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Association between birth length, linear growth velocities, and primary school achievement at age 10 years: evidence from the Ethiopian iABC birth cohort

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Abstract

Background Childhood is a period marked by dynamic growth. Evidence of the association between childhood linear growth and school achievement comes mostly from cross-sectional data. We assessed associations between birth length, childhood linear growth velocities, and stunting with school achievement.

Methods Newborns were recruited into the Ethiopian infant Anthropometry and Body Composition (iABC) birth cohort and followed from birth to 10 years. Velocities from 0 to 6 years were computed using linear spline mixed effect modelling. Stunting (height-for-age < -2 z-scores) was assessed at the ages of 1, 2, 4, 5, and 6 years. School achievement was measured by having a high (≥ 80%) combined high math, English, and science (MES) score and being at appropriate grade-for-age. Logistic regression models assessed associations between birth length, linear growth velocities and stunting with school achievement.

Results Children's mean age was 9.8 years (standard deviation, SD 1.0, range 7–12 years). A 1 SD greater birth length increased the odds of achieving a high MES combined score by 1.42 (95% CI: 0.99, 2.03). A 1 SD increase in linear growth velocity from 6 to 24 months increased the odds of being in the appropriate grade-for-age by 1.66 (95% CI: 1.14, 2.43). Stunting at ages 4 and 6 years was associated with lower odds of achieving a high MES combined score: 0.43 (95% CI: 0.20, 0.93) and 0.31 (95% CI: 0.11, 0.89), respectively. Faster post-natal linear growth was not associated with school achievement.

Conclusion Greater birth length and higher growth velocity from 6 to 24 months were associated with higher school achievement and being in the appropriate grade-for-age, respectively. Children who experienced growth failure were less likely to achieve a high MES score. Interventions aimed at improving school achievement should address maternal and fetal nutrition and health, and monitor post-natal growth.

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Keywords Linear growth velocity, Stunting, School achievement, Grade-for-age, Ethiopia

Background

Primary education lays a crucial foundation for future academic success and personal development [1]. Despite increased access to education in the low- and middle-income countries [2], in 2019, 18% of primary school-age children in Sub-Saharan Africa were out of school, 36% did not complete primary education, and 23% were over-age for their grade [3]. Educational achievement (or school performance) is influenced by individual factors, including nutritional status, class absenteeism, household socio-economic status, parental education, and parental involvement, as well as school-related factors such as teacher quality, teaching methods, and teacher-pupil ratios [4, 5]. Growth is a function of nutrition and health, and its progression is a sign of adequate nutrition [6]. Nutrition from conception through childhood is vital for neurodevelopment, impacting processes ranging from neuron proliferation to neural apoptosis [7]. As a result, nutrition is likely to affect cognitive, motor, and socio-emotional abilities, all of which impact on school achievement [7, 8].

Our current understanding of the associations between childhood growth and school achievement is mainly from studies of linear growth faltering, i.e., stunting (height-for-age < -2 z-scores). Studies conducted in Ethiopia, India, Peru, Vietnam and Malawi have found that stunting was associated with lower cognitive development and school performance [9–11]. Research from Nepal also indicates that poor linear growth from birth to 2 years of age increases the likelihood of entering pre-primary school late and completing less schooling by the age of 8.5 years [12]. However, these studies have only examined linear growth up to the age of 2 years, initial enrollment age and attained grade, rather than achievement.

In Ethiopia, evidence of the link between linear growth and school achievement comes from prospective studies of stunting [9, 11] or from cross-sectional studies [13, 14]. Given the dynamic nature of early childhood growth and its different sensitive periods [15], examining linear growth velocities may provide insights into critical periods of growth and their potential association with school achievement. There is a scarcity of evidence assessing the association between linear growth velocities and stunting at various points during childhood with school achievement. To fill this gap in knowledge, this study aimed to assess the associations between birth length, linear growth velocities and stunting from 0 to 6 years of age with educational achievement (using a math, English and science (MES) combined exam score) and attending the appropriate grade-for-age at 10 years. This study helps to identify critical periods of growth when interventions could enhance school achievement, particularly in resource-constrained areas where undernutrition and poor educational outcomes are common.

Methods

Study setting and participants

This study was part of the prospective infant Anthropometry and Body Composition (iABC) birth cohort in Jimma town, Ethiopia, which has population of ~240,000 [16] and is located 350 km southwest of the capital city, Addis Ababa. Mother-newborn pairs were recruited from Jimma University Specialized Hospital between December 2008 and October 2012.

Newborns were enrolled in the study within 48 h of delivery. Inclusion criteria included birth weight of ≥1500 g, absence of congenital malformations, term delivery according to the Ballard score [17], and residence in Jimma town. Details of the sample size calculation and recruitment process have been explained elsewhere [18, 19]. A total of 644 newborns were initially assessed. After excluding 10 preterm births and 63 infants not residing in Jimma, 571 children were entered into the study. Children were followed from birth to 10 years and invited to participate 14 times: at birth, 1.5, 2.5, 3.5, 4.5, 6 months, and at 1, 1.5, 2, 3, 4, 5, 6, and 10 years of age. At the 10-year follow-up, 355 children were included; of these, 276 and 343 children had full-year MES scores and current grade data, respectively.

Data collection and measurements

Outcome variables: school achievement

School achievement was measured using two markers. The first marker was exam scores in math, English and science ranging from 0 to 100% collected directly from official school records. School name, grade and type of school (private or public) were also recorded.

Schools in Ethiopia do not adhere to a common curriculum to guide teaching and learning [20]. However, all schools teach math, English and science. These subjects are globally recognized as core components of primary education [21]. For instance, the Program for International Student Assessment (PISA) evaluates student performance in these three essential subjects on a global scale [22].

For our first outcome variable, ‘high exam score’ (yes/no), we performed principal component analysis (PCA) to explore potential groupings among math, English, and science. Although English appeared as a separate component on the component loading graph (Supplementary Fig. 1), its loading (0.566) was similar to those of science (0.582) and math (0.584). As a result, we combined the scores for math, English, and science (MES), using the unweighted mean of these three subjects in subsequent analyses. Considering that undernutrition impacts the proportion with higher cognitive development more than the average cognitive function [23], we categorized the MES combined score based on the Ethiopian educational system's national cut-off of ≥80% for scoring 'very good or above' [24].

Our second marker of school achievement, 'appropriate grade-for-age' (yes/no), indicated whether a child was progressing through school as expected. A lower grade-for-age suggests either late enrollment in pre-primary or primary grade 1, or grade repetition. Grade repetition indicates academic failure or insufficient exam scores to advance to the next grade [25]. Grade-for-age was calculated by subtracting the child's current grade from the expected grade, based on the official age of entry into primary grade one, which is 7 years in Ethiopia [3]. According to the United Nations Educational, Scientific and Cultural Organization (UNESCO) classification, children are considered to be in a lower grade-for-age if they are at least 2 grades behind the expected level for their age [26]. Thus, grade-for-age was categorized as a binary outcome based on this classification [26], with negative one and above indicating attendance in the appropriate grade-for-age, and negative two and below indicating attendance in a lower grade-for-age.

Main exposure: length/height measurements

Trained nurses measured all children and administered the questionnaires to their mothers. A SECA 416 Infantometer (Seca, Hamburg, Germany) was used to measure length for children aged less than 24 months, and a SECA 213 (Seca, Hamburg, Germany) was used to measure height for children aged 24 months and above. Measurements were taken at birth, 1.5, 2.5, 3.5, 4.5, 6 months, and at 1, 1.5, 2, 3, 4, 5, 6 and 10 years. Each measurement was taken in duplicate to the nearest 0.1 cm, and mean length/height was calculated.

Covariables

Covariables were selected based on a review of relevant literature, from which a conceptual framework was developed (Supplementary Fig. 2) [9–11, 14, 27, 28]. Head circumference at birth was measured in duplicate using a non-stretchable tape, and the mean was taken. Data on maternal age, maternal education level, and the infant's birth order were obtained at enrollment. Maternal education was categorized as per the Ethiopian education system: none, primary (1–8 years), secondary (9–12 years) and higher (college and universities). Mothers were asked about household wealth, which recorded ownership of material possessions: car, motorcycle, bicycle, electric stove, refrigerator, mobile phone, land line telephone, television, radio, access to electricity, source of drinking water and type of latrine. A wealth index was then computed from these material possessions using PCA [29].

Statistical methods

Data were double-entered and verified using EpiData version 4.4.2.0, then exported to Stata version 16 (StataCorp LLC, College Station, Texas, USA) for data management and analysis. For continuous variables with normal distributions, means and standard deviations (SD) were reported. Categorical variables were expressed as percentages.

Computing exposure variables

Our first exposure variable was 'childhood linear growth velocity'. Given the curvilinear nature of linear growth over time, linear spline mixed effects modelling (LSMEM) was used to model growth from 0 to 6 years of age. The model included children who had at least 2 length/height measurements from birth to 6 years. LSMEM assesses growth as a function of time. Compared to fractional polynomial, LSMEM provides coefficients which are easier to interpret. LSMEM computes random intercepts -each child's length at birth-, and random slopes -each child's linear growth rates [30]. A linear spline consists of a series of connected linear lines assumed to have a similar velocity between knot points (pre-defined age at which each linear pieces are connected) and varying velocity across knot points. Several knot points were tested based on domain knowledge, prior literature [31], and our observed data. The model with knot points at 3, 6, 24, 48, and 76 months of age achieved the lowest Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC). Consequently, child-specific length at birth and linear growth velocities between 0 and 3 months, 3–6 months, 6–24 months, 24–48 months, and 48–76 months of age were obtained and treated as separate exposures.

Velocities between each knot point were calculated by subtracting the predicted values at two consecutive knot points and then dividing by the time interval between them, expressed in cm/month. For instance, the 3–6 months linear growth velocity was determined by subtracting the predicted length at 3 months from the predicted length at 6 months, and dividing this difference by 3. To ensure comparability, length at birth and linear growth velocities were converted into sex-specific z-scores. Standardized values for length at birth and linear growth velocities from 0 to 3 months, 3–6 months, 6–24 months, 24–48 months, and 48–76 months were used for subsequent analyses in separate models. Velocities were computed using R statistical software, version 4.2.2 (R Foundation for Statistical Computing, Vienna, Austria).

Our second exposure variable, 'stunting', was determined using WHO cut-offs. The predicted length or height measurements were used to compute stunting status. For children under 60 months, the z-score06 Stata package was used to compute height-for-age z-score (HAZ) [32]. For children 60 months and older, the WHO Reference 2007 Stata macro package was used to compute HAZ [33].

Testing the association of linear growth velocities and stunting with school achievement

The associations between length at birth and linear growth velocities with a high MES combined score and appropriate grade-for-age separately using three multiple logistic regression models. Similar multiple logistic regression models were used to assess the association between stunting and school achievement. Model 1 adjusted for sex and current age. Model 2 included Model 1 plus head circumference at birth, birth order, and gestational age. Model 3 included Model 2 and additionally adjusted for maternal educational status, household wealth index, maternal age and child's school type. Since grade-for-age was calculated based on current age, the child's current age was not included in the grade-for-age models. Goodness-of-fit was assessed using the Hosmer-Lemeshow test.

Students within the same school share similar learning environments, making them more alike compared to students from different schools. As a result, errors between observations would not be independent, thus violating one of the assumptions of logistic regression [34]. Therefore, failing to account for potential clustering effects could lead to inaccurate standard errors, confidence intervals, *t*-statistics, and *p*-values. Each school was therefore assigned a unique identifier, and all regression outputs were adjusted for clustering, resulting in estimates based on cluster-robust standard errors.

Four sensitivity analyses were conducted to test the robustness of our results. The first sensitivity analysis was conducted without accounting for school clustering. Since linear growth serves as a proxy for nutritional status, which can also affect head circumference, we excluded head circumference from Models 2 and 3 in the second sensitivity analysis. Data was predicted based on observed data and the assumptions of LSMEM. Thus, a third sensitivity analysis was carried out to examine whether the constants and coefficients derived from the observed and predicted data differed (sex- and age-adjusted model) using suest test (Seemingly unrelated estimation test). A fourth sensitivity analysis was conducted for each of the subject scores separately (math, English and science).

Results

Participant description

A total of 644 children were recruited at birth. Due to loss to follow-up or incomplete attendance at some follow-up visits, the number of participants varied over time. At the 10-year visit, 355 children were followed up, but 2 were excluded due to having fewer than 2 linear growth measurement from birth to 6 years (Fig. 1).

Among the 353 children followed up at the 10-year visit, 276 (78.2%) had complete MES combined score and 343 (97.2%) had data on their current grade. The average age of participants was 9.8 years (SD 1), 51.8% were male, and 65.6% attended private schools (Table 1). Children lacking school achievement data had younger mothers, were from poorer households, first-born, and had a lower birth weight. However, other maternal and child characteristics were similar to those with school achievement data (Supplementary Table 1).

Linear growth accretion rate

Figure 2 illustrates length at birth and linear growth velocities of three children to show how predicted data from LSMEM fitted with observed data. Linear growth velocities had different distributions at different time points. Children grew rapidly from 0 to 3 months, with an average linear growth velocity of 4.0 cm/month (SD 0.3), and more slowly from 48 to 76 months, with a velocity of 0.6 cm/month (SD 0.03) (Table 2).

School achievement

The mean MES combined score was 73 (SD 13). The average scores were 74 (SD 15) for math, 72 (SD 15) for English, and 75 (SD 14) for science. Approximately one-third (35.5%) of children had a high MES combined score (≥80%), while 11.9% were in a lower than expected grade-for-age.

Association of length at birth, linear growth velocities, and stunting with school achievement

Associations between birth length, linear growth velocities from 0 to 3, 3–6, 6–24, 24–48 and 48–76 months and school achievement at 10 years are presented in Fig. 3 (regression results are reported in Supplementary Table 2). A 1 SD increase in length at birth increased the odds of achieving a high MES combined score by 1.42 (95% CI: 0.99, 2.03, $p=0.055$). However, post-natal linear growth velocities were not associated with a high MES combined score.

Length at birth and linear growth velocity from 6 to 24 months showed a significant positive association with appropriate grade-for-age in Model 1. However, after adjusting for maternal and child characteristics and school type, only the association of linear growth velocity from 6 to 24 months remained statistically significant. A

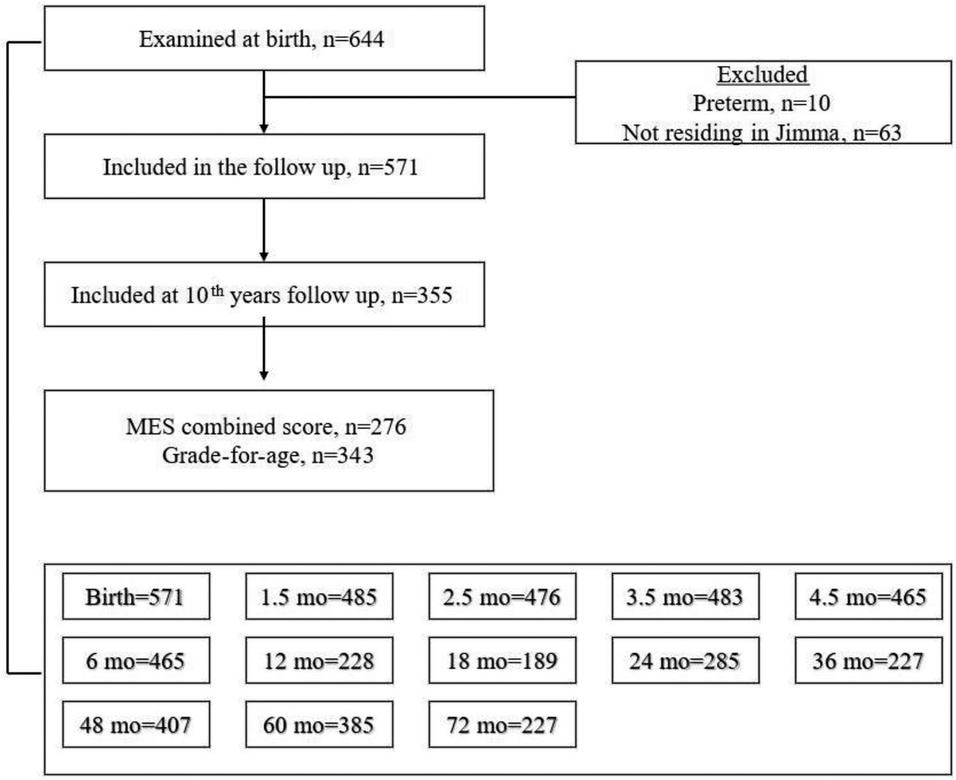

Fig. 1 Flow chart of study participants included in the iABC follow-ups. Out of 355 children included at the 10-year follow-up, 2 were excluded because they had less than 2 linear growth measurements from 0–6 years, leaving 353 for the 10-year analysis. MES = math, English and science. mo = months

1 SD increase in velocity was associated with higher odds of being in the appropriate grade-for-age, 1.66 (95% CI: 1.14, 2.43) (Fig. 3).

Children who were stunted at ages 4 and 6 years had a decreased odds of achieving a high MES combined score: adjusted odds ratio (aOR) 0.43 (95% CI: 0.20, 0.93) and aOR 0.31 (95% CI: 0.11, 0.89), respectively (Fig. 4). In Model 1, stunting at ages 1, 2, 4, 5, and 6 years was negatively associated with being in the appropriate grade-for-age. However, this association was no longer statistically significant except for stunting at 2 years of age, aOR 0.39 (95% CI: 0.18, 0.88) after adjusting for child and maternal characteristics. Ever being stunted decreased the odds of scoring a high MES combined score: aOR 0.47 (95% CI: 0.27, 0.83) and was negatively associated with appropriate grade-for-age in Model 1. However, this association was not statistically significant in the final model (Supplementary Table 3). All p-values for the Hosmer-Lemeshow test were higher than 0.05, indicating that the models fitted the data well (Supplementary Table 4).

Sensitivity analyses

The first sensitivity analysis was conducted without accounting for school cluster and the results did not differ significantly from the cluster-adjusted results (Supplementary Tables 5–6). In the second sensitivity analysis excluding head circumference, the existing association between birth length and high MES combined score was no longer significant (Supplementary Table 7). In the third sensitivity analysis, the regression coefficients for predicted and observed data did not differ at any time point (Supplementary Table 8). In the fourth sensitivity analysis, the regression coefficients for models analyzing math, English, and science scores separately were broadly similar to those obtained for the MES combined score (Supplementary Tables 9–11).

Discussion

This study assessed the association between birth length, linear growth velocity from 0 to 6 years, and stunting with school achievement at 10 years. Children experienced the fastest growth during the first 6 months of life, with the highest growth rate observed between 0 and 3 months, followed by 3–6 months. Higher birth length was associated with achieving a high MES combined score. Stunting at 4 and 6 years were negatively associated with achieving a high MES combined score. Linear growth velocity from 6 to 24 months was positively associated with being in the appropriate grade-for-age. Stunting at age 2 was inversely associated with being in the appropriate grade-for-age.

Table 1 Maternal, household and child characteristics of children at the 10-year follow-up

Characteristics	% or Mean (SD)
Maternal and household characteristics at delivery of cohort child	
Maternal age (years)	24.8 (SD 4.7)
Maternal Education (level)	
No school	21 (5.9%)
Primary	214 (60.6%)
Secondary	67 (19.0%)
Higher	51 (14.4%)
Wealth index	
Poorest	54 (15.4%)
Poor	62 (17.7%)
Middle	86 (24.6%)
Rich	82 (23.4%)
Richest	66 (18.9%)
Child characteristics	
Gestation (weeks)	39.0 (SD 1.0)
Birth weight (kg)	
≤ 2.5	30 (8.5%)
>2.5 to 3.0	116 (33.1%)
>3.0 to 3.5	152 (43.3%)
>3.5	53 (15.1%)
Birth order	
First-born	172 (48.7%)
Second-born	95 (26.9%)
≥ Third	24.4% (86)
Sex (Male)	183 (51.8%)
Head circumference at birth (cm)	34.9 (SD 1.6)
Stunted at 1st year of life (Yes)	31 (19.5%)
Stunted at 2nd year of life (Yes)	52 (24.6%)
Stunted at 4th year of life (Yes)	66 (20.4%)
Stunted at 5th year of life (Yes)	46 (14.7%)
Stunted at 6th year of life (Yes)	22 (12.1%)
Age at 10-year follow-up (years)	9.8 (SD 1.0)
Type of school (Private school)	198 (65.6%)

n, number. %, percentage. SD, standard deviation

Several mechanisms may explain how growth rates relate to school outcomes. One potential mechanism might be brain development, which could link birth length to primary school achievement. The prefrontal cortex, the brain region responsible for high-order cognition required for academic success, is sensitive to pre-natal exposures [35]. Evidence suggests that fetal growth is associated with both neurodevelopment [36, 37] and school attainment [37]. Birth measurements serve as proxy indicators of the pre-natal environment, and could potentially explain the observed association between birth length and a high MES combined score in our study. Previous research has assessed the association between birth length and post-natal linear growth with intelligence quotient (IQ) and cognitive development [43, 44]. In these studies, birth length was consistently associated with IQ and cognitive function.

Our study found a positive association between linear growth accretion rate from 6 to 24 months and being in the appropriate grade-for-age at 10 years. Similarly, a study from Nepal demonstrated that children with poorer linear growth from birth to 2 years were more likely to have below 2 years of schooling by age 8.5 [12]. The first 1,000 days are critical for both growth and cognitive development [38], and evidence suggests that the most effective way to address educational inequalities would be to intervene during these early years, before nutritional deficiencies arise [38, 39].

Stunting, indicative of multiple adverse exposures, can compromise brain development during critical early developmental periods [7]. Our study found that stunting at ages 4 and 6 were inversely associated with a high MES combined score. Similarly, another study noted that stunting in late childhood had a stronger association with being overage-for-grade compared to early childhood stunting [10]. In our study, experiencing stunting at any point between 0 and 6 years was associated with lower odds of achieving a high MES combined score. Studies from Malawi [10] and the Young Lives cohort in Ethiopia, India, Peru, and Vietnam [9] have also reported associations between stunting at various ages and grade attainment at ages 11 and 15, respectively. Poor childhood linear growth in a rural Indian cohort was associated with increased drop-out rates in secondary school [40].

Multiple factors may explain the association between stunting and school achievement. Nutrition plays a crucial role in brain development, influencing cognition and IQ, which are essential for success in school [7]. Stunting, however, is a multifactorial syndrome that is caused by a variety of factors, including nutritional deficiencies and repeated infections [41]. Infections can impair nutrition by either reducing appetite or increasing the energy expenditure required to fight illnesses. Consequently, children who are ill not only experience poor growth, but may also struggle with engagement and performance in school [42].

Stunted children may receive insufficient psychosocial stimulation and show reduced engagement with their environment [43]. This lack of stimulation may lead to delayed synaptic pruning, a process that typically starts after the first year of life [44]. Additionally, these children may exhibit lower neuroplasticity, which is essential for cognition and learning [7, 8], These factors are likely to negatively impact on school achievement and retention.

Stunted children may also be more likely to be absent from school, which would disrupt their learning [45]. They may exhibit behavioral and learning difficulties, including reduced activity levels and attention, which may diminish their interest in education [46]. Furthermore, stunted children generally look smaller for their age. As a result, children who are not as engaged with

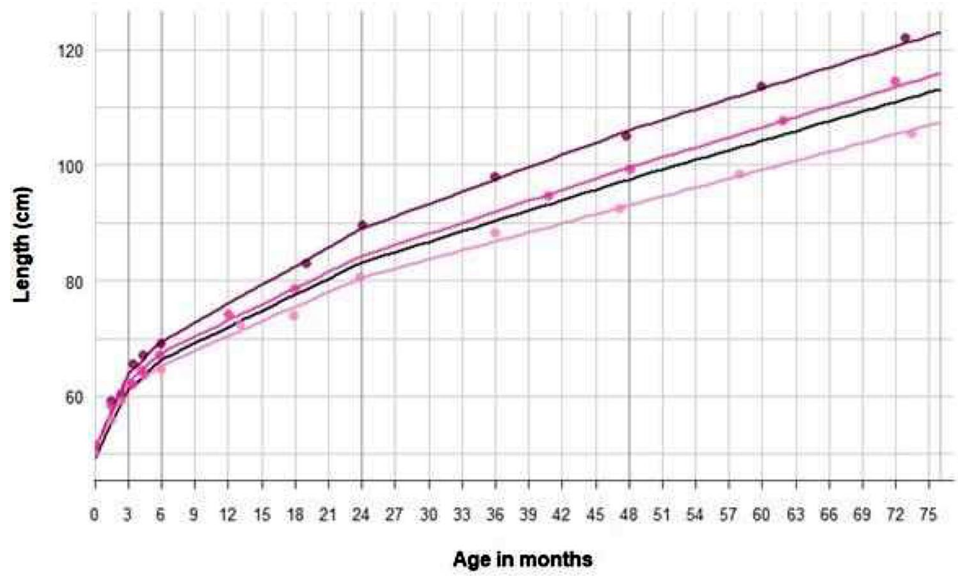

Fig. 2 A linear growth velocity model based on linear spline mixed effect modelling. The black line represents the fixed effect, and the colored lines represent the child-specific velocities of randomly selected three children. Observed data for these children are represented by dots

Table 2 Distribution of length at birth and linear growth velocities from 0–6 years ($n=353$)

Variable	Mean	SD	Min	Max
Length at birth (cm)	49.3	1.6	43.0	53.6
Linear growth velocities (cm/month)				
0–3 months	4.0	0.3	3.4	4.7
3–6 months	1.7	0.2	1.2	2.4
6–24 months	0.9	0.1	0.7	1.3
24–48 months	0.6	0.1	0.4	0.8
48–76 months	0.6	0.03	0.5	0.6

SD, standard deviation. Min, minimum. Max, maximum

their external environment, or who seem smaller in size for their age may be treated differently by parents and other adults. Parents may therefore enroll them into school at an older age [12]. The reasons outlined above might explain the association of stunting with lower grade-for-age in our study.

The first sensitivity analysis, which excluded school clustering, yielded results similar to models adjusting for clustering. This absence of major variability between schools may be attributed to the high proportion of students attending private schools. In our second sensitivity analysis, excluding head circumference showed that the association between birth length and high MES a combined score was no longer statistically significant. When head circumference was included in the model, birth length was associated with a high MES combined score. This implies that if all children had the same head size, then better educational outcomes would be expected from those with greater birth length. The third sensitivity analysis found that the regression coefficients for stunting computed from predicted and observed data were not different across time points.

Strengths and limitations

To our knowledge, this is the first study to assess the relationship between linear growth velocities from birth through childhood with primary school achievement (both a MES combined score and grade-for-age) in Sub-Saharan Africa. Another strength is that we followed children prospectively from birth to 10 years. We also used LSMEM to compute linear growth accretion rates, which accounts for the non-linear relationship between length/height and age, providing easily interpretable coefficients. LSMEM does not require children to have measurements at every visit.

Our study also had some limitations. Among children who were followed up at 10-years, 20% did not have a math, English or science score. Children not included in the school achievement analysis had younger mothers, came from poorer households, were first-born, and had lower birth weights; however, other maternal and child characteristics did not differ. Variables such as child feeding practices and morbidity were not taken into account, and these may confound the association between early growth and educational outcomes. Data on parent-child interaction, maternal and child IQ and school-based factors were also not collected, and these could affect school achievement. However, school-related factors were controlled for in models through the adjustment of each school as a cluster term, which provided cluster-robust estimations.

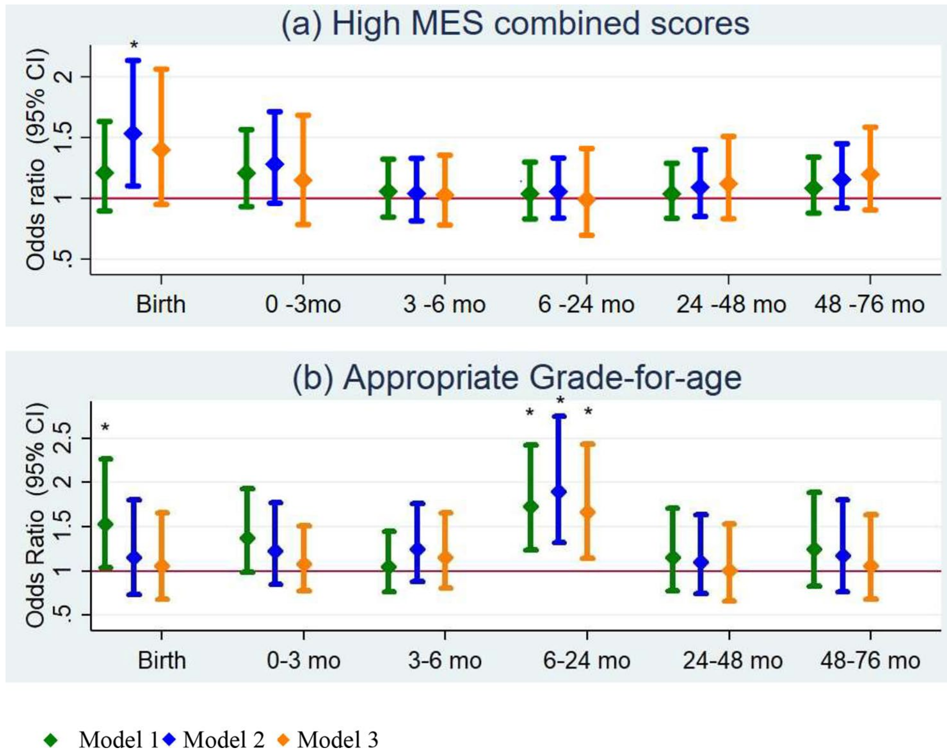

Fig. 3 Association between length at birth and linear growth velocities with (**a**) a high MES combined score and (**b**) appropriate grade-for-age at 10 years. The Y-axis shows Odds Ratios from multiple logistic regression models with 95% Confidence Intervals. $^{*}p < 0.05$. Model 1 adjusts for age and sex. Model 2 includes Model 1 plus head circumference at birth, birth order, and gestational age. Model 3 includes Model 2 plus maternal schooling, wealth index, maternal age, and school type. Age was not considered in grade-for-age models since grade-for-age was calculated based on age. The reference groups in models were < 80 MES combined score and attending a lower grade-for-age. MES = math, English and science. mo = months. CI, Confidence Interval. Data reported in Supplementary Table 2

Implications

Following the Millennium Development Goals [47], which concluded in 2015, and the current Sustainable Development Goals [48], countries have focused on universalizing primary education. However, beyond enrollment, school achievement is also critical, as it forms the foundation for subsequent educational progression and success, as well as overall national development. Brain development, which is crucial for cognitive development and school performance, begins early during conception and continues through adulthood. However, the brain is particularly sensitive to environmental factors during the early years. Identifying these critical periods is vital for designing interventions to enhance primary school achievement. This will contribute to reducing educational inequalities and achieving broader national and international development objectives.

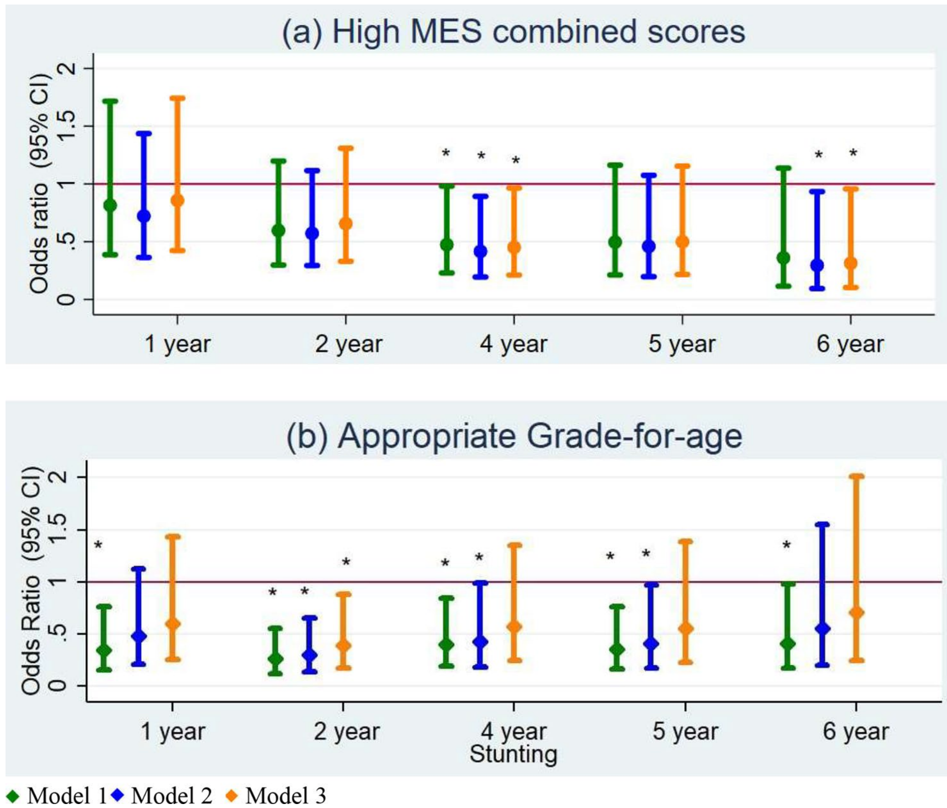

Fig. 4 Association between stunting at different ages with (**a**) a high MES combined score and (**b**) appropriate grade-for-age at 10 years. The Y-axis shows Odds Ratios from logistic regression models with 95% Confidence Intervals. *$p < 0.05$. Model 1 adjusts for age and sex. Model 2 includes Model 1 plus head circumference at birth, birth order, and gestational age. Model 3 includes Model 2 plus maternal schooling, wealth index, maternal age, and school type. Age was not considered in grade-for-age models since grade-for-age was calculated based on age. The reference groups in models were <80 MES combined score and attending a lower grade-for-age. MES = math, English and science. mo = months. CI, Confidence Interval. Data reported in Supplementary Table 3

Conclusion

Birth length was associated with a high MES combined score at 10 years of age. In addition, linear growth velocity from 6 to 24 months was associated with appropriate grade-for-age. Stunting at 2 years of age and later were found to reduce the likelihood of higher achievement at 10 years of age. Interventions aimed at improving school performance should comprehensively address both maternal and fetal nutrition and health to ensure optimal early growth and development. Additionally, these interventions should incorporate regular post-natal growth monitoring for early identification of growth faltering and intervention to improve growth. In low- and middle-income countries where stunting is common, improving primary school achievement should also include addressing chronic malnutrition and promoting child growth.

Abbreviations

HAZ	Height-for-age z-score
LSMEM	Linear Spline Mixed Effects Model
MES	Math, English and science combined score

Supplementary Information

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Supplementary Material 1

Supplementary Material 2

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Author contributions

The authors' responsibilities were as follows HF, JCKW, TG, DY, GSA, RW, MFO, MA, AAM and RA designed the study; RA, BZ and BSM supervised the data collection; HF, JCKW, TG, GSA, RW, MFO, MA, AAM and RA participated in methodology; RA analyzed the data and interpreted the findings and RW and AAM contributed to the analysis. RA wrote the first draft of the manuscript and had responsibility for the whole work. RA, AAM, JCKW, RW and MA had primary responsibility for the final content. All authors contributed to the manuscript revisions and read the final manuscript and approved it for submission.

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Data availability
The datasets generated and/or analysed during the current study are not publicly available due confidentiality and ethical issues but are available from the corresponding author on reasonable request.

Declarations

Ethical approval and consent to participate
Ethical approval for this study was granted by Jimma University Ethical Review Board of the College of Public Health and Medical Sciences (Reference IHRPHD/333/18) and the London School of Hygiene and Tropical Medicine (Reference 15076). Detailed information about the study was provided, and informed written consent was obtained from mothers or caregivers. For illiterate mothers or caregivers, the information was explained in detail in the presence of an impartial witness. Both the mothers or caregivers and the witness signed the consent forms. No copies of school achievement data were retained, ensuring that confidentiality was maintained.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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