

This is the final pre-publication version of an article submitted to [The Annals of the New York Academy of Science](#) in March 2017.

Published details:

Schott, Whitney, Elisabetta Aurino, Mary Penny, Jere Behrman, Adolescent mothers' anthropometrics and grandmothers' schooling predict infant anthropometrics in Ethiopia, India, Peru, Vietnam. Issue: Adolescent Women's Nutritional Status, DOI: 10.1111/nyas.13455

Adolescent mothers' anthropometrics and grandmothers' schooling predict infant anthropometrics in Ethiopia, India, Peru, Vietnam

Authors: Whitney Schott¹, Elisabetta Aurino², Mary E. Penny³, Jere R. Behrman⁴

¹ Population Studies Center, University of Pennsylvania, USA

² Imperial College London and Young Lives, University of Oxford, UK

³ Instituto de Investigación Nutricional, Peru

⁴ Economics, Sociology and Population Studies Center, University of Pennsylvania, USA

Corresponding Author:

Whitney Schott, PhD, MA
Population Studies Center
University of Pennsylvania
239 McNeil Building
3718 Locust Walk
Philadelphia, PA 19104

wschott@pop.upenn.edu
571-758-5013

Short Title: Adolescent Maternal Growth and Infant Anthropometrics

Key Words: Growth; Birthweight; Intergenerational; HAZ; Adolescent Mothers

Abstract

We investigated intergenerational associations of adolescent mothers' and grandmothers' anthropometrics and schooling with adolescent mothers' offspring's anthropometrics in Ethiopia, India, Peru, and Vietnam. We examined birthweight (n=283), birthweight z-score (BWZ), conditional growth in weight-for-age-z-score (cWAZ, residuals from a regression of WAZ at last survey round on BWZ, sex, and age), and HAZ of children born to Older Cohort adolescent girls of the Young Lives Study. Our key independent variables were adolescent mothers' body size: height-for-age z-scores (HAZ) and body-mass-index-for-age z-scores (BMIZ) at age 8, conditional HAZ (cHAZ, residuals from a regression of HAZ at the end of a growth period on prior HAZ, age, sex), conditional BMIZ growth (cBMIZ, calculated analogously), and grandmaternal BMIZ, HAZ, and schooling. We adjusted for child, maternal, and household characteristics. Adolescent mothers' cHAZ (ages 8-15) predicted birthweight ($\beta=130\text{g}$, 95% Confidence Interval (CI) [31 - 228]), BWZ ($\beta=0.31$ CI [0.09 - 0.53], and cWAZ, ($\beta=0.28$, CI [0.04 - 0.51]). Adolescent mothers' BMIZ at age 8 predicted birthweight ($\beta=79\text{g}$, CI [16 - 43]) and BWZ ($\beta=0.22$, CI [0.08 - 0.36]). Adolescent mothers' cBMIZ (ages 12-15) predicted child cWAZ and HAZ. Grandmothers' schooling predicted grandchild birthweight ($\beta=22\text{g}$, CI [1 - 44]) and BWZ ($\beta=0.05$, CI [0.01 - 0.10]).

Introduction

Birthweight is a major indicator of nutritional status at birth, and together with other intrauterine conditions, helps set the scene for future child growth and development. Several longitudinal studies have shown that birthweight is positively associated with adult height in low- and middle-income countries (LMICs), even adjusting for socioeconomic factors.¹⁻⁴ Birthweight is also predictive of infant mortality⁵ cardiovascular risk,⁶ blood lipid concentrations,⁷ and a number of behavioral and cognitive outcomes.⁸⁻¹⁰ After birth, infant and childhood nutritional intake, socioeconomic status (SES), and various other factors influence a child's growth and development trajectories, but birthweight is a major indicator of to what extent a child may be off to a good start, or what ground must be covered to catch-up with average birthweight children growing at an average pace.

Maternal birthweight is correlated with infant birthweight,¹¹⁻¹⁶ even when there is exposure to adverse prenatal conditions for the infant.¹⁷ While much of the previous literature on intergenerational body-size relationships has focused on parental-child relations in European settings,^{12,18-20} some important studies have examined this topic in LMICs. Using the COHORTS datasets, a set of studies tracking children over time in five LMICs (Brazil, Guatemala, India, the Philippines, and South Africa),^{13,15,21-26} a body of work has examined the longitudinal association of maternal height at various points in childhood with infant birthweight, finding a robust, positive relationship.^{21,22,27,28} This work has also found that both maternal and paternal birthweight predicted next-generation birthweight, with a stronger matrilineal than patrilineal association.²¹

There is also evidence that interventions during childhood may be associated with next generation anthropometrics. A randomized nutritional intervention during childhood in Guatemala that increased the child body size of female recipients demonstrated a positive association with next-generation child anthropometrics.²⁹

Previous work examining associations across three generations in LMICs is more limited. We conducted a series of literature searches (N=64) in the Web of Science database on anthropometrics over three generations and found 12 studies, of which 8 were from North American or European cohorts, such as the United Kingdom and Sweden.^{12,16,28} We found only 4 studies examining the relations among body size over three generations in LMICs. Two studies in Brazil examined birthweight and size controlling for grandmaternal height and living conditions.^{30,31} One study from Mexico examined living conditions experienced by grandmothers and their associations with grandchild height and leg length.³¹ Finally, one study of child-mother-grandmother triads in India suggested that children living with an educated grandmother had higher HAZ.³²

Beyond parental nutritional status (expressed by their birthweight and linear growth), there is ample literature on further predictors of infant birthweight, including maternal and paternal genetics, demographic and psychosocial factors, gestational events (such as toxic exposures and maternal morbidity) and antenatal care.³³ Risk factors for low-birthweight infants in developing countries that we can examine in this study include rural residence,³⁴ low maternal education,¹⁶ low socio-economic status,³⁵⁻³⁷ and, for higher birthweight, pre-pregnancy maternal overweight and obesity.³⁸

Adolescent motherhood is thought to result not only in greater socioeconomic and other risks for mothers but also in increased risks of adverse outcomes for their children.^{23,26,35,39,40} We examined intergenerational relations in anthropometrics for children born to this higher-risk population in LMICs. Specifically, this study examines associations between the outcomes of birthweight, birthweight z-scores (BWZ), conditional weight-for-age z-scores (cWAZ) and height-for-age z-scores (HAZ), and the following predictors: adolescent mothers' childhood growth and characteristics (HAZ, BMIZ, cHAZ, cBMIZ, schooling) and grandmaternal factors (BMIZ, HAZ, age, schooling, and household characteristics), all in four geographically and ethnically diverse populations (Ethiopia, India, Peru and Vietnam).

Materials and Methods

We use data on three generations from the Young Lives study, a longitudinal survey of two cohorts of children from Ethiopia, India (Andhra Pradesh, Telangana), Peru and Vietnam. The children that represent the third generation (henceforth referred to as “next-generation children”) we analyzed were born to adolescent mothers (henceforth referred to as “the mothers” or “adolescent mothers”) from the older cohort of the Young Lives study. The 1,802 girls in the older cohort (roughly 500 girls per country) were born in 1994-1995 and were approximately age 19 years in the fourth round of data collection (in 2013). Of those adolescents, 302 (16.8%) had given birth to 343 children (302 mothers total; 41 had two children). Data on child anthropometrics were available for 285 next-generation children (n=285 for BWZ, n=253 for cWAZ, and n=243 for HAZ). There were two children for whom maternal height from ages 8 to 12 was recorded as having declined (by as much as 15 cm); these two observations were dropped from the analysis, leaving us with final sample sizes of: n=283, n=281, n=251 and n=242 for birthweight, BWZ, cWAZ, and HAZ, respectively. Anthropometric, demographic, schooling, and other data were collected at roughly ages 8, 12, 15 and 19 years for the adolescent mothers. Young Lives cohorts were randomly sampled from 20 sentinel sites reflecting a variety of geographic and socioeconomic contexts in each country. Further details on sampling and the Young Lives Study are reported elsewhere⁴¹ and available at www.younglives.uk.org. Trained personnel collected detailed information about adolescent mothers and their households through a structured questionnaire, also available at www.younglives.uk.org. This study received institutional review board (IRB) approval from the University of Pennsylvania. The YL study was approved by the IRB from the University of Oxford and local ethics review boards at each participating country's lead institution.

Anthropometric Measures

Next-generation birthweight was confirmed by documentation for 47% of children (enumerators were instructed to record birthweight listed on hospital/health center documentation or vaccine cards and document when this was available; if not available, the enumerator recorded adolescent mothers' reports of birthweights). Child height/length and weight were measured in 2013. Length was measured in children age 0-2 years to 1 mm; height was measured to 1 mm with standardized stadiometers (for simplicity, we refer to both measurements as height). Weight was measured to 100-g using platform scales or clock balances. Adolescent mothers' heights and weights at ages 8, 12, 15, and 19 years were measured in all four countries in 2002 (Round 1), 2006 (Round 2), 2009 (Round 3), and 2013 (Round 4). Heights and weights were measured following WHO procedures and repeat measures ensured accuracy. BWZ, HAZ, and BMIZ at each age were calculated using the WHO 2006 and 2007 reference distributions.^{42,43} Maternal conditional HAZ for a given period, henceforth cHAZ, was calculated as the residuals from the regression

of HAZ at the end of the period on all HAZ measurements prior to the period, separately for each country, controlling for age in months. In other words, cHAZ was the residual above or below what was predicted by the adolescent mother's position in the WHO reference distribution at the beginning of the growth period.^{27,44} A positive cHAZ value represented faster than expected growth, and negative cHAZ value represented slower than expected growth. We constructed cBMIZ with analogous equations. Conditional WAZ (cWAZ) was calculated for next-generation children as the residuals from the regression of WAZ in 2013 on BWZ, child sex, and age in 2013, separately by country. We did not consider the conditional HAZ of the next-generation children because there were not enough non-missing values for reported birth length (while we could have used BWZ as a proxy for birth length z-score, we opted not to pursue this approach since birth length was not sufficiently correlated with birth weight among those who reported values for both). The advantages of examining conditional measures was that they took into account correlations between independent measures over different ages for each child and for a tendency for regression to the mean. Available measurements for heights and weights in 2013 allowed the calculation of cWAZ for 253 next-generation children and HAZ for 243 next-generation children. Grandmaternal adult heights and weights, from which HAZ and BMIZ were calculated (using the WHO reference distributions for age 19 to represent adult heights and BMI), were measured at Round 2 (when the adolescent mothers were ~12 years, the only point at which these measures were obtained).

Other Measures

Additional child characteristics included child sex, age in months at the time of the 2013 survey (calculated as the difference between the interview month and year and the reported birth year and birth month), and an indicator for whether the birth was primiparous. Antenatal characteristics included indicators for prenatal care received and maternal ratings of their health during pregnancy (indicating "good," of the possibilities good, average or poor). Adolescent mothers' characteristics included age at child's birth; attending school at Round 3 (age ~15 years); maternal pregnancy with child at Round 3 when height at that round was measured (this variable was calculated retrospectively from the next-generation child's age in months, in order to control for pregnancy at the time of maternal anthropometric measurement); maternal menarche by Round 2 (age ~12 years); adolescent mother was firstborn; and indicators for maternal diet at Round 3, including binary indicators for consumption of each of 6 food groups (grains/roots/tubers, fruits and vegetables, meat/fish, eggs, legumes, and dairy) in the previous 24 hours. Grandmaternal characteristics included age at Round 2 of the Young Lives study when the adolescent mothers-to-be were ~8 years old, completed grades of schooling. Household characteristics included a wealth index at Round 3 (constructed by the Young Lives team for the full sample of Young Lives children as a composite of access to services, housing quality, and asset ownership, scaled by us to range 0-100) and an indicator for urban location at Round 3.

Methods

We constructed a simple conceptual model shown in figure 1. We used ordinary least squares (OLS) regression to estimate reduced-form associations between the outcomes of next-generation birthweight, BWZ, cWAZ, and HAZ and the key independent variables of maternal HAZ at age 8 (our earliest data point), conditional HAZ growth between ages 8 and 15, maternal BMIZ at age 8, and conditional BMIZ growth between ages 8 and 15, and schooling, as well as grandmaternal BMIZ, HAZ and schooling. We pooled data from the four different countries in all analyses to increase power due to the low number of observations per country and included binary variables as country indicators. We employed multiple

imputation (with the ice command in Stata 13, specifying 15 imputations) in order to utilize all observations with data on the outcome variables of interest in our regressions.⁴⁵ We first assessed the unadjusted relationships with these variables with child sex and binary country controls. For the regressions of next-generation HAZ and cWAZ, age in months was also included in unadjusted regressions. We then adjusted for the set of antenatal, maternal, and grandmaternal controls outlined above. Since we had data on two growth periods in the adolescent mothers' childhood, from ages 8 to 12 and from ages 12 to 15, in alternative estimates we allowed for two periods of conditional growth, including cHAZ and cBMIZ for these two periods separately. These two periods for some adolescent mothers may represent (1) pre-pubertal growth and (2) the pubertal growth spurt, while for others (e.g., those with later menarche), these two growth periods may confound premenarchial and pubertal growth. To avoid the pubertal timing issue from potentially confounding estimates, we used the total conditional growth in HAZ and BMIZ from age 8 to 15 in our basic estimates and included a dummy for early menarche.

We also conducted extensive sensitivity analysis. While we included covariates that have demonstrated associations with child anthropometrics in previous literature in the regressions outlined above, some might argue that some maternal characteristics that we included are descendent of the childhood nutritional status of the mother. In order to examine the relations between maternal childhood nutritional status and next generation anthropometrics without possibly confounding with downstream effects of childhood nutritional status, we also conducted the regressions listed above but excluding maternal dietary indicators at age 15 years, maternal schooling enrolment at age 15 years, prenatal health care received, and self-rated prenatal health.

We further examined OLS regressions of birthweight, BWZ, cWAZ, and next-generation HAZ on alternative measures of child growth, including maternal childhood HAZ and BMIZ levels and changes in growth between measurements (calculated as the simple difference in HAZ between two ages and the difference between BMIZ between the two ages); we looked at these changes from 8 to 12 and 12 to 15 separately in one model and the total change from 8 to 15 years in another. We further regressed next-generation child outcomes on maternal heights and BMI levels and changes in heights and BMI between measurements, defined as the simple differences in heights (and BMI) between the two ages (8 to 12 years, 12 to 15 years in one model, ages 8 to 15 years in a separate model).

We also examined whether the lack of birth documentation for about half of the cases might have affected estimates and whether there were differences in the coefficients on maternal growth by whether the adolescent mothers experienced menarche early. First, we interacted the presence of birth documentation with each of the maternal growth variables and tested to see whether these interactions were jointly different from zero. Given the low number of observations to power such an analysis, we also conducted the main analysis on the subset of birthweights for whom documentation was available. Finally, we interacted the early menarche dummy with each of the maternal growth variables and tested whether the coefficient on conditional HAZ growth from age 8-12 interacted with early menarche was the same as the coefficient on conditional HAZ growth from age 12-15 interacted with early menarche. All the analyses were undertaken in Stata 13.1.

Results

Of the 283 next generation children in our sample, the mean birthweight was 2,942g; country averages ranged from 2,764g (India) to 3,147 (Ethiopia) (Table 1). Nine percent were born to adolescents age 15 or younger. Birthweights were recorded from documentation for about half of the sample overall, ranging from 10.5% in Ethiopia to 66.3% in Peru. Reported birthweights were on average about 140g higher among those whose birthweight was recorded from documentation (t-test, $p<0.05$). Next-generation children with birthweight documentation had adolescent mothers with higher HAZ and height at age 8, greater BMI change from 12-15, BMIZ change from 8-12 and from 12-15, and cBMIZ from 12-15 ($p<0.05$), compared with the mothers of next-generation children without birthweight documentation. However, there were no differences in adolescent mothers' BMI or BMIZ at age 8, BMIZ change from 8-15, BMI change from 8-12 or 8-15, cBMIZ 8-15 or cBMIZ 8-12 by birthweight documentation availability. There were also no differences in grandmaternal BMIZ by whether the next-generation child had birthweight documentation. Next-generation children with birthweight documentation were also more often from urban areas and from households with higher wealth indices and grandmaternal schooling (t-tests, $p<0.05$), but there were no differences by whether the mother was enrolled in school at age 15. Average BWZ for the sample was lower than the WHO reference median value, at -0.80, with country averages ranging from -1.21 (India) to -0.36 (Peru). The age in months of the next-generation children at weight and height measurements in 2013 ranged from 0 to 78 months (median = 11 months). Conditional WAZ (cWAZ) ranged from -4.99 to 4.73 for the full sample (with a mean of zero for each country by construction). HAZ in 2013 averages by country ranged from -1.52 (India) to -0.54 (Ethiopia), and the percentages of next-generation children who were stunted ($HAZ<-2$) ranged from 25.0% (Peru) to 45.3% (India).

Maternal HAZ at age 8 did not predict birthweights or BWZ in adjusted models (Table 2). However, conditional maternal height growth between 8 and 15, cHAZ(8-15), predicted 130 g ($p<0.01$, column IV) higher birthweights, and predicted 0.31 ($p<0.01$, column VIII) higher BWZ in adjusted models. Maternal BMIZ at age 8 predicted higher birthweights in adjusted specifications, with a one-unit higher BMIZ associated with 65g ($p<0.05$, column II) higher birthweights when two growth periods (8-12 vs. 12-15) were included, and 79g ($p<0.05$, column IV) higher birthweights in the specification with total cBMIZ from ages 8-15 (adjusted). Maternal BMIZ at age 8 in the models of BWZ predicted 0.19 ($p<0.01$, column VI) higher BWZ (adjusted) when the growth period was split into two periods (8-12 vs. 12-15), and 0.22 ($p<0.01$, column VIII) when the combined growth period was considered. Maternal childhood cBMIZ (ages 12-15) predicted 84g ($p<0.10$, column IV) higher birthweights (adjusted). Maternal childhood cBMIZ did not predict higher infant BWZ.

Antenatal and other maternal covariates predictive of next-generation children's birthweights included good maternal health during pregnancy ($\beta=141$, $p<0.05$, column II; $\beta=121$, $p<0.10$, column IV), received prenatal care during pregnancy ($\beta=342$, $p<0.05$, column II; $\beta=351$, $p<0.05$, column IV), and mother enrolled in school at age 15 ($\beta=169$, $p<0.05$, column II; $\beta=139$, $p<0.10$, column IV). Antenatal and other maternal covariates predictive of next-generation BWZ were maternal prenatal health good ($\beta=0.26$, $p<0.10$, column VI), maternal prenatal care received ($\beta=0.82$, $p<0.05$, column VI; $\beta=0.85$, $p<0.05$, column VIII) and mother enrolled in school at age 15 ($\beta=0.33$, $p<0.10$, column VI).

Predictive grandmaternal covariates for next-generation birthweight included grandmaternal schooling attainment ($\beta=22$, $p<0.05$, column II; $\beta=22$, $p<0.05$, column IV); grandmaternal schooling also predicted BWZ ($\beta=0.05$, $p<0.05$, column VI; $\beta=0.05$, $p<0.05$, column VIII). Grandmaternal HAZ and BMIZ were

not predictive of grandchild BWZ or birthweights. Covariates not shown were not significant (see Table A1 for full set of results).

Maternal HAZ at age 8 predicted higher next-generation conditional weight growth (cWAZ, Table 3) from birth to 2013 ($\beta=0.21$, $p<0.05$, column IV). Maternal cHAZ, specifically between ages 12 and 15, predicted next-generation child cWAZ ($\beta=0.34$, $p<0.05$, column II; $\beta=0.41$, $p<0.01$, column IV), as did maternal cBMIZ, particularly between ages 12 and 15 ($\beta=0.41$, $p<0.01$, column II; $\beta=0.28$, $p<0.05$, column IV). BMIZ levels at age 8 did not predict cWAZ. Dairy consumption predicted higher cWAZ ($\beta=0.38$, $p<0.10$, column II; $\beta=0.42$, $p<0.05$, column IV). The only other maternal covariate predicting higher cWAZ between birth and 2013 (Round 4) was mother's age at birth ($\beta=0.46$, $p<0.10$, column II, $\beta=0.53$, $p<0.05$, column V).

Faster than expected maternal growth in BMIZ, or cBMIZ, between ages 12-15 was associated with higher next-generation HAZ in 2013 ($\beta=0.54$, $p<0.05$, column VI). Other maternal predictors of HAZ in 2013 in adjusted models were good self-rated prenatal health ($\beta=0.64$, $p<0.05$, column VI; $\beta=0.62$, $p<0.05$, column VIII). None of the grandmaternal characteristics were associated with cWAZ or HAZ in 2013 (except for an inverse association between grandmaternal schooling attainment and cWAZ at $p<0.10$, Table A1). Figure 2 provides a summary of findings.

In sensitivity analysis excluding possible downstream effects of child nutritional status, coefficients on the maternal nutritional status variables were slightly attenuated (Tables 4 and 5). For example, cHAZ(8-15) for Table 2 shows $\beta=130$, 95%CI [31 - 228], in column VIII, while for Table 4, $\beta=118$, 95%CI [22 - 214], in column VIII.

In other sensitivity analyses, we examined alternative definitions of maternal childhood growth. Using specifications of growth measured as (i) change in HAZ and BMIZ during the two growth periods and (ii) change in height and BMI during the two growth periods, we found comparatively more of the relations were significant compared with the aforementioned analyses (Table 6). This analysis suggested that the simple associations between maternal childhood growth and next-generation children outcomes are quite robust, with the estimates presented in Tables 2 and 3 representing the most conservative estimates, since they remove the issue of correlation in HAZ/BMIZ measures over time. A full set of regression results are available in the online appendix table A1.

In robustness analysis examining the possible bias that could be introduced by including children with birthweight that was not documented, we found that the full set of interactions between the dummy of having birthweight documentation with the maternal growth variables was not jointly statistically distinguishable from zero for any of the four outcomes (estimates available upon request). Conducting the analysis on the sub-set of children for whom birthweight was documented, we found an even more robust relationship (larger in magnitude and more precisely estimated) between the key maternal growth variables and birthweights, suggesting that our full-sample results may represent lower-bound estimates. When early menarche was interacted with each of the maternal growth variables during adolescence, we similarly found that none of the interaction terms with the maternal growth variables were significant, and they were jointly statistically no different from zero (estimates available upon request). Thus, we concluded that

biases from differences in the sample by the existence of birth documentation and by pubertal timing were negligible.

Discussion

This study showed that adolescent girls' growth trajectories prior to pregnancy were associated with the anthropometrics of their children, and, in addition, some third-generation (grandmaternal) characteristics were associated with grandchildren's anthropometrics. We reported robust associations between the key independent variables of maternal cHAZ and cBMIZ (measures of growth velocity in terms of height and BMI, respectively, above or below what would be expected given HAZ and BMIZ at age 8 years) during childhood, grandmaternal BMIZ and HAZ and the outcomes of next-generation child birthweights, BWZ, conditional WAZ growth (a measure of the growth velocity in terms of weight in the early months of the infant or child's life), and HAZ. Figure 2 provides a visual summary of these findings. It is not clear to what extent such influences are due to genetic components that drive greater-than-expected growth for both mothers and children, despite the possibility of competition for nutrients resulting from the co-occurrence of pubertal growth and pregnancy, or socioeconomic and environmental conditions that may have influenced maternal growth. It has been estimated that genetics may account for about 30% of the variance in birthweight.⁴⁶ Previous work on the younger cohort of the Young Lives data showed that parental schooling, household consumption, and mother's height were key correlates with conditional HAZ growth during childhood.⁴⁴ Thus, it is likely that both genetic and environmental influences during a mother's childhood drive these findings.

We also examined whether antenatal and maternal factors predicted next-generation children's outcomes. Having good self-rated maternal prenatal health was associated with higher next-generation BWZ and HAZ in 2013, possibly suggesting both immediate and persisting effects of better developmental conditions in utero. Maternal diet at age 15 had few significant associations with next-generation children's outcomes, with the exception of a positive association between intakes of dairy products and cWAZ ($p < 0.01$), which has been reported in previous studies.⁴⁷⁻⁴⁹ Maternal school enrollments at age 15 years were associated with higher birthweights and BWZ, but not cWAZ or HAZ, consistent with a hypothesis that higher SES is associated with better birth outcomes as reported in previous literature.³² It is possible that later measures of schooling (following childbirth) might be associated with later child growth outcomes such as cWAZ and HAZ; we hope that additional work planned in this area will illuminate this hypothesis.

We found that grandmothers' completed grades of schooling were associated with higher BWZ and birthweights (though not cWAZ, or HAZ), consistent with a model of three-generational direct transmission of poverty and educational status in addition to any grandparental effects transmitted indirectly through the included maternal characteristics. Grandmaternal ages were associated with slightly higher birthweights, suggesting there is no penalty of grandmaternal age on next-generation children.

In the analysis eliminating variables that were possibly determined by childhood nutritional status (i.e., maternal schooling enrollment at age 15 years, maternal prenatal health, prenatal care received, and maternal diet), we found that coefficients on the mothers' childhood growth variables were somewhat attenuated. If these variables were truly determined by childhood nutritional status, we would have

expected the coefficients on the maternal growth variables to be under-estimated in the models that did include those covariates. Since results remained robust and instead were slightly attenuated, these associations may reflect a relationship that exists regardless of childhood nutritional status.

This study examines growth measures collected longitudinally for adolescent mothers and their associations with next-generation growth within a three-generational framework in a diverse set of four LMICs. Adolescent mothers are of particular interest because of the perceived high risks and the economic, health, and social costs of adolescent motherhood. It is known that births during adolescence are more likely among mothers with lower socio-economic status.^{23,26,35-37} Children born to teen mothers may be at greater risk of poor infant outcomes at birth^{35,39} and in early childhood^{23,26}, particularly in the case of early adolescence (aged 15 and 16 years) as compared to older ones (in our sample, about 1/3 are age 16 or less at first birth and 2/3 are older than 16).^{26,40} While births occurring to adolescent mothers may not be representative of patterns of growth among the broader population, these results are of considerable interest in themselves because they portray the lasting impact of maternal childhood growth on next-generation growth for this high-risk group. We find some persisting associations between grandmaternal characteristic (age and schooling attainment) and grandchild anthropometrics, even when controlling for maternal anthropometrics, antenatal factors and household characteristics.

There were several limitations to this study. First, we did not have birthweight data for the mothers of the next-generation children; the earliest observation of anthropometrics for the Young Lives Older Cohort is at age 8 years. The Young Lives Younger Cohort might be useful for a study focusing on intergenerational birthweights, since (reported) birthweights were collected, but few of the females in this cohort gave birth by the end of Round 5 (presently the final round) of Young Lives collected in 2016 (but not available for this study), at which time the Young Lives Younger Cohort were ~age 15. While there were no concrete plans to follow births of the Young Lives Younger Cohort at the time of writing this paper, data collection for the next generation would be highly informative for future work in this area. The fifth round of Young Lives data will provide greater numbers of births for the Young Lives Older Cohort, as its members were around age 22 at Round 5, but will still lack data on members' early lives (prior to age 8 years) and have fewer subjects compared to the Young Lives Younger Cohort, which is roughly twice the size.

Second, birthweight data were self-reported in a number of cases, with documentation available for less than half of our sample. In high-income countries, recall data on birthweights are quite reliable⁵⁰⁻⁵². Evidence on the reliability of recall birthweight data from LMICs is somewhat more mixed, especially since most of the available cross-country studies employing Demographic Health Surveys used birthweight data in which the mothers were reporting data on the relative size of their baby, rather than a continuous measure of weight (e.g., very small, small, normal, large, and very large). This assessment based on categories, which was mostly prevalent in the surveys conducted in the 1990s, may have affected the accuracy of low birthweight estimates in the developing world.⁵³⁻⁵⁶ A more recent assessment of the reliability of birthweight data from Demographic Health Surveys (DHS) underscored that even when continuous numerical values are available for recalled birthweight (rather than categories of size at birth), there may still be some systematic bias induced by this method as compared to the measures of birthweight reported on health cards.⁵⁷ These issues may in turn lead to misclassifications, particularly in the case of babies that are classified as low birthweight.^{54,56,57} Given that reported birth weight data should be treated with caution, we conducted robustness checks to investigate whether there was any systematic bias

between birthweights as measured by maternal recall and health certificates. The results for this check suggest that our estimates may represent a lower bound, since findings were more robust among the subset with documented birthweights.

Third, data on next-generation children's birth month and year were mother-reported and not verified with documentation. While one would expect these data to be relatively reliable, it appeared that some dates may have been reported or recorded incorrectly, as some children's height and weight measurements were out of the acceptable range for reported age in months (this was true for 31 out of 240 with height measurements, 27 out of 243 with weight measurements). If these children were misrecorded at random, then we would not expect bias to be introduced to the estimates, but imprecision would be increased. We did not find significant differences in having out of range height measurements by most of the covariates considered, with the exception of mother's age at birth (positive association), mother's BMI at age 8 (negative association), and the next generation child being female (negative association).

Fourth, we did not have data on paternal anthropometrics. Some literature suggests that both maternal and paternal body size can contribute to child birthweight and birth length,^{11,21,28} Most studies found a stronger relationship between maternal anthropometrics with child birthweight, though one study found that paternal and maternal birthweights equally predicted infant birthweights¹³ (and another found no relationship between paternal anthropometrics and child birthweight at all²⁷). One study posited that the interaction between the intrauterine environment and maternal genetic composition may moderate the paternal genetic influence.⁵⁸ We were not able to examine this paternal-child relationship as anthropometric data on fathers were not collected in Young Lives.

Other issues for consideration are that we did not have a measure of the socio-economic status at the time of conception or birth because these data were collected only for the time when households were visited by the Young Lives team, when adolescents were 15 and 19 years of age, yet births occurred between these ages. For the same reason, the ages at measurement for cWAZ and HAZ vary widely, which makes comparisons across children subject to variation in the relevance of various controls (e.g., wealth index, rural residence) taken at a given point in time, even though controls for age in months were included. We also note that maternal smoking during pregnancy has been associated with lower birthweight.^{18,59,60} The prevalence of smoking in the study was very low with only 7 (Peruvian and Vietnamese) adolescent mothers out of the 302 total mothers reporting smoking at age 15. Thus, we did not have sufficient power to examine the relationship between maternal smoking and child anthropometrics. Further, we note that in Ethiopia, the percentage of adolescents who have become mothers (4.2%) is quite low compared to the three other countries (10.9% in India, 12.0% in Peru, and 6.7% in Vietnam) and compared with estimates from the World Development Indicators,⁶¹ which suggest the adolescent fertility birth rate for girls ages 15-19 was 63.6 per 10,000 in 2013. We speculate that the lower prevalence in adolescent motherhood in the Ethiopian Young Lives sample may be related to recent efforts to end child marriage in Ethiopia, though we did not have sufficient data to test that hypothesis. We also note that Ethiopian girls experience menarche later than Indian, Peruvian, and Vietnamese girls -- at 12 years, only 5% of Ethiopian girls experienced menarche as compared to just under half of Indian and Peruvian girls and a fifth of Vietnamese girls.

In addition, it is difficult to assess the extent to which menarcheal timing influenced maternal cHAZ and cBMIZ growth and next-generation anthropometrics. It is known that higher levels of BMIZ prior to menarche are associated with earlier menarche, which is then associated with an earlier growth spurt^{62,63} for adolescents. Adolescents with early menarche likely have greater-than-expected HAZ velocity between ages 8 and 12, but perhaps less-than-expected HAZ velocity between the ages of 12 and 15. These girls are also likely to be shorter as adults, as adult height is reached earlier.⁶⁴ We found no significant associations for greater-than-expected HAZ growth between ages 8 and 12 but did find associations between greater-than-expected HAZ growth between ages 12 and 15 and next-generation birthweights, BWZ, and cWAZ. These findings are consistent with the possibility that girls who have later growth spurts, accompanied by greater-than-expected growth from ages 12-15, and who are likely to have higher adult height, transmit this greater growth velocity to their children. On the other hand, it could be that healthy nutrition and growth in childhood both optimizes timing (i.e., neither exceptionally early nor exceptionally late) of menarche and provides a better environment *in utero* for development of the next-generation child. It is also possible that during the pregnancy of those adolescents with later pubertal growth spurts there was competition for nutrients between the mothers and their *in utero* children. We note that in robustness checks using interactions with early menarche we did not find significant differences in coefficients, suggesting that associations between maternal growth and next-generation child growth were not different for early- versus late-developing mothers.

This study offered robust evidence on the persistent associations of growth, and other characteristics such as grandmaternal and maternal schooling, for adolescent mothers across three generations from four LMICs with diverse geographic, ethnic, and socioeconomic contexts. While some proportion of maternal growth propensity may be passed along to next-generation children through genetics, non-genetic factors apparently also played a role, probably through the conditional growth measures in particular, suggesting that interventions even after age 8 years may positively influence outcomes of next-generation children among adolescent mothers in developing countries who, along with their children, are at high risk. Interventions aiming at providing nutritional supplements (e.g., dairy products or relevant micronutrients), improving opportunities for healthy growth and weight gain (e.g., reducing intake of high sugar beverages and of low-nutrition/high-caloric foods), and delaying ages at first pregnancies, in both late childhood and early adolescence, may improve the health of the next generation.

Acknowledgements

This work was supported by grants from the Sackler Institute Collaborative Initiative Aimed at Using Existing Datasets to Conduct Research on Adolescent Women's Nutritional Status, the Eunice Kennedy Shriver National Institute of Child Health and Human Development (NICHD, Grant R01 HD070993), and Grand Challenges Canada (Grant 0072-03). We thank Nykia Perez Kibler for her valuable assistance conducting a large number of literature searches for our review. We also thank attendees at the Sackler grantee meeting 3-4 November 2016 at the Sackler Institute in New York and at the Young Lives Conference on *Adolescence, Youth and Gender: Building Knowledge for Change*, 8-9 September 2016 at the University of Oxford for valuable comments on our research findings. WS, EA, MP, and JB contributed the conceptualization, data interpretation, writing, and revising of this paper. WS conducted data analysis.

References

1. Sachdev HS, Fall CH, Osmond C, et al. Anthropometric indicators of body composition in young adults: relation to size at birth and serial measurements of body mass index in childhood in the New Delhi birth cohort. *The American journal of clinical nutrition* 2005; **82**(2): 456-66.
2. Adair LS. Size at birth and growth trajectories to young adulthood. *American Journal of Human Biology* 2007; **19**(3): 327-37.
3. Haeffner L, Barbieri M, Rona R, Bettiol H, Silva A. The relative strength of weight and length at birth in contrast to social factors as determinants of height at 18 years in Brazil. *Annals of human biology* 2002; **29**(6): 627-40.
4. Gigante D, Nazmi A, Lima R, Barros F, Victora CG. Epidemiology of early and late growth in height, leg and trunk length: findings from a birth cohort of Brazilian males. *European journal of clinical nutrition* 2009; **63**(3): 375-81.
5. Katz J, Lee AC, Kozuki N, et al. Mortality risk in preterm and small-for-gestational-age infants in low-income and middle-income countries: a pooled country analysis. *The Lancet* 2013; **382**(9890): 417-25.
6. Drake A, Walker B. The intergenerational effects of fetal programming: non-genomic mechanisms for the inheritance of low birth weight and cardiovascular risk. *Journal of Endocrinology* 2004; **180**(1): 1-16.
7. Victora CG, Adair L, Fall C, et al. Maternal and child undernutrition: consequences for adult health and human capital. *The lancet* 2008; **371**(9609): 340-57.
8. Landon J, Davison M, Breier B. The developmental environment: influences on subsequent cognitive function and behaviour. *Developmental origins of health and disease* 2006: 370-8.
9. Torche F, Conley D. A Pound of Flesh The Use of Birthweight as a Measure of Human Capital Endowment in Economics Research. In: Komlos J, Kelly IR, eds. *The Oxford Handbook of Economics and Human Biology*. Oxford, UK: Oxford University Press; 2016.
10. Behrman JR, Rosenzweig MR. Returns to Birthweight. *The Review of Economics and Statistics* 2004; **86**(2): 586-601.
11. Magnus P, Gjessing H, Skrandal A, Skjaerven R. Paternal contribution to birth weight. *Journal of Epidemiology and Community Health* 2001; **55**(12): 873-7.
12. Hyppönen E, Power C, Smith GD. Parental growth at different life stages and offspring birthweight: an intergenerational cohort study. *Paediatric and perinatal epidemiology* 2004; **18**(3): 168-77.
13. Veena S, Kumaran K, Swarnagowri M, et al. Intergenerational effects on size at birth in South India. *Paediatric and perinatal epidemiology* 2004; **18**(5): 361-70.
14. Emanuel I, Kimpo C, Moceri V. The association of maternal growth and socio-economic measures with infant birthweight in four ethnic groups. *International journal of epidemiology* 2004; **33**(6): 1236-42.
15. Ramakrishnan U, Martorell R, Schroeder DG, Flores R. Role of intergenerational effects on linear growth. *The Journal of nutrition* 1999; **129**(2): 544S-9S.
16. De Stavola BL, Leon DA, Koupil I. Intergenerational Correlations in Size at Birth and the Contribution of Environmental Factors The Uppsala Birth Cohort Multigenerational Study, Sweden, 1915–2002. *American journal of epidemiology* 2011; **174**(1): 52-62.
17. Stein AD, Lumey LH. The relationship between maternal and offspring birth weights after maternal prenatal famine exposure: the Dutch Famine Birth Cohort Study. *Human biology* 2000: 641-54.
18. Mattsson K, Rylander L. Influence of Maternal and Paternal Birthweight on Offspring Birthweight—a Population-based Intergenerational Study. *Paediatric and perinatal epidemiology* 2013; **27**(2): 138-44.
19. Morton S, De Stavola BL, Leon DA. Intergenerational determinants of offspring size at birth: a life course and graphical analysis using the Aberdeen Children of the 1950s Study (ACONF). *International journal of epidemiology* 2014; **43**(3): 749-59.

20. Emanuel I, Filakti H, Alberman E, Evans SJ. Intergenerational studies of human birthweight from the 1958 birth cohort. 1. Evidence for a multigenerational effect. *BJOG: An International Journal of Obstetrics & Gynaecology* 1992; **99**(1): 67-74.
21. Addo O, Stein A, Fall C, et al. Parental childhood growth and offspring birthweight: pooled analyses from four birth cohorts in low and middle income countries. *American Journal of Human Biology* 2015; **27**(1): 99-105.
22. Addo OY, Stein AD, Fall CH, et al. Maternal height and child growth patterns. *The Journal of pediatrics* 2013; **163**(2): 549-54. e1.
23. Fall CH, Sachdev HS, Osmond C, et al. Association between maternal age at childbirth and child and adult outcomes in the offspring: a prospective study in five low-income and middle-income countries (COHORTS collaboration). *The Lancet Global Health* 2015; **3**(7): e366-e77.
24. Gomes FMdS, Valente MH, Escobar AMdU, Brentani AVM, Grisi SJ. The intergenerational effects on birth weight and its relations to maternal conditions, Sao Paulo, Brazil. *BioMed research international* 2015; **2015**.
25. Kuzawa CW, Eisenberg DT. Intergenerational predictors of birth weight in the Philippines: correlations with mother's and father's birth weight and test of maternal constraint. *PloS one* 2012; **7**(7): e40905.
26. Fall CH, Osmond C, Haazen DS, et al. Disadvantages of having an adolescent mother. *The Lancet Global Health* 2016; **4**(11): e787-e8.
27. Horta BL, Gigante DP, Osmond C, Barros FC, Victora CG. Intergenerational effect of weight gain in childhood on offspring birthweight. *International Journal of Epidemiology* 2009; **38**(3): 724-32.
28. Martin RM, Smith GD, Frankel S, Gunnell D. Parents' growth in childhood and the birth weight of their offspring. *Epidemiology* 2004; **15**(3): 308-16.
29. Behrman JR, Calderon MC, Preston SH, Hoddinott J, Martorell R, Stein AD. Nutritional supplementation in girls influences the growth of their children: prospective study in Guatemala. *The American Journal of Clinical Nutrition* 2009; **90**(5): 1372-9.
30. Gigante DP, Horta BL, Matijasevich A, et al. Gestational age and newborn size according to parental social mobility: an intergenerational cohort study. *Journal of Epidemiology and Community Health* 2015; **69**(10): 944-9.
31. Azcorra H, Dickinson F, Bogin B, Rodríguez L, Varela-Silva MI. Intergenerational influences on the growth of Maya children: The effect of living conditions experienced by mothers and maternal grandmothers during their childhood. *American Journal of Human Biology* 2015; **27**(4): 494-500.
32. Moestue H, Huttly S. Adult education and child nutrition: the role of family and community. *Journal of epidemiology and community health* 2008; **62**(2): 153-9.
33. Kramer MS. Determinants of low birth weight: methodological assessment and meta-analysis. *Bulletin of the World Health Organization* 1987; **65**(5): 663.
34. Gebremedhin M, Ambaw F, Admassu E, Berhane H. Maternal associated factors of low birth weight: a hospital based cross-sectional mixed study in Tigray, Northern Ethiopia. *BMC pregnancy and childbirth* 2015; **15**(1): 1.
35. Chen X-K, Wen SW, Fleming N, Demissie K, Rhoads GG, Walker M. Teenage pregnancy and adverse birth outcomes: a large population based retrospective cohort study. *International journal of epidemiology* 2007; **36**(2): 368-73.
36. Conde-Agudelo A, Belizan JM, Lammers C. Maternal-perinatal morbidity and mortality associated with adolescent pregnancy in Latin America: Cross-sectional study. *Am J Obstet Gynecol* 2005; **192**(2): 342-9.
37. Haldre K, Rahu K, Karro H, Rahu M. Is a poor pregnancy outcome related to young maternal age? A study of teenagers in Estonia during the period of major socio-economic changes (from 1992 to 2002). *European journal of obstetrics, gynecology, and reproductive biology* 2007; **131**(1): 45-51.
38. McDonald SD, Han Z, Mulla S, Beyene J. Overweight and obesity in mothers and risk of preterm birth and low birth weight infants: systematic review and meta-analyses. *Bmj* 2010; **341**: c3428.

39. Conde-Agudelo A, Belizán JM, Lammers C. Maternal-perinatal morbidity and mortality associated with adolescent pregnancy in Latin America: Cross-sectional study. *American journal of obstetrics and gynecology* 2005; **192**(2): 342-9.
40. Shaw M, Lawlor DA, Najman JM. Teenage children of teenage mothers: psychological, behavioural and health outcomes from an Australian prospective longitudinal study. *Social science & medicine* 2006; **62**(10): 2526-39.
41. Achenbach TM, Vermont VDoPUo, Edelbrock CS. Manual for the child behavior checklist and revised child behavior profile: Department of Psychiatry of the University of Vermont; 1983.
42. WHO M. Growth. *Reference, Study, Group: WHO Child Growth Standards: Length/height-for-age, weight-for-age, weight-for-length, weight-for-height and body mass index-for-age: Methods and development* 2006.
43. Onis Md, Onyango AW, Borghi E, Siyam A, Nishida C, Siekmann J. Development of a WHO growth reference for school-aged children and adolescents. *Bulletin of the World health Organization* 2007; **85**(9): 660-7.
44. Schott WB, Crookston BT, Lundeen EA, Stein AD, Behrman JR. Periods of child growth up to age 8 years in Ethiopia, India, Peru and Vietnam: key distal household and community factors. *Social Science & Medicine* 2013; **97**: 278-87.
45. Allison PD. Missing data: Sage Thousand Oaks, CA; 2012.
46. Lunde A, Melve KK, Gjessing HK, Skjærven R, Irgens LM. Genetic and environmental influences on birth weight, birth length, head circumference, and gestational age by use of population-based parent-offspring data. *American journal of epidemiology* 2007; **165**(7): 734-41.
47. Hjertholm KG, Iversen PO, Holmboe-Ottesen G, et al. Maternal dietary intake during pregnancy and its association to birth size in rural Malawi: A cross-sectional study. *Maternal & child nutrition* 2017.
48. Lee SE, Talegawkar SA, Meriadi M, Caulfield LE. Dietary intakes of women during pregnancy in low-and middle-income countries. *Public health nutrition* 2013; **16**(08): 1340-53.
49. Rao S, Yajnik CS, Kanade A, et al. Intake of micronutrient-rich foods in rural Indian mothers is associated with the size of their babies at birth: Pune Maternal Nutrition Study. *The Journal of nutrition* 2001; **131**(4): 1217-24.
50. Sou SC, Chen WJ, Hsieh W-S, Jeng S-F. Severe obstetric complications and birth characteristics in preterm or term delivery were accurately recalled by mothers. *Journal of clinical epidemiology* 2006; **59**(4): 429-35.
51. Catov JM, Newman AB, Kelsey SF, et al. Accuracy and reliability of maternal recall of infant birth weight among older women. *Annals of epidemiology* 2006; **16**(6): 429-31.
52. Buka SL, Goldstein JM, Spartos E, Tsuang MT. The retrospective measurement of prenatal and perinatal events: accuracy of maternal recall. *Schizophrenia research* 2004; **71**(2): 417-26.
53. Boerma JT, Weinstein K, Rutstein SO, Sommerfelt AE. Data on birth weight in developing countries: can surveys help? *Bulletin of the World Health Organization* 1996; **74**(2): 209.
54. Mahumud RA, Sultana M, Sarker AR. Distribution and determinants of low birth weight in developing countries. *Journal of Preventive Medicine and Public Health* 2017; **50**(1): 18.
55. Robles A, Goldman N. Can accurate data on birthweight be obtained from health interview surveys? *International Journal of Epidemiology* 1999; **28**(5): 925-31.
56. Blanc AK, Wardlaw T. Monitoring low birth weight: an evaluation of international estimates and an updated estimation procedure. *Bulletin of the World Health Organization* 2005; **83**(3): 178-85d.
57. Channon AA, Padmadas SS, McDonald JW. Measuring birth weight in developing countries: Does the method of reporting in retrospective surveys matter? *Maternal and child health journal* 2011; **15**(1): 12-8.
58. Rice F, Thapar A. Estimating the relative contributions of maternal genetic, paternal genetic and intrauterine factors to offspring birth weight and head circumference. *Early human development* 2010; **86**(7): 425-32.

59. Flower A, Shawe J, Stephenson J, Doyle P. Pregnancy planning, smoking behaviour during pregnancy, and neonatal outcome: UK Millennium Cohort Study. *BMC pregnancy and childbirth* 2013; **13**(1): 1.
60. Ko T-J, Tsai L-Y, Chu L-C, et al. Parental smoking during pregnancy and its association with low birth weight, small for gestational age, and preterm birth offspring: a birth cohort study. *Pediatrics & Neonatology* 2014; **55**(1): 20-7.
61. World Bank. World Development Indicators 2016. 2016.
<https://openknowledge.worldbank.org/handle/10986/23969>.
62. Sloboda DM, Hart R, Doherty DA, Pennell CE, Hickey M. Age at menarche: influences of prenatal and postnatal growth. *The Journal of Clinical Endocrinology & Metabolism* 2007; **92**(1): 46-50.
63. Marcovecchio ML, Chiarelli F. Obesity and growth during childhood and puberty. Nutrition and Growth: Karger Publishers; 2013: 135-41.
64. He Q, Karlberg J. BMI in childhood and its association with height gain, timing of puberty, and final height. *Pediatric research* 2001; **49**(2): 244-51.