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Original Article

Nutritional status and cognitive performance of mother–child pairs in Sidama, Southern Ethiopia

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Abstract

The purpose of this study was to assess the nutritional status and cognitive performance of women and their 5-year-old children using a cross-sectional design. Cognitive performance of mothers and children was assessed with Raven's Colored Progressive Matrices (CPM) and Kaufman Assessment Battery for Children-II (KABC-II). Demographic characteristics, food consumption patterns and anthropometry were also measured. Four rural districts in Sidama, southern Ethiopia served as the setting for this study. Subjects were one hundred women and their 5-year-old children. Mean ± standard deviation age of the mothers was 29 ± 6 years and family size was 7.0 ± 2.6. Maternal body mass index (BMI) ranged from 15.3 to 29.0 with 14% of the mothers having BMI < 18.5. Anthropometric assessment of children revealed 29% to be stunted (height-for-age z-score < –2) and 12% to be underweight (weight-for-age z-score < –2). Mothers' education significantly contributed to prediction of both mothers' and children's cognitive test scores. There were significant differences in mean cognitive test scores between stunted and non-stunted, and between underweight and normal-weight children. Height-for-age z-scores were correlated with scores for short-term memory ($r = 0.42$, $P < 0.001$), and visual processing ($r = 0.42$, $P < 0.001$) indices and weight-for-age z-scores were also correlated with scores of short-term memory ($r = 0.41$, $P < 0.001$) and visual processing ($r = 0.43$, $P < 0.001$) indices. Malnutrition in the community likely contributed to the cognitive performance of the subjects. Performance on memory and visual processing tasks was significantly lower in children with growth deficits suggesting that efficient and cost effective methods to alleviate malnutrition and food insecurity would impact not only child health but also cognitive function.

Keywords: malnutrition, cognition, raven's CPM, KABC-II, Ethiopia, anthropometry.

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Introduction

A number of neurological processes during fetal and postnatal development are vulnerable to poor nutritional status, and cognitive deficits have been associated with malnutrition (Grantham-McGregor 1995; Georieff 2007). Nutrition affects processes ranging from gene regulation to neural systems that involve the infant's behavioural interaction with the environment. The more complex components of behavioural interaction encompass capabilities in various forms of learning, memory and problem solving and are collectively referred to as cognition (Wainwright & Colombo 2006). Neural systems that are involved in cognitive processes differ in their biochemical and functional aspects and have critical times for development. Defects in one part of the neural system because of lack of a certain nutrient may affect a specific type of learning, and memory and nutritional disorders remain a common cause of damage to the nervous system (Gorman 1995; Mendoza-Salonga 2007). Periods of rapid brain growth are characterised by vulnerability for cognitive development. Although the sensitivity of the brain to malnutrition can differ from stage to stage, the actual period for most rapid brain growth is gestation through the first 2 years of life (Tran *et al*. 2010). Regardless of differences across studies, nutrition supplements during the pre-school period had significant effects on broad measures of cognitive development (Gorman 1995). Nutrition plays a decisive role in defining biological and developmental factors that mediate brain growth (Rosales *et al*. 2009).

Widespread malnutrition is often perceived as macronutrient deficits but also includes micronutrient deficiencies (Kretchmer *et al*. 1996). A poor diet will likely result in an inadequate intake of several nutrients. A number of nutrients, specifically iodine, iron, Vitamin B_{12} and perhaps zinc, are related to specific physiological processes that affect early cognitive development (Black 2003).

Stunting during early childhood is associated with cognitive deficits and poor development during later childhood (Walker *et al*. 2007). Major causes of stunting in developing countries are chronic undernutrition and micronutrient deficiencies, particularly zinc. Nationally in Ethiopia, stunting, underweight and wasting of children under 5 years of age were 46.5%, 38.4% and 10.5%. In the Southern Nations and Nationalities Peoples Region where this study was conducted, a similarly large number of children were at risk of malnutrition. Children suffering from stunting, underweight and wasting were 51.6%, 34.7% and 6.5% (Ethiopian Central Statistic Authority 2005).

Twenty-seven per cent of women in Ethiopia has been reported to be chronically malnourished [body mass index (BMI) less than 18.5], while 4% were overweight or obese (Ethiopian Central Statistic Authority 2005). Pregnant women in the study area had a mean plasma zinc concentration of 6.97(1.07) mmol l^{-1} and cognitive performance was associated with their zinc status as measured by Raven's Colored Progressive Matrices (CPM) Scale A (Stoecker *et al*. 2009). To our knowledge, there have been few studies in Ethiopia that have evaluated relation of malnutrition to the cognitive performance of women or children. Thus, this study assessed anthropometric status and cognitive performance of women and their 5-year-old children and determined relations between maternal and child variables. Use of selected test batteries to evaluate maternal and child cognitive performance provided additional insight to the nature of the damage from malnutrition.

Materials and methods

Study design and sampling methods

A cross-sectional community-based study was conducted in rural Sidama Zone, Southern Ethiopia from February to March 2007. Three *kebeles* (the smallest administrative unit) were selected randomly from the Wondogenet district in Southern Ethiopia. Mothers of 5-year-old children were eligible for the study, and the list of these women was obtained from the local health post. Sample size was estimated using GPower version 3.1.2 (Christian-Albrechts-Universität Kiel, Kiel, Germany) (Faul *et al*. 2007). After setting the desired statistical power (0.8), alpha level (0.05) and effect size (0.5), the *t*-test analysis suggested the most

Key messages

- In this study, malnutrition existed in both mothers and children and significantly related to the children's cognitive performance. Community nutrition programmes that address child malnutrition might contribute to alleviate the problem.
- Mothers' education contributed to prediction of most cognitive test scores for both mothers and the children in the regression model. Ways of improving women's education should be set in place in the study area and in the country as children of educated mothers do better in most cognitive tests.
- Community awareness about the gravity of nutritional problems should be promoted.

subjects ($n = 102$). On this basis, 100 women with 5-year-old non-twin children were recruited from the list for this study. After setting the desired statistical power and alpha level, 100 women with 5-year-old non-twin children were recruited from the list for this study. Only women having a 5-year-old child were included. Exclusion criteria were having twins ($n = 1$) or mental instability of a child ($n = 1$). Ethical approval was obtained from the Institutional Review Board of Oklahoma State University and the Ethics Committee of Hawassa University. Consent and assent were obtained from the women and the children prior to initiation of the study. The objective and the methods of the study were explained, and the subjects were asked to give their verbal agreement, which was recorded on an audio tape.

Questionnaire administration

A semi-structured questionnaire was used to collect data on demographic and socio-economic characteristics and household food consumption patterns. The questionnaire and cognitive tests were pre-tested with 10 women who resided in the *kebeles* but were not part of the study. The food consumption pattern was obtained by asking the women how often the household consumed the following food groups: cereals, legumes, fruits, vegetables, animal source foods, and oil. The options included daily, once in 3 days, once in a week, once in 15 days, once in a month, only on holidays and never consumed. Trained Ethiopian research assistants utilised translators to administer the pre-tested questionnaire in the local language.

Anthropometry

Anthropometric measurements were taken for assessment of nutritional status. Heights and weights of women and children were obtained in light-weight clothing without head scarves or shoes. Height was measured to the nearest 0.1 cm using a portable wooden stadiometer (Shorr Productions, Olney, MD, USA), and weight was measured to the nearest 0.1 kg using a digital scale (Uniscale, UNICEF, Copenhagen, Denmark). Measurements were repeated if the first two measures differed more than 0.5 cm for height or 0.1 kg for weight. For children, z-scores for height-for-age and weight-for-age were computed using the WHO AnthroPlus software (World Health Organization, Geneva, Switzerland) (2007). BMI was calculated as (Wt (kg)/Ht (m^2)) for mothers.

Cognitive tests

Raven's CPM (board version) and the Kaufman Assessment Battery for Children-II (KABC-II) were used to evaluate cognition. The KABC-II contains little culture specific content and is designed to minimise verbal interaction. For children, tests from the KABC-II included hand movement, number recall and word order for short-term memory as well as conceptual thinking, triangles and pattern reasoning for visual processing assessment. The particular subscales were selected as appropriate for the Ethiopian context. Children's scores were scaled based on the KABC-II manual to normalise for small age differences (Kaufman & Kaufman 2004). For mothers, the Raven's CPM was used in addition to short-term memory (number recall and word order), visual processing (block counting and rover), and planning (pattern reasoning) indices from KABC-II. For each test, the possible minimum and maximum scores are in parentheses. For all cognitive tests, higher scores indicate better performance. Composite scores for short-term memory and visual processing indices were obtained by adding the scores of each subtest. For each test, a single trained research assistant was assigned for administration to all women and the children.

Raven's CPM

The Raven's CPM has been widely used in multicultural settings (Raven 2000) to evaluate the effect of nutrient deficiency on the ability to reason and solve problems (Neumann *et al*. 2007). The test is made up of 36 coloured designs, each with a missing section. The subject selects from six possible displayed patterns to complete each design (0–36).

Pattern reasoning (KABC-II)

A series of pictures each with one section missing are presented. The subject selects the correct item to complete the series from six available options. The test requires sequential reasoning for logical problem solving and was used to evaluate planning abilities in mothers (0–36).

Block counting (KABC-II)

In this test, the number of blocks in two dimensional pictures of stacked blocks is determined. The test assesses visual memory and ability to identify spatial relations (0–44).

Rover (KABC-II)

The Rover test requires visualisation, distance estimation and the ability to engage in manipulative thinking. The subject must follow rules and find the shortest path to get a toy dog to a bone on a checker board grid with obstacles (0–44).

Triangles (KABC-II)

This test measures the ability to manipulate visual patterns. The subject uses geometric plastic pieces to copy the presented illustrations (0–29).

Conceptual thinking (KABC-II)

This test measures reasoning and classification skills. The subject is shown pictures and asked to point to a picture that does not belong with the other illustrations (0–28).

Number recall (KABC-II)

Subjects are asked to repeat multiple series of several numbers after the examiner. This test measures short-term memory that requires storing information and using it in a few seconds (0–22).

Word order (KABC-II)

This test involves pointing to pictures of common objects in the same order as the examiner. This test also measures short-term memory (0–31).

Hand movements (KABC-II)

This test of short-term memory is conducted by showing patterns of hand taps on a table and asking the child to repeat the same sequences (0–23) (Kaufman & Kaufman 2004).

Data analysis

The data were analysed using WHO AnthroPlus version 1.03 to determine stunting, underweight and body mass index z-scores of children. SAS version 9.1 (SAS Institute Inc., Cary, NC, USA) was used to calculate frequency distributions, means, standard deviations, inter-quartile ranges and correlations. A general linear model was used for analysis of variance and mean separation, and significance level was set at $P \leq 0.05$. Significant Pearson's correlation coefficients guided selection of education, demographic, socio-economic and anthropometric variables for linear regression models. A stepwise procedure was employed to explore relations of these factors to the cognitive test outcomes of mothers as well as children. For the regression models, factors significant at <0.1 were included.

Results

Demographic and socio-economic characteristics

The study population ($n = 200$) was 100 mother–child pairs. Table 1 shows subjects' characteristics. The average family size was 7 ± 3 and 67% of families had more than three children; households had the prospect of growth with the average age of mothers being only 29 ± 5.6 years. Forty-eight per cent of the mothers had never been to school. Animal ownership including poultry was 85%.

Daily consumption of grains was reported by 76%, of legumes by 14%, of fruits by 33% and of vegetables by 33% of the participants. Although animal ownership including poultry was 85%, animal products were rare in the diets of the households. No families reported daily consumption of egg, chicken, meat (beef, mutton) or fish. Weekly consumption of egg was 19%, meat was 4%, chicken was 1% and fish was 1%.

Although 76% of families owned land, nearly 41% of the families had small plots of only about 500–1000 m^2. In this study, 56% of families depended entirely on farming for income and 20% were partially engaged in farming. Most of the houses (93%) were made of mud and wood with thatched roofs. Only 57% of the respondents had windows in their houses. Fifty-nine per cent of the households had built pit latrines but 37% had only unimproved pits. A community tap was the major source (78.8%) of water supply for families in the study area, while others used water sources such as springs and wells.

Table 1. Anthropometric characteristics of women and children in Sidama, Ethiopia

Variables	Mean ± SD*	IQR (25th,75th) or %
Mothers' age (year)	28.7 ± 5.6	(25.0, 34.0)
Mothers' height (cm)	159.3 ± 5.8	(155.0, 163.8)
Mothers' weight (kg)	52.4 ± 6.8	(48.2, 55.8)
Mothers' BMI (kg m^{-2})	20.6 ± 2.4	(19.1, 21.9)
Children's age (mo)	61.0 ± 3.0	(60.0, 63.0)
Children's height (cm)	104.0 ± 6.0	(99.2, 108.9)
Children's weight (kg)	16.4 ± 2.1	(15.0, 18.0)
Stunting (<–2 HAZ)	–1.3 ± 1.3	29%
Children's underweight (<–2WAZ)	–1.0 ± 0.9	12%
Children's <–2 BMIZ	–0.2 ± 0.9	4%

SD, standard deviation; IQR, interquartile range; HAZ, height-for-age z-score; WAZ, weight-for-age z-score; BMIZ, z-score for body mass index.
*Mean and standard deviation (n = 96–100).

Health service was available through local health centres and clinics for all.

Mother and child anthropometrics

Fourteen per cent of the mothers' had a BMI below 18.5 indicating the existence of malnutrition. Four per cent of mothers were overweight and none were obese. Maternal BMI correlated with child weight-for-age ($r = 0.21$ $P = 0.03$) (Table 2). Severe plus moderate stunting totalled 29%; moderate underweight was 12%, and there were no children <–3 z-score for weight-for-age z-score (WAZ). The mean z-score for height-for-age was –1.3 ± 1.3, and weight-for-age was –1.0 ± 0.9. Children with <–2 z-score for body mass index (BMIZ) were 4%, and the mean BMIZ was –0.2 ± 0.9.

Cognitive test scores of mothers and children

For all cognitive tests, higher scores indicate better performance. Both short-term memory and visual processing indices were significantly correlated for mothers and children (Table 2). Mothers' education was significantly correlated to Raven's CPM and to Pattern Reasoning and to composite scores for short-term memory and visual processing indices for themselves and their children. In addition, mothers' education correlated with WAZ of children, and education of the father correlated with height-for-age

Table 2. Pearson correlation coefficient for selected parent–child variables (n = 95–100)

	BMI	M-Sho	M-Vis	M-Ed	F-Ed	M-Rav	M-PR	C-Sho	C-Vis	HAZ
BMI										
M-Sho	0.047									
M-Vis	0.033	0.287**								
M-Ed	0.029	0.476***	0.434***							
F-Ed	–0.077	0.249*	0.195*	0.527***						
M-Rav	0.161	0.366***	0.452***	0.360***	0.246*					
M-PR	–0.007	0.399***	0.374***	0.533***	0.263**	0.402***				
C-Sho	0.184	0.193*	0.087	0.231*	0.213*	0.147	0.243*			
C-Vis	0.051	0.087	0.325**	0.322***	0.202*	0.178	0.344***	0.402***		
HAZ	0.048	0.131	0.082	0.153	0.200*	0.131	0.108	0.426***	0.422***	
WAZ	0.213*	0.102	0.098	0.179*	0.212*	0.150	0.122	0.412***	0.439***	0.754***

BMI, mothers' body mass index; M-Sho, mothers' short-term memory; M-Vis, mothers' visual processing; M-Ed, mothers' education; F-Ed, fathers' education; M-Rav, mothers' Raven; M-PR, pattern reasoning; C-Sho, children's short-term memory; C-Vis, children's visual processing; HAZ, child height-for-age; WAZ, child weight-for-age.
*$P \leq 0.05$; **$P \leq 0.01$; ***$P \leq 0.001$.

Table 3. Analysis of cognitive scores (mean ± standard deviation) for children by categories of HAZ and WAZ using Student's *t* test

	N	Visual†	Tri‡	CT§	PR¶	Short**	WO††	NR‡‡	HM§§
HAZ									
<–2	29	14.7 ± 3.2	2.8 ± 2.0	4.1 ± 1.4	7.9 ± 1.8	18.1 ± 5.8	5.2 ± 2.7	6.2 ± 2.5	6.7 ± 2.1
≥–2	71	17.4 ± 4.1	4.6 ± 2.4	4.7 ± 1.8	8.2 ± 1.8	22.4 ± 5.4	6.8 ± 3.0	7.3 ± 2.2	8.4 ± 2.1
P		0.003	0.001	0.107	0.422	0.001	0.014	0.031	0.001
WAZ									
<–2	12	12.8 ± 2.6	1.7 ± 1.0	3.3 ± 1.3	7.9 ± 1.7	16.2 ± 5.1	4.8 ± 2.0	5.4 ± 2.5	5.9 ± 1.1
≥–2	88	17.0 ± 3.9	4.3 ± 2.4	4.7 ± 1.8	8.1 ± 1.8	21.7 ± 5.6	6.5 ± 3.0	7.1 ± 2.2	8.1 ± 2.1
P		0.003	0.001	0.017	0.726	0.006	0.100	0.025	0.004

HAZ, height-for-age *z*-score; WAZ, weight-for-age *z*-score. †Visual, visual processing (TR + CT + PR) (0–93*). ‡TR, triangles (0–29*). §CT, conceptual thinking (0–28*). ¶PR, pattern reasoning (0–36*). **Short, short-term memory (WO + NR + HM) (0–76*). ††WO, word order (0–31*). ‡‡NR, number recall (0–22*). §§HM, hand movement (0–23*). *The range of possible cognitive test scores.

Table 4. Cognitive test scores of mothers and children analysed by maternal education*†

	Level of education (mean)±standard deviation			
	No education	1–4 years	≥5–8 years	
Mothers	$n = 47–48$	$n = 29$	$n = 23$	*P*-value
Raven's CPM	18.8 ± 3.6[a]	19.6 ± 5.0[a]	22.3 ± 4.0[b]	0.005
Visual processing	19.4 ± 9.1[a]	24.5 ± 10.5[b]	29.6 ± 8.1[c]	<0.001
Short-term memory	23.3 ± 5.6[a]	27.7 ± 6.2[b]	29.6 ± 5.6[b]	<0.001
Pattern reasoning	3.3 ± 2.5[a]	5.9 ± 4.6[b]	8.9 ± 5.8[c]	<0.001
Children	$n = 46–47$	$n = 28–29$	$n = 22–23$	
Visual processing	15.7 ± 3.6[a]	16.5 ± 3.9[a]	19.1 ± 4.3[b]	0.004
Short-term memory	20.2 ± 5.3	21.4 ± 6.4	23.0 ± 5.7	0.15

CPM, colored progressive matrices. *Analysis of variance with least square means separation tests. †Means in a row not sharing a superscript (a, b or c) are significantly different using the least squares means separation test ($P \leq 0.05$).

z-score (HAZ) and WAZ. Based on the correlation between mothers' and fathers' education ($r = 0.52$; $P = 0.001$), men with some formal education married women who had also attended school.

Child malnutrition and cognitive scores

Both HAZ and WAZ were significantly correlated with short-term memory and visual processing indices (Table 2). When nutritional status was categorised as malnourished or adequate based on *z*-scores below or above –2 *z*-score, there were significant differences for children in cognitive test scores analysed by the Student's *t*-test (Table 3). Scores on number recall, hand movements, triangles and for overall short-term memory and visual processing indices were significantly higher in the non-stunted and normal-weight groups compared with the stunted or underweight groups. Conceptual thinking scores were significantly lower in underweight children, and word order scores were significantly lower in stunted children.

Cognitive scores for mothers and children differed between groups based on level of maternal education (Table 4). If mothers had ≥ 5 years of education, children had significantly higher visual processing cognitive test scores. The same pattern of findings applied to mothers; however, in addition, mothers with no formal education scored significantly lower than both other groups on the KABC-II measures.

Predictors of cognitive test scores

A stepwise regression procedure examined the influence of mothers' and fathers' education, mothers' BMI and latrine availability on cognitive performance of mothers (Table 5). Education significantly

Table 5. Stepwise regression showing factors predicting cognitive test scores of mothers*†‡

Variables	β-coefficient	Partial R^2	P-value
Mothers' visual processing $R^2 = 0.23$			
Intercept	14.95		
Mother's education	1.91	0.18	<0.001
Household latrine availability	4.43	0.04	0.017
Mothers' short-term memory $R^2 = 0.22$			
Intercept	21.78		
Mother's education	1.41	0.22	<0.001
Mothers' Ravens CPM $R^2 = 0.26$			
Intercept	9.75		
Mothers education	0.63	0.09	0.001
Household latrine availability	2.95	0.13	0.001
BMI	0.31	0.03	0.049
Mothers' pattern reasoning $R^2 = 0.25$			
Intercept	2.18		
Mother's education	0.98	0.25	<0.001

CPM, colored progressive matrices. *$n = 94$–100. †Range of values for independent variables: mother's education 0–6; household latrine availability 0–1; and BMI 15.2–29.0 kg m^{-2}. ‡Variables tested in the stepwise model were: mothers' education, husbands' education, household latrine availability and mothers' body mass index. All variables that entered the model with a P-value < 0.1 are shown in the table.

Table 6. Stepwise regression showing factors predicting cognitive test scores of children*†‡

Variables	β-coefficient	Partial R^2	P-value
Children's visual processing $R^2 = 0.24$			
Intercept	16.72		
HAZ	1.19	0.17	<0.001
Maternal education	0.49	0.06	0.005
Children's visual processing $R^2 = 0.25$			
Intercept	16.88		
WAZ	1.73	0.19	<0.001
Maternal education	0.46	0.05	0.009
Children's short term-memory $R^2 = 0.24$			
Intercept	25.39		
HAZ	1.91	0.17	<0.001
Household roof type	2.90	0.03	0.012
Family size	–0.38	0.02	0.073
Children's short term-memory $R^2 = 0.20$			
Intercept	22.84		
WAZ	2.59	0.17	<0.001
Household roof type	2.27	0.03	0.043

HAZ, height-for-age z-score; WAZ, weight-for-age z-score. *$n = 94$–100. †Range of values for independent variables: HAZ –4.29 to 1.92; WAZ –3.28 to 0.94; mothers' education 0–6; roof type 0–1; family size 3–16. ‡Variables tested in the stepwise model were: either HAZ or WAZ with mother's education, household head's education, roof type and family size. All variables that entered the model with a P-value < 0.1 are shown in the table.

predicted mothers' visual processing, short-term memory and Raven's CPM and Pattern Reasoning (planning) scores. Additionally, household latrine availability contributed to maternal models for visual processing and Raven's CPM, while BMI contributed only to Raven's CPM score.

For children, HAZ or WAZ with mother's and father's education, roof type and family size were examined. Both HAZ or WAZ and mothers' education contributed significantly to predict the child's visual processing index with the anthropometry explaining most of the variation. For short-term memory, HAZ or WAZ with roof type were the major predictors (Table 6). A regression model including maternal visual processing (which was correlated with maternal education ($r = 0.43$, $P \leq 0.001$) and HAZ or WAZ explained slightly more of the variation in child's visual processing (data not shown). HAZ, household size and roof type (thatch or corrugated iron) were significant predictors for children's short-term memory as were WAZ and roof type.

Discussion

Evaluating the relations of nutritional status of women and children with their cognitive performance was the primary purpose of this study. Secondly, the role of maternal education in cognitive performance of mothers and children was investigated. Although cause and effect cannot be demonstrated with a cross-sectional study and the R^2 of each model is moderate, important demographic and socio-economic characteristics of the subjects were shown to be related to the outcomes. In this study, 48% of the mothers had no formal education. Of the remaining women, more than half had less than 4 years of formal education and only one had attended school for more than 6 years. This lack of education may affect mothers' knowledge regarding healthy food habits and sanitation practices. Increasing maternal education has been shown to be effective in addressing the problem of malnutrition (Christiaensen & Alderman 2001).

Based on UNICEF's conceptual frame work of determinants of malnutrition, maternal illiteracy and unhealthy environment were classified as underlying causes of malnutrition (UNICEF 1997). In our study, maternal education correlated with WAZ of children and education of the husband correlated with HAZ and WAZ. The strong correlation between education of mothers and husbands indicated that men with some formal education tended to marry women who had also attended school. Both parents' education might contribute to the significant improvements in child malnutrition by providing additional income, improved living conditions and better housing. Presence of a latrine, which may reflect readiness to adopt new ideas or technologies, improves the health environment for the household and in our study added 4.4 and 2.9 units to the mother's visual processing and Raven's CPM scores.

The relation between maternal education and cognition in our study was consistent with previous findings showing a link between education and adult cognition measured by Raven's CPM (Smits *et al*. 1997). In our study, each additional year of maternal education was predicted to add 1.9 and 1.4 units to a mother's visual processing and short-term memory scores. Compared with children whose mothers had no education, children of mothers with at least 5 years of education had 22% higher scores for visual processing and 14% higher scores in tests compiled to form a short-term memory index. Similarly, in Brazil, more than 5 years of maternal education improved the child's mean Wechsler Pre-school and Primary Scale of Intelligence – Revised (WPPSI-R) score by 3.9 points (Santos *et al*. 2008).

Animal source foods are rich in key micronutrients related to brain development, such as iron and zinc, as well as macro nutrients (Black 2003; Benton 2008). Most of the households owned animals and poultry but only 2% reported family egg consumption as frequently as three times per week. Meat was available even less frequently, and only 4% of households reported consumption as often as once per week. In this study, in addition to macronutrient deficits, the cognitive test results might also be affected by deficiencies of iodine, iron and zinc based on the rare inclusion of animal source foods or iodised salt in the household diets. Iodised salt was used by only 2% of the households in the study area, but despite low urinary iodine excretion values, UIE was not significantly correlated with cognitive performance (Bogale *et al*. 2009). In a nearby rural area, zinc consumption of pregnant women was reported to be only 5 mg per day (Abebe *et al*. 2008). A randomised control trial was conducted in Kenya in which school children were assigned to four different groups (non-supplemented controls, a traditional plant-based food supplement or the plant-based food with either meat or milk). Fat was added to make the three supplemented groups isocaloric. The group with added meat had a sharp increase in cognitive performance measures among other improved functional outcomes compared with the other groups (Neumann *et al*. 2007).

Anthropometric data obtained from this study shows the presence of malnutrition among the mothers and children in the community. Undernutrition, together with environmental factors such as poor stimulation, can affect children's brain development and cognitive function (Walker *et al*. 2005). Undernutrition also contributes to sensory impairment and lethargy (Hall *et al*. 2001). In addition, poor cognitive performance of children has been related to stunting ($\leq$–2 HAZ), diarrheal disease and parasitic infections in which malnutrition has a role (He *et al*. 2009). Overall for both mothers and the children in our study, the mean cognitive test scores were generally less than half of the maximum possible score. Children's cognitive scores of most indices were severely reduced by malnutrition. In multiple regression models, one unit increase in HAZ would be predicted to raise the child's visual processing and short-term memory scores by 1.2 and 1.9 units, respectively. This result implies the consequence of long-term malnutrition on over-all cognitive development of children. In this model, an increase in family size was predicted to lower the child's short-term memory index by 0.4 units. The presence of recent hunger also significantly reduced the cognitive performance of the children where a unit increase in WAZ predicted 1.7 point and 2.6-point improvement in visual processing and short-term memory indices, respectively. (Table 6). In Bangladesh, cognitive scores, measured by the CPM and the Wechsler abbreviated scale of intelligence, were associated with height-for-age and weight-for-age in children. Age of child, mothers' and fathers' education, as well as socio-economic status indicators such as family income and possession of radio and type of school the children attend were also significantly associated with Raven's CPM in the Bangladeshi study (Tarleton *et al*. 2006). A dietary supplementation and stimulation study of stunted children (9–24 months) in Jamaica resulted in a significant improvement of cognitive test outcomes in all groups (Walker *et al*. 2005).

Poor socio-economic status often has been strongly related to impaired cognitive development of children (Najman *et al*. 2004). Poverty is associated with inadequate food, poor sanitation and limited maternal education among other factors that lead to increased infections and stunting in children (Grantham-McGregor *et al*. 2007). Children from families with fewer socio-economic resources might have less access to cognitively stimulating experiences and materials that restricts their cognitive development. Dietary patterns, psychosocial stimulation and educational exposure of the parents may also contribute to similarities in cognitive function of the child and the mother (Walker *et al*. 2007).

In our study, three-quarters of the families relied at least partially on income from farming despite the fact that 41% had only 500–1000 m^2 of land and family size was large with an average of 7 ± 3) individuals per household. In villages in the study area as families acquire more wealth, they tend to use a corrugated iron roof instead of a thatched roof making the type of roof an indicator of socio-economic status. Living in a house with a corrugated roof predicted an increase of 2.9 units in children's short-term memory scores. A study conducted in Brazil showed poor socio-economic conditions, poor maternal education, stunting and inadequate sanitary facilities at home and in the neighbourhood were among factors negatively associated with cognitive function (Santos *et al*. 2008).

Nutritionally disadvantaged children do not reach their full developmental potential at any age. Our study showed the existence of moderate malnutrition in the community as measured by anthropometry. The limited maternal education, small landholdings, lack of appropriate nutrition knowledge and poverty may contribute to the results. Although it is difficult to explain variation in human studies, the practical significance of our model lies in the fact that the reduced cognitive function of children at 5 years of age might affect their potential to perform academically as well as in society as an adult. Ways of improving women's education and children's malnutrition should be set in place in the study area and in the country as children of educated mothers performed better on cognitive tests. This study assessed only overall malnutrition as an independent variable. Further research is needed in the study area to assess individual micronutrient deficiencies that affect cognitive development and specific cognitive functions.

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Conflicts of interest

The authors declare that they have no conflicts of interest.

Contributions

AB designed the research project, managed in-country logistics, collected, entered and analyzed the data, wrote the first manuscript draft and edited subsequent drafts of the manuscript. BJS designed the research project, advised on study methodology, assisted with the statistical analysis and edited all drafts of the manuscripts. TK advised on study design and interpretation of data and edited the manuscript. LH-T advised on study design and selection of cognitive tests and reviewed the manuscript. DT advised on study design, on cognitive tests and on statistical analysis and interpretation of data and reviewed the manuscript. YA assisted with study design, managed in-country logistics and reviewed the manuscript. KMH advised on study design and reviewed the manuscript.

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