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Height in healthy children in low- and middle-income countries: an assessment[1,2]

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ABSTRACT

Background: Despite rapid economic development and reductions in child mortality worldwide, continued high rates of early childhood stunting have put the global applicability of international child-height standards into question.

Objectives: We used population-based survey data to identify children growing up in healthy environments in low- and middle-income countries and compared the height distribution of these children to the height distribution of the reference sample established by the WHO.

Design: Height data were extracted from 169 Demographic and Health Surveys (DHSs) that were collected across 63 countries between 1990 and 2014. Children were classified as having grown up in ideal environments if they *1*) had access to safe water and sanitation; *2*) lived in households with finished floors, a television, and a car; *3*) were born to highly educated mothers; *4*) were single births; and *5*) were delivered in hospitals. We compared the heights of children in ideal environments with those in the WHO reference sample.

Results: A total of 878,249 height records were extracted, and 1006 children (0.1%) were classified as having been raised in an ideal home environment. The mean height-for-age z score (HAZ) in this sample was not statistically different from zero (95% CI: −0.039, 0.125). The HAZ SD for the sample was estimated to be 1.3, and 5.3% of children in the sample were classified as being stunted (HAZ <-2). Similar means, SDs, and stunting rates were found when less restrictive definitions of ideal environments were used.

Conclusion: The large current gaps in children's heights relative to those of the reference sample likely are not due to innate or genetic differences between children but, rather, reflect children's continued exposure to poverty, a lack of maternal education, and a lack of access to safe water and sanitation across populations. *Am J Clin Nutr* doi: 10.3945/ajcn.116.136705.

Keywords: child stunting, Demographic and Health Surveys, height distributions, height-for-age, international growth standards, low- and middle-income countries, WHO

INTRODUCTION

In 2010, >167 million children (25.6%) aged ≤5 y in low- and middle-income countries were estimated to be stunted (1). Although substantial progress has been made toward reducing child mortality worldwide (2), progress on child height and stunting has been slow, particularly in South Asia and parts of sub-Saharan Africa. The continued high rates of stunting, despite rapid improvements in child survival and economic development in many regions, has led to a resurgence of concerns regarding the suitability of applying international child growth standards across all populations globally.

Although the MGRS[5] (Multicenter Growth Reference Study), which was conducted by the WHO to establish international child growth standards, made a considerable effort to include children from all regions of the world, the extent to which the final MGRS sample may be representative of the global child population remains somewhat unclear. In particular, the final MGRS sample did not include any populations from East Asia (3), and even within participating countries (Brazil, Norway, Oman, India, Ghana, and the United States), the representativeness of the children who were eventually selected is a continued source of debate. To assess growth trajectories in children who were not exposed to any major risk factors, the MGRS intentionally restricted sampling to women who were living in high-income areas with easy access to health services. In practice, this sampling strategy generally resulted in the selection of relatively homogeneous groups of mothers who lived in a small number of privileged, urban neighborhoods of each country (4); the use of these mothers may not capture the full social, behavioral, and genetic diversity of their respective countries and is even less likely to fully reflect global genetic and environmental variations (3, 5, 6).

Empirical evidence on the adequacy of global growth standards for different populations of children <5 y old has been mixed (3). Studies from Hong Kong (7) and Saudi Arabia (8) have argued that local height patterns are not consistent with international standards. A recent systematic review of child growth concluded that global height and weight reference curves for children <5 y

[1] The authors reported no funding received for this study.

[2] Supplemental Figures 1 and 2 and Supplemental Tables 1–6 are available from the "Online Supporting Material" link in the online posting of the article and from the same link in the online table of contents at http://ajcn.nutrition.org.

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[5] Abbreviations used: DHS, Demographic and Health Survey; HAZ, height-for-age z score; MGRS, Multicenter Growth Reference Study.

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old may not be justified for all subpopulations and that the use of WHO standards for head circumference would put many children at risk of a misdiagnosis of macrocephaly or microcephaly (9). These findings are in contrast with a large body of evidence including historical work and, more recently, comparative studies from Togo, Haiti, and Egypt (10), which suggests that the WHO MGRS growth standards are appropriate as a reference for healthy child development and that height and weight distributions can be inferred from well-to-do children (11).

In this study, we combined all available height data for children <5 y of age in low- and middle-income countries that were collected through the Demographic and Health Survey (DHS) program and compared the empirical height distribution of children who were living in ideal home environments in developing countries with that of the reference sample that was established by the MGRS.

METHODS

Study design

The study used cross-sectional data from the DHS program to compare the height distribution of children who were growing up in safe environments in developing countries with the age- and sex-specific height distributions that were observed in the MGRS.

Data and setting

DHSs are nationally representative household surveys that provide information on a wide range of indicators in the areas of population, maternal and child health, and nutrition. More than 300 DHSs have been collected in >90 countries since 1984. For the purposes of this study, we restricted the analysis to surveys with anthropometric data as well as complete data on key indicators of health-intervention coverage. A total of 1,115,198 anthropometric records for children <5 y of age were available from the DHS program. We excluded child observations with missing information in the following covariates: the child's place of delivery; whether the child received a bacille Calmette-Guérin and their first diphtheria, pertussis, and tetanus vaccination; the level of education of the child's mother; information on the quality of water and sanitation in the child's household; whether the child's household had access to a television; whether the child's household had access to a car; and the type of flooring in the child's household. **Supplemental Table 1** and **Supplemental Figure 1** provide further details on the sample selection and the final sample composition.

Statistical methods

We pooled all available anthropometric data on children aged ≤5 y from the DHSs, and we used existing covariate data to identify children who were growing up in ideal home environments. Because only limited biomedical information is available on children in the DHSs, we primarily focused on social determinants of health outcomes when generating our classification of ideal environments. Specifically, we defined a child as having grown up in an ideal home environment if the child was *1*) a single birth; *2*) born to a mother with higher education; *3*) living in a household with finished floors, a television, and a car; *4*) living in a household with access to safe water and sanitation; and *5*) delivered in a hospital and received both bacille Calmette-Guérin and their first diphtheria, pertussis, and tetanus vaccinations.

As a first step, we compared children who met these conditions with the general (pooled DHS) sample and plotted the distribution of height-for-age z scores (HAZs) in children who were living in ideal home environments against the standard normal distribution of the MGRS reference sample.

We computed the HAZ deficit that could be attributed to each of the 5 key factors that were used for defining an ideal home environment by first estimating a multiple linear regression of child HAZs on these factors together and taking the product of the estimated factor coefficients, each of which captured the association between that particular factor and the child HAZ, and the proportion of the pooled DHS sample who did not exhibit that factor.

Sensitivity analysis

To illustrate the sensitivity of our results, we explored alternative definitions of ideal home environments and compared means ± SDs of the resulting HAZ distributions to the standard normal distribution that was observed in the MGRS. We also showed separate results for children ≤2 and >2 y of age to address concerns surrounding the imprecise measurement of children's lengths at very young ages.

As an additional robustness check, we assessed whether differences in height distributions between children in the ideal group and children in the remaining nonideal sample might have been driven by underlying differences in maternal height across these 2 subsamples. To do so, we first overlaid the height distributions of mothers of children in the ideal–home environment group and of mothers of children in the nonideal sample, and we calculated the difference in means between these 2 groups by running a multiple linear regression of maternal height on a binary variable that indicated whether the mother belonged to the ideal group. In this regression, the coefficient estimate on the binary variable described the adjusted mean difference between mothers of children who belonged to the ideal-group sample and mothers of children in the nonideal sample with respect to maternal height. To examine the relation between maternal height and child height in ideal home environments, we nonparametrically estimated the relation between maternal height and child height for the ideal-group subsample with the use of a local polynomial smoothed regression. In estimating this regression, we adopted the Epanechnikov kernel-density function for weights and used the rule-of-thumb method to determine the bandwidth.

For our analysis, all significance tests of means and linear estimations were conducted with the use of multiple linear regressions that were controlled for survey (country-year) fixed effects, and coefficient SEs were clustered at the primary sampling unit (DHS cluster) level. All analyses were performed with the use of Stata software (version 13; StataCorp LP).

Ethical considerations

The study obtained a human-subjects exemption from the Institutional Review Board at Harvard University (protocol IRB16-0515). Only de-identified data were obtained from the DHSs.

RESULTS

A total of 878,249 child anthropometric records with complete covariate data were extracted from 169 DHSs that were conducted between 1990 and 2014 in 63 countries. A total of 1006 children (0.1%) who were born to 824 mothers (mothers reported on all children <5 y of age) from 23 countries met all of the target criteria for having grown up in an ideal home environment. The lists of countries that made up the full DHS sample and the sample of children who were living in ideal environments are presented in **Supplemental Tables 2** and **3**, respectively. **Table 1** compares mother and household characteristics between children who were living in ideal home environments and children who were not living in ideal home environments. No major differences were shown with respect to age and sex when children from nonideal home environments in the pooled DHS sample were compared with children in our ideal group. By construction, the children in our ideal group had better-educated mothers and lived in substantially wealthier households. Children in our ideal group were also much more likely to live in urban areas and were much less likely to be born to a teenage mother. In **Supplemental Table 4**, we compare mean sample characteristics of children in our ideal group sample with those of children in the reference sample that was used to generate the WHO child growth standards. On average, mothers of children in our ideal-group sample were slightly older and more educated but were also slightly shorter than mothers of children from the WHO reference sample. In general, children from our ideal-group sample came from very similar households with similar socioeconomic characteristics compared with those of children from the WHO reference sample.

Figure 1 shows the empirical distribution of HAZs of children living in an ideal home environment relative to the distribution of

TABLE 1
Socioeconomic characteristics of children and mothers: descriptive statistics[1]

	Nonideal home environment (n = 877,243)	Ideal home environment (n = 1006)
Covariates, n (%)		
Child		
Sex, F	433,524 (49.4)	482 (47.9)
Age, y		
0	189,376 (21.6)	171 (17.0)
1	187,775 (21.4)	198 (19.7)
2	178,659 (20.4)	215 (21.4)
3	165,273 (18.8)	231 (23.0)
4	156,160 (17.8)	191 (19.0)
Multiple birth	20,941 (2.4)	0 (0.0)
Mother		
Age, y		
<20	119,275 (13.6)	29 (2.9)
20–34	628,688 (71.7)	825 (82.0)
≥35	129,280 (14.7)	152 (15.1)
Education		
None	322,715 (36.8)	0 (0.0)
Primary	299,685 (34.2)	0 (0.0)
Secondary	210,638 (24.0)	0 (0.0)
Tertiary	44,155 (5.0)	1006 (100.0)
Married	651,107 (74.2)	644 (64.0)
Urban residence	299,619 (34.2)	880 (87.5)
Household assets		
Television	320,397 (36.5)	1006 (100.0)
Car	47,451 (5.4)	1006 (100.0)
Finished floor	374,103 (42.6)	1006 (100.0)
Flush toilet	114,651 (13.1)	1006 (100.0)
Household purchases drinking water	20,392 (2.3)	1006 (100.0)
Delivery at hospital	255,971 (29.2)	1006 (100.0)
Child received vaccinations		
BCG vaccine	734,170 (83.7)	1006 (100.0)
DPT-1 vaccine	705,425 (80.4)	1006 (100.0)
Outcomes		
Child HAZ	−1.416 ± 1.659[2]	0.043 ± 1.332
n	877,243	1006
Height of mother, cm	156.41 ± 7.133	159.67 ± 6.116
n	798,861	526

[1] Descriptive statistics are presented for each of the key variables in the analysis. Each variable in the covariates subsection was defined as a binary indicator (yes or no), whereas outcome variables were continuous. BCG, bacille Calmette-Guérin; DPT-1, diphtheria, pertussis, and tetanus; HAZ, height-for-age z score

[2] Mean ± SD (all such values).

HAZs in the WHO reference sample, which was, by construction, normally distributed with a mean ± SD of 0 ± 1. The overall distributions were relatively closely aligned with a mean HAZ of 0.043 (95% CI: −0.039, 0.125) in the ideal–home environment group. Compared with the WHO reference sample, the empirical distribution of HAZs in children with ideal home environments appeared to be slightly more dispersed with an SD of 1.33.

Figure 2 further highlights the differences in dispersion between the ideal-group sample and the WHO reference sample by comparing the mean HAZ in each percentile. Although the mean HAZ in children in the ideal-group sample was very close to zero (0.03) at the 50th percentile, larger HAZ differentials for this sample were observed in the bottom and top percentiles. In the ideal-group sample, the mean HAZ at the third percentile was −2.6, and 5.3% of children in this sample had an HAZ <−2 and, thus, would be classified as stunted. Similarly, the mean HAZ at the 97th percentile of the ideal-group sample was 2.5, with 5.3% of children having an HAZ >2.

Figure 3 shows the results of our sensitivity analysis in which we relaxed each of the specific target criteria that were used to select children from ideal home environments. When we removed the restriction on the coverage of health services (namely, the receipt of skilled delivery at birth and receipt of vaccinations), the sample size increased to n = 1296 with very little change in the mean ± SD (−0.09 ± 1.34) of the HAZ in the subsample. When we removed the restriction on water and sanitation, the sample size increased to n = 6638 with a lower mean ± SD HAZ of −0.25 ± 1.44. Finally, the removal of the asset and education restrictions resulted in sample sizes of n = 2572 and n = 2132, respectively, with means ± SDs of −0.07 ± 1.24 and −0.10 ± 1.33, respectively.

In **Supplemental Figure 2**, we present estimated densities stratified by child age. The mean ± SD HAZ was 0.088 ± 1.44 for children <2 y old; for children between 24 and 59 mo of age, the mean ± SD HAZ was 0.017 ± 1.26.

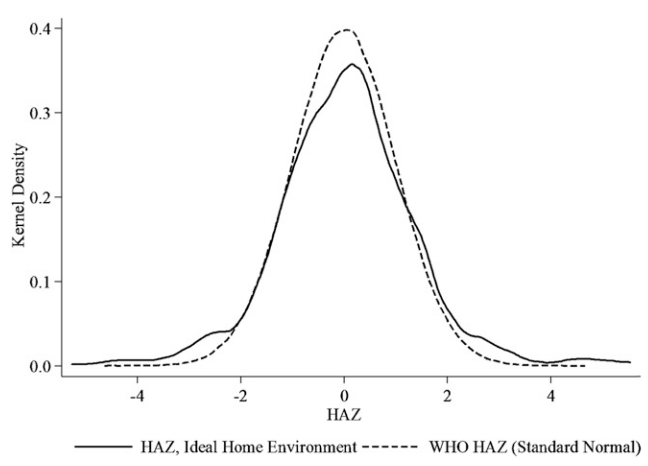

FIGURE 1 Kernel-density plot of empirical HAZ distribution in the ideal–home environment sample compared with the WHO HAZ (standard normal) distribution. The solid line represents the distribution of HAZs for children from ideal home environments (n = 1006). The sample is distributed with a mean ± SD of 0.043 ± 1.33, which was estimated with the use of a linear regression that was controlled for survey (country-year) fixed effects and coefficient SEs that were clustered at the primary sampling unit (Demographic and Health Survey cluster) level. The dashed line represents the distribution of HAZs from the WHO reference sample, which, by construction, is normally distributed with a mean ± SD of 0 ± 1. HAZ, height-for-age z score.

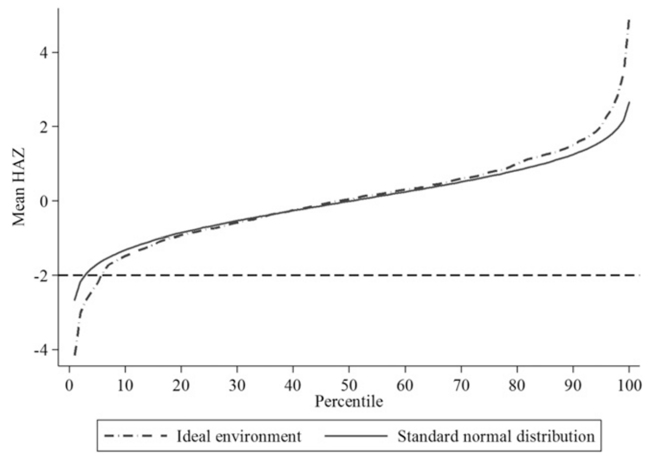

FIGURE 2 Percentile-specific HAZ distribution in the ideal–home environment sample compared with the WHO reference sample. The dash-dotted curve represents the distribution of HAZs for children from ideal home environments by percentile (n = 1006), whereas the solid curve presents the distribution of HAZs for the WHO reference sample by percentile. The dashed horizontal line at an HAZ of −2 represents the WHO-established child-stunting cutoff. HAZ, height-for-age z score.

Figure 4A compares the height distribution of mothers of children in the ideal group with the height distribution of mothers of children from nonideal settings. On average, mothers of children in the ideal group were 3.28 cm (β = 3.28; 95% CI: 2.68, 3.88 cm) taller than mothers of children who were not from ideal home environments. Moreover, 6.1% of mothers in the ideal–home environment sample were shorter than 150 cm, whereas the same was result was true for 17.7% of mothers in the non-ideal–home environment sample. Figure 4B presents the empirical association between maternal height and child HAZ in mothers and children from the ideal-group subsample. We showed that the overall relation was linear in the 145- to 180-cm range with larger declines for very short (<145 cm) mothers. Moreover, the mean child HAZ increased from ∼1 SD below the mean for children born to mothers whose heights were ∼145 cm to a mean child HAZ of 1 SD above the mean for children born to mothers whose heights were ∼175 cm. These findings suggest that a child-HAZ differential of ∼0.067 SDs/cm maternal height.

Supplemental Table 5 presents results from our multivariable regression model as well as calculations of the contribution to the overall HAZ deficit for each of our target criteria. The mean HAZ in children who were not exposed to any of the 5 target criteria was −2.2 (95% CI: −2.19, −2.13). Large and highly significant associations with the HAZ were shown for all 5 target criteria, and the largest associations were shown for being a single birth (β = 0.597; 95% CI: 0.568, 0.625) followed by being born to a mother with higher education (β = 0.537; 95% CI: 0.521, 0.554). When the overall contribution of each criterion to the total HAZ deficit was assessed, we estimated that high maternal education accounted for ∼25% of the pooled HAZ deficit, whereas hospital delivery, which served as our proxy for health-service coverage, accounted for ∼13% of the deficit. Household wealth and socioeconomic status accounted for ∼19% of the total HAZ deficit, and access to water and sanitation accounted for ∼14% of the deficit. The contribution

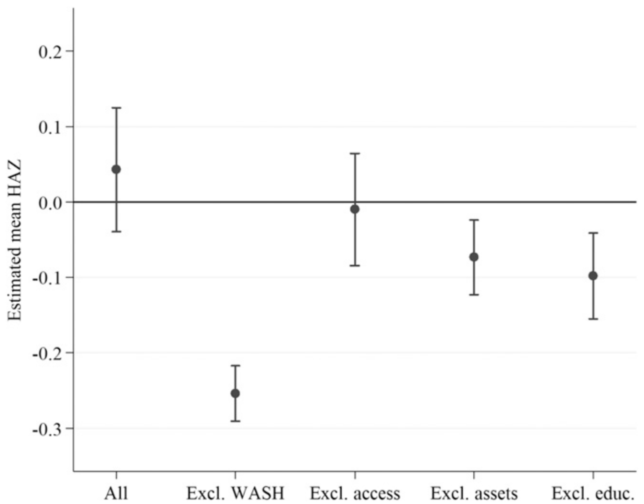

FIGURE 3 Sensitivity analysis of mean (95% CI) HAZs under alternative ideal–home environment definitions that were estimated by selecting children from alternative ideal home environments with each of the target criteria used to select the ideal child sample individually removed. The first specification (All) presents the value for which all target criteria that were used for selection were imposed (n = 1006). The second (Excl. WASH), third (Excl. access), fourth (Excl. assets), and fifth specifications (Excl. educ.) present values for which restrictions were removed for WASH (n = 6638), health-service access and coverage (namely the receipt of skilled delivery at birth and receipt of vaccinations; n = 1296), household possession of assets (television, car, and finished flooring; n = 2572), and maternal educ. (n = 2132), respectively. Values for each home-environment specification were estimated with the use of linear regressions, controlled for survey (country-year) fixed effects and coefficient SEs that were clustered at the primary sampling unit (Demographic and Health Survey cluster) level. educ., education; Excl., excluding; HAZ, height-for-age z score; WASH, safe water and sanitation.

of being a multiple birth to the deficit was small because of the low prevalence of the risk factor.

In **Supplemental Table 6**, we present the relative contribution of each target criterion by country and showed similar results to those presented in the pooled analysis. In particular, we showed that, for most countries, a lack of maternal education and exposure to household poverty were the principal factors that contributed to the large HAZ deficits that were observed.

DISCUSSION

The results presented in this study indicate that the global reference curves that are currently used to track and assess children's height effectively describe the empirical distribution of height when sampling is restricted to children who live in presumably well-off environments. Our results suggest that the mean HAZ in children who grow up in well-off home environments in developing countries today is very close to zero with mean and median heights that are very close to the reference values that were developed in the MGRS study. Compared with the WHO reference sample, the distribution of heights appeared slightly more dispersed in the ideal–home environment sample with an estimated SD of 1.3, and slightly $>$5% of children in our ideal-environment sample either had an HAZ <-2 or an HAZ $>$2. The slightly thicker tails of the distribution could, in theory, have been be created by the more-diverse genetic and environmental mix in our ideal-environment sample; however, it is also possible that the observed height measures varied more because of the likely larger variation in survey and measurement qualities in the DHSs than in the original MGRS (12).

The main advantage of our analytic approach was that the large DHS sample allowed us to directly work with a representative sample of children rather than focusing on specific, locally identified privileged subpopulations. Although the resulting subsample of interest (i.e., the ideal-group sample) was very small compared with the size of the larger DHS sample ($\sim$0.1% of the entire DHS sample), the group could be easily compared with more-general populations and enabled us to make direct inferences on key risk factors that we believe are driving the large observed gaps in current HAZ outcomes.

The current study has several limitations. First, and most importantly, it might be argued that the identified ideal-group sample may not have been an ideal normative or clinical benchmark for the wider population. The most obvious theoretical concern

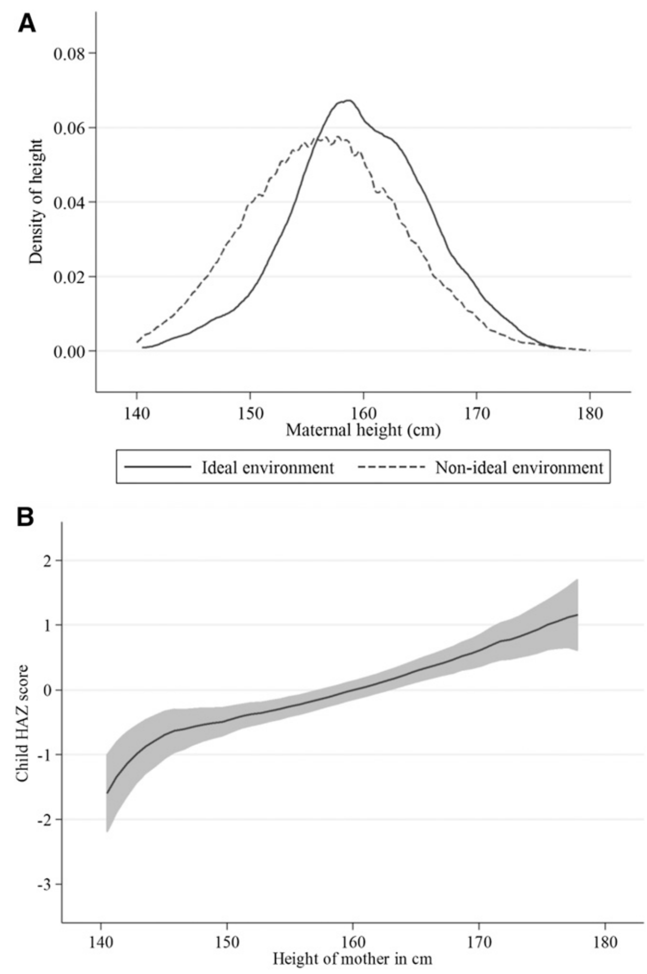

FIGURE 4 Histogram plots of HAZ distributions in the ideal–home environment sample stratified by maternal height. (A) Comparison of maternal height distributions of mothers from ideal home environments with those of mothers from nonideal home environments. The solid line represents the distribution of HAZs for mothers of children from ideal home environments (n = 824). The dashed line represents the distribution of HAZs for mothers of children from the remaining pooled Demographic and Health Survey sample (n = 556,255). (B) Nonparametric relation between maternal height and child HAZ in the sample of mothers and children from ideal home environments. A local polynomial smoothed regression was calculated with the use of the Epanechnikov kernel-density function for the weights and the rule-of-thumb estimation method to determine the bandwidth. Gray areas depict 95% confidence bands around the estimated regression plot. HAZ, height-for-age z.

that surrounds such nonrepresentative sampling is the existence of underlying genetic variations in height, whereby it may be possible that economically privileged mothers globally are taller, on average, although it is not obvious why this should be the case. All of the evidence presented in this study suggests that there was a height gap between our reference sample and the general population; however, this height gap almost certainly did not just reflect differences in genetic compositions but was, to an arguably large degree, attributable to differential exposures to poverty and malnutrition in childhood and adolescence. Even if the 3.28-cm mean difference in maternal height between mothers in our ideal group and mothers from nonideal home environments as an estimate of the true underlying genetic difference was taken into account, this observed difference would have only been able to explain less than one-quarter of an SD of the global HAZ deficit.

A second limitation of the study is that all of the empirical estimates presented were based on cross-sectional data, and although we included survey (country-year) fixed effects in our regressions, we could not completely account for potential global- and country-level trends in child height over time. In choosing a limited number of risk factors for our analysis, we may also have missed other key risk factors that could have significantly explained the global child-height deficit. Therefore, the associations that we estimated between risk factors and the mean HAZ presented may have been confounded by these other factors that were not included in our model, and thus, the attributed HAZ deficits overstated the true causal effects of the factors analyzed. Finally, we acknowledge that, although our choice of child height as a proxy for accumulated health stock and early-life environment has been commonly used in the literature (13–15), there are other metrics that may also be appropriate for assessing child growth and development including weight-for-age, head circumference, and upper arm circumference.

Proponents of global growth standards have long emphasized that differences in children's heights during the first 5 y of life are primarily influenced by nutrition, feeding practices, environment, and the receipt of health care rather than by genetic or ethnic factors and have cited that children aged <5 y who are given the optimum start in life tend to grow and develop similarly (11, 16, 17). The setting of such a standard would be achieved by restricting children in a reference sample to those who are growing optimally under conditions that facilitate the achievement of their full genetic growth potential and who can be viewed, therefore, as a model for other children to follow (18).

In conclusion, all of the data analyzed in this study suggest that the large differences in the mean HAZ, including the high stunting rates that have been observed in South Asia and in parts of Sub-Saharan Africa, are not due to genetic or other nonmodifiable traits but simply reflect the continued presence of large disparities in maternal education, health-service coverage, and general living conditions. Therefore, policies and programs that aim to improve early life environments for children are likely to not only yield substantial increases in the coverage rates of critical health and development interventions but also may contribute to further improving child growth and wellbeing.

All data used for this study are available from the DHS program at http://dhsprogram.com/data/.

The authors' responsibilities were as follows—all authors: participated in the conception, analysis, design, and writing of the article; read and approved the final manuscript; and were aware that the manuscript was submitted for publication. None of the authors reported a conflict of interest related to the study.

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