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Postinfancy growth, schooling, and cognitive achievement: Young Lives[1–4]

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ABSTRACT

Background: Early life growth failure and resulting cognitive deficits are often assumed to be very difficult to reverse after infancy.

Objective: We used data from Young Lives, which is an observational cohort of 8062 children in Ethiopia, India, Peru, and Vietnam, to determine whether changes in growth after infancy are associated with schooling and cognitive achievement at age 8 y.

Design: We represented the growth by height-for-age *z* score at 1 y [HAZ(1)] and height-for-age *z* score at 8 y that was not predicted by the HAZ(1). We also characterized growth as recovered (stunted at age 1 y and not at age 8 y), faltered (not stunted at age 1 y and stunted at age 8 y), persistently stunted (stunted at ages 1 and 8 y), or never stunted (not stunted at ages 1 and 8 y). Outcome measures were assessed at age 8 y.

Results: The HAZ(1) was inversely associated with overage for grade and positively associated with mathematics achievement, reading comprehension, and receptive vocabulary. Unpredicted growth from 1 to 8 y of age was also inversely associated with overage for grade (OR range across countries: 0.80–0.84) and positively associated with mathematics achievement (effect-size range: 0.05–0.10), reading comprehension (0.02–0.10), and receptive vocabulary (0.04–0.08). Children who recovered in linear growth had better outcomes than did children who were persistently stunted but were not generally different from children who experienced growth faltering.

Conclusions: Improvements in child growth after early faltering might have significant benefits on schooling and cognitive achievement. Hence, although early interventions remain critical, interventions to improve the nutrition of preprimary and early primary school–age children also merit consideration. *Am J Clin Nutr* 2013;98:1555–63.

INTRODUCTION

Health and nutrition in the first 2 y of life are fundamental determinants of linear growth and are critical for child survival (1–3), the prevention of morbidity (2, 3), motor development (4), cognitive development and achievement (5–12), and schooling (12–14). Worldwide, 171 million children (167 million in developing countries) <5 y old have growth stunting, which is defined as a height-for-age *z* score (HAZ)[5] >2 SDs below the reference for their age and sex (15).

Researchers and policymakers often assume that growth failure and resulting cognitive deficits are very difficult to reverse after ∼2 y of age, and health and nutritional interventions directed toward older children who have already experienced growth failure may not be effective (16–18). As a result of this focus on early life, initiatives directed to older preschool and school-age children may not be considered worthwhile. Consequently, decisions about where to invest development resources are often made on the assumption that the window of opportunity closes at age 2 y.

Recent evidence from multiple settings has suggests that a meaningful recovery from early growth failure can take place

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[5] Abbreviations used: aHAZ(1), age-adjusted height-for-age *z* score at 1 y; EGRA, Early Grade Reading Assessment; HAZ, height-for-age *z* score; HAZ(1), growth by height-for-age *z* score at age 1 y; PPVT, Peabody Picture Vocabulary Test; uHAZ(1:8), height at age 8 y that was unpredicted by the age-adjusted height-for-age *z* score at age 1 y; YL, Young Lives.

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(19–21). Studies of children who experienced prenatal (22, 23) or postnatal (24, 25) undernutrition showed that it is possible to recover from early growth deficits and experience cognitive outcomes similar to those of children who never experienced stunting. However, previous studies that showed a relation between recovery and cognitive outcomes have come from highly selected populations (19) or may have been biased by the high correlation between the initial height and subsequent growth (8, 20, 25). We addressed these limitations by studying population-based cohorts by using a conditional growth measure that is not correlated with the initial HAZ, which allowed for a more-accurate examination of the association of postinfancy growth with key developmental outcomes. We assessed the association of postinfancy changes in height with schooling and cognitive achievement by age 8 y. We hypothesized that postinfancy improvements in linear growth (after age 1 y) would be positively associated with schooling advancement and cognitive development.

SUBJECTS AND METHODS

We analyzed data from Young Lives (YL), which is a study of 8062 children in Ethiopia, India, Peru, and Vietnam enrolled at ∼1 y of age in 2002. Subsequent waves of data collection occurred in 2006 when the children were 4–5 y old (round 2) and in 2009 when the children were 7–8 y old (round 3). Hereafter, we refer to children's ages as 1, 5, and 8 y old, respectively. A multistage sampling strategy was used to identify study participants. In the first stage, 20 clusters were selected in a semipurposive fashion that took account of demographic, geographic, policy, and socioeconomic variables to allow for oversampling of poor clusters within a range of diverse contexts. Nationwide sampling frames were used in all locations but India, which used a statewide sampling of Andhra Pradesh. Within each cluster, ∼100 households with a child ∼1 y of age were randomly selected. Less than 2% of selected households refused to participate. There was only one study child per household. Additional details regarding country-specific sampling protocols and strategies are available in country reports.

Child nutritional status

Supine length (at age 1 y) and height (at ages 5 and 8 y) were measured to 1 mm by using standardized length boards and stadiometers. The HAZ was calculated with reference to the 2006 and 2007 WHO reference distributions (26, 27). The HAZ in round 1 was inversely associated with age at recruitment in all 4 countries. Failure to adjust for this age trend would have biased estimates of the change in HAZ between ages 1 and 8 y. Therefore, we adjusted the HAZ to the value at 1 y (age-adjusted height-for-age z score at 1 y [aHAZ(1)]) by adding the difference between the child's observed HAZ and the mean country-specific HAZ for all children within 1 mo of the child's age to the mean country-specific HAZ for children aged 11–13 mo. This adjustment was preferable to adding age as a covariate in the model because the adjustment did not assume a linear relation between the HAZ and age.

The variability in growth between ages 1 and 8 y is only partly predicted by the HAZ(1). We computed the height at age 8 y that was unpredicted by the age-adjusted height-for-age z score at age 1 y [uHAZ(1:8)] as the residuals from regressing growth by height-for-age z score at age 8 y on aHAZ(1) alone for each country separately. This measure captured both upward and downward deviations from the linear growth trajectory that would have been predicted given only the aHAZ(1) (28–32). Because the HAZ is already sex specific, we did not calculate uHAZ(1:8) separately by sex.

Stunting at ages 1 and 8 y

We developed a 4-category representation of growth based on the aHAZ(1) and growth by the height-for-age z score at age 8 y, namely recovered (stunted at age 1 y and not stunted at 8 y), faltered (not stunted at age 1 y and stunted at age 8 y), persistently stunted (stunted at ages 1 and 8 y), or never stunted (not stunted at ages 1 or 8 y; considered the reference). The mean change in the HAZ varied by category as follows: recovered [range: from 1.08 (Vietnam) to 1.88 (Ethiopia)], faltered [range: from −1.45 (Ethiopia) to −0.85 (Peru)], persistently stunted [range: from 0.15 (Vietnam) to 0.83 (Ethiopia)], and never stunted [range: from −0.08 (Ethiopia) to 0.03 (Peru)]. These results suggested that the average change for children in recovered and faltered groups was substantial.

Schooling overage

The primary caregiver provided information at age 8 y on whether the child was currently enrolled in school and the highest grade completed. With the use of this information, we defined schooling overage as whether or not there was a difference ≥1 y between the child's current grade and the grade that the child would have been in if he or she initially entered school at the appropriate age and progressed one grade per school year. Delayed entry into school was the most common reason for schooling overage.

Mathematics achievement

A mathematics test was administered in round 3 by using 29 items on counting, number discrimination, knowledge of numbers, and basic operations with numbers. Interviewers read questions aloud to avoid a bias resulting from poor reading skills. The YL study team tested the psychometric characteristics of the mathematics scores and corrected some scores for items with poor indicators of reliability and validity (33).

Reading comprehension

The Early Grade Reading Assessment (EGRA) from the World Bank Living Standards Measurement Study was used to assess verbal achievement (34). This test is typically administered orally and used to evaluate the most basic skills for literacy acquisition in early grades, including prereading skills such as listening comprehension. The YL adaptation of the EGRA explored the child's ability to identify familiar words, read and comprehend a small text, and to understand a small text read to them. In each language pilot, the EGRA met psychometric standards as a reliable and valid measure of early reading skills (33).

Receptive vocabulary

The Peabody Picture Vocabulary Test (PPVT) was administered. The PPVT uses items that consist of a stimulus word and a set of pictures and is commonly used to represent child cognitive and intellectual ability in developing countries (7, 9). The Spanish PPVT (125 items) was used in Peru, whereas the PPVT III (204 items) was used in Ethiopia, India, and Vietnam. The PPVT was adapted and standardized by YL researchers in each country. Findings were assessed by an extensive analysis of psychometric characteristics, which indicated a high reliability and validity. Raw scores were standardized by using established criteria (33).

Child, household, and community characteristics

Child measures included the sex of the child, age in months in round 3, the language in which cognitive tests were taken [to control for the documented bias from the language of the examination (33)], and whether the child was tested in his or her native language. Household measures included an asset index [the first component derived from a principal components analysis by using 9 consumer durables, 5 indicators of housing quality, and 4 indicators of sanitation and service availability (*see* Table S1 under "Supplemental data" in the online issue)], maternal and paternal schooling (in grades attained), mother's age (in y), whether the household moved since round 1, and an urban or rural residence in round 1. The asset index was constructed by pooling data across the 3 rounds to capture the context during the period from 1 to 8 y old. Community measures were derived from values in round 1 and included the presence of a hospital, population, and community wealth (calculated as the average asset index value for other households in the community).

Ethics

The YL protocol was reviewed by the Ethics Committee of Oxford University. Ethical approval for this analysis was obtained from the University of Pennsylvania Institutional Review Board.

Sample for analysis

We analyzed data on children who were between ages 6 and 17.9 mo at the initial observation [from 96.5% (Vietnam) to 100% (Ethiopia) of total observations] and excluded children who did not have HAZs for all 3 rounds [from to 4.1% (Vietnam) to 8.4% (Ethiopia) of total observations] or children with changes in HAZs between rounds that were >4 SDs [from 0.1% (Vietnam) to 3.9% (Ethiopia) of total observations]. Our resulting final sample size was 7266 children (87.9% of initial observations for Ethiopia, 90.8% of initial observations for India, 90.0% of initial observations for Peru, and 94.4% of initial observations for Vietnam). Mothers of excluded children were shorter but had higher levels of schooling than did children retained in the study (*see* Table S2 under "Supplemental data" in the online issue).

Statistics

We conducted multivariable regressions for each of the outcomes on each growth indicator [aHAZ(1), uHAZ(1:8), and stunting status at ages 1 and 8 y] by controlling for the set of child and household and community characteristics separately by country. For schooling overage, we used multivariable logistic regressions, and for cognitive test scores, we used ordinary least-squares regressions. We used multiple imputation procedures to fill in missing values for the child, family, and community characteristics by using the ice command in Stata 12.1 software (StataCorp LP) and the option of 25 imputations. We allowed for clustering of SEs by the community of residence in round 1.

We undertook a range of examinations to explore the robustness of our findings. To enable comparisons in estimates for each cognitive outcome, we calculated effect sizes from coefficient estimates and SEs. For each growth indicator, we tested whether dividing growth into 2 periods (ages 1–5 and 5–8 y) improved the model fit, which it did not (*see* Tables S3and S4 under "Supplemental data" in the online issue). Thus, we present models by using growth from 1 to 8 y of age. We also estimated a pooled model with country interactions to formally test for heterogeneity of associations by country. We examined heterogeneity by sex and by urban or rural residence by using specifications in which all right-side variables were interacted separately with an urban or rural residence and with the sex of the child (*see* Tables S5–S12 under "Supplemental data" in the online issue). We explored nonlinearities of continuous predictors by including squared terms (*see* Table S13 under "Supplemental data" in the online issue). Last, according to Kling et al (35) and Clingingsmith (36), we also calculated the average (standardized) effect sizes by using the seemingly unrelated regression framework to permit covariance across the 3 test outcomes (*see* Table S14 under "Supplemental data" in the online issue).

RESULTS

The mean aHAZ(1) for each country was below -1.00 with Ethiopia experiencing the lowest aHAZ(1) (**Table 1**). The average paternal schooling was lowest in Ethiopia (4.9 completed grades) and highest in Peru (9.1 completed grades). The average maternal schooling was 3.0 grades in Ethiopia, 3.7 grades in India, 7.0 grades in Vietnam, and 7.8 grades in Peru. An urban residence in Peru was >2 times that of every other country, and households in Peru were most likely to move between rounds 1 and 3. Although all countries experienced decreases in stunting from ages 1–8 y, the magnitude varied by country with the most growth recovery occurring in Ethiopia (26.1%) and the least occurring in Vietnam (9.3%) (*see* Figure S1 under "Supplemental data" in the online issue).

Schooling overage

Compared with children who were never stunted, children who were persistently stunted were more likely to be overage for grade (OR range across countries: 1.71–2.79; **Table 2**); children who faltered or recovered were only more likely to be overage for grade in one-half of cases (OR range: 1.35–2.40 and 0.85–2.20, respectively). The aHAZ(1) was inversely associated with overage for grade in all 4 countries (OR range: 0.65–0.90). The uHAZ(1:8) was also inversely associated with being overage for grade in all 4 countries (OR range: 0.64–0.73). There was heterogeneity (statistically significant at $P < 0.05$) across countries for stunting status at ages 1 and 8 y and for the aHAZ(1) but not for the uHAZ(1:8).

Cognitive achievement

Compared with children who were never stunted, mathematics scores of children who were persistently stunted or recovered

TABLE 1
Participant characteristics, Young Lives[1]

	Ethiopia (n = 1757)	India (n = 1825)	Peru (n = 1847)	Vietnam (n = 1837)
Child level				
Never stunted: ages 1–8 y (%)	52.3	56.9	65.8	71.0
Persistently stunted: ages 1–8 y (%)	15.6	17.4	14.4	11.0
Recovered: ages 1–8 y (%)	26.1	13.6	13.9	9.3
Faltered: ages 1–8 y (%)	6.0	12.1	6.0	8.8
aHAZ(1)	−1.83 ± 1.65[2]	−1.35 ± 1.41	−1.33 ± 1.22	−1.14 ± 1.15
uHAZ(1:8)	0.00 ± 0.90	0.00 ± 0.85	0.00 ± 0.75	0.00 ± 0.78
Age at round 1 (mo)	11.7 ± 3.6	11.8 ± 3.4	11.5 ± 3.5	11.8 ± 3.1
Age at round 2 (mo)	61.9 ± 3.8	64.2 ± 3.8	63.5 ± 4.7	63.1 ± 3.5
Age at round 3 (mo)	97.0 ± 3.7	95.4 ± 3.7	95.0 ± 3.6	96.6 ± 3.4
F (%)	46.6	46.3	49.8	48.8
Household level				
Asset index, standardized: rounds 1–3[3]	−0.9 ± 0.7	−0.0 ± 0.8	0.3 ± 0.9	0.6 ± 0.9
Paternal schooling at round 2 (grades)	4.9 ± 4.3[4]	5.6 ± 5.0[5]	9.1 ± 3.9[5]	7.7 ± 4.0[5]
Maternal schooling at round 2 (grades)	3.0 ± 3.9[5]	3.7 ± 4.4[5]	7.8 ± 4.4[5]	7.0 ± 4.0[5]
Mother is care provider (no. of rounds)	2.8 ± 0.6	2.9 ± 0.3	2.9 ± 0.4	2.8 ± 0.6
Mother's age at round 1 (y)	27.5 ± 6.4[5]	23.6 ± 4.3[5]	26.8 ± 6.8[5]	27.1 ± 5.7[5]
Moved communities after round 1 (%)	20.6	11.5	48.6	15.4
Community level				
No. of communities	26	101	82	31
Community population at round 1	8063 ± 7227	3072 ± 3673	4272 ± 3849	10 317 ± 5810
Community wealth at round 1[6]	−3.3 ± 1.9[4]	−0.1 ± 2.1[7]	1.1 ± 2.6[5]	2.2 ± 2.4
Urban residence at round 1 (%)	35.2	24.8	66.3	19.4
Community has hospital at round 1 (%)	31.9[4]	47.4[5]	34.4	89.8
Achievement and schooling at round 3				
School overage (%)	19.2	17.4[5]	4.8[5]	8.6[5]
Mathematics achievement	6.6 ± 5.4[4]	12.0 ± 6.4[5]	14.3 ± 5.8[4]	18.6 ± 5.8[5]
Receptive vocabulary	67.9 ± 36.6[5]	49.0 ± 26.7[5]	47.0 ± 13.4[4]	77.3 ± 23.6[7]
Reading comprehension	5.5 ± 3.1[8]	5.4 ± 3.4[5]	8.4 ± 3.2[7]	10.1 ± 2.6[5]

[1] Mathematics achievement test consisted of 29 items, reading comprehension (Early Grade Reading Assessment) consisted of 74 items, and receptive vocabulary (Peabody Picture Vocabulary Test) consisted of 204 items (Ethiopia, India, and Vietnam) and 125 items (Peru). aHAZ(1), age-adjusted height-for-age z score at age 1 y; uHAZ(1:8), unpredicted change in height-for-age z score (height at age 8 y not predicted by age-adjusted height-for-age z score at age 1 y).

[2] Mean ± SD (all such values).

[3] From principal component analysis.

[4] Missing 50–100 observations.

[5] Missing <50 observations.

[6] Calculated as the average asset index value for other households in the community.

[7] Missing 101–200 observations.

[8] Missing 353 observations.

were lower (effect-size ranges: 0.22–0.48 and 0.12–0.21, respectively), whereas children who faltered showed no clear difference from children who were never stunted (**Table 3**). However, the effect size for children who recovered was one-half or less than for children who were persistently stunted. Children who faltered, children who were persistently stunted, and children who recovered all had lower receptive vocabulary scores (effect-size ranges: 0.07–0.24, 0.13–0.31, and 0.01–0.25, respectively) than did children who were never stunted. Again, the effect size for children who recovered was approximately one-half or less than that of children who were persistently stunted. Children who faltered and those who were persistently stunted had lower reading-comprehension scores than those of children who were never stunted (effect-size ranges: 0.05–0.37 and 0.24–0.38, respectively). Children who recovered also had lower reading-comprehension scores, although once again, the effect size was smaller in magnitude than for children who were persistently stunted (effect-size range: 0.10–0.23). In most cases, for each cognitive measure, children who recovered had significantly better scores than did children who were persistently stunted, although generally scores were similar to those of children who faltered. There was significant heterogeneity across sites in estimates.

The aHAZ(1) was positively associated with the mathematics score (effect-size range: 0.05–0.15), receptive vocabulary (effect-size range: 0.04–0.10), and reading comprehension (effect-size range: 0.06–0.14) (**Table 4**). The uHAZ(1:8) was also positively associated with the mathematics score (effect-size range: 0.04–0.09), receptive vocabulary (effect-size range: 0.04–0.08), and reading-comprehension score (effect-size range: 0.01–0.10). There were several cross-country differences that were significant at $P < 0.05$ for the aHAZ(1) but none for the uHAZ (1:8).

Estimates for the aHAZ(1) and uHAZ(1:8) for all 4 cognitive and schooling outcomes were not substantively altered by controlling for the set of child and family and community characteristics. Furthermore, the inclusion of interactions of all

TABLE 2
Multivariable probit regression models for overage grade on the change in stunting status, height-for-age *z* score, and unpredicted growth in the Young Lives cohort[1]

	Ethiopia	India	Peru	Vietnam	Heterogeneity of country estimates[2]
School overage: stunting status 1–8 y of age					
Persistently stunted	2.45 (1.78, 3.39)[3,4]	1.71 (1.25, 2.34)[4]	2.32 (1.19, 4.54)[5]	2.79 (1.42, 2.21)[4]	None
Recovered	0.85 (0.57, 1.28)	1.00 (0.64, 1.55)	2.20 (1.06, 4.55)[5]	1.61 (1.01, 2.55)[5]	Ethiopia ≠ Peru, Ethiopia ≠ Vietnam
Faltered	2.40 (1.18, 4.90)[5]	1.88 (1.26, 2.82)[4]	1.35 (0.55, 3.29)	1.41 (0.87, 2.30)	None
Observations	1757	1815	1845	1829	—
Pseudo R^2 [6]	0.30	0.06	0.13	0.22	—
Test: *B* (falter) = *B* (recover)	0.00	0.03	0.88	0.02	—
Test: *B* (recover) = *B* (persist)	0.01	0.01	0.31	0.69	—
Test: *B* (persist) = *B* (falter)	0.96	0.65	0.22	0.01	—
School overage: uHAZ					
aHAZ(1)	0.90 (0.81, 1.00)	0.86 (0.79, 0.93)[4]	0.65 (0.51, 0.83)[4]	0.69 (0.59, 0.80)[4]	Ethiopia ≠ Peru, Ethiopia ≠ Vietnam, Peru ≠ Vietnam, Vietnam ≠ India
uHAZ(1:8)	0.70 (0.60, 0.83)[4]	0.73 (0.61, 0.87)[4]	0.64 (0.48, 0.85)[4]	0.65 (0.55, 0.77)[4]	None
Observations	1757	1815	1845	1829	—
Pseudo R^2	0.29	0.06	0.15	0.23	—

[1] School overage represents whether a child was behind in comparison with the appropriate age for the grade given country-specific schooling norms. Regressions controlled for the sex of the child, age of the mother, years of schooling of the mother, years of schooling of the father, asset index, urban residence, community population, community wealth, presence of a community hospital, and country. Stunting status from 1 to 8 y of age was defined as follows: recovered [stunted (height-for-age *z* score less than −2.0) at age 1 y and not stunted at age 8 y], faltered (not stunted at age 1 y and stunted at age 8 y), persistently stunted (stunted at ages 1 and 8 y), or never stunted (not stunted at ages 1 and 8 y, considered the reference). aHAZ(1), age-adjusted height-for-age *z* score at age 1 y; uHAZ, height at age 8 y that was unpredicted by the age-adjusted height-for-age *z* score; uHAZ(1:8), unpredicted change in height-for-age *z* score (height at age 8 y not predicted by the age-adjusted height-for-age *z* score at age 1 y).

[2] Pooled country estimates were derived from a pooled model with country interactions to formally test for the heterogeneity of associations by country (country differences reported at $P < 0.05$).

[3] OR; 95% CI in parentheses (all such values). ORs are from probit regression models.

[4] $P < 0.01$.

[5] $P < 0.05$.

[6] Average pseudo R^2 over 25 imputations.

right-side variables with either sex or urban residence did not substantially alter the associations (*see* Tables S5–S12 under "Supplemental data" in the online issue). The addition of squared terms did not change the basic results markedly (*see* Table S13 under "Supplemental data" in the online issue). The only significant squared term was for age at round 3 for the test scores in Vietnam, which suggested some declining marginal effect of age. Average effects by using a seemingly unrelated regression for the aHAZ were significant in all 4 countries, and the effect size was highest in India, where it was associated with a 0.13-SD increase in the test score, on average, and lowest in Ethiopia (0.04). The uHAZ(1:8) was significant in all countries except Peru and highest in Ethiopia, where it was associated with an increase in 0.09 SDs in the test score on average and slightly lower in India and Vietnam (0.06) (*see* Table S14 under "Supplemental data" in the online issue).

DISCUSSION

This is the first multinational study, to our knowledge, to examine the relation between postinfancy growth and medium-term child-development outcomes across several low- and middle-income countries by using a standardized recruitment and assessment protocol. Our study built on previous research by using multiple methods for characterizing improved linear growth and by using several robust measures of schooling and cognitive achievement from panel data in 4 population-based samples to establish the consistency of our findings.

Similar to in previous studies (5–14), the aHAZ(1) was consistently associated with schooling and cognitive outcomes. Upward linear growth between ages 1 and 8 y was associated, in most instances, with positive outcomes. Similarly, children who recovered from stunting were better off than children who remained persistently stunted, whereas children who became stunted tended to perform worse than children who were never stunted. Effect estimates were generally in the same direction but varied in magnitude across countries. These findings add to a small but important literature that showed a positive association of postinfancy growth improvement with school progression and cognitive scores (8, 20, 25, 37).

Our study had some limitations. We had only 3 growth measurements over the early course of the child's life, which limited our ability to determine the precise timing of postinfancy growth improvements. However, growth improvements from

TABLE 3

Multivariable linear regression models for cognitive outcomes on the change in stunting status in the Young Lives cohort[1]

	Ethiopia	India	Peru	Vietnam	Heterogeneity of country estimates[2]
Mathematics achievement					
Persistently stunted	−0.22 (−0.32, −0.13)[3,4]	−0.48 (−0.58, −0.37)[4]	−0.31 (−0.43, −0.18)[4]	−0.37 (−0.52, −0.21)[4]	Ethiopia ≠ India, Peru ≠ India
Recovered	−0.12 (−0.21, −0.02)[5]	−0.21 (−0.35, −0.06)[4]	−0.13 (−0.23, −0.04)[4]	−0.18 (−0.33, −0.03)[5]	None
Faltered	−0.31 (−0.48, −0.14)[4]	−0.06 (−0.21, 0.09)	−0.13 (−0.32, 0.06)	0.08 (−0.11, 0.26)	Ethiopia ≠ India, Ethiopia ≠ Vietnam
Observations	1687	1803	1793	1806	—
R^2	0.45	0.26	0.35	0.37	—
Test: *B* (falter) = *B* (recover)	0.01	0.21	1.00	0.04	—
Test: *B* (recover) = *B* (persist)	0.04	0.00	0.02	0.06	—
Test: *B* (persist) = *B* (falter)	0.26	0.00	0.15	0.00	—
Reading comprehension					
Persistently stunted	−0.24 (−0.38, −0.10)[4]	−0.38 (−0.51, −0.26)[4]	−0.29 (−0.46, −0.12)[4]	−0.36 (−0.53, −0.18)[4]	None
Recovered	−0.15 (−0.26, −0.04)[5]	−0.23 (−0.36, −0.09)[4]	−0.16 (−0.28, −0.04)[4]	−0.10 (−0.28, 0.07)	None
Faltered	−0.37 (−0.55, −0.19)[4]	−0.05 (−0.21, 0.10)	−0.22 (−0.43, −0.01)[5]	−0.23 (−0.42, −0.03)[5]	Ethiopia ≠ India
Observations	1404	1775	1659	1800	—
R^2	0.26	0.14	0.26	0.21	—
Test: *B* (falter) = *B* (recover)	0.03	0.10	0.58	0.43	—
Test: *B* (recover) = *B* (persist)	0.14	0.04	0.12	0.07	—
Test: *B* (persist) = *B* (falter)	0.16	0.00	0.57	0.17	—
Receptive vocabulary					
Persistently stunted	−0.18 (−0.30, −0.06)[4]	−0.31 (−0.44, −0.19)[4]	−0.30 (−0.45, −0.14)[4]	−0.13 (−0.25, −0.02)[5]	Peru ≠ India, Vietnam ≠ India
Recovered	−0.09 (−0.18, −0.01)[5]	−0.25 (−0.38, −0.11)[4]	−0.13 (−0.26, −0.01)[5]	−0.01 (−0.11, 0.13)	Peru ≠ India, Vietnam ≠ India
Faltered	−0.24 (−0.41, −0.07)[4]	−0.16 (−0.30, −0.03)[5]	−0.14 (−0.29, 0.00)	−0.07 (−0.25, 0.11)	Ethiopia ≠ Peru
Observations	1733	1800	1753	1734	—
R^2	0.46	0.17	0.44	0.33	—
Test: *B* (falter) = *B* (recover)	0.10	0.36	0.91	0.41	—
Test: *B* (recover) = *B* (persist)	0.13	0.36	0.03	0.02	—
Test: *B* (persist) = *B* (falter)	0.48	0.07	0.14	0.58	—

[1] The mathematics achievement test consisted of 29 items, the reading comprehension test (Early Grade Reading Assessment) consisted of 74 items, and the receptive vocabulary test (Peabody Picture Vocabulary Test) consisted of 204 items (Ethiopia, India, and Vietnam) and 125 items (Peru). Stunting status from 1 to 8 y of age was defined as follows: recovered [stunted (height-for-age z score less than −2.0) at age 1 y and not stunted at age 8 y], faltered (not stunted at age 1 y and stunted at age 8 y), persistently stunted (stunted at ages 1 and 8 y), or never stunted (not stunted at ages 1 and 8 y, considered the reference). Regressions controlled for age (in mo) at round 3, sex of the child, age of the mother, years of schooling of the mother, years of schooling of the father, asset index, urban residence, community population, community wealth, presence of a community hospital, country, examination administered in the native language, and language in which the examination was taken.

[2] Pooled country estimates were derived from a pooled model with country interactions to formally test for heterogeneity of associations by country (country differences reported at $P < 0.05$).

[3] Effect size; 95% CI in parentheses (all such values). Effect sizes are presented from ordinary least-squares regression models for cognitive outcomes (effect size = coefficient estimate ÷ SD). *See* Table 1 for SDs.

[4] $P < 0.01$.

[5] $P < 0.05$.

TABLE 4
Multivariable linear regression models for cognitive outcomes on height-for-age *z* score and unpredicted growth in the Young Lives cohort[1]

	Ethiopia	India	Peru	Vietnam	Heterogeneity of country estimates[2]
Mathematics achievement					
aHAZ(1)	0.05 (0.03, 0.07)[3,4]	0.15 (0.11, 0.19)[4]	0.07 (0.04, 0.11)[4]	0.10 (0.06, 0.14)[4]	Ethiopia ≠ India, Peru ≠ India, Vietnam ≠ India, Ethiopia ≠ Vietnam, Peru ≠ Vietnam
uHAZ(1:8)	0.09 (0.05, 0.13)[4]	0.08 (0.02, 0.14)[4]	0.06 (0.00, 0.12)[5]	0.04 (−0.01, 0.10)	None
Observations	1687	1803	1793	1806	—
R^2	0.46	0.28	0.35	0.36	—
Reading comprehension					
aHAZ(1)	0.07 (0.03, 0.10)[4]	0.14 (0.10, 0.17)[4]	0.06 (0.03, 0.10)[4]	0.10 (0.06, 0.15)[4]	Ethiopia ≠ India, Peru ≠ India, Vietnam ≠ India
uHAZ(1:8)	0.08 (0.03, 0.14)[4]	0.01 (−0.04, 0.07)	0.05 (−0.01, 0.11)	0.10 (0.03, 0.17)[4]	None
Observations	1404	1775	1659	1800	—
R^2	0.26	0.16	0.25	0.21	—
Receptive vocabulary					
aHAZ(1)	0.04 (0.02, 0.07)[4]	0.10 (0.07, 0.14)[4]	0.07 (0.02, 0.11)[4]	0.04 (0.00, 0.08)[4]	Peru ≠ India, Vietnam ≠ India
uHAZ(1:8)	0.08 (0.03, 0.14)[4]	0.07 (0.02, 0.12)[4]	0.07 (0.01, 0.14)[5]	0.04 (−0.03, 0.11)	None
Observations	1733	1800	1753	1734	—
R^2	0.47	0.18	0.44	0.33	—

[1] The mathematics achievement test consisted of 29 items, the reading comprehension test (Early Grade Reading Assessment) consisted of 74 items, and the receptive vocabulary test (Peabody Picture Vocabulary Test) consisted of 204 items (Ethiopia, India, and Vietnam) and 125 items (Peru). Stunting status from 1 to 8 y of age was defined as follows: recovered [stunted (height-for-age *z* score less than −2.0) at age 1 y and not stunted at age 8 y], faltered (not stunted at age 1 y and stunted at age 8 y), persistently stunted (stunted at ages 1 and 8 y), or never stunted (not stunted at ages 1 and 8 y, considered the reference). Regressions controlled for age (in mo) at round 3, sex of the child, age of the mother, years of schooling of the mother, years of schooling of the father, asset index, urban residence, community population, community wealth, presence of a community hospital, country, examination administered in the native language, and language in which the examination was taken. aHAZ(1), age-adjusted height-for-age *z* score at age 1 y; uHAZ(1:8), unpredicted change in height-for-age *z* score (height at age 8 y not predicted by the age-adjusted height-for-age *z* score at age 1 y).

[2] Pooled country estimates were derived from a pooled model with country interactions to formally test for heterogeneity of associations by country (country differences reported at $P < 0.05$).

[3] Effect size; 95% CI in parentheses (all such values). Effect sizes are presented from ordinary least-squares regression models for cognitive outcomes (effect size = coefficient estimate ÷ SD). *See* Table 1 for SDs.

[4] $P < 0.01$.

[5] $P < 0.05$.

1 to 5 y of age and from 5 to 8 y of age were associated with better schooling and cognitive outcomes (*see* Tables S3 and S4 under "Supplemental data" in the online issue). Hence, meaningful growth improvements took place for both preprimary and primary school–age children. The study was also limited by some loss to follow-up. However, attrition was low, and only modest differences were observed, between included and excluded children. Last, we acknowledge that a birth-cohort study with standardized growth assessments at birth and 2 y of age might have been a more-appropriate design for this particular research question. However, this was not the primary purpose of the YL study, which sought to maximize the diversity of study settings while also providing a broad context of childhood experiences, including health and nutrition. Still, although in many contexts the mean HAZ declines from birth to age 24 mo (38), the HAZ at ∼1 y of age is a meaningful measure of early growth because of the high correlation between HAZs at 1 and 2 y in studies for which this information is available. For example, the correlation between HAZs at 12 and at 24 mo ranged from 0.65 (South Africa) to 0.85 (India) (all $P < 0.0001$) in 5 birth cohorts in low- and middle-income countries (EA Lundeen, unpublished observations, 2013).

Note that the magnitude of reported associations may have been underestimated. For example, our findings by using the unpredicted change in the HAZ instead of actual growth may have exacerbated problems of measurement error in the HAZ that, if random, would have led to underestimation of the true magnitudes of associations between the unpredicted change and any given outcome. This possible latter measurement issue strengthened our findings of a number of positive significant associations because it meant that true magnitudes of the associations would have likely been greater if there was no measurement error. In addition, our method focused on that part of growth after age 1 y that is, by definition, uncorrelated with the HAZ(1). This approach attributed all effects of growth after age 1 y that were also correlated with the HAZ(1) to the HAZ(1) itself. Thus method likely understated associations of school overage and cognitive achievement with growth from 1 to 8 y of age. Thus, if we showed significant associations with the uHAZ (1:8), they were probably underestimates of the true associations with growth between ages 1 and 8 y.

In this article, we have not considered factors that may have led to improvements in postinfant growth such as investments in community infrastructure and nutrition (28). In addition, we were unable to determine whether improved growth in either infancy or postinfancy is beneficial in the long-term. For example, it is possible that improved growth may unintentionally contribute to problems of overweight an obesity in children, which has increased substantially worldwide since 1990 (39–41).

In conclusion, our findings suggest that improving growth in children who are stunted in infancy and maintaining nutrition in children who otherwise might falter may have significant benefit for schooling and cognitive achievement. Our work reinforces the need to prevent nutritional insults in early life but also emphasizes the importance of promoting child growth and preventing faltering beyond infancy. Hence, although early interventions are critical, interventions to improve nutrition of preprimary and primary school–age children also merit serious consideration.

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The authors' responsibilities were as follows—MEP and SC: were involved in the design of the YL study and instruments developed for each round as well as study implementation in Peru; SC was responsible for the testing of cognitive function in all 4 countries; BTC, KAD, ADS, and JRB: oversaw the initial design of the analysis; BTC, WS, and JRB: analyzed data; and all authors: wrote the manuscript, had primary responsibility for the final content of the manuscript, and [except PE (deceased)] approved the final version of the manuscript. None of the authors reported a conflict of interest.

REFERENCES

1. Black RE, Morris SS, Bryce J. Where and why are 10 million children dying every year? Lancet 2003;361:2226–34.
2. Caulfield LE, Richard SA, Black RE. Undernutrition as an underlying cause of malaria morbidity and mortality in children less than five years old. Am J Trop Med Hyg 2004;71(2 suppl):55–63.
3. Black RE, Allen LH, Bhutta ZA, Caulfield LE, de Onis M, Ezzati M, Mathers C, Rivera J. Maternal and child undernutrition: global and regional exposures and health consequences. Lancet 2008;371:243–60.
4. Kuklina EV, Ramakrishnan U, Stein AD, Barnhart HH, Martorell R. Growth and diet quality are associated with the attainment of walking in rural Guatemalan infants. J Nutr 2004;134:3296–300.
5. Grantham-McGregor S. Linear growth retardation and cognition. Lancet 2002;359:542.
6. Behrman J, Hoddinott J, Maluccio J, Soler-Hampejsek E, Behrman E, Martorell R, Ramirez-Zea M, Stein AD. What determines adult cognitive skills? impacts of pre-schooling, schooling and post-schooling experiences in Guatemala. PIER Working Paper No. 06-027. Philadelphia, PA: Population Aging Research Center, University of Pennsylvania, 2006.
7. Walker SP, Grantham-McGregor SM, Powell CA, Chang SM. Effects of growth restriction in early childhood on growth, IQ, and cognition at age 11 to 12 years and the benefits of nutritional supplementation and psychosocial stimulation. J Pediatr 2000;137:36–41.
8. Mendez MA, Adair LS. Severity and timing of stunting in the first two years of life affect performance on cognitive tests in late childhood. J Nutr 1999;129:1555–62.
9. Walker SP, Chang SM, Powell CA, Grantham-McGregor SM. Effects of early childhood psychosocial stimulation and nutritional supplementation on cognition and education in growth-stunted Jamaican children: prospective cohort study. Lancet 2005;366:1804–7.
10. Crookston BT, Dearden KA, Alder S, Porucznik C, Stanford J, Merrill R, Dickerson T, Penny M. Impact of early and concurrent stunting on cognition. Matern Child Nutr 2011;7:397–409.
11. Grantham-McGregor S, Cheung YB, Cueto S, Glewwe P, Richter L, Strupp B. Developmental potential in the first 5 years for children in developing countries. Lancet 2007;369:60–70.
12. Alderman H, Hoddinott J, Kinsey B. Long term consequences of early childhood malnutrition. Oxf Econ Pap 2006;58:450–74.
13. Victora CG, Adair L, Fall C, Hallal PC, Martorell R, Richter L, Sachdev HS. Maternal and child undernutrition: consequences for adult health and human capital. Lancet 2008;371:340–57.
14. Maluccio J, Hoddinott J, Behrman J, Quisumbing A, Martorell R, Stein AD. The impact of nutrition during early childhood on education among Guatemalan adults. Econ J 2009;119:734–63.
15. de Onis M, Blössner M, Borghi E. Prevalence and trends of stunting among pre-school children, 1990-2020. Public Health Nutr 2012;15: 142–8.
16. Checkley W, Epstein LD, Gilman RH, Cabrera L, Black RE. Effects of acute diarrhea on linear growth in Peruvian children. Am J Epidemiol 2003;157:166–75.
17. Martorell R, Khan L, Schroeder DG. Reversibility of stunting: epidemiologic findings from children in developing countries. Eur J Clin Nutr 1994;48(suppl 1):S45–7.
18. Walker SP, Grantham-McGregor S, Himes J, Powell C, Chang S. Early childhood supplementation does not benefit the long-term growth of stunted children in Jamaica. J Nutr 1996;126:3017–24.
19. Johnson DE. Adoption and the effect on children's development. Early Hum Dev 2002;68:39–54.
20. Crookston BT, Penny ME, Alder SC, Dickerson TT, Merrill RM, Stanford JB, Porucznik CA, Dearden KA. Children who recover from early stunting and children who are not stunted demonstrate similar levels of cognition. J Nutr 2010;140:1996–2001.
21. Prentice AM, Ward KA, Goldberg GR, Jarjou LM, Moore SE, Fulford AJ, Prentice A. Critical windows for nutritional interventions against stunting. Am J Clin Nutr 2013;97:911–8.
22. Morgane PJ, Austin-LaFrance R, Bronzino J, Tonkiss J, Diaz-Cintra S, Cintra L, Kemper T, Galler JR. Prenatal malnutrition and development of the brain. Neurosci Biobehav Rev 1993;17:91–128.
23. Strauss RS, Dietz WH. Growth and development of term children born with low birth weight: effects of genetic and environmental factors. J Pediatr 1998;133:67–72.
24. Pollitt E, Gorman KS, Engle PL, Martorell R, Rivera J. Early supplementary feeding and cognition: effects over two decades. Monogr Soc Res Child Dev 1993;58:1–99; discussion 111–8.
25. Cheung YB, Ashorn P. Continuation of linear growth failure and its association with cognitive ability are not dependent on initial length-for-age: a longitudinal study from 6 months to 11 years of age. Acta Paediatr 2010;99:1719–23.
26. WHO Multicentre Growth Reference Study Group. WHO Child Growth Standards based on length/height, weight and age. Acta Paediatr Suppl 2006;450:76–85.
27. de Onis M, Onyango AW, Borghi E, Siyam A, Nishida C, Siekmann J. Development of a WHO growth reference for school-aged children and adolescents. Bull World Health Organ 2007;85:660–7.
28. Schott W, Crookston BT, Lundeen EA, Stein AD, Behrman JR; The Young Lives Determinants and Consequences of Child Growth Project Team. Child growth from ages 1 to 5 and 5 to 8 years in Ethiopia, India, Peru and Vietnam: key distal household and community factors. Soc Sci Med (Epub ahead of print 28 May 2013).
29. Adair LS, Fall CH, Osmond C, Stein AD, Martorell R, Ramirez-Zea M, Sachdev HS, Dahly DL, Bas I, Norris S, et al. Associations of linear growth and relative weight gain during early life with adult health and human capital in countries of low and middle income: findings from five birth cohort studies. Lancet 2013;382:525–34.
30. Gandhi M, Ashorn P, Maleta K, Teivaanmäki T, Duan X, Cheung YB. Height gain during early childhood is an important predictor of schooling and mathematics ability outcomes. Acta Paediatr 2011;100: 1113–8.
31. Martorell R, Horta BL, Adair LS, Stein AD, Richter L, Fall CHD, Bhargava SK, Biswas SKD, Perez L, Barros FC, et al. Weight gain in the first two years of life is an important predictor of schooling outcomes in pooled analyses from five birth cohorts from low- and middle-income countries. J Nutr 2010;140:348–54.

32. Lasky RE, Klein RE, Yarbrough C, Engle PL, Lechtig A, Martorell R. The relationship between physical growth and infant behavioral development in rural Guatemala. Child Dev 1981;52:219–26.
33. Cueto S, Leon J. Psychometric characteristics of cognitive development and achievement instruments in round 3 of Young Lives. Technical Note No. 25. Oxford, United Kingdom: Young Lives), 2012.
34. Glewwe P. Schooling, skills, and the returns to government investment in education: an exploration using data from Ghana. Working Paper No. 76. Washington, DC: World Bank, 1991.
35. Clingingsmith D, Khwaja AI, Kremer M. Estimating the impact of the Hajj: religion and tolerance in Islam's global gathering. Q J Econ 2009; 124:1133–70.
36. Kling JR, Liebman JB, Katz LF. Experimental Analysis of Neighborhood Effects. Econometrica 2007;75:83–119.
37. Yang S, Tilling K, Martin R, Davies N, Ben-Shlomo Y, Kramer MS. Pre-natal and post-natal growth trajectories and childhood cognitive ability and mental health. Int J Epidemiol 2011;40:1215–26.
38. Victora CG, de Onis M, Hallal PC, Blössner M, Shrimpton R. Worldwide timing of growth faltering: revisiting implications for interventions. Pediatrics 2010;125:e473–80.
39. de Onis M, Blössner M, Borghi E. Global prevalence and trends of overweight and obesity among preschool children. Am J Clin Nutr 2010;92:1257–64.
40. Ong KK. Size at birth, postnatal growth and risk of obesity. Horm Res 2006;65(suppl 3):65–9.
41. Monteiro PO, Victora CG. Rapid growth in infancy and childhood and obesity in later life–a systematic review. Obes Rev 2005;6: 143–54.