred to the nearby health center for treatment (Standard treatment guidelines for general hospital, Food, Medicine and Healthcare Administration and Control Authority FMHACA of Ethiopia 2014).

Statistical analysis

Data processing

Cognitive outcomes. The score for forward span and backward span represents the maximum number of digits the child correctly responded. Digit span was estimated by summing up forward and backward scores. The RCPM tests were scored out of a maximum of 36; the responses were given 1 or 0 if the child provided a correct or an incorrect answer for each task. The score of the visual search cancellation task is the average of the two-times repeated test (number of omissions, number of commission and execution time). Analysis is done based on the performance index, which is generated according to Geldmacher [Performance = (correct response/total target) x (correct response/total time)] (Geldmacher 1998). The three cognitive outcomes indicators were standardized to a mean of 0 and a standard deviation of 1 (Z-score) by class grade.

The 25 items of SDQ were categorized into 5 domains as follow: hyperactivity, emotional symptoms, conduct problems, peer problems, and prosocial scale with scores ranging between 0–10. Total Difficulty Score is the sum of the 4 domains (hyperactivity, emotional symptoms, conduct problems, and peer problems) and prosocial scale is considered separately. Assessment of stimulation of the child around the home environment were measured using HOME score sheet. Items are normalized to ensure equal contribution to the generation of the index, and then their values are summed.

Nutritional indicators. Hemoglobin concentrations were adjusted for the altitude of the village of their residency using this equation [Adjusted Hemoglobin = hemoglobin − ((−0.32) × (altitude in meters × 0.0033) + 0.22 × (altitude in meters × 0.0033)2)] (Nestel and Inacg Steering Committee 2002; WHO 2011a). Children with hemoglobin concentrations below 8.0 g/dL are categorized as severely anemic, those with hemoglobin ranging between 8.0 g/dL and 10.9 g/dL are moderately anemic, 11.0–11.4 g/dL are mildly anemic, and non-anemic if their hemoglobin concentrations were above 11.4 g/dL (WHO 2011a). HAZ and BMIAZ were calculated using WHO AnthroPlus software using the 2006 WHO Child Growth Standards and using STATA macros (WHO 2009). Stunting and thinness are defined as HAZ and BMIAZ lower than −2 SDs, respectively. Children whose HAZ or BMIAZ are below −3 SD are severely stunted or severely thin, respectively.

Socio-economic indicators. The wealth index was developed based on the household characteristics, asset and availability of farm animals using principal component analysis (Vyas and Kumaranayake 2006). The Household Food Insecurity Access Score (HFIAS) measures of the degree of food insecurity in the household and is based on a set of questions that encompass three domains of food insecurity: (1) anxiety and uncertainty about the household food supply; (2) insufficient quality; and (3) insufficient food intake and its physical

consequences. Households were categorized based on the response for each question (Coates, Swindale, and Bilinsky 2007). Household Food Insecurity Access Prevalence was used to categorize households into one of the four levels of food insecurity access: food secure, or mild, moderately and severely food insecure (Coates, Swindale, and Bilinsky 2007).

Variables assessing dietary diversity of children over the previous month were constructed based on FAO Guideline for individual dietary diversity score (FAO and FHI-360 2016). In addition, breakfast intake, meal frequency and intake of sugary drinks were assessed based on the child's report during the previous day. Helminthic infections were determined based on the presence of eggs in the stool for the four common infections (*Ascaris lumbricoides*, *Trichuris trichiura*, Hookworms (*Necator americanus* or *Ancylostoma duodenale*), and *Schistosomiasis mansoni* infection). Helminthic infection was defined by the presence of eggs in the child's stool of one or more of helminths indicated above, in addition to *Enterobius vermicularis*, *Hymenolepis nana* and *Taenia saginata*.

Recent illness was considered if the child reported that they were sick during the two weeks preceding the day of the data collection. These include common infections (malaria, diarrhea, cough, common cold) and chronic diseases (asthma and diabetes). Good hygienic practices were defined if the child's hand was clean and nails were trimmed and clean. Moderate hygienic practices were defined if the child's hand seems washed recently and nails were trimmed and not clean, or not trimmed but clean. Poor hygienic practices were considered if the child's hand was not clean at all and nails not trimmed and not clean.

Associations between nutritional status and cognitive outcomes

Descriptive statistics were used to assess the independent variables and nutritional status and cognitive development of the children. Continuous variables were assessed for normality (Shapiro – Wilk test >0.05) and cognitive development outcomes were transformed following a two-step approach (Templeton 2011). P-values of less than 0.05 were considered as cutoff for statistical significance. Stata 14 statistical software was used in the analyses. The associations were assessed in models that adjusted for variables whose association with the dependent variables (HAZ, BMIAZ and hemoglobin concentrations), in a bivariate analysis, has a p-value <.2. Collinearity was checked for independent variables by estimating variable inflation factor. Outliers were checked by predicting Studentized residual and appropriate measures (±3) were taken based on the result. Normality of residuals was tested using Shapiro-Wilk W test. Model specification errors were checked using link text (to test whether the regression is properly specified) and ovtest (regression specification error test for omitted variables). Homoscedasticity of residuals was checked using Breusch-Pagan/Cook-Weisberg test.

Results

Characteristics of the study children, their primary caretakers and households

This study reports on the data collected from 994 children (98.6% of the expected sample size). Second round data of 88 children who participated in the two cross-sectional surveys were dropped from this analysis. A total of 906 schoolchildren participated in the study with a mean (± SD) age of 9.6 ± 1.7 years (8.7 ± 1.6, 9.4 ± 1.5, 10.2 ± 1.5 and 10.9 ± 1.5 years for grade 1, 2, 3 and 4, respectively). Children consumed in average 3.5 ± 1.6 food groups out of 10 per day. Slightly more than half (52.7%) of the participants were male. Hemoglobin concentration, HAZ and BMIAZ of the study children were 12.3 ± 1.4 g/dL, −1.07 ± 1.35 SD and −0.73 ± 0.84 SD, respectively. The prevalence (95%, confidence interval, CI) of anemia, stunting, and thinness among schoolchildren were 23.6% (95% CI: 20.96–26.53), 24.4% (95% CI: 21.71–27.34) and 7.5% (95% CI: 5.92–9.39), respectively. The child's primary caretakers were in majority mothers (70%), were 37.2 ± 8.6 years old, and more than half of the primary caretakers had no formal education. Around 45% of the households were food secure (Table 2).

One in five children reported that they have illness recently. More than half (57.2%) of the children were infected with intestinal helminths. One in five schoolchildren were infected with *Schistosoma mansoni* (22.6%), *Ascaris lumbricoides* (19.8%), and *Trichuris trichiura* (20.5%) (Table 2).

Scores of forward, backward and total digit span, number of omissions, number of commission and performance index for the visual search task increased significantly ($p < .05$) with the grade of the pupil. The same pattern was found with AB, B and total of RCPM, except for grades 2 and 3 for Part AB and total RCPM, and grade 1 and 2 for Part A (Table 3).

Association between nutritional status and cognitive development

In adjusted models, HAZ was significantly associated with digit span, RCPM and performance index of visual search task. The finding showed that a unit increase in HAZ was associated with increases of 0.12 SD (95% CI 0.06, 0.18) in standardized digit span (Table 4), 0.08 SD (95% CI 0.03, 0.14) in standardized RCPM (Table 5), and of 0.12 SD (95% CI 0.06, 0.18) in standardized performance index of visual search task (Table 6). A unit increase in BMIAZ was associated with an increase of 0.11 SD (95% CI 0.02, 0.20) in the standardized digit span (Table 4).

In multivariate linear regression analysis, digit span was significantly associated with child age (in the three models), *Schistosoma mansoni* infection ($\beta = 0.18$, $p = .046$ in the association with hemoglobin concentrations), caretaker's age ($\beta = 0.01$, $p < .05$ in the three models), and household food security status (in the three models) (Table 4). RCPM was significantly

Table 2. Schoolchildren and their household and primary caretaker characteristics at Arba Minch HDSS.

Variable	Categories	Freq.	Percent
Child sex	Male	478	52.8
	Female	428	47.2
Class year (grade) of the child	1	267	29.5
	2	299	33.0
	3	216	23.8
	4	124	13.7
Child hygienic practice	Good	325	35.9
	Moderate	275	30.4
	Poor	306	33.8
Recent history of illness	No	733	80.9
	Yes	173	19.1
Helminthic infections	*Ascaris lumbricoides*	179	19.8
	Trichuris trichiura	186	20.5
	Hookworm infection	134	14.8
	Schistosoma mansoni	205	22.6
	Other helminthics	73	8.1
Hemoglobin g/dL (Mean SD)		12.3	±1.40
HAZ (Mean SD)		−1.07	±1.35
BMIA (Mean SD)		−0.73	±0.84
Thinness	Normal	836	92.5
	Moderate	63	7.0
	Severe	5	0.6
Stunting	Normal	683	75.6
	Moderate	153	16.9
	Severe	67	7.4
Anemia	Normal	688	76.4
	Mild	81	9.0
	Moderate	119	13.3
	Severe	12	1.3
Primary caretaker sex	Male	203	22.4
	Female	703	77.6
Primary caretaker relationship	Mother of the child	633	69.9
	Father of the child	173	19.1
	Other	100	11.0
Primary caretaker educational status	Illiterate	481	53.1
	Grade 1–4	141	15.6
	Grade 5–8	203	22.4
	9 & above	81	8.9
Primary caretaker occupation	Agriculture related	425	46.9
	Other	180	19.9
	No occupation	301	33.2
Residency	Urban	305	33.7
	Rural	601	66.3
Food security	Food secure	408	45.0
	Mildly insecure	91	10.0
	Moderately insecure	321	35.4
	Severely insecure	86	9.5

Height-for-age z-score (HAZ), Body mass index-for-age z-score (BMIAZ).

associated with child age (in the three models), negatively associated with the child sex (in the three models, male sex being the reference), negatively associated with hookworm infection (in the three models), and wealth index (in the three models) (Table 5). Performance index of visual search task was associated with child age (in the three models), and negatively associated with the child sex (in the three models, male sex being the reference) (Table 6).

Table 3. Cognitive development outcome of schoolchildren by class grade.

Cognitive development outcome	Total Mean (SD)	Grade 1 Mean (SD)	Grade 2 Mean (SD)	Grade 3 Mean (SD)	Grade 4 Mean (SD)	F
Digit forward	3.76 (0.75)	3.57 (0.70)	3.75 (0.71)	3.84 (0.79)	4.05 (0.77)	13.15*
Digit backward	2.25 (0.87)	1.94 (0.75)	2.19 (0.82)	2.38 (0.84)	2.84 (0.95)	36.34*
Digit span	6.01 (1.32)	5.51 (1.13)	5.94 (1.17)	6.22 (1.36)	6.89 (1.46)	37.20*
RCPM A	7.70 (1.41)	7.56 (1.50)	7.78 (1.32)	7.66 (1.41)	7.90 (1.42)	2.10
RCPM AB	3.22 (1.67)	2.67 (1.40)	3.30 (1.58)	3.31 (1.70)	4.02 (1.94)	20.85*
RCPM B	2.74 (1.36)	2.52 (1.19)	2.58 (1.22)	2.91 (1.35)	3.33 (1.74)	13.27*
Total RCPM	13.66 (3.13)	12.75 (2.63)	13.66 (2.73)	13.88 (3.15)	15.26 (4.12)	19.82*
No. omission	4.21 (3.91)	5.54 (4.72)	3.95 (3.80)	3.67 (2.84)	2.94 (2.98)	17.40*
No. Commission	3.81 (8.82)	5.19 (10.54)	3.45 (7.95)	3.23 (7.34)	2.71 (8.88)	3.30*
Total marked	28.35 (10.03)	28.08 (11.21)	28.3 (8.34)	28.8 (11.40)	28.28 (8.45)	0.22
Performance index	0.08 (0.03)	0.06 (0.03)	0.07 (0.03)	0.08 (0.03)	0.10 (0.04)	57.08*

*_p-value_ less than 0.05; No., Number; RCPM, Ravens Colour Progressive Matrices.

Table 4. Association between nutritional status and digit span of schoolchildren in southern Ethiopia.

Variables		Model 1	Model 2	Model 3
HAZ		0.12 (0.06, 0.18)*		
BMIAZ			0.11 (0.02, 0.20)*	
Hemoglobin concentration				−0.001 (−0.01, 0.004)
Child age		0.09 (0.04, 0.13)*	0.06 (0.02, 0.10)*	0.04 (0.002, 0.08)*
Child hygienic practice	Good			
	Moderate	0.02 (−0.15, 0.18)	0.02 (−0.14, 0.18)	0.02 (−0.14, 0.18)
	Poor	−0.09 (−0.25, 0.07)	−0.10 (−0.26, 0.06)	−0.11 (−0.27, 0.06)
Ascaris infection	No			
	Yes	−0.01 (−0.19, 0.17)	−0.06 (−0.24, 0.12)	−0.02 (−0.20, 0.16)
Schistosoma infection	No			
	Yes	0.16 (−0.01, 0.34)	0.16 (−0.01, 0.34)	0.18 (0.003, 0.35)*
Caretakers' age		0.01 (0.002, 0.02)*	0.01 (0.002, 0.02)*	0.01 (0.002, 0.02)*
Caretakers' educational status	Illiterate			
	Grade 1 – 4	0.07 (−0.15, 0.287)	0.08 (−0.14, 0.29)	0.06 (−0.15, 0.28)
	Grade 5 – 8	0.12 (−0.08, 0.32)	0.10 (−0.10, 0.30)	0.11 (−0.10, 0.31)
	Grade 9 & above	0.18 (−0.10, 0.45)	0.16 (−0.11, 0.43)	0.16 (−0.11, 0.44)
Wealth index score		0.01 (−0.02, 0.05)	0.01 (−0.03, 0.05)	0.01 (−0.03, 0.04)
Food secure	No			
	Yes	0.19 (0.05, 0.33)*	0.24 (0.10, 0.37)*	0.25 (0.11, 0.39)*
Residency	Urban			
	Rural	−0.03 (−0.19, 0.14)	−0.07 (−0.23, 0.10)	−0.06 (−0.23, 0.10)
HOME score		−0.002 (−0.02, 0.02)	1.6E-04 (−0.02, 0.02)	0.002 (−0.02, 0.02)
Difficulties at home		−0.003 (−0.02, 0.01)	0.001 (−0.01, 0.02)	0.001 (−0.01, 0.02)
Prosocial scale		0.01 (−0.03, 0.05)	0.02 (−0.01, 0.06)	0.02 (−0.02, 0.06)

Adjusted multivariate regressions with Height-for-age z-score (HAZ) (model 1), Body mass index-for-age z-score (BMIAZ) (model 2) and hemoglobin concentration (model 3). *_p_-value less than 0.05.

Discussion

Our findings support partially the hypothesis that nutritional status is associated with cognitive development of schoolchildren. In Southern Ethiopia, HAZ was associated with working memory, attention, and non-verbal intelligence of the schoolchildren and BMIAZ was associated with their working memory. However, BMIAZ was not associated with attention and non-verbal intelligence of the schoolchildren. No association was found between hemoglobin concentrations and digit span, performance index of visual search task and RCPM.

Table 5. Association between nutritional status and Raven's colored progressive matrices (RCPM) of schoolchildren in southern Ethiopia.

Variables		Model 1	Model 2	Model 3
HAZ		0.08 (0.03, 0.14)*		
BMIAZ			0.03 (−0.05, 0.12)	
Hemoglobin concentration				0.004 (−4E-04, 0.01)
Child age		0.08 (0.04, 0.12)*	0.06 (0.01, 0.10)*	0.05 (0.01, 0.09)*
Child sex	Male			
	Female	−0.17 (−0.30, −0.04)*	−0.15 (−0.29, −0.02)*	−0.17 (−0.31, −0.04)*
Dietary diversity score		−0.003 (−0.01, 0.01)	−0.002 (−0.01, 0.01)	−0.002 (−0.01, 0.01)
Child hygienic practice	Good			
	Moderate	−0.08 (−0.24, 0.08)	−0.08 (−0.24, 0.07)	−0.08 (−0.24, 0.08)
	Poor	−0.10 (−0.25, 0.06)	−0.10 (−0.25, 0.06)	−0.10 (−0.25, 0.06)
Hookworm infection	No			
	Yes	−0.30 (−0.48, −0.11)*	−0.27 (−0.46, −0.08)*	−0.27 (−0.46, −0.08)*
Caretakers' educational status	Illiterate			
	Grade 1 – 4	−0.08 (−0.29, 0.12)	−0.07 (−0.28, 0.14)	−0.08 (−0.28, 0.13)
	Grade 5 – 8	0.05 (−0.15, 0.24)	0.04 (−0.15, 0.24)	0.04 (−0.15, 0.23)
	Grade 9 & above	0.01 (−0.24, 0.27)	−0.001 (−0.26, 0.26)	0.02 (−0.24, 0.27)
Caretakers' occupation	Farming			
	Non-farming	0.06 (−0.13, 0.24)	0.07 (−0.11, 0.26)	0.09 (−0.10, 0.27)
	None	0.07 (−0.08, 0.22)	0.07 (−0.08, 0.22)	0.07 (−0.08, 0.22)
Wealth index score		0.07 (0.03, 0.11)*	0.06 (0.02, 0.10)*	0.07 (0.02, 0.11)*
Food secure	No			
	Yes	0.06 (−0.08, 0.20)	0.09 (−0.04, 0.22)	0.09 (−0.04, 0.23)
Residency	Urban			
	Rural	−0.03 (−0.18, 0.12)	−0.04 (−0.19, 0.11)	−0.03 (−0.18, 0.12)

Adjusted multivariate regressions with Height-for-age z-score (HAZ) (model 1), Body mass index-for-age z-score (BMIAZ) (model 2) and hemoglobin concentration (model 3). *p-value less than 0.05.

Table 6. Association between nutritional status and performance index of schoolchildren in southern Ethiopia.

Variables		Model 1	Model 2	Model 3
HAZ		0.12 (0.06, 0.18)*		
BMIAZ			0.02 (−0.06, 0.11)	
Hemoglobin concentration				−0.002 (−0.01, 0.003)
	Child age	0.12 (0.07, 0.16)*	0.08 (0.03, 0.12)*	0.07(0.03, 0.11)*
Child sex	Male			
	Female	−0.16 (−0.29, −0.03)*	−0.14 (−0.27, −0.01)*	−0.15 (−0.28, −0.02)*
Wealth index score		0.01 (−0.02, 0.04)	0.01 (−0.02, 0.04)	0.01 (−0.02, 0.04)
HOME score		0.02 (−0.004, 0.04)	0.02 (−0.003, 0.04)	0.02 (−0.01, 0.04)
Total difficulties at home		−0.003 (−0.02, 0.01)	−0.002 (−0.02, 0.01)	−0.003 (−0.02, 0.01)
Prosocial scale		0.01 (−0.02, 0.05)	0.02 (−0.02, 0.05)	0.02 (−0.02, 0.05)

Adjusted multivariate regressions with Height-for-age z-score (HAZ) (model 1), Body mass index-for-age z-score (BMIAZ) (model 2) and hemoglobin concentration (model 3). *p-value less than 0.05.

The association between HAZ and cognitive development of schoolchildren was consistent with other studies conducted in African (Adedeji et al. 2017; Ajayi et al. 2017; Kabero et al. 2021) and Asian countries (Perignon et al. 2014; Pradhan et al. 2020; Sakti et al. 1999; Sandjaja et al. 2013). Studies showed that HAZ was associated with working memory (Ajayi et al. 2017; Kabero et al. 2021; Kar, Rao, and Chandramouli 2008; Sakti et al. 1999), non-verbal intelligence (Adedeji et al. 2017; Kabero et al. 2021; Kar, Rao, and Chandramouli 2008; Perignon et al. 2014; Sandjaja et al. 2013), and attention (Kabero et al. 2021; Kar, Rao, and Chandramouli 2008; Sakti et al. 1999) in school age children. A study

conducted in Soddo area, Southern Ethiopia found that HAZ of children 7–10 years old was significantly associated with RCPM, pattern reasoning, sequential scale and simultaneous scale (Kabero et al. 2021). Other studies found no significant associations between HAZ and working memory of schoolchildren (Sari et al. 2020) or between HAZ and Test of Nonverbal Intelligence including RCPM (Akubuilo et al. 2020; Al-Mekhlafi et al. 2011; Hamid et al. 2011). A study in the city of Jos, Nigeria found a significant increase in odds of optimal non-verbal intelligence among non-stunted schoolchildren, an association that became not significant after adjusting for covariates (Adedeji et al. 2017). Early life stunting is an indicator of child chronic undernutrition and is exceptionally an important marker because of its association with poorer cognitive and educational outcomes in later childhood and adolescence (Chang et al. 2002; Walker et al. 2007). Undernutrition affects cognition through the damage caused to the brain development due to lack of nutrients and reduced brain functional connectivity (Xie et al. 2019). Undernutrition can affect also indirectly the cognitive development through reduced interaction of the child because of the lack of energy (fatigue), low self-esteem, anxiety, and depression (Brown and Pollitt 1996; Kar, Rao, and Chandramouli 2008; Walker et al. 2007).

The associations between BMIAZ and cognitive function outcomes of schoolchildren were inconsistent. Our results are in line with the findings of a study conducted in school in Bhubaneswar City, India which showed a significant association between BMI and working memory of 8–9 year old children (Pradhan et al. 2020). However, others reported that BMIAZ (indicator of thinness) was not significantly associated with the working memory of the schoolchildren (Kabero et al. 2021; Sakti et al. 1999). Similarly, other studies showed a non-association between BMIAZ and non-verbal intelligence of school age children (Adedeji et al. 2017; Kabero et al. 2021; Sakti et al. 1999). Additionally, studies conducted in Iraq and the Philippines showed an association between non-verbal intelligence and BMIAZ (Ezeamama et al. 2005; Ghazi et al. 2012), which is inconsistent with our findings. The study from the Philippines assessed memory of 7–18 years old children and adolescents and found an association with BMIAZ and memory test (Ezeamama et al. 2005), which is also different from this finding. In a review based on four Southeast Asian countries (Indonesia, Malaysia, Thailand, and Vietnam), Sandjaja et al. (2013) indicated that thinness significantly increased the odds of school-aged children having a low non-verbal IQ (Sandjaja et al. 2013). Sakti et al. (1999) showed that there is no significant association between BMI and the different indicators used to determine the cognitive function of the children (Sakti et al. 1999). Thinness is an indicator of an acute undernutrition, a status that may change rapidly over a short period of time. Whereas most of the cognitive function indicators change may not be affected within short periods. This might be the reason for inconsistent association between BMIAZ and cognitive function of the children.

Our study did not find an association between hemoglobin concentrations and digit span, performance index of visual search task, and RCPM. Similarly, studies from South Africa (Ajayi et al. 2017) and Indonesia (Sakti et al. 1999) indicated, respectively, that Atlantis and Hand Movement of Kauffman Assessment battery and Grover Counter Scale, and digit span forward were not associated with hemoglobin concentrations in children. Contrarily, other studies reported significant associations between hemoglobin concentrations of schoolchildren and Raven's test (Hamid et al. 2011), and with memory test (Ezeamama et al. 2005). Associations between hemoglobin concentrations and cognitive development could be affected by iron status. Additionally, we found that the study population had a prevalence of iron deficiency anemia of less than 4% (Gutema et al. 2024). A study among schoolchildren in Cambodia showed that only in boys, those with iron-deficiency anemia scored significantly lower in RCPM test (Perignon et al. 2014). A study conducted in southern Thailand demonstrated that hemoglobin concentration was only associated with cognition in iron deficient children (Sungthong, Mo-Suwan, and Chongsuvivatwong 2002).

Similar to other studies, child, parents and household characteristics, namely child's age (Ezeamama et al. 2005; Kar, Rao, and Chandramouli 2008) and sex (Ezeamama et al. 2005; Perignon et al. 2014), hookworm/*Schistosomiasis mansoni* infections, caretakers' age, HOME score, wealth index (Al-Mekhlafi et al. 2011; Ezeamama et al. 2005; Perignon et al. 2014) and household food security were significantly associated with one or more of the cognitive development indicators. *Schistosomiasis mansoni* infection was positively related with digit span in this study. This finding should be interpreted with caution. More than two-thirds (74.1%) of the infected children were from two schools. The same two schools were ranked first and second highest in the digit span.

Our study assessed different domains of cognition (non-verbal intelligence, working memory and attention) using adapted tools to the local context. However, we recognize the limitations of our study including the cross-sectional design, which provides a snapshot of the situation and cannot refer to any causality. Even though the cognitive tools were adapted and pre-tested for applicability in the area by the experts, each tool has their limitations. For instance, RCPM might favor those children with oral expressive language problems or spatial learners.

Conclusions

HAZ was associated with working memory, non-verbal intelligence, and concentration of schoolchildren. BMIAZ was associated with working memory of the schoolchildren. Hemoglobin concentration was not associated with cognitive outcomes of the schoolchildren in southern Ethiopia. Our results confirm that chronic malnutrition affects child's cognitive development during school-age. Health and nutrition interventions within school programs should address the reduction of chronic undernutrition in schoolchildren. A longitudinal study

design may enhance our understanding of the relationship between acute malnutrition (BMIAZ and hemoglobin) and the cognitive development of schoolchildren.

Acknowledgments

We would like to thank the children who participated in this study, their parents/guardians, schoolteachers and the research team who made this study possible. We want to give special thanks to Judith Tumaini Dzombo for supporting the training of BTG and data collectors on the tools used for the assessment of cognitive development of schoolchildren. We want to acknowledge Tsegaye Yohanis, a parasitologist at Arba Minch University Department of Medical Laboratory, for his support in parasitological analyses.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

This work was conducted under the PhD studies of BTG, whose scholarship was partially funded by the Flemish Interuniversity Council (VLIR-UOS) in the context of the Institutional University Cooperation Program (IUC) with Arba Minch University https://www.vliruos.be/en/projects/project/22?pid=3604. Assessment of cognitive development was funded through the Global Minds Fund of Ghent University https://www.ugent.be/en/research/funding/devcoop/globalmindsfund.htm. (GRANT BE2017GMUUG0A103). The funders had no role in the study design, data collection and analysis, decision to publish, or the preparation of the manuscript.

Author contributions

SA, SD and BTG were responsible for the design of the study. BTG, MB, SB, and THZ conducted the research and SA, SD, BL, AA and BTG supervised data collection. BTG completed the statistical analyses and drafted the manuscript. SA contributed to the writing of the manuscript. All authors read and approved the final manuscript.

References

Adedeji, I., C. John, S. Okolo, A. Ebonyi, H. Abdu, and M. Bashir. 2017. Malnutrition and the intelligence quotient of primary school pupils in Jos, Nigeria. *British Journal of Medicine and Medical Research* 21 (2):1–13. doi:10.9734/BJMMR/2017/32504.

Ajayi, O. R., G. Matthews, M. Taylor, J. Kvalsvig, L. L. Davidson, S. Kauchali, and C. A. Mellins. 2017. Factors associated with the health and cognition of 6-year-old to 8-year-old children in KwaZulu-Natal, South Africa. *Tropical Medicine & International Health* 22 (5):631–37. doi:10.1111/tmi.12866.

Akubuilo, U., K. Iloh, J. Onu, O. Iloh, A. Ubesie, and A. Ikefuna. 2020. Nutritional status of primary school children: Association with intelligence quotient and academic performance. *Clinical Nutrition ESPEN* 40:208–13. doi:10.1016/j.clnesp.2020.09.019.

Al-Mekhlafi, H. M., M. A. Mahdy, A. A. Sallam, W. Ariffin, A. M. Al-Mekhlafi, A. A. Amran, and J. Surin. 2011. Nutritional and socio-economic determinants of cognitive function and educational achievement of Aboriginal schoolchildren in rural Malaysia. *The British Journal of Nutrition* 106 (7):1100–06. doi:10.1017/S0007114511001449.

Arcanjo, F., C. Arcanjo, and P. Santos. 2016. Schoolchildren with learning difficulties have low iron status and high anemia prevalence. *Journal of Nutrition and Metabolism* 2016:1–5. doi: 10.1155/2016/7357136.

Assemie, M. A., A. A. Alamneh, D. B. Ketema, A. M. Adem, M. Desita, P. Petrucka, and M. M. Ambaw. 2020. High burden of undernutrition among primary school-aged children and its determinant factors in Ethiopia; a systematic review and meta-analysis. *Italian Journal of Pediatrics* 46 (1):1–14. doi: 10.1186/s13052-020-00881-w.

Barrett, D. E., M. Radke-Yarrow, and R. E. Klein. 1982. Chronic malnutrition and child behavior: Effects of early caloric supplementation on social and emotional functioning at school age. *Developmental Psychology* 18 (4):541–56. doi:10.1037/0012-1649.18.4.541.

Berkman, D. S., A. G. Lescano, R. H. Gilman, S. L. Lopez, and M. M. Black. 2002. Effects of stunting, diarrhoeal disease, and parasitic infection during infancy on cognition in late childhood: A follow-up study. *Lancet* 359 (9306):564–71. doi:10.1016/S0140-6736(02)07744-9.

Best, C., N. Neufingerl, L. Van Geel, T. van den Briel, and S. Osendarp. 2010. The nutritional status of school-aged children: Why should we care? *Food and Nutrition Bulletin* 31 (3):400–17. doi:10.1177/156482651003100303.

Bilker, W. B., J. A. Hansen, C. M. Brensinger, J. Richard, R. E. Gur, and R. C. Gur. 2012. Development of abbreviated nine-item forms of the Raven's standard progressive matrices test. *Assessment* 19 (3):354–69. doi:10.1177/1073191112446655.

Brown, J. L., and E. Pollitt. 1996. Malnutrition, poverty and intellectual development. *Scientific American* 274 (2):38–43. doi:10.1038/scientificamerican0296-38.

Cattell, R. B. 1963. Theory of fluid and crystallized intelligence: A critical experiment. *Journal of Educational Psychology* 54 (1):1–1. doi: 10.1037/h0046743.

Central Statistical Agency (CSA) of Ethiopia, and ICF. 2016. *Ethiopia demographic and health survey*. Addis Ababa, Ethiopia and Rockville, Maryland, USA: Central Statistical Agency of Ethiopia and ICF International.

Chang, S., S. Walker, S. Grantham-McGregor, and C. Powell. 2002. Early childhood stunting and later behaviour and school achievement. *Journal of Child Psychology and Psychiatry* 43 (6):775–83. doi: 10.1111/1469-7610.00088.

Coates, J., A. Swindale, and P. Bilinsky. 2007. Household food insecurity access scale (HFIAS) for measurement of food access: Indicator guide: Version 3. (https://www.fantaproject.org/sites/default/files/resources/HFIAS_ENG_v3_Aug07.pdf.

Cogill, B. 2003. Anthropometric indicators measurement guide. Washington, D.C: Food and Nutrition Technical Assistance (FANTA) Project, FHI 360.

Crookston, B. T., R. Forste, C. McClellan, A. Georgiadis, and T. B. Heaton. 2014. Factors associated with cognitive achievement in late childhood and adolescence: The young lives cohort study of children in Ethiopia, India, Peru, and Vietnam. *BMC Pediatrics* 14 (1):1–9. doi:10.1186/1471-2431-14-253.

Deng, I. D., L. Chung, N. Talwar, F. Tam, N. W. Churchill, T. A. Schweizer, and S. J. Graham. 2019. Functional MRI of letter cancellation task performance in older adults. *Frontiers in Human Neuroscience* 13:13. doi:10.3389/fnhum.2019.00097.

Ellis, L., A. W. Hoskin, and M. Ratnasingam. 2018. Intellectual and academic factors. In Handbook of social status correlates, 1st ed. 147–74. Academic Press. doi: 10.1016/b978-0-12-805371-3.00006-6.

Ezeamama, A. E., J. F. Friedman, L. P. Acosta, D. C. Bellinger, G. C. Langdon, D. L. Manalo, R. M. Olveda, J. D. Kurtis, and S. T. McGarvey. 2005. Helminth infection and cognitive impairment among Filipino children. *The American Journal of Tropical Medicine and Hygiene* 72 (5):540. doi:10.4269/ajtmh.2005.72.540.

Falkingham, M., A. Abdelhamid, P. Curtis, S. Fairweather-Tait, L. Dye, and L. Hooper. 2010. The effects of oral iron supplementation on cognition in older children and adults: A systematic review and meta-analysis. *Nutrition Journal* 9 (1):4. doi:10.1186/1475-2891-9-4.

FAO,and FHI-360. 2016. Minimum dietary diversity for women: A Guide for measurement. Food and agriculture organization (FAO) & USAID's food and nutrition technical assistance III project (FANTA) managed by FHI 360. .

Gebreyesus, S. H., T. Lunde, D. H. Mariam, T. Woldehanna, and B. Lindtjørn. 2015. Is the adapted household food insecurity access scale (HFIAS) developed internationally to measure food insecurity valid in urban and rural households of Ethiopia? *BMC Nutrition* 1 (1):2–2. doi:10.1186/2055-0928-1-2.

Geldmacher, D. S. 1998. Stimulus characteristics determine processing approach on random array letter-cancellation tasks. *Brain & Cognition* 36 (3):346–54. doi:10.1006/brcg.1997.0978.

Georgiadis, A. 2017. The sooner the better but it's never too late: The impact of nutrition at different periods of childhood on cognitive development. *Young Lives Working Papers*. .

Ghazi, H. F., Z. M. Isa, S. Aljunid, A. M. Tamil, and M. A. Abdalqader. 2012. Nutritional status, nutritional habit and breakfast intake in relation to IQ among primary school children in Baghdad city, Iraq. *Pakistan Journal of Nutrition* 11 (4):379. doi: 10.3923/pjn.2012.379.382.

Goodman, R. 1997. The strengths and difficulties questionnaire: A research note. *Journal of Child Psychology and Psychiatry* 38 (5):581–86. doi:10.1111/j.1469-7610.1997.tb01545.x.

Grantham-McGregor, S., Y. B. Cheung, S. Cueto, P. Glewwe, L. Richter, B. Strupp, and I. C. D. S. Group. 2007. Developmental potential in the first 5 years for children in developing countries. *Lancet* 369 (9555):60–70. doi: 10.1016/S0140-6736(07)60032-4.

Gutema, B. T., B. Levecke, M. B. Sorrie, N. D. Megersa, T. H. Zewdie, G. E. Yesera, S. De Henauw, A. Abubakar, and S. Abbeddou. 2024. Effectiveness of intermittent iron and high-dose vitamin a supplementation on cognitive development of school children in southern Ethiopia: A randomized placebo-controlled trial. *The American Journal of Clinical Nutrition* 119 (2):470–84. doi:10.1016/j.ajcnut.2023.11.005.

Hailegebriel, T. 2020. Prevalence and determinants of stunting and thinness/wasting among schoolchildren of Ethiopia: A systematic review and meta-analysis. *Food and Nutrition Bulletin* 41 (4):474–93. doi:10.1177/0379572120968978.

Halterman, J. S., J. M. Kaczorowski, C. A. Aligne, P. Auinger, and P. G. Szilagyi. 2001. Iron deficiency and cognitive achievement among school-aged children and adolescents in the United States. *Pediatrics* 107 (6):1381–86. doi:10.1542/peds.107.6.1381.

Hamid, J. J., M. K. Amal, H. Hasmiza, C. D. Pim, L. O. Ng, and M. W. Wan. 2011. Effect of gender and nutritional status on academic achievement and cognitive function among primary school children in a rural district in Malaysia. *Malaysian Journal of Nutrition* 17 (2):189–200.

Harris, P. A., G. Delacqua, R. Taylor, S. Pearson, M. Fernandez, and S. N. Duda. 2021. The REDCap Mobile application: A data collection platform for research in regions or situations with internet scarcity. *JAMIA Open* 4 (3):ooab078. doi:10.1093/jamiaopen/ooab078.

Harris, P. A., R. Taylor, B. L. Minor, V. Elliott, M. Fernandez, L. O'Neal, L. McLeod, G. Delacqua, F. Delacqua, J. Kirby, et al. 2019. The REDCap consortium: Building an

international community of software platform partners. *Journal of Biomedical Informatics* 95:103208. doi: 10.1016/j.jbi.2019.103208.

Harris, P. A., R. Taylor, R. Thielke, J. Payne, N. Gonzalez, and J. G. Conde. 2009. Research electronic data capture (REDCap)—A metadata-driven methodology and workflow process for providing translational research informatics support. *Journal of Biomedical Informatics* 42 (2):377–81. doi: 10.1016/j.jbi.2008.08.010.

Holden, K. R. 2007. Malnutrition and brain development: A review. *Neurologic Consequences of Malnutrition* 6:19.

Huitt, W., and J. Hummel. 2003. Piaget's theory of cognitive development. *Educational Psychology Interactive* 3 (2):1–5.

Kabero, T. H., T. Bosha, F. W. Feleke, D. H. Weldegebreal, and B. Stoecker. 2021. Nutritional status and its association with cognitive function among school aged children at Soddo Town and Soddo Zuriya District, Southern Ethiopia: Institution based comparative study. *Global Pediatric Health* 8:2333794x211028198. doi: 10.1177/2333794x211028198.

Kar, B. R., S. L. Rao, and B. Chandramouli. 2008. Cognitive development in children with chronic protein energy malnutrition. *Behavioral and Brain Functions* 4 (1):31. doi:10.1186/1744-9081-4-31.

Low, M., A. Farrell, B.-A. Biggs, and S.-R. Pasricha. 2013. Effects of daily iron supplementation in primary-school–aged children: Systematic review and meta-analysis of randomized controlled trials. *Cmaj* 185 (17):E791–802. doi: 10.1503/cmaj.130628.

Lundeen, E. A., J. R. Behrman, B. T. Crookston, K. A. Dearden, P. Engle, A. Georgiadis, M. E. Penny, and A. D. Stein. 2014. Growth faltering and recovery in children aged 1–8 years in four low-and middle-income countries: Young lives. *Public Health Nutrition* 17 (9):2131–37. doi: 10.1017/S1368980013003017.

Negussu, N., B. Mengistu, B. Kebede, K. Deribe, E. Ejigu, G. Tadesse, K. Mekete, and M. Sileshi. 2017. Ethiopia schistosomiasis and soil-transmitted helminthes control programme: Progress and prospects. *Ethiopian Medical Journal* 55 (Suppl 1):75.

Nestel, P., and INACG Steering Committee. 2002. Adjusting hemoglobin values in program surveys. https://pdf.usaid.gov/pdf_docs/Pnacq927.pdf.

Perignon, M., M. Fiorentino, K. Kuong, K. Burja, M. Parker, S. Sisokhom, C. Chamnan, J. Berger, and F. T. Wieringa. 2014. Stunting, poor iron status and parasite infection are significant risk factors for lower cognitive performance in Cambodian school-aged children. *PLOS ONE* 9 (11):e112605. doi: 10.1371/journal.pone.0112605.

Pradhan, B., and H. R. Nagendra. 2008. Normative data for the letter-cancellation task in school children. *International Journal of Yoga* 1 (2):72–75. doi:10.4103/0973-6131.43544.

Pradhan, J., A. Mukhi, S. Mohanty, and M. Parida. 2020. Correlation between nutritional status and level of memory among school children. *European Journal of Molecular & Clinical Medicine* 7 (10):2020.

Richardson, J. T. 2007. Measures of short-term memory: A historical review. *Cortex, A Journal Devoted to the Study of the Nervous System and Behavior* 43 (5):635–50. doi: 10.1016/s0010-9452(08)70493-3.

Sakti, H., C. Nokes, W. Subagio Hertanto, S. Hendratno, A. Hall, and D. A. Bundy. 1999. Evidence for an association between hookworm infection and cognitive function in Indonesian school children. *Tropical Medicine & International Health* 4 (5):322–34. doi: 10.1046/j.1365-3156.1999.00410.x.

Sandjaja, B. K. P., B. K. Rojroonwasinkul, N. Le Nyugen, L. O. Budiman, B. Ng, H. T. Soonthorndhada, K. Xuyen, P. Parikh, and P. Deurenberg. 2013. Relationship between anthropometric indicators and cognitive performance in Southeast Asian school-aged children. *The British Journal of Nutrition* 110 (Suppl S3):S57–64. doi: 10.1017/s0007114513002079.

Sari, W. D., C. O. Lada, R. L. Nurina, and M. A. E. Dedy. 2020. Comparison of short-term memory between stunting and non-stunting children in urban and rural elementary school students in Kupang 2019. *World Nutrition Journal* 4 (1):46–55. doi: 10.25220/WNJ.V04.i1.0008.

Shonkoff, J. P., D. A. Phillips National Research Council, and Institute of Medicine. 2000. The developing brain. In From neurons to neighborhoods: The science of early childhood development. Washington, D.C.: National Academies Press (US).

Standard treatment guidelines for general hospital, Food, Medicine and Healthcare Administration and Control Authority (FMHACA) of Ethiopia. 2014.

Stebbins, G. T. 2007 Neuropsychological Testing. In *Textbook of clinical neurology* Christopher, G. G. Third Edition, 539–57 doi:https://doi.org/10.1016/B978-141603618-0.10027-X. Philadelphia PA: Saunders.

Sungthong, R., L. Mo-Suwan, and V. Chongsuvivatwong. 2002. Effects of haemoglobin and serum ferritin on cognitive function in school children. *Asia Pacific Journal of Clinical Nutrition* 11 (2):117–22. doi:10.1046/j.1440-6047.2002.00272.x.

Tariku, E. Z., G. A. Abebe, Z. A. Melketsedik, B. T. Gutema, and A. Laar. 2018. Prevalence and factors associated with stunting and thinness among school-age children in arba minch health and demographic surveillance site, Southern Ethiopia. *PLOS ONE* 13 (11):e0206659–0206659. doi:10.1371/journal.pone.0206659.

Tariku, E. Z., G. A. Abebe, Z. A. Melketsedik, B. T. Gutema, N. D. Megersa, M. B. Sorrie, F. G. Weldehawariat, and E. A. Getahun. 2019. Anemia and its associated factors among school-age children living in different climatic zones of Arba Minch Zuria District, Southern Ethiopia. *BMC Hematology* 19 (1):1–9. doi:10.1186/s12878-019-0137-4.

Templeton, G. F. 2011. A two-step approach for transforming continuous variables to normal: Implications and recommendations for is research. *Communications of the Association for Information Systems* 28 (1):4. doi:10.17705/1CAIS.02804.

Tezera, R., Z. Sahile, D. Yilma, E. Misganaw, and E. Mulu. 2018. Prevalence of anemia among school-age children in Ethiopia: A systematic review and meta-analysis. *Systematic Reviews* 7 (1):80. doi:10.1186/s13643-018-0741-6.

Totsika, V., and K. Sylva. 2004. The home observation for measurement of the environment revisited. *Child and Adolescent Mental Health* 9 (1):25–35. doi:10.1046/j.1475-357X.2003.00073.x.

Udani, P. 1992. Protein energy malnutrition (PEM), brain and various facets of child development. *Indian Journal of Pediatrics* 59 (2):165–86. doi:10.1007/BF02759978.

Ulijaszek, S. J., and D. A. Kerr. 1999. Anthropometric measurement error and the assessment of nutritional status. *The British Journal of Nutrition* 82 (3):165–77. doi:10.1017/s0007114599001348.

UNESCO Institute for Statistics. 2019a. Combining data on out-of-school children, completion and learning to offer a more comprehensive view on SDG 4 (UNESCO Institute for Statistics) https://uis.unesco.org/sites/default/files/documents/ip61-combining-data-out-of-school-children-completion-learning-offer-more-comprehensive-view-sdg4.pdf. Accessed 12 03 2022. Information Paper No. 61

UNESCO Institute for Statistics. 2019b. New methodology shows that 258 million children, adolescents and youth are out of school (UNESCO Institute for Statistics). https://uis.unesco.org/sites/default/files/documents/new-methodology-shows-258-million-children-adolescents-and-youth-are-out-school.pdf. Accessed 12 03 2022. UIS Fact Sheet No. 56 | September 2019

Vyas, S., and L. Kumaranayake. 2006. Constructing socio-economic status indices: How to use principal components analysis. *Health Policy and Planning* 21 (6):459–68. doi:10.1093/heapol/czl029.

Walker, S. P., S. M. Chang, C. A. Powell, E. Simonoff, and S. M. Grantham-McGregor. 2007. Early childhood stunting is associated with poor psychological functioning in late adolescence and effects are reduced by psychosocial stimulation. *The Journal of Nutrition* 137 (11):2464–69. doi:10.1093/jn/137.11.2464.

Weiss, L., D. Saklofske, D. Coalson, and S. Raiford. 2010. *WAIS-IV clinical use and interpretation: Scientist-practitioner perspectives*. London, UK: Academic Press.

WHO. 2009. *WHO AnthroPlus for personal computers manual: Software for assessing growth of the world's children and adolescents*. World Health Organization. Accessed10 03 2023. https://www.who.int/tools/growth-reference-data-for-5to19-years/application-tools.

WHO. 2011a. Haemoglobin concentrations for the diagnosis of anaemia and assessment of severity. Vitamin and Mineral Nutrition Information System. World Health Organization.

WHO. 2011b. *Helminth control in school-age children: A guide for managers of control programmes*. Geneva, Switzerland: World Health Organization.

WHO. 2015. *The global prevalence of anaemia in 2011*. Geneva, Switzerland: World Health Organization.

WHO. 2017. *Guideline: Preventive chemotherapy to control soil-transmitted helminth infections in at-risk population groups*. Geneva, Switzerland: World Health Organization.

WHO. 2019. *Bench aids for the diagnosis of intestinal parasites*, Second ed. Geneva, Switzerland: World Health Organization.

Xie, W., S. K. G. Jensen, M. Wade, S. Kumar, A. Westerlund, S. H. Kakon, R. Haque, W. A. Petri, and C. A. Nelson. 2019. Growth faltering is associated with altered brain functional connectivity and cognitive outcomes in urban Bangladeshi children exposed to early adversity. *BMC Medicine* 17 (1):199. doi: 10.1186/s12916-019-1431-5.