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Correlates of early child development among children with stunting: A cross-sectional study in Uganda

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Abstract

Many children in low- and middle-income countries are not attaining their developmental potential. Stunting is associated with poor child development, but it is not known which correlates of stunting are impairing child development. We explored potential socioeconomic, nutritional, clinical, and household correlates of early child development among 12–59-month-old children with stunting in a cross-sectional study in Uganda. Development was assessed using the Malawi Development Assessment Tool (MDAT) across four domains of gross and fine motor, language, and social skills. Linear regression analysis was used to assess correlates of development in the four domains and total MDAT score. Of 750 children included, the median [interquartile range] age was 30 [23–41] months, 55% of the children resided in rural settings with 21% from female-headed households and 47% of mothers had no schooling. The mean ± standard deviation height-for-age z-score (HAZ) was −3.02 ± 0.74, 40% of the children had a positive malaria test and 65% were anaemic (haemoglobin < 110 g/L). One-third had children's books at home, majority (96%) used household objects to play with and most of them (70%) used toys as pretence items like those to mimic cooking. After age, sex, and site adjustments, HAZ (0.24, 95% confidence interval [CI]: 0.14–0.33) and head circumference (0.07, 95% CI: 0.02–0.12) were positive correlates of total MDAT score, whereas weight-for-height z-score (WHZ) was not. Current breastfeeding was

Henrik Friis and Mette F. Olsen are contributed equally to this study.

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associated with 0.41 (95% CI: 0.17–0.65) lower total MDAT score. Children from households with a single income earner had 0.22 (95% CI: 0.06–0.37) lower total MDAT score. Furthermore, severe food insecurity, inflammation and positive malaria test were associated with lower scores for motor development. All family care indicator subscales (FCIs) positively correlated with the total MDAT score and this association was independent of household's socioeconomic status. In conclusion, stunting degree, head circumference, number of household income earners and stimulation by improved FCIs correlate with early child development among stunted children. The negative association with prolonged breastfeeding is likely due to reverse causality. Identified correlates may inform initiatives to support children with stunting attain their development potential.

KEYWORDS

child development, correlation, Malawi Development Assessment Tool, stunting

1 | INTRODUCTION

Around 250 million children (43%) under 5 years in low- and middle-income countries (LMICs) are at risk of not reaching their developmental potential (Black et al., 2017). Additionally, 22% of children under 5 years exhibit linear growth faltering (UNICEF & World Bank, 2023) which if were eliminated would possibly increase global annual income by ~$176.8 (Fink et al., 2016). The association between stunting and poor child development is well documented (Perkins et al., 2017). Stunted children tend to suffer short- and long-term consequences including increased morbidity and mortality, poor cognitive, motor, and language development, and increased risk of noncommunicable diseases later in life (Koshy et al., 2022; WHO, 2017a, 2017b).

Child development entails the physiological, psychological and emotional changes that occur in humans from conception to the end of adolescence as they progress from dependency to increasing autonomy (Choo et al., 2019). Africa has a high burden of risk factors for poor child development including intrauterine growth restriction, stunting, iodine-deficiency, iron-deficiency anaemia, positive malaria test, lead exposure, HIV, inadequate cognitive stimulation, maternal depression and anaemia during pregnancy (Donald et al., 2019; Ford & Stein, 2016; WHO, 2017a, 2017b). On the contrary, maternal education, higher birth weight and socioeconomic status, and breastfeeding have been identified as protective of child development (Donald et al., 2019; Hadi et al., 2021). Although these have mainly been studied among nonstunted children.

However, it is unlikely stunting per se, but rather the determinants and other correlates of stunting that impairs child development (Leroy & Frongillo, 2019). Therefore, we explored the socioeconomic, anthropometric, clinical and household correlates of early child development among children with stunting in an LMIC setting in Uganda.

Key messages

- Our findings reinforce the association between stunting and early child development.
- The negative association with prolonged breastfeeding is likely due to reverse causality as a result of mothers nursing their smaller, thinner, and more sickly children longer.
- The strong correlation between all family care indicators with development may express the benefit of improved home stimulation such as provision of reading materials and varied play materials on early child development even among already stunted children in poor settings.

2 | METHODS

2.1 | Study design and participants

This was a cross-sectional study using baseline data collected between February and September 2020 as part of the MAGNUS trial (Hannah Pesu et al., 2021) (ISRCTN13093195). As previously described (Hannah Pesu et al., 2021; Mbabazi et al., 2023), the study was conducted at two public health centres in Walukuba division and Buwenge town council in Jinja district of East Central Uganda (Busoga sub region). The current cross-sectional study nested within the RCT uses the maximum available sample at baseline of 750 children. Participants were identified by village health teams in nearby villages. Children with height-for-age z-score (HAZ) <−2 and weight-for-height z-score (WHZ) >−3, were referred to a study clinic for assessment of eligibility. Those found with severe acute malnutrition (SAM) that is WHZ < −3, MUAC < 11.5, or bipedal pitting oedema were referred for treatment. The village-level screening was halted between 26 March to 14 June 2020 due to the global corona pandemic, a period during which specific infection prevention and control study operating procedure was established in compliance with the national and ethical committee regulations.

At the study clinic, children were included if they met the following eligibility criteria: lived within the catchment area, their caregivers were willing to return for follow-up visits and agreed to home visits. Children with SAM, medical complications requiring hospitalisation, a history of peanut or milk allergies, overt disability impeding ability to eat or impeding measurement of length/height were excluded. Children were also excluded if they participated in another study or if their family planned to move away from the catchment area. One child was recruited per household and in case of multiple stunted children, one was randomly selected aided by phone app (True random generator). Nonetheless, the caregiver was asked to take all the children to the study clinic on their appointment day just in case the sampled child did not meet inclusion criteria. Any siblings or twin under 5 years received similar supplements irrespective of their stunting status (unless if SAM) but were not included in the study.

2.2 | Assessment of child development and household stimulation

Child development was assessed using the Malawi Development Assessment Tool (MDAT) version 6 (Gladstone et al., 2010) translated to both Lusoga and Luganda. The tool has been adapted and validated for use in LMICs including Uganda and was developed in an African setting. It focuses on four domains including gross motor, fine motor, language, and social skills with 39, 42, 40 and 36 milestones in each domain, respectively. The MDAT is primarily an observation-based tool with standardised items assessed by a trained research assistant referred to as a child development officer (CDO). During assessments, most of the items were observed while some, mainly in the social domain, were assessed based on caregiver report. Normal age-specific reference values for each domain were used as a starting point while testing each child. The CDO first performed a forward test until the child failed six consecutive items thereby marking the rest of the items above as failed. If the child passed six consecutive items in the forward test, all items below were marked passed; otherwise, a backward test was performed until six consecutive items were passed. To minimise distraction, child development assessments took place in a separate tent located away from the rest of the stations. After every 20 child development assessments per CDO, a quality check was performed by another CDO concurrently and results were compared. In case of any discrepancy, consensus was arrived at in consultation with the respective standard operating procedures and views from other CDOs.

The child's participation during the MDAT assessment was observed by the CDO. This was evaluated based on an adapted version of the Behaviour Observation Inventory from the Bayley Scale of Infant and Toddler Development (Bayley, 2006) as previously used to support MDAT assessment (Olsen et al., 2020; van den Heuvel et al., 2017). It was assessed how happy, engaged, cooperative and anxious, children appeared during the assessment, and how much support their caregiver provided without necessarily influencing the test.

The child's developmental stimulation at home was assessed using an African validated family care indicators (FCI) structured interview (Hamadani et al., 2010). The caregiver was asked about the level of stimulating home environment in four subscales including availability of reading materials at home and their number, source of play materials, variety of play materials, and engagement with an older family member (≥15 years) in various interactive activities over the past 3 days. These activities included reading books, telling stories, singing songs, taking the child out, playing with the child, and counting or drawing with the child.

2.3 | Sociodemographic, socioeconomic and dietary intake data collection

A questionnaire was used to collect data on sociodemographic and socioeconomic information. Breastfeeding status was assessed by asking the mother if the child was still breastfeeding at the time of data collection. Dietary intake was based on 24-h recall and dietary diversity was calculated based on the WHO global nutrition monitoring framework operational guidance that recommends consumption of at least five out of eight food groups including breastmilk in past 24 h (WHO, 2017a, 2017b). Minimum dietary diversity has been documented to be associated with socioeconomic status in low-income settings (Scarpa et al., 2022). Food security was calculated using the USAID household food insecurity access scale (Coates et al., 2007). All caregivers received nutrition counselling using the national guidelines on infant and young child feeding (MOH, 2009).

2.4 | Anthropometric measures

All anthropometric measurements were repeated in triplicate and the median used. Weight was taken using an electronic scale with double weighing function (Seca 876). Length (measured in children < 24 months) and height (measured in children 24 months and older) was taken using a wooden ShorrBoard® (Weigh and Measure) ensuring 5-points of contact with repositioning between measurements. Mid-upper arm circumference (MUAC) and head circumference were measured using a nonelastic MUAC tape (UNICEF SD) and head circumference tape (Seca 212).

2.5 | Blood sampling and analysis

Venous blood was drawn from each child, transported to the field laboratory, processed, and temporarily stored at −20°C before being transported to Kampala for storage at −80°C. Processed samples were later transferred to Denmark and Germany on dry ice for analysis of the micronutrient biomarkers and acute phase proteins as elaborated elsewhere including justification for cut-offs (Mutumba et al., 2023). Before processing, whole blood was used to diagnose malaria (rapid diagnostic test RDT, SD bioline malaria Ag Pf, Abbott) and measure haemoglobin concentration (Hb201+, HemoCue).

2.6 | Data management and statistical analyses

Data was collected using paper case report forms and double entered in EpiData before submission to a secure server periodically. Statistical analysis was done using Stata SE 14 (StataCorp LP). Descriptive statistics are presented as mean ± SD, median [interquartile range] and frequency, *n* (%). We generated internal MDAT developmental age-adjusted z-scores using the generalised additive model for location scale and shape (GAMLSS) (Stasinopoulos et al., 2022) in R software. This model enables fitting regression models where the distribution of the outcome does not fit a typical distribution and allows for fine-tuning of the location, scale, and shape parameters in its construction, to better adapt the model to the shape of the data.

Internal MDAT scores were generated using an item response theory (IRT) analysis through the use of unidimensional 2-paramter-logistic (2PL) models based upon responses to the MDAT. Thereafter, GAMLSS were utilised to then generate an age-contingent measure of ability based on the development scores from the IRT analysis, thus removing the impact of age on development, and converting the outcome to a z-score.

Linear regression analysis was used to assess correlates of gross motor, fine motor, language development, social skills and the total MDAT z-scores. Potential correlates included sociodemographic characteristics (age, sex, current breastfeeding, urban residence and household size), socioeconomic factors (income earners, food expenditure, food insecurity and dietary diversity) and anthropometry (head circumference, HAZ, WHZ and WAZ). We also explored micronutrient status and other clinical factors for their correlation with child development. These included haemoglobin (Hb), anaemia (Hb < 110 g/L), ferritin, iron deficiency anaemia (IDA) (Hb < 110 g/L and serum ferritin < 12 µg/L), serum soluble transferrin receptors (>8.3 mg/L), inflammatory markers serum C-reactive protein (CRP, >10 mg/L) and α−1-acid glycoprotein (AGP, ≥1 g/L), plasma cobalamin (<148 pmol/l), plasma methylmalonic acid (MMA, >0.75 µmol/L) and malaria (positive RDT). The cutoffs used are as previously described (Mutumba et al., 2023) and serum ferritin was corrected for inflammation as described elsewhere (Cichon et al., 2018).

Our analysis included adjustment for age and sex as fixed effects and sites as random effects to obtain adjusted measures at 95% confidence interval (CI) and $p < 0.05$ significance level. FCIs, as proxies for household stimulation, were assessed for their correlation with child development using linear regression analysis. Furthermore, we examined the correlation between the socioeconomic factors with the four respective FCI subscales of (a) children's books at home, (b) sources of play materials, (c) variety of play materials, and (d) family interaction.

2.7 | Ethical statement

The study was approved by the School of Medicine Research and Ethics Committee of Makerere University, Kampala and the Uganda National Council of Science and Technology. A consultative approval was obtained from the Danish National Committee on Biomedical Research Ethics. The study was conducted in accordance with the principles of the Helsinki Declaration (World Medical Association, 2014) and followed local guidelines for human research. All study staff undertook a course in Good Clinical Practice and Human Subject Protection. Oral and written information was provided in Lusoga, Luganda or English. Before caregivers gave written informed consent, their understanding of the information was checked by a different staff member, using a questionnaire.

3 | RESULTS

In this study, 750 children with stunting were enroled. The median [IQR] age was 30 [23–41] months and slightly over half of them resided in rural settings (Table 1). Three-quarters of the households spent more than half of their income on food, nearly half of the children had mothers who had not been to school, and one fifth lived in female-headed households. Of the 95 (12.7%) currently breastfed children, 86 (38.7%) were among 222 children between 12 and 23 months and the remaining 9 (3.5%) among 256 children between 24 and 35 months. Almost half of the children were severely stunted with a mean ± SD HAZ of −3.02 ± 0.74, more than One-third had positive malaria test and about two thirds were anaemic.

The mean ± SD total MDAT score was −0.20 ± 1.00, gross motor: −0.19 ± 1.02, fine motor: −0.13 ± 1.04, language: −0.15 ± 1.03, and social skills: −0.13 ± 1.03. During the assessments, 654 (87%) of the children were assessed as cooperative, 544 (73%) were happy, 714 (95%) very engaged, and 683 (91%) unfearful and without signs of anxiety. Additionally, 593 (79%) of the caregivers were assessed as being supportive to their children during the MDAT assessment.

One-third had children's books at home. Nearly all used household objects as playing materials, about half used home-made toys and one-third had purchased toys (Table 2). Out of the seven varieties of play materials assessed, a large proportion (70%) used imitational materials such as things for pretending to cook, while only few (3%) used toys for learning shapes or colours. Across the six interactive activities that children might engage in with older family members, 'reading books' and 'counting or drawing' were uncommon with only 20% and 29% engaged in these two, respectively (Supporting Information S1: Figure 1). It was mainly mothers who engaged with the children (49%) followed by other relatives (36%) while the fathers were the least engaged, with only 12% found to engage with their children in any interactive activity at home. Notably, 4% of the children had no engagement whatsoever with any older family member during the past 3 days (Supporting Information S1: Figure 1).

TABLE 1 Baseline characteristics of 750 children with stunting.

Sociodemographic data	
Age (months)	30 [23–41]
Male sex	54.9% (412)
Rural residence	55.2% (415)
Household size	5 [4–7]
Socioeconomic status and diet	
Single income earner	70.2% (526)
Female-headed households	21.3% (157)
No maternal schooling	47.4% (338)
Income spent on food >50%	68.4% (513)
Severe household food insecurity (Access)	63.7% (478)
Access to agricultural land	41.5% (311)
Diverse diet[a]	26.3% (196)
Currently breastfed	12.7% (95)
Anthropometric data	
Mid-upper arm circumference (cm)	14.4 ± 1.2
Head circumference (cm)	47.2 ± 1.8
Height-for-age (z-score)	−3.02 ± 0.74
Weight-for-height (z-score)	−0.36 ± 0.99
Weight-for-age (z-score)	−1.93 ± 0.85
Micronutrient and clinical data	
Positive malaria rapid diagnostic test	39.6% (292)
Haemoglobin < 110 g/L	64.5% (479)
Serum C-reactive protein > 10 mg/L	22.0% (163)
Serum α−1-acid glycoprotein ≥ 1 g/L	63.6% (471)
Serum ferritin[b] < 12 µg/L	42.9% (318)
Plasma cobalamin <148 pmol/L	3.5% (25)
Plasma methylmalonic acid >0.75 µmol/L	15.8% (116)

Note: Data reported as mean ± SD, median [IQR] and % (*n*).
[a]Based on minimum dietary diversity score, eating from 5+ of 8 food groups including breastmilk in the past 24 h.
[b]Corrected for inflammation (Cichon et al., 2018).

TABLE 2 Family care indicators of 750 children with stunting.

Children's books at home	
None	66.9% (501)
Any books	33.2% (249)
Sources of play materials	
Home-made toys	55.3% (415)
Purchased toys	36.7% (275)
Household objects	96.3% (722)
Summary score[a]	1.9 ± 0.7
Varieties of play materials	
Things that can make or play music	10.3% (77)
Drawing or writing objects	61.5% (461)
Children's picture books	25.6% (192)
Things meant for stacking, construction, or building	59.1% (443)
Things for moving around (e.g., bicycles)	41.9% (314)
Toys for learning shapes or colours	2.9% (22)
Things for pretending (e.g., to pretend to cook)	70.3% (527)
Summary score[b]	2.7 ± 1.6
Family interaction	
Read books or looked at picture books	19.7% (148)
Tell stories	36.0% (270)
Sing songs	73.7% (553)
Take your child outside the home	56.5% (424)
Played with the child	81.2% (609)
Counted or drew things with the child	28.5% (214)
Summary score[c]	3.0 ± 1.4

Note: For sources of play materials, varieties of play materials, and family interaction, numbers exceed 100 as it was possible to choose more than one option. Data reported as % (*n*) or mean ± SD.
[a]Range from 0 (no source of play material) to 3 (having all source of play materials).
[b]Range from 0 (no varieties play material) to 7 (having all varieties of play materials).
[c]Range from 0 (no family interaction) to 6 (family interaction in all activities).

3.1 | Anthropometric, sociodemographic and socioeconomic correlates

After adjustments for age, sex and site, HAZ was a positive correlate of total MDAT score, whereas WHZ was not (Table 3a). For HAZ, the total MDAT score was 0.24 (95% CI: 0.14–0.33) higher for each 1-unit higher HAZ and reflected associations in all the four MDAT domains. Head circumference was also a correlate of total MDAT score (0.07, 95% CI: 0.02–0.12), driven by associations with gross motor and language scores. Children who were currently breastfed had lower total MDAT score (−0.41, 95% CI: −0.65 to −0.17) than children who had been weaned, with negative associations in all the domains. The association between breastfeeding and MDAT scores was not different between those below and above 24 months (interaction, $p > 0.113$). For the total MDAT score, the associations were −0.32 (95% CI: −0.59 to −0.05) and −0.73 (95% CI: −1.39 to −0.06) respectively (interaction $p = 0.272$). Conversely, compared to the nonbreastfed, currently breastfed children generally had poorer anthropometric indices, with bigger proportion of anaemic and cobalamin deficient cases (Table S1). Additionally, children from households with a single income earner had 0.22 (95% CI: 0.06–0.37) lower total MDAT score. This was driven by

TABLE 3a Anthropometric, sociodemographic and socioeconomic correlates of child development among 750 children with stunting.

Characteristic	Gross motor β (95% CI)	P	Fine motor β (95% CI)	p	Language β (95% CI)	p	Social skills β (95% CI)	p	Total score β (95% CI)	p
Anthropometric data										
Height-for-age z-score	0.28 (0.18–0.37)	<0.001	0.16 (0.06–0.26)	0.002	0.15 (0.05–0.25)	0.003	0.12 (0.02–0.22)	0.02	0.24 (0.14–0.33)	<0.001
Weight-for-height z-score	0.05 (−0.02 to 0.13)	0.16	0.01 (−0.06 to 0.09)	0.71	0.03 (−0.04 to 0.11)	0.40	0.02 (−0.06 to 0.09)	0.68	0.04 (−0.03 to 0.11)	0.29
Head circumference (cm)	0.07 (0.02–0.13)	0.008	0.04 (−0.01 to 0.10)	0.13	0.07 (0.01–0.12)	0.01	0.03 (−0.03 to 0.08)	0.31	0.07 (0.02–0.12)	0.01
Sociodemographic status										
Age (years)	0.08 (0.01–0.16)	0.03	0.06 (−0.02 to 0.14)	0.15	0.06 (−0.01 to 0.14)	0.11	0.01 (−0.07 to 0.09)	0.80	0.06 (−0.01 to 0.14)	0.095
Girl sex	−0.14 (−0.29 to 0.003)	0.05	−0.05 (−0.20 to 0.10)	0.53	−0.08 (−0.23 to 0.07)	0.30	0.22 (0.07–0.37)	0.004	−0.06 (−0.21 to 0.08)	0.38
Urban residence	−0.08 (−0.32 to 0.16)	0.52	−0.12 (−0.37 to 0.18)	0.34	−0.09 (−0.34 to 0.15)	0.45	−0.05 (−0.30 to 0.19)	0.68	−0.11 (−0.35 to 0.13)	0.36
Household size > 5 people	−0.09 (−0.24 to 0.06)	0.23	−0.04 (−0.20 to 0.11)	0.61	−0.06 (−0.21 to 0.10)	0.47	0.13 (−0.02 to 0.29)	0.08	−0.03 (−0.18 to 0.12)	0.70
Socioeconomic status										
Single income earner	−0.19 (−0.35 to −0.03)	0.02	−0.15 (−0.31 to 0.02)	0.08	−0.18 (−0.34 to −0.02)	0.03	−0.12 (−0.28 to 0.05)	0.17	−0.22 (−0.37 to −0.06)	0.008
Income spent on food (>50%)	0.08 (−0.10 to 0.25)	0.38	0.12 (−0.06 to 0.30)	0.18	−0.07 (−0.25 to 0.10)	0.42	−0.02 (−0.20 to 0.15)	0.81	0.06 (−0.11 to 0.24)	0.45
Food insecurity										
Mildly	−0.38 (−0.90 to 0.13)	0.15	−0.33 (−0.86 to 0.21)	0.23	0.07 (−0.46 to 0.59)	0.80	−0.17 (−0.69 to 0.36)	0.53	−0.20 (−0.71 to 0.31)	0.43
Moderately	−0.25 (−0.62 to 0.13)	0.20	−0.08 (−0.47 to 0.31)	0.69	−0.14 (−0.53 to 0.24)	0.47	0.08 (−0.30 to 0.46)	0.68	−0.15 (−0.52 to 0.22)	0.44
Severely	−0.47 (−0.83 to −0.11)	0.01	−0.18 (−0.55 to 0.19)	0.35	−0.26 (−0.63 to 0.11)	0.17	−0.02 (−0.39 to 0.34)	0.91	−0.30 (−0.65 to 0.06)	0.10
No diverse diet	0.11 (−0.17 to 0.39)	0.44	0.08 (−0.21 to 0.37)	0.60	−0.16 (−0.44 to 0.13)	0.28	−0.09 (−0.37 to 0.20)	0.54	0.01 (−0.27 to 0.29)	0.93
Female-headed households	−0.09 (−0.27 to 0.09)	0.35	−0.04 (−0.23 to 0.14)	0.65	−0.04 (−0.23 to 0.14)	0.64	0.07 (−0.11 to 0.25)	0.46	−0.07 (−0.25 to 0.11)	0.45
No maternal schooling	−0.11 (−0.26 to 0.04)	0.15	−0.11 (−0.27 to 0.04)	0.15	−0.06 (−0.21 to 0.10)	0.47	0.05 (−0.10 to 0.20)	0.54	−0.13 (−0.28 to 0.01)	0.08
Currently breastfed	−0.31 (−0.55 to −0.06)	0.01	−0.25 (−0.50 to 0.003)	0.05	−0.32 (−0.57 to −0.07)	0.01	−0.55 (−0.80 to −0.30)	<0.001	−0.41 (−0.65 to −0.17)	0.001

Note: Data reported as regression coefficients (95% CI), adjusted for age, sex and study site. For categorical variables, the following references were used: girls versus boys, currently versus not currently breastfed, urban versus rural residence; household size >5 versus ≤5; single versus more than one income earner, income spent on food < versus ≥50%, food insecurity versus food secure; no diverse versus diverse diet.

negative associations with language, gross and fine motor although the latter was only marginally significant. Finally, severe household food insecurity was associated with lower developmental scores in the gross motor domain (−0.47, 95% CI: −0.83 to −0.11).

3.2 | Micronutrient and clinical correlates

Neither Hb nor any of the micronutrient or inflammatory markers were associated with total MDAT score (Table 3b). Elevated serum AGP and positive malaria RDT were negative correlates of gross motor scores. Whereas very low plasma cobalamin was insignificantly associated with low development, elevated plasma MMA, a specific marker of cobalamin deficiency, was associated with lower fine motor score.

3.3 | Household correlates

All FCIs were associated positively with total MDAT score (Table 3c) For every 1 more children's book owned at home, there was an associated 0.23 (95% CI: 0.08–0.38) higher total MDAT score. Additionally, having more than 2 sources of play materials, more than 3 varieties of play materials and more than 3 interactions with family members were associated with 0.18 (95% CI: 0.002–0.37), 0.40 (95% CI: 0.24–0.55) and 0.23 (95% CI: 0.07–0.38) higher total MDAT scores, respectively. The >3 varied play materials and >3 family interactions had positive associations across all the four MDAT domains. Having children's books at home correlated with gross and fine motor, and language skills (marginally) but did not correlate with acquisition of social skills. On the contrary, having >2 sources of play materials correlated with language and social skills acquisition (marginally) but did not correlate with gross and fine motor development. The observed associations were independent of the households' SES and thus were retained after further adjustments for maternal schooling and/or number of income earners (Supporting Information S1: Table 2).

Further exploration of the characteristics of stimulative households, children from those households with a single income earner and no maternal schooling were negatively associated with all the four FCIs (Supporting Information S1: Table 3). In addition, urban residence was associated with having more sources of, and varied play materials. We did not observe any differences by sex and estimates suggested that older children received more stimulation especially with regard to sources and variety of play materials.

4 | DISCUSSION

In our study among 1–5-year-old children with stunting, linear growth status and head circumference positively correlated with child development scores, whereas ponderal growth status was not associated. Children from households with a single income earner and those that were breastfed had lower development scores. Similarly, we found that lower scores in some specific child development domains were associated with inflammation, cobalamin status, and positive malaria test. Finally, we found all indicators of family care to be associated with higher child development scores and that this was independent of household's SES.

Our findings concur with recent literature that has reported stunting to be associated with delayed development with odds ratios (ORs) ranging between 3.0 and 3.71 (Hikmahrachim & Ronoatmodjo, 2020; Oumer et al., 2022; Rosyidah et al., 2021). A meta-analysis noted stunting increased the risk of abnormal development 3.7 times compared to nonstunted < 5 year-old children (Rosyidah et al., 2021). Findings from other studies have confirmed both growth faltering and head circumference to be related to cognitive outcomes at 2 years (Scharf et al., 2018) as well as in older children aged 6−12 years (Mutapi et al., 2021; Poh et al., 2013), and among HIV-exposed but uninfected children (Sirajee et al., 2021).

The negative association between current breastfeeding and child development is contrary to reports from previous studies, where breastfeeding has been associated with better development, especially motor skills, with effect sizes ranging from 0.5 to 10.9 between breastfed versus nonbreastfed (Bernardo et al., 2013; Horta et al., 2015; Quinn et al., 2001; Sacker et al., 2006). However, the results of these studies are prone to confounding, and in adjusted analyses, the effect sizes between breastfed versus nonbreastfed tend to be attenuated: 0.4–8.2 (Bernardo et al., 2013; Hernández-Luengo et al., 2022; Horta et al., 2007; Horta et al., 2015; Quinn et al., 2001; Sacker et al., 2006). In fact, Renee et al. who studied the extent to which confounding explained the association between breastfeeding duration and cognitive development up to 14 years of age, reported that adjusting for SES tended to halve the effect sizes, while further adjustment for maternal cognitive scores explained the remaining association at 5 years of age, while there was still an effect at ages 7, 11 and 14 (Pereyra-Elías et al., 2022). In line with this, a systematic review of 17 studies in Sub-Saharan Africa concluded that much of the effect of breastfeeding that is, exclusive or prolonged breastfeeding on child development has to do with 'who breastfeeds' and that confounders are rarely adequately considered in analyses (Mohammed et al., 2022). In fact, prolonged breastfeeding in itself has been associated with undernutrition in several studies (Briend & Bari, 1989; Syeda et al., 2021). One study reported the odds of severe development delay were higher among children breastfed in third year (adjusted OR, AOR: 6.19, 95% CI: 3.31−11.56) compared to children breastfed in their second year of life (AOR: 2.84, 95% CI: 1.18−4.46) (Syeda et al., 2021). In another systematic review, all studies identified poor growth and nutritional status in children breastfed for >1 year (Lackey et al., 2021). The negative association between prolonged breastfeeding and nutritional status could be a result of reverse causality. This has been demonstrated in studies (Caulfield et al., 1996; Grummer-Strawn, 1993; Marquis et al., 1997) showing that still breastfed children were shorter and lighter than their nonbreastfed counterparts of the same age. This is in line with

TABLE 3b Micronutrient and clinical correlates of child development among 750 children with stunting.

Characteristics	Gross motor β (95% CI)	p	Fine motor β (95% CI)	p	Language β (95% CI)	p	Social skills β (95% CI)	p	Total score β (95% CI)	p
Haemoglobin (Hb, g/L)	0.005 (−0.001 to 0.01)	0.08	−0.00 (−0.01 to 0.004)	0.90	0.002 (−0.003 to 0.01)	0.42	−0.00 (−0.01 to 0.01)	0.98	0.002 (−0.002 to 0.01)	0.29
Anaemia (Hb <110 g/L)	−0.06 (−0.22 to 0.09)	0.42	0.04 (−0.12 to 0.20)	0.61	−0.02 (−0.18 to 0.14)	0.83	0.07 (−0.09 to 0.22)	0.41	−0.02 (−0.17 to 0.13)	0.81
Serum ferritin[a] (μg/L)	−0.14 (−0.35 to 0.06)	0.18	−0.01 (−0.22 to 0.21)	0.94	−0.04 (−0.25 to 0.17)	0.72	0.08 (−0.13 to 0.29)	0.45	−0.09 (−0.29 to 0.12)	0.40
24+	Ref		Ref		Ref		Ref		Ref	
12–<24	0.15 (−0.04 to 0.35)	0.13	0.06 (−0.14 to 0.27)	0.55	0.15 (−0.05 to 0.35)	0.14	0.06 (−0.14 to 0.26)	0.53	0.17 (−0.02 to 0.36)	0.08
<12	0.12 (−0.08 to 0.32)	0.26	0.01 (−0.20 to 0.21)	0.95	0.09 (−0.12 to 0.29)	0.41	0.002 (−0.20 to 0.21)	0.98	0.12 (−0.07 to 0.32)	0.22
Serum transferrin receptor >8.3 mg/L	0.10 (−0.06 to 0.25)	0.23	0.04 (−0.13 to 0.20)	0.66	−0.004 (−0.16 to 0.16)	0.96	0.10 (−0.06 to 0.26)	0.21	0.06 (−0.10 to 0.21)	0.46
Serum AGP (g/L)										
<0.8	Ref		Ref		Ref		Ref		Ref	
0.8–1.2	−0.18 (−0.40 to 0.03)	0.09	−0.04 (−0.26 to 0.18)	0.74	0.18 (−0.04 to 0.40)	0.10	−0.12 (−0.33 to 0.10)	0.29	0.02 (−0.19 to 0.23)	0.82
1.2+	−0.29 (−0.49 to −0.09)	0.01	−0.06 (−0.27 to 0.15)	0.59	0.03 (−0.18 to 0.24)	0.80	−0.15 (−0.36 to 0.06)	0.16	−0.13 (−0.33 to 0.08)	0.22
Plasma cobalamin (pmol/L)										
222+	Ref		Ref		Ref		Ref		Ref	
148–<222	0.12 (−0.07 to 0.31)	0.21	0.10 (−0.10 to 0.30)	0.33	0.09 (−0.11 to 0.28)	0.37	0.32 (0.13–0.51)	0.001	0.14 (−0.04 to 0.33)	0.13
<148	0.03 (−0.38 to 0.43)	0.90	−0.03 (−0.45 to 0.39)	0.89	−0.04 (−0.45 to 0.37)	0.85	0.14 (−0.27 to 0.54)	0.51	−0.02 (−0.41 to 0.38)	0.93
Plasma MMA (μmol/L)										
<0.45	Ref		Ref		Ref		Ref		Ref	
0.45–0.75	−0.08 (−0.29 to 0.12)	0.42	−0.27 (−0.48 to −0.07)	0.01	−0.16 (−0.36 to 0.05)	0.14	0.02 (−0.18 to 0.22)	0.85	−0.18 (−0.38 to 0.02)	0.07
>0.75	−0.10 (−0.31 to 0.11)	0.36	−0.22 (−0.44 to 0.001)	0.05	−0.002 (−0.22 to 0.22)	0.98	0.14 (−0.07 to 0.36)	0.19	−0.10 (−0.31 to 0.11)	0.34
Malaria (RDT positive)	−0.17 (−0.33 to −0.01)	0.03	0.02 (−0.14 to 0.14)	0.80	−0.13 (−0.29 to 0.04)	0.13	−0.02 (−0.18 to 0.14)	0.80	−0.13 (−0.28 to 0.03)	0.11

Note: Data reported as regression coefficients (95% CI), adjusted for age, sex, and study site.

Abbreviations: AGP, α-1-acid glycoprotein; MMA, methylmalonic acid; RDT, rapid diagnostic test.

[a]Corrected for inflammation (Cichon et al., 2018).

our findings including by (Mutumba et al., 2023), given that on top of poorer anthropometric indices, breastfed children had more anaemia and cobalamin deficient cases compared to the nonbreastfed, all suggesting that the poor development was not due to breastfeeding per se but rather the prolonged breastfeeding was being used as a countermeasure to other nutritional, clinical or physiological disruptions.

Our findings that inflammation and a positive malaria test were associated with lower gross motor scores concur with recent cohort studies among mother−child dyads and younger children < 2 years (Heesemann et al., 2021; Olsen et al., 2020) that also found elevated serum AGP and positive malaria tests to be associated with lower developmental scores. It should be noted that malaria remains one of the greatest contributors to morbidity and mortality in sub-Saharan Africa, including Uganda where almost half of children had a positive malaria RDT in the 2016 DHS (ICF, U. B. o. S. U. a., 2017). Moreover, a study by Milner et al. further revealed that the association between malaria infection and early childhood development was actually mediated by anaemia (Milner et al., 2020). We did not find Hb or anaemia to be associated with child development scores. Previous studies have reported inconsistent results; studies in India (Heesemann et al., 2021) and Burkina Faso (Prado et al., 2017), respectively, found higher Hb to be associated with improved child development and higher test scores, while a Ugandan study found lower Hb levels to be associated with reduced psychomotor scores at 15 months of age and no evidence that anaemia or IDA were associated with cognitive or motor scores at 5 years (Nampijja et al., 2022).

We found all FCI subscales to correlate with higher total MDAT score. Our results concur with findings from the iLiNS trial where variety of play materials positively correlated with both language and motor development (Prado et al., 2017). Indicators of family care are crucial for ascertaining whether families provide their children with an enabling environment that would in turn lead to positive developmental outcomes. Results from our exploratory analysis showed that households with a single income earner and no maternal schooling correlated with poor FCIs across all four subscales. Poor home stimulation is a key factor affecting development of children living in impoverished areas like LMICs (Black et al., 2017). With chronic undernutrition, this becomes double-jeopardy as such children are at high risk of developmental delay. Despite challenges in ascertaining as to whether it's poverty or lack of stimulation affecting development, understanding the stunted children's home environment is key for planning and selecting appropriate mitigation measures.

Our findings on children's interaction with older family members concur with some previous studies alluding that compared to fathers, mothers interact more with the children (McBride & Mills, 1993). Children experience rapid growth and development during early years as they learn new things vital for their future success. Prospective studies have shown that family environment, and play are associated with literacy skills (Nyah, 2021). Moreover, mothers have been shown to participate in childrearing activities at higher

TABLE 3c Family care indicators as correlates of child development among 750 children with stunting.

	Gross motor		Fine motor		Language		Social skills		Total score	
	β (95% CI)	p	β (95% CI)	p	β (95% CI)	p	β (95% CI)	p	β (95% CI)	p
Any children's book at home	0.27 (0.11–0.42)	0.001	0.19 (0.03–0.35)	0.02	0.15 (−0.004 to 0.31)	0.06	0.13 (−0.03 to 0.28)	0.12	0.23 (0.08–0.38)	0.003
Sources of play materials > 2	0.06 (−0.13 to 0.24)	0.55	0.16 (−0.04 to 0.35)	0.11	0.20 (0.01–0.39)	0.04	0.16 (−0.03 to 0.35)	0.10	0.18 (0.002–0.37)	0.048
Variety of play materials > 3	0.32 (0.15–0.48)	<0.001	0.25 (0.09–0.42)	0.003	0.37 (0.21–0.54)	<0.001	0.30 (0.13–0.46)	<0.001	0.40 (0.24–0.55)	<0.001
Family interaction > 3	0.22 (0.06–0.38)	0.01	0.14 (−0.02 to 0.30)	0.09	0.19 (0.03–0.35)	0.02	0.28 (0.12–0.44)	0.001	0.23 (0.07–0.38)	0.004

Note: Data reported as regression coefficients (95% CI), adjusted for age, sex and study site.

rates than fathers and this pattern holds for both dual-earner and single-earner families (McBride & Mills, 1993). Notably, fewer children with stunting in our study had access to books (33%), moreover with low motor scores which could partly explain the limited reading, and counting/drawing interaction as observed being the activity with the highest proportion of children not engaged by their older family members. This is alluded to in a study among Jamaican children on behaviour and development of stunted and nonstunted children in which the former were more apathetic, with less enthusiasm and varied exploration, less happy and more fussy than the latter (Gardner et al., 1999).

Among the key strengths of our study include the large sample size of stunted children, the wide range of exposures explored and the use of an African developed tool validated in Uganda. However, the cross-sectional nature of our study limits the ability to establish causal relationships and having studied only stunted children limits comparability with studies among nonstunted children. We relied on caregiver reports for such information like on FCIs, which may be subject to recall and information bias.

5 | CONCLUSION AND RECOMMENDATIONS

We found that among children with stunting, HAZ was positively associated with all child development domains. FCIs were consistently correlated with better scores, independent of socioeconomic status. If these associations reflect cause-effect relationships, then there may be a potential for development of interventions to alleviate impaired development associated with stunting. The negative association between prolonged breastfeeding and development is most likely explained by reverse causality, but this may warrant further research.

AUTHOR CONTRIBUTIONS

The authors' contributions were as follows: Henrik Friis, Benedikte Grenov, Ezekiel Mupere, Hannah Pesu, Joseph Mbabazi and Rolland Mutumba designed the MAGNUS study. Hannah Pesu, Benedikte Grenov, Henrik Friis, Ezekiel Mupere, Joseph Mbabazi and Rolland Mutumba wrote the trial protocol. Henrik Friis and Ezekiel Mupere were principal investigators. Joseph Mbabazi, Rolland Mutumba, Hannah Pesu and Benedikte Grenov implemented the study and Ezekiel Mupere, Joseph Mbabazi, Hannah Pesu, Rolland Mutumba and Benedikte Grenov supervised data collection. The statistical analysis plan was developed by Henrik Friis, Christian Ritz and Mette F. Olsen. Statistical analysis was performed by Joseph Mbabazi and all coauthors interpreted the results. This manuscript was written by Joseph Mbabazi with input from Mette F. Olsen. All authors critically reviewed and approved the final version of the manuscript. Benedikte Grenov, Joseph Mbabazi, Rolland Mutumba and Henrik Friis accessed and verified the data. Joseph Mbabazi and Mette F. Olsen had final responsibility for the decision to submit the manuscript for publication.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

The Ugandan act on Data Protection and Privacy and the European act on General Data Protection Regulation do not allow for personal data to be made available to other researchers without prior written approval from relevant institutions and authorities. The Data Protection Officer of the University of Copenhagen can be contacted about data inquiries at dpo@adm.ku.dk.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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