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ASSOCIATION OF HUMAN CAPITAL WITH PHYSICAL GROWTH FROM BIRTH TO ADULTHOOD

EVIDENCE FROM THE NEW DELHI BIRTH COHORT, INDIA

DISCUSSION PAPER JUNE 2020

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WORLD BANK GROUP
Health, Nutrition & Population

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List of Acronyms

BMI	Body mass index
CNNS	Comprehensive National Nutrition Survey
DALY	Disability-adjusted life year
FCS	Fully conditional specification
HH	Household
HNP	Health, Nutrition, and Population
ICDS	Integrated Child Development Services
Rs.	Indian rupees
LMICs	Low- and middle-income countries
MCMC	Markov Chain Monte Carlo
NCDs	Non-communicable Diseases
NCHS	National Center for Health Statistics
NDBC	New Delhi Birth Cohort
NFHS	National Family Health Survey
OECD	Organisation for Economic Co-operation and Development
SD	Standard Deviation
SDI	Socio-demographic Index
UNICEF	United Nations Children's Fund
WASH	Water, Sanitation and Hygiene
WB	World Bank
WHO	World Health Organization

Health, Nutrition, and Population (HNP) Discussion Paper

Association of Human Capital with Physical Growth from Birth to Adulthood
Evidence from the New Delhi Birth Cohort, India

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This paper was prepared for the World Bank. It contributes to the literature on the association of attained adult human capital (education, male occupation, and wealth score) with measures of growth from birth to adulthood. The findings support evidence-based policy recommendations, especially for low- and middle-income countries (LMICs) to focus on interventions to improve growth during periods of maximal benefit for attainment of human capital.

Abstract

Undernutrition begins early in life and has lifelong consequences. The cost of undernutrition both for the individual and the economy are substantial. Analyzing data from an Indian cohort, the New Delhi Birth Cohort, formed between 1969 and 1972, this paper provides evidence on the associations between attained human capital in the third and fourth decade of life and measures of growth from birth to adulthood.

For the purpose of this paper, attained human capital is defined through three metrics: educational status, male occupation, and material possession score. Growth measures (height, weight, body mass index) during five age intervals (0–6 months, 6–24 months, 2–5 years, 5–11 years, and 11 years–adulthood) were related to human capital metrics using multivariate regression models. Sensitivity analyses were also performed to assess the stability of associations.

All three human capital metrics had a significant positive association with birth size and measures of physical growth in children under-five years of age, in particular for children under two years. Length at birth and height gain from 6 to 24 months were consistently associated with all metrics. Faster weight and BMI gain from five years onward significantly predicted material possession scores. Among socioeconomic and behavioral characteristics at birth, maternal and paternal education, and paternal occupation also had a consistent positive association with all three human capital metrics.

The findings reinforce the focus on interventions during the first 1,000 days of life to promote larger birth size and linear growth and suggest an additional window of opportunity between 2 to 5 years to improve human capital. The benefits can be enhanced by simultaneous investments in parental (especially maternal) literacy, livelihoods, safe water supply and sanitation, access to health care, and enhancing incomes. These interventions also have a "nutrition-sensitive" effect to promote early life growth.

Keywords: Human capital, stunting, intergenerational, nutrition, 1,000 days

Disclaimer: The findings, interpretations, and conclusions expressed in the paper are entirely those of the authors, and do not represent the views of the World Bank, its Executive Directors, or the countries they represent.

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EXECUTIVE SUMMARY

BACKGROUND

Undernutrition begins early in life and has lifelong consequences. The cost of undernutrition both for the individual and the economy are substantial. Faster weight gain and linear growth in children in low- and middle-income countries (LMICs) are associated with enhanced survival and possibly improved human capital. Evidence also suggests that rapid weight gain in children might increase risk of obesity and related adult cardiometabolic diseases. Identifying optimum age intervals and types of growth patterns associated with enhanced adult human capital could help strike the best balance with later adverse trade-offs. We therefore evaluated the associations between various measures of physical growth from birth to adulthood and subsequent attainment of adult human capital.

METHODS

The study was conducted on the New Delhi Birth Cohort (NDBC), which was formed between 1969 and 1972 from a population residing in a 12 kilometers squared (km^2) area of south Delhi. In this prospective, population-based study, we evaluated 1,184 available and consenting participants (672 males, 512 females) who had been measured at birth and at intervals of 3 to 6 months during infancy, childhood, and adolescence until 21 years of age, and three waves of adulthood (26–32 years, 35–39 years, and 40–45 years, considered respectively as the first, second, and third adult waves). The adult human capital metrics included educational status, male occupation, and material possession score. Growth measures (height, weight, body mass index [BMI]) were evaluated for five physiologically relevant and intervention-related age intervals from birth to adulthood (0–6 months, 6–24 months, 2–5 years, 5–11 years, and 11 years–adulthood). The adjusted socioeconomic and behavioral characteristics at birth included utilization of health services, maternal and paternal education, paternal occupation, household income, crowding, housing condition, and water and sanitation facilities. Multivariate linear regression models were used to relate human capital to statistically independent (uncorrelated) growth measures in the five age periods. Sensitivity analyses were also performed to assess the stability of associations.

RESULTS

Birth size and growth measures, mostly during the under-five or under-two years age intervals, had significant positive associations with subsequent attainment of one or more

of the three adult human capital metrics, education, male occupation, and material possession score. Birth length and height gain from 6 to 24 months were consistently associated with all three metrics, while height gain in the 0 to 6 months and 2 to 5 years age group also predicted material possession score and male occupation, respectively. Faster weight and BMI gains from five years onward, also significantly predicted material possession scores. The magnitude of growth associations was modest, with height gain reflecting association of slightly higher magnitude. Among the socioeconomic and behavioral characteristics at birth, maternal and paternal education, and paternal occupation also had a consistent positive association with attained human capital.

CONCLUSIONS

Larger birth size and faster growth, especially in height, in children under-five, in particular in under-twos were modestly associated with improved adult human capital metrics—education, occupation, and material possession scores. Similarly, boys with faster height growth from 2 to 5 years were in adult life employed in occupations requiring higher skills. The evidence base, from a human capital perspective, thus reinforces the focus on interventions in the first 1,000 days (from conception to 2 years of age) to promote larger birth size and linear growth, with an additional opportunity between 2 to 5 years. Optimum growth patterns in early life are also likely to lead to the best balance of outcomes, that is, reduced undernutrition, increased human capital, and lower risks of obesity and noncommunicable diseases (NCDs). However, birth size and linear growth promotion alone, will at best, have modest human capital gains. The human capital benefits can be boosted considerably by simultaneous investments in parental (especially maternal) literacy, livelihoods, safe water supply and sanitation, access to health care, and enhancing income. These interventions through their “nutrition-sensitive” effect contribute to promoting early life growth.

INTRODUCTION

BACKGROUND AND RATIONALE

The benefits of investing in human capital are being increasingly recognized and advocated. The Organisation for Economic Co-operation and Development (OECD) defines human capital as *"the knowledge, skills, competencies and attributes embodied in individuals that facilitate the creation of personal, social and economic well-being"* (Keeley 2007). According to the World Bank, "*Human capital consists of the knowledge, skills, and health that people accumulate over their lives, enabling them to realize their potential as productive members of society. It has large payoffs for individuals, societies, and countries*" (World Bank 2019). It is believed that developing human capital can contribute to ending extreme poverty and creating more inclusive societies. This necessitates investments in people through nutrition, health care, quality education, jobs, and skills (World Bank 2018). However, a key intermediating variable for accruing these payoffs is the ability of the economy to utilize human capital; thus, it's not about accumulating human capital alone but also about using it to reap potential economic benefits.

Undernutrition is a major contributor to the global disease burden in children under five years of age. Low- and middle-income countries (LMICs), especially in Africa and Asia, bear the greatest share of malnutrition in all its forms. (UNICEF, WHO, and World Bank 2020). The 2020 estimates indicate that the global prevalence of stunting, although declining since 2000, remains high, with more than one in five or 144.0 million stunted children under five years of age. The corresponding prevalence for wasting globally is 6.9 percent with 47.0 million children under-five wasted, of which 14.3 million are severely wasted (UNICEF, WHO, and World Bank 2020). In India too, successive National Family Health Surveys (NFHSs) show a decline in prevalence of stunting and underweight, but wasting has remained static or has increased marginally (Sachdev 2018). Between NFHS-1 (1992–93) and NHFS-4 (2015–16), stunting declined from 52 to 38 percent; underweight from 53 to 36 percent; and wasting increased from 18 to 21 percent. However, despite slow and steady progress, the latest Comprehensive National Nutrition Survey (CNNS) conducted between 2016 and 2018 confirms that the burden of undernutrition in India is still high with 34.7 percent of children stunted, 33.4 percent underweight, and 17.3 percent wasted (MoHFW, UNICEF, and Population Council 2019). This huge burden contributes enormously to morbidity and mortality among children. Global projections suggest that stunting and underweight attribute to the highest proportions of child deaths, about 14 percent for each; wasting accounts for 12.6 percent (severe wasting for 7.4 percent) of child deaths. (Black et al. 2013). In the Indian context, projections indicate that "*Malnutrition was the predominant risk factor for death in children younger than 5 years of age in every state of India in 2017, accounting for 68.2 percent (95 percent UI 65.8–70.7) of the total under-five deaths, and the leading risk factor for health loss for all ages, responsible for 17.3 percent (16.3–18.2) of the total disability-adjusted life years (DALYs). The malnutrition DALY rate was much higher in the low socio-demographic Index (SDI) than in the middle SDI and high SDI state groups*" (India State-Level Disease Burden Initiative Malnutrition Collaborators 2019). Considering the magnitude of these health benefits, it is not surprising that investments in nutrition form an important component for enhancing human capital. Recent advocacy efforts have focused on improving nutrition, particularly in the first 1,000 days of life or the period from conception until two years of age, for enriching adult cognitive skills (Hoddinott et al. 2008; Hoddinott et al. 2013a; Martorell 2017; Victora et al. 2008). This advocacy emanates from recent evidence (nonexperimental, quasi-experimental, experimental, and prospective cohorts), suggesting that improved linear growth during childhood, especially in the first 1,000 days, enriches human capital.

In this analysis we draw upon data from a prospective birth cohort in New Delhi that has been followed up for the past five decades, to determine the association between various longitudinal measures of growth (height, weight, and body mass index [BMI]) from birth to adulthood and subsequent attainment of human capital as adults (age 26–45 years). The analysis provides evidence of long-lasting benefits of improved preschool linear growth on adult human capital, contributing to the policy dialogue in the country on the subject. Value addition to earlier literature includes other adult human capital metrics (occupation), interrogation of anthropometry beyond five years of age, and comparison of different growth measures (height, weight, and BMI). Introduction of extra confounders, novel imputation techniques, independent measures of linear growth and weight gain unrelated to linear growth, and sensitivity analyses enhance the statistical methods.

The terms "human resources," "human development," and "human capital" are often used interchangeably in literature. We use the term "human capital" to emphasize the linkages of child growth as an investment to improve economic outcomes. Further, we examine the effect of physical growth measures from birth until adulthood on education, occupation, and material possession in adulthood. Superior education and occupation are dependent upon better knowledge, skills, competencies, and attributes (human capital), and these contribute to acquisition of wealth, for which material possessions are a crude surrogate measure. Typically, occupation and material possessions are thought of as economic rather than core human capital metrics. However, to retain the above focus, we refer to them collectively as "human capital," but also distinguish these three metrics wherever specificity is important.

Optimal nutrition throughout the life span especially during the first 1,000 days is essential for good brain development. The period from pregnancy to the first few years after birth is particularly important because of rapid brain development (Prado 2014). Undersize in children below five years of age, in comparison to World Health Organization (WHO) standards, is conventionally regarded as a measure of undernutrition (Sachdev 2018). Several mechanistic pathways have been suggested that link undersize in children, predominantly stunting, with suboptimal child and later development and cognitive outcomes. These include neurological, hormonal, functional isolation, stress, stigma, and infectious disease–related channels (Perkins et al. 2017).

Much of the undernutrition occurs during pregnancy and in the first two years of a child's life; without appropriate interventions, the damage to physical and cognitive development, future economic productivity, and human capital is largely irreversible (Black et al. 2013; Martorell 2017; Victora et al. 2008). In terms of human capital, malnutrition (stunting) in early years is linked to loss of height in adolescence and adulthood, loss in grade attainment, and delay in starting school leading to per capita income penalty of around 7%, with Africa and South Asia incurring larger penalties – around 9-10% of GDP per capita (Galasso et al. 2017). Evidence from low-income and middle-income countries suggests that the prenatal period (Christian et al. 2014) and the first 24 months after birth (Black et al. 2013; Hamadani et al. 2014; Manji et al. 2015) are the most sensitive time periods for stunting to impact later cognition, executive function, and school attainment; after 24 months the association is not as strong (Sudfeld et al. 2015; Hamadani et al. 2014). Malnutrition at any stage of childhood affects schooling and, thus, the lifetime-earnings potential of the child (Alderman et al. 2006). Cognitive losses associated with childhood undernutrition, iron deficiency anemia, and with being born to a mother deficient in iodine are more or less irreversible by the time a child reaches school. Malnourished children are more likely to repeat school years or to drop out of school. These cognitive losses are associated with lower productivity in adulthood. The losses due to cognitive impairments are pervasive but difficult to quantify. Estimates suggest that protein-energy malnutrition in childhood is associated with a 15-point decrease in IQ, which in turn is associated with a 10 percent drop in earnings and hence productivity (Selowsky and Taylor 1973). Similarly, childhood anemia is associated with about one-half of one standard deviation (SD) on cognitive test scores, which in turn is associated with a 4 percent decrease in hourly earnings (Ross and Horton 1998). Supplementation for pregnant women with iron and folate has been linked with improvements in cognition of the offspring at 7 to 9 years (Christian et al. 2010). Undernutrition affects a nation's economic advancement by at least 8 percent because of direct productivity losses, losses via poorer cognition, and losses via reduced schooling (Horton and Steckel 2013).

Linear growth is currently regarded as a better nutritional indicator of adult outcomes including cardiovascular disease risk and human capital (Adair et al. 2013). There is enough evidence from human cross-sectional studies indicating positive association between linear growth among under-two children and variable domains of cognitive and motor development in LMICs (Miller et al. 2015; Perkins et al. 2017; Sudfeld et al. 2015; Walker et al. 2007, 2011). Quasi-experimental studies, using exogenous or instrumental variables approach, document a negative effect of stunting on cognitive development in childhood with varying effect sizes (Dercon and Porter 2014; Leight, Glewwe, and Park 2015; Perkins et al. 2017; Umana-Aponte 2011). Systematic reviews of longitudinal observational (cohort) studies also suggest that impaired linear growth in the first 2 to 3 years of life is associated with variable domains of motor and psychosocial development in later childhood (Perkins et al. 2017; Sudfeld et al. 2015). However, such study designs cannot ascertain causality with certainty, especially due to confounding bias, for example for various indicators of poverty and learning opportunities. Experimental studies from social welfare and nutritional supplementation programs provide some supportive, but not unambiguous, evidence for a beneficial effect of these interventions on childhood motor and cognitive development in infants and children (Aboud and Yousafzai 2015; Larson and Yousafzai 2017; Perkins et al. 2017). However, as these follow-up studies are restricted until childhood, they provide no direct evidence of beneficial effect on human capital in adulthood.

Quasi-experimental designs using instrumental variables have also documented that increased height-for-age Z scores in preschool age were associated with higher schooling in Guatemala and rural Zimbabwe; and better cognition test scores and per capita household expenditure and lower probability of living in poverty in adulthood in Guatemala (Alderman, Hoddinott, and Kinsey 2006; Hoddinott et al. 2013a).

Evidence on direct effects on human capital is also available from prospective birth cohorts followed up until adulthood. The Consortium of Health Outcomes Research in Transitional Societies (COHORTS) collaboration was formed by researchers who had followed up prospective birth cohorts until adulthood in five LMICs (Brazil, Guatemala, India, the Philippines, and South Africa), (Victora et al. 2008). Their pooled analyses indicate that birthweight and weight-for-age and height-for-age at two years (positive direction), and undernutrition indexes (negative direction) were associated with attained educational status at adulthood (excludes younger South African cohort). An association, inverse to that reported above, was noted with grade failure, that is, failing at least one grade in school (excludes Indian cohort) (Martorell et al. 2010; Victora et al. 2008). Weight gain during the first two years of life had the strongest association with attained education, followed by birthweight and weight gain between 2 and 4 years. In nonpooled analyses, most indicators of undernutrition were significantly associated with lower income in Brazil and fewer assets in India, but in Guatemala few associations were statistically significant ($P>0.05$). The most consistent significant results were for men and were seen with height-for-age at two years, while associations with weight were less consistent (Victora et al. 2008). A subsequent analysis, also by the COHORTS collaboration, evaluated the association of these outcomes to birthweight and to statistically independent measures representing linear growth, and to weight gain independent of linear growth (relative weight gain) in three age periods: 0 to 2 years, 2 years to mid-childhood, and mid-childhood to adulthood. Higher birthweight and linear growth during the first two years of life resulted in gains in years of attained schooling. There were no consistent associations with relative weight gain (Adair et al. 2013). However, these analyses did not provide information on effect on occupation or on relative importance of different growth metrics (height, weight, and BMI) beyond five years of age. Nutrition intervention in the Guatemalan cohort improved diets and reduced stunting at three years of age (Martorell 1995) with long-term effects on schooling (women), cognitive development (men and women), and wages (men) (Hoddinott et al. 2008; Maluccio et al. 2009; Martorell 2017; Stein et al. 2008), which provides additional support for a causal effect. However, external validation of these findings from other regions is not available.

In contrast to some earlier analyses (Victora et al. 2008), using appropriate statistical techniques to analyze this rich dataset, we were able to distinguish the independent associations of various longitudinal growth measures with adult education, occupation, and material possessions. The age intervals used were (i) birth to 6 months—period of rapid infant growth and recommended exclusive breastfeeding; (ii) 6 months to 24 months—remaining period of rapid infant growth and postnatal 1,000 days; (iii) 2 to 5 years—remainder of vulnerable under-five period; (iv) 5 to 11 years—preadolescent period; and (v) 11 years to adulthood (first adult wave, 26–32 years)—adolescence and beyond. Longitudinal anthropometry (height, weight, or BMI) at these age intervals was used to derive standardized residuals at each time point by regressing measurements at each age on birth and all prior ages. These standardized residuals, referred to as conditional growth, thus represented a child's deviation from the predicted anthropometry at the start of the interval in the context of typical growth in the population. These standardized residuals (SD scores) are uncorrelated measures of longitudinal growth, which circumvent the stochastic issue of simultaneous modeling of correlated measures in life-course regression analyses (Osmond and Fall 2017). This also removed the phenomenon of regression to the mean and controlled for common error terms (e.g., measurement error will generate a negative correlation between initial and change values because larger-than-true measurements at baseline will lead to smaller change values, and smaller-than-true initial values will lead to larger change values) (Martorell et al. 2010). We were also able to separate out the effect of linear growth from relative weight gain through conditional measures of weight growth, allowing for height growth (Adair et al. 2013; Osmond and Fall 2017). Weight gain is a result of linear growth and soft tissue gain (fat mass and fat-free mass); the conditional relative weight variables represent weight change that is separated from change in height. Conditional relative weight and conditional height variables not being correlated, expressing them in SD units allows direct comparison of coefficients within regression models. These variables therefore have advantages when compared with other representations of growth, and give more nuanced results than those that are based on weight gain alone (Adair et al. 2013).

Our analysis had other notable strengths. Few studies from settings in LMICs undergoing rapid nutrition and socioeconomic transition, and probably none from South Asia, have prospectively followed up population-based birth cohorts until adulthood. Trained personnel collected anthropometry at frequent intervals, permitting creation of five meaningful age intervals, including adolescence and early adulthood, which are also important periods for brain development. Practical measures of adult human capital connected to livelihoods and income generation were considered—namely, attained educational status and occupation in males. Different growth measures (height, weight, and BMI) could be compared. Adjustment for important socioeconomic and behavioral characteristics at birth was possible, and the choice of all these confounders was justified by observed associations with both exposures and outcomes. Appropriate techniques and sensitivity analyses enhanced the statistical methods.

LIMITATIONS

Important limitations merit consideration. Since only 14.5 percent of the original cohort participated, the subjects may not be representative of the entire group. However, the observed differences in some baseline socio-demographic characteristics, and the mean size at birth and in childhood, though statistically significant, were either small or trivial. Data availability precluded adjustment for some important confounders like educational systems, and of a comprehensive set of human capital indicators. We could not explore different domains of cognition and development in childhood or adulthood, to gain mechanistic insights. These findings are only representative of urban Delhi, experiencing a transition over five decades, and may not be directly generalizable to other parts of India or other LMICs, especially in the current era, when these associations may have changed. Future research leads from this work include validation in similar long-term prospective birth cohorts, evaluation of a comprehensive set of human capital indicators, cost-benefit ratio analyses, and mechanistic exploration including higher brain functioning and mediating effect of cardiometabolic disease.

There are significant policy implications of our principal findings. Larger birth size and faster growth, especially in height, in under-two children were modestly associated with improved adult human capital metrics. Similarly, boys with faster height growth from 2 to 5 years were subsequently employed in occupations requiring higher skills. This evidence base, from a human capital perspective, thus reinforces the focus on the first 1,000 days (from conception to 2 years of age) to promote larger birth size and linear growth, but there may be an additional window of opportunity between 2 to 5 years. Optimum growth patterns in early life are also likely to lead to the best balance of outcomes with less undernutrition, increased human capital, and reduced risks of obesity and NCDs. However, birth size and linear growth promotion alone, will at best, have modest human capital gains. Several socioeconomic and behavioral characteristics at birth were significantly associated with human capital benefits, and after their adjustment the advantages related to growth promotion were attenuated. Thus, the human capital benefits can be boosted considerably by simultaneous investments in parental (especially maternal) literacy, livelihoods, safe water supply and sanitation, access to health care, and income enhancement. These interventions through their "nutrition-sensitive" effect contribute to promoting early life growth.

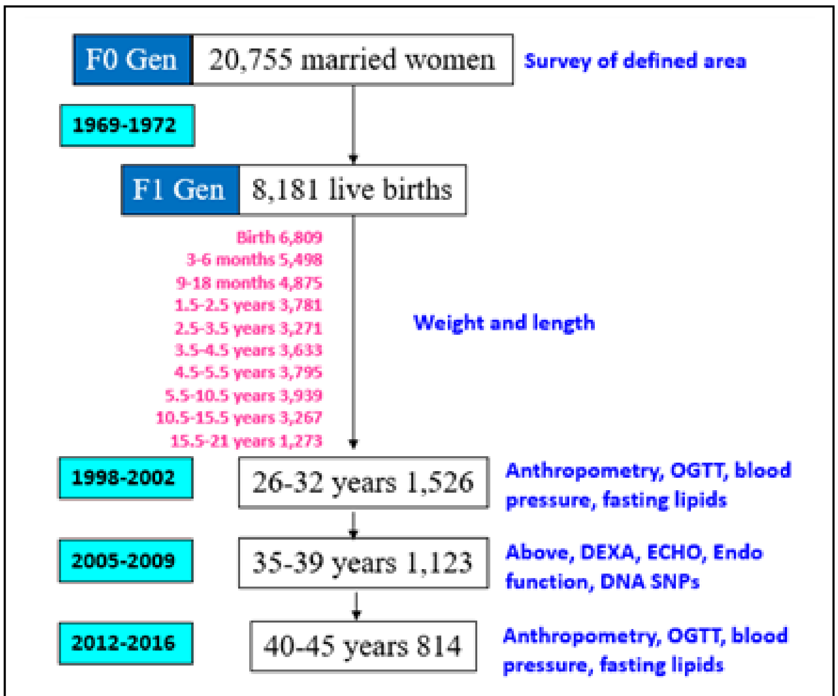
Having outlined above the context and rationale for undertaking this analysis with the relevant literature review, the advantages and limitations of the data and the approach, and the potential implications for future research and policy, next we discuss the methodology adopted for the research and analyses. After this is a description of the results of the analysis—the longitudinal associations. Finally, there is a discussion relating the findings of the paper to the available global evidence on the subject. Relevant tables, figures, and boxes are included in the methodology and results sections to enable easy scrutiny of key findings, with detailed tables and figures presented in the annexes.

METHODS

ABOUT THE COHORT

The study was conducted in the New Delhi Birth Cohort (NDBC), which was established between 1969 and 1972, as a collaborative research project between the Department of Pediatrics, Safdarjung Hospital, New Delhi (Professor Shanti Ghosh and Professor Santosh K. Bhargava) and the National Center for Health Statistics (NCHS), USA (Professor I. M. Moriyama). The project entitled, "Longitudinal Study of the Survival and Outcome of a Birth Cohort" received support from the Indian Council of Medical Research and funding from the NCHS. The primary inception objectives comprised evaluation of contraceptive practices, pregnancy outcomes, birthweight, gestation, and childhood growth and survival in the local population (Bhargava et al. 2004; Richter et al. 2012; Bhargava 2018). The study area was selected based on easy accessibility to Safdarjung Hospital, with an estimated population of 100,000 individuals with a substantial proportion of married couples planning to start or expand their family, cooperative enrolled subjects who were

Figure 1: Summary of Sequential Attrition over Time and Relevant Outcomes Recorded in Different Waves in the New Delhi Birth Cohort



Source: Authors

Notes:
DEXA: Dual-energy X-ray absorptiometry;
DNA SNP: Deoxyribonucleic acid single nucleotide polymorphism;
ECHO: Echocardiography;
F0 Gen: F0 Generation
F1 Gen: F1 Generation
OGTT: Oral glucose tolerance test.

unlikely to migrate, and on obtaining regulatory authorities' permissions. The cohort was finally formed from a population of 119,799 living in a 12 kilometer squared (km^2) area of south Delhi, namely, Lajpat Nagar (Parts I–IV) and a few adjacent colonies (Bhargava 2018). The exact location of the study area is depicted in the map of Delhi in Annex 1.

At the time of recruitment, 59.9 percent of families had an income above Rs. 50 per month[1] (national average, Rs. 28.4[2]), and 14.9 percent of parents were illiterate (national average, 66.3 percent). Among the families, 43.0 percent lived in only one room. In terms of religion, 84.3 percent were Hindus; 11.6 percent, Sikh; 2.1 percent, Christian, 1.1 percent, Muslim; and 0.7 percent were Jain. There was a slight overrepresentation of Sikhs and underrepresentation of Muslims in comparison to national averages.

Married women of reproductive age were recruited (F0 generation; n=20,755) and followed regularly every other month to record menstrual dates. Information on the socio-demographic profile of the family was collected during recruitment by a social worker. This included maternal schooling, paternal occupation, and household socioeconomic characteristics (type of family and house, and water supply and sanitation facilities). Women who became pregnant were visited every two months initially and on alternate days from the 37th week of gestation. Among 9,169 recorded pregnancies, after exclusion of fetal losses (n=867), stillbirths (n=202), and out-migrations for delivery, there were 8,181 live births (8,030 singletons and 151 twins) of cohort children (F1 generation). Trained personnel recorded the length and weight of the infants within 72 hours of birth, at the ages of 3, 6, 9 and 12 months (±7 days) and every 6 months (± 15 days) thereafter until 14 to 21 years using standardized techniques. These F1 participants were again followed up sequentially as adults in various phases, namely at 26 to 32 years (first adult wave), 35 to 39 years (second adult wave), and 40 to 45 years (third adult wave), for their anthropometry and cardiometabolic risk factors. Socio-demographic profile recorded during these recent visits included education and occupation of the F1 participant, occupation of F1 spouse, type of housing, material possessions, family size, toilet, drinking water source and supply, and general water source and supply.

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[1] Constant 2019 Rs. prices = 1,903 (US$27).
[2] Constant 2019 Rs. prices = 1,081 (US$15).

ATTRITION

There was substantial attrition of the original cohort with the passage of time (Figure 1) due to mortality and out-migration related to demolition of unauthorized housing (2,414 subjects or ~30 percent between 1972 and 1975), relocation after marriage and occupation (Bhargava et al. 2004). Further, a proportion of subjects did not consent to participation in the study.

OUTCOMES: MEASURES OF HUMAN CAPITAL

Measures of human capital for F1 subjects were recorded at adult age and included educational status, occupation, and material possession score. The highest value among the three adulthood data collection waves was used, which was mostly identical to that recorded in the first adult phase (26–32 years). Education was categorized as follows: up to middle class (≤8th class), high school (10th class, also referred to as "matric" in females), high school+ (12th class), graduate and professional degree (postgraduate or higher, also referred to as "college" in females). Only male participants' occupations were evaluated as an outcome because many women were housewives, which creates difficulties in interpretation. Male occupation categories were: unemployed/unskilled/semiskilled/skilled worker, trained clerical/medium business/teacher/middle-level farmer, and professional/ big business/landlord/Class I officer[3]. Material possession score was computed as the sum of possession (Y/N) of household items, including electricity, fan, cycle, radio, two-wheeler, gas stove, television, cable TV, electric mixer, air cooler, washing machine, car, air conditioner, home computer, dish antenna, landline phone, and mobile phone.

EXPOSURE: CONDITIONAL GROWTH VARIABLES

Conditional growth models' approach was adopted for the analysis of this data: for each subject, size measures—typically, height and weight—are combined to form a growth trajectory, and the interest is in summarizing the association of growth trajectory with an outcome measured at or after the last size measurement (Martorell et al. 2010; Osmond and Fall 2017). Growth is assessed in sequential age intervals as a deviation from what might have been predicted at the start of the interval (Osmond and Fall 2017).

[3] Class I officers are public servants and belong to the managerial or highest class of government servants.

The details of the age categories and the various anthropometric measurements included in the analysis are provided below.

Age categories were constructed empirically, adhering to the principles of maximum data availability, physiologically defined growth periods, and alignment with current understanding on intervention windows. The created age categories were (i) birth to 6 months—period of rapid infant growth and recommended exclusive breastfeeding, (ii) 6 to 24 months—remaining period of rapid infant growth and postnatal 1,000 days, (iii) 2 to 5 years—remainder of vulnerable under-five period, (iv) 5 to 11 years—preadolescent period, and (v) 11 years to adulthood (first adult wave, 26–32 years)—adolescence and beyond.

Longitudinal anthropometry (height, weight, or BMI) of cohort (F1) subjects at birth, 6 months, 2, 5, and 11 years, and adult ages were used to derive standardized residuals, for males and females separately, at each time point by regressing measurements at each age on birth and all prior ages. These standardized residuals, referred to as conditional growth, thus represented a child's deviation from the predicted anthropometry at the start of the interval in the context of typical growth in the population. For example, conditional SD score for height at 11 years was derived by regressing height at 11 years on length/height at birth, 6 months, and 2 and 5 years. This measure represented standardized deviation of height at age 11 years from that predicted at 5 years; a child with a positive value is taller than expected at 5 years and thus has a faster rate of linear growth between 5 and 11 years. These standardized residuals (SD scores) were uncorrelated measures of longitudinal growth (data not presented), which circumvented the stochastic issue of modeling correlated measures.

It is important to separate out the effects of linear growth and weight gain relative to linear growth on outcomes in later life (Adair et al. 2013; Osmond and Fall 2017), because, although early linear growth favorably predicts adult human capital, excess adiposity is also a well-recognized risk factor for cardiometabolic diseases. Such analyses may inform public health policy about the optimum age for promotion of growth for enhanced survival and human capital, and whether this promotion will necessarily lead to an increase in cardiometabolic disease (Adair et al. 2013).

Further, a modified conditional models' approach is needed to separate the effects of linear growth and weight gain because they are strongly correlated. We derived standardized residuals by regressing current size (weight and length/height) on all previous size measures to produce conditional size measures (Adair et al. 2013). Conditional height is present length or height accounting for previous length or height, and weight (but not present weight); while conditional *relative weight* is present weight accounting for present height and all previous weight and height measures (Adair et al. 2013). For example, conditional size gain at 11 years was represented by conditional height at 11 years and *relative weight* at 11 years. Conditional height at 11 years was derived by regressing height at 11 years on height and weight at birth, 6 months, and 2 and 5 years. Conditional *relative weight* at 11 years was derived by regressing weight at 11 years on height at 11 years, and length/height and weight at birth, 6 months, and 2 and 5 years. A child with a positive *relative weight* value at 11 years is heavier than expected at 5 years even after allowing for current height, and thus has a faster rate of height-adjusted weight gain between 5 and 11 years. These standardized residuals (SD scores) too were uncorrelated measures of longitudinal growth (data not presented), which circumvented the stochastic issue of modeling correlated measures.

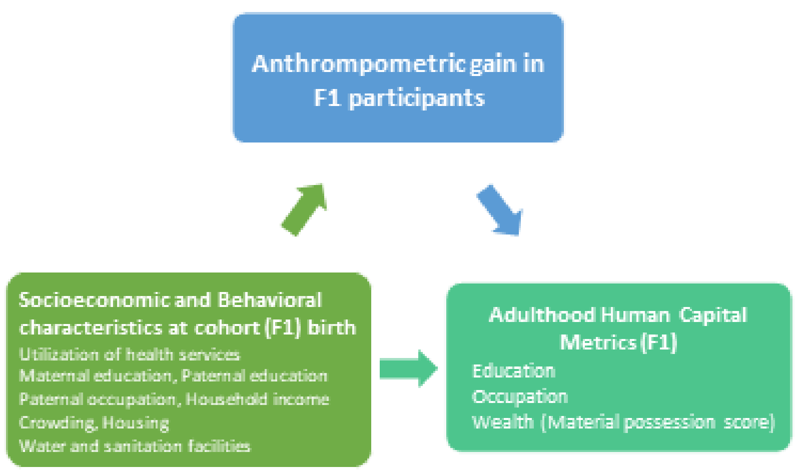
COVARIATES

Socioeconomic and behavioral characteristics at the time of participants' birth were used as covariates. These included utilization of health services, maternal and paternal education, paternal occupation, household income (in rupees), crowding, housing condition, and water and sanitation facilities. To maximize the sample size for the multivariate model, multiple imputation technique in SPSS (Azur et al. 2011; IBM SPSS Statistics 20 Algorithms 2017) was used for imputing the missing values for socioeconomic and behavioral variables. Multiple imputation in SPSS for missing values using fully conditional method is an iterative Markov Chain Monte Carlo (MCMC) method that can be used when the pattern of missing data is arbitrary. For each iteration and for each variable in the order specified in the variable list, the fully conditional specification (FCS) method fits a univariate (single dependent variable) model using all other available variables in the model as predictors, then imputes missing values for the variable being fit. The method continues until the maximum number of iterations is reached, and the imputed values at the maximum iteration are saved to the imputed dataset. These imputed variables were used for the multivariate adjustments and computation of derived variables such as utilization of health services and Water, Sanitation and Hygiene (WASH) scores. Utilization of health services was computed as a sum of smallpox vaccination and place of delivery, where higher scores represented better access to health services. Crowding was defined as number of members per room. WASH score was derived as first principal component score for water and sanitation facilities using Principal Component Analysis for type of toilet, water supply, and toilet and water facilities (Vyas and Kumaranayake 2006).

STATISTICAL ANALYSIS

Data were analyzed using SPSS 20. Multivariate linear regression was used to study the association between human capital metrics (adult education, occupation, and material possession score) and growth conditional measures at birth, 6 months, 2, 5, and 11 years, and adult age. For growth conditional measures, individual (height, weight, or BMI) and simultaneous height and weight measures (conditional height and relative weight gain) SD scores were used in separate models. These analyses were performed in a stepwise manner: first, a crude model for association of adulthood human capital metrics with growth conditional measure(s) adjusted for sex, followed by multivariate model with additional adjustment for socioeconomic and behavioral covariates. Crude models were also analyzed

Figure 2: Conceptual Model for Analysis



Source: Authors

for association of human capital metrics and anthropometric conditional variables with all individual socioeconomic and behavioral variables.

Sensitivity analyses were also done for these univariate and multivariate models for male participants' occupations using multinomial logistic regression to explore the possibility that this outcome may not be strictly ordered. Similarly, sensitivity analyses were performed to compare available and imputed measures for missing variables. As results were largely comparable, only the latter analyses are being depicted. Figure 2 shows the conceptual model for the analysis.

RESULTS

DESCRIPTIVE CHARACTERISTICS

We derived conditional growth SD scores for 1,184 subjects (males: 672, i.e., 57 percent) for whom outcomes and anthropometry were available at all specified time points, namely, birth, 6 months, 2, 5, and 11 years, and adult age. This analyzed cohort (n=1,184) is largely comparable to the original cohort with small differences in some characteristics. The cohort was comparable for birthweight, paternal education, and occupation, but there were marginal differences in mean birth length (1 millimeter [mm] higher), maternal literacy (6 percent higher), nuclear families (7 percent higher), household income, type of housing, utilization of health services, water supply and sanitation (Annex 2). In comparison with the original cohort, the first adult wave analyzed cohort (n=1,526) had 7 percent more male subjects, the mean birthweight was 32 grams (g) higher, and the mean birth length was 2 mm longer. The height, weight, and BMI in childhood and adolescence were approximately 0.1 SD lower than in the original cohort (Bhargava et al. 2004). Among those participating in the first adult wave (n=1,526), except for marginal difference in birthweight, subjects providing conditional growth measures (n=1,184) had comparable anthropometry to those excluded (Annex 3).

Table 1 summarizes the socioeconomic and behavioral characteristics of F1 participants at the time of birth, their anthropometric growth, and adult human capital metrics. Most (59 percent) were born in a health care facility and nearly all (96 percent) were immunized for smallpox. Among parents of F1 subjects, more fathers (61 percent) had completed 10 or more years of education than mothers (27 percent), and nearly two-thirds of fathers were working as medium-level workers or as Class I officers/professionals. One-third were residing in a flat or bungalow (rented or owned), geometric mean household per capita income was Rs. 716 (SD 1.9), with a geometric mean of 3.3 (SD 1.7) members per room. Only 35 percent had access to flush toilets, and the majority shared toilets (81 percent) and water (62 percent) facilities. Except for paternal education and occupation, sex differences were not significant for socioeconomic and behavioral variables. Males had significantly greater height and weight than females at all ages. Two-thirds (63 percent) of participants had ≥15 years education with significantly higher numbers of female graduate/postgraduates. Three-fourth of males were trained clerical/medium-level worker or professional/Class I officers, whereas 59 percent of females were housewives. Mean (SD) material possession score was 13.2 (2.3) with significantly higher values in males.

Table 1: Descriptive Characteristics for the Cohort Subjects (F1)

Variables	Total		Male		Female		P value^
	N	Mean (SD)/No. (%)	N	Mean (SD)/No. (%)	N	Mean (SD)/No. (%)	
At birth							
Place of delivery							
Home	812	332 (40.9)	453	181 (40.0)	359	151 (42.1)	0.566
Health care facilities		480 (59.1)		272 (60.0)		208 (57.9)	
Immunization							
Smallpox vaccination	751	718 (95.6)	414	401 (96.9)	337	317 (94.1)	0.074
Maternal education							
Illiterate	817	283 (34.6)	455	155 (34.1)	362	128 (35.4)	0.905
Primary		160 (19.6)		94 (20.7)		66 (18.2)	
Middle		156 (19.1)		85 (18.7)		71 (19.6)	
Matric		163 (20.0)		92 (20.2)		71 (19.6)	
College		55 (6.7)		29 (6.4)		26 (7.2)	
Paternal education							
Illiterate	752	80 (10.6)	420	46 (11.0)	332	34 (10.2)	**0.004**
Primary		87 (11.6)		53 (12.6)		34 (10.2)	
Middle		123 (16.4)		83 (19.8)		40 (12.0)	
High school/High school+		275 (36.6)		131 (31.2)		144 (43.4)	
Graduate/Professional degree		187 (24.9)		107 (25.5)		80 (24.1)	
Paternal occupation							
Unskilled manual, landless labor/Semiskilled labor, marginal landowner	786	108 (13.7)	447	57 (12.8)	339	51 (15.0)	**<0.001**
Skilled manual, small business/farmer		182 (23.2)		126 (28.2)		56 (16.5)	
Trained clerical, medium business, teacher, middle farmer		395 (50.3)		187 (41.8)		208 (61.4)	

Variables	Total		Male		Female		P value^
	N	Mean (SD)/No. (%)	N	Mean (SD)/No. (%)	N	Mean (SD)/No. (%)	
Professional, big business, landlord, Class I		101 (12.8)		77 (17.2)		24 (7.1)	
HH annual income (Rs.) *^^	817	716 (1.9)	455	727 (2.0)	362	702 (1.9)	0.458
Crowding* (members/room)	816	3.3 (1.7)	456	3.3 (1.7)	360	3.3 (1.7)	0.998
Housing							
Owned thatched hut	809	2 (0.2)	452	1 (0.2)	357	1 (0.3)	0.392
Not-owned masonry building		90 (11.1)		52 (11.5)		38 (10.6)	
Owned masonry building		428 (52.9)		229 (50.7)		199 (55.7)	
Not-owned apartment		122 (15.1)		68 (15.0)		54 (15.1)	
Owned apartment		141 (17.4)		89 (19.7)		52 (14.6)	
Not-owned bungalow		7 (0.9)		5 (1.1)		2 (0.6)	
Owned bungalow		19 (2.3)		8 (1.8)		11 (3.1)	
Toilet							
Open field	818	121 (14.8)	456	67 (14.7)	362	54 (14.9)	0.451
Scavenger cleaned		403 (49.3)		216 (47.4)		187 (51.7)	
Pit		5 (0.6)		2 (0.4)		3 (0.8)	
Flush		289 (35.3)		171 (37.5)		118 (32.6)	
Toilet facilities							
Shared	818	666 (81.4)	456	374 (82.0)	362	292 (80.7)	0.651
Not shared		152 (18.6)		82 (18.0)		70 (19.3)	
Water supply							
Unprotected	818	89 (10.9)	456	47 (10.3)	362	42 (11.6)	0.689
Both		52 (6.4)		27 (5.9)		25 (6.9)	
Protected		677 (82.8)		382 (83.8)		295 (81.5)	
Water supply facilities							
Shared	818	510 (62.3)	456	276 (60.5)	362	234 (64.6)	0.245
Not shared		308 (37.7)		180 (39.5)		128 (35.4)	
Cohort anthropometry							
Height (cm)							
Birth	1,184	48.4 (2.1)	672	48.6 (2.1)	512	48.1 (1.9)	**<0.001**
0.5 years		64.6 (2.5)	672	65.4 (2.4)	512	63.7 (2.4)	**<0.001**
2 years		80.5 (3.6)	672	81.2 (3.5)	512	79.6 (3.7)	**<0.001**
5 years		101.3 (4.5)	672	101.9 (4.4)	512	100.5 (4.4)	**<0.001**
11 years		135.1 (6.5)	672	135.9 (5.6)	512	134.2 (7.4)	**<0.001**
Adulthood		163.3 (9.5)	672	169.7 (6.3)	512	155.0 (5.8)	**<0.001**
Weight (kg)							
Birth	1,184	2.8 (0.4)	672	2.9 (0.4)	512	2.8 (0.4)	**<0.001**
0.5 years		6.7 (0.9)	672	7.0 (0.9)	512	6.3 (0.9)	**<0.001**
2 years		10.1 (1.3)	672	10.4 (1.3)	512	9.7 (1.3)	**<0.001**
5 years		15.2 (1.8)	672	15.5 (1.8)	512	14.8 (1.7)	**<0.001**
11 years		28.0 (4.9)	672	28.2 (4.4)	512	27.6 (5.4)	**0.019**

Variables	Total		Male		Female		P value^
	N	**Mean (SD)/No. (%)**	**N**	**Mean (SD)/No. (%)**	**N**	**Mean (SD)/No. (%)**	
Adulthood		66.3(14.8)	672	71.8 (13.5)	512	59.0 (13.2)	**<0.001**
Adulthood outcomes							
Education							
Up to middle (8th class)	1,184	97 (8.2)	672	67 (10.0)	512	30 (5.9)	**0.009**
High school (10th class)		136 (11.5)		84 (12.5)		52 (10.2)	
High school+ (12th class)		206 (17.4)		126 (18.8)		80 (15.6)	
Graduate (bachelor's degree)		549 (46.4)		288 (42.9)		261 (51.0)	
Professional degree (master's degree)		196 (16.6)		107 (15.9)		89 (17.4)	
Occupation$							
Unemployed /unskilled manual, landless labor/semiskilled labor, marginal landowner/ skilled manual, small business/farmer			672	151 (22.5)			n.a.
Trained clerical, medium business, teacher, middle farmer				361 (53.7)			
Professional, big business, landlord, Class I				160 (23.8)			
Housewife				n.a.	511	303 (59.3)	n.a.
Working (unskilled /trained clerical/ professional, big business, Class I)						208 (40.7)	
Material possession score#	1184	13.2 (2.3)	672	13.4 (2.2)	512	13.0 (2.4)	**0.005**

Source: Authors

Notes: Information on paternal and maternal education was recorded during different waves of data collection under these respective categories; n.a. = Not applicable; HH = Household.

^P value for sex differences.

* Geometric mean for log transformed variable.

^^Rs. 716 (1971), constant 2019 Rs. prices = 27,257 (US$389); Rs. 727 (1971), constant 2019 Rs. prices = 27,676 (US$395); Rs. 702 (1971), constant 2019 Rs. prices = 26,724 (US$382).

$ Different categories for F1 male and female cohort subjects.

Material Possession score is sum of possession of household items (electricity, fan, cycle, radio, two-wheeler, gas stove, television, cable TV, electric mixer, air cooler, washing machine, car, air conditioner, home computer, dish antenna, landline phone and mobile phone), categorized either as "0" (No) or "1" (Yes).

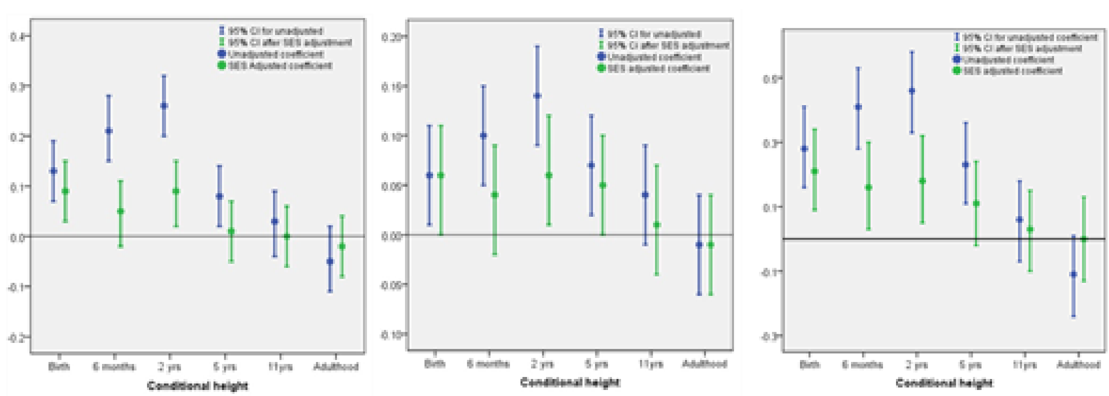
CORRELATION BETWEEN THE OUTCOMES

The three human capital metrics were significantly (P<0.001) correlated with each other. The correlation coefficients for education with male occupation and material possession score, and for male occupation with material possession score were 0.661, 0.531, and 0.509, respectively.

BIRTH LENGTH AND HEIGHT GAIN

In the crude model, birth length and height gain from 0 to 6 months, 6 to 24 months, and 2 to 5 years had a statistically significant association with better education (P range 0.011 to <0.001), material possession score (P<0.001), and occupation for males in adulthood (P range 0.029 to <0.001). The coefficients were greater for height gain from 0 to 6 months and 6 to 24 months. On further adjustment for socioeconomic and behavioral covariates, these associations were substantially attenuated, with statistical significance remaining only for height gains in the under-five and mostly under-two age groups. The statistically significant associations for each of the three metrics were: education with length at birth and height gains from 6 months to 2 years; material possession score with length at birth and height gains from birth to 6 months and 6 to 24 months; and male occupation with length at birth and height gains from birth to 2 years and 2 to 5 years (Table 2 and Figure 3).

Figure 3: Association of Height with (a) Adult Education, (b) Male Occupation, and (c) Material Possession Score



(a) (b) (c)

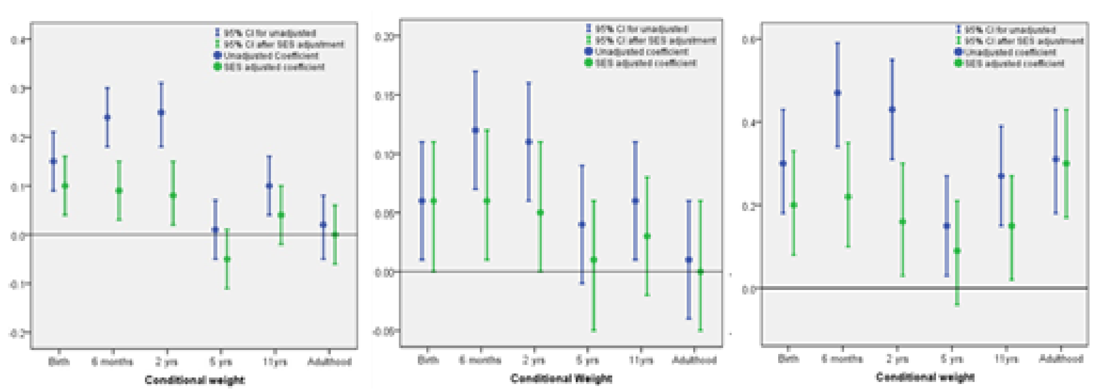
Source: Authors

Notes:
Y-axis: β coefficient values (dots) from the crude (blue) and adjusted (green) models, respectively while the two vertical arms represent the 95% confidence intervals.
X-axis: upper limit of age intervals for which the β coefficients are depicted in the Y axis; for example, the β coefficients above 6 months refer to conditional growth between 0 (birth) and 6 months.

BIRTHWEIGHT AND WEIGHT GAIN

In the crude model, birthweight and weight gain from 0 to 6 months, 6 to 24 months, and 5 to 11 years had a statistically significantly association with better education (P≤0.001) and occupation for males in adulthood (P range 0.021 to <0.001). Material possession score was associated with greater birthweight and weight gain in all intervals until adulthood (P range 0.017 to <0.001). The coefficients were greater for weight gain from 0 to 6 months and 6 to 24 months. On further adjustment for socioeconomic and behavioral covariates, these associations were substantially attenuated with statistical significance being restricted to under-two years of age for education and male occupation. However, for material possession score, except for the interval 2 to 5 years, statistical significance was evident for all age periods (Table 2 and Figure 4).

Figure 4: Association of Weight with (a) Adult Education, (b) Male Occupation, and (c) Material Possession Score



(a) (b) (c)

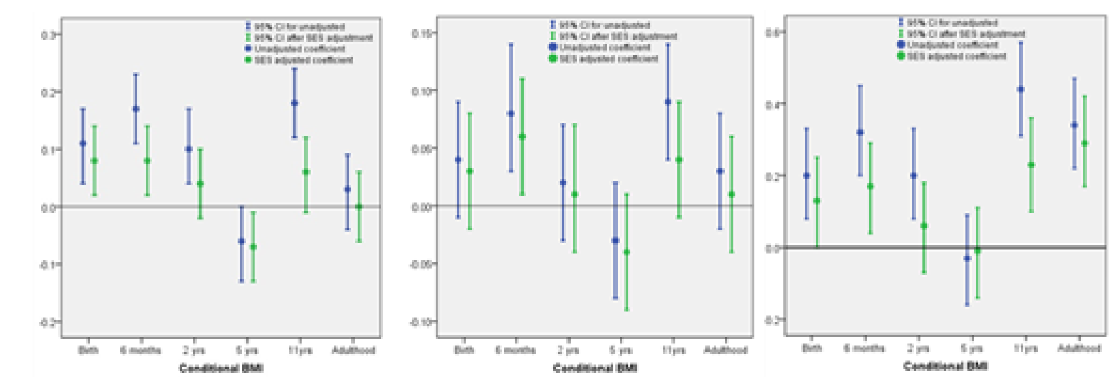
Source: Authors

Notes:
Y-axis: β coefficient values (dots) from the crude (blue) and adjusted (green) models, respectively while the two vertical arms represent the 95% confidence intervals.
X-axis: Upper limit of age intervals for which the β coefficients are depicted in the Y axis; for example, the β coefficients above 6 months refer to conditional growth between 0 (birth) and 6 months.

BIRTH BMI AND BMI GAIN

In the crude model, birth BMI and BMI gain in various intervals had somewhat different associations with human capital metrics. Education was positively associated with birth BMI and BMI gain from 0 to 6 months, 6 to 24 months, and 5 to 11 years (P≤0.001) and negatively with BMI gain from 2 to 5 years (P=0.048). Male occupation was positively associated with BMI gain from 0 to 6 months and 5 to 11 years (P=0.001). Material possession scores were positively associated (P range 0.002 to <0.001) with birth BMI and all age intervals except for the 2 to 5 years interval. The coefficients were generally greater for intervals 0 to 6 months and 5 to 11 years. On further adjustment for socioeconomic and behavioral covariates, these associations were generally attenuated. Statistically significant associations remained for the following age intervals: education at birth and 0 to 6 months (positive), and 2 to 5 years (negative); male occupation at 0 to 6 months; and material possession score at birth, 0 to 6 months, 5 to 11 years, and 11 years to adulthood (Table 2 and Figure 5).

Figure 5: Association of BMI with (a) Adult Education, (b) Male Occupation, and (c) Material Possession Score



(a) **(b)** **(c)**

Source: Authors

Notes:
Y-axis: β coefficient values (dots) from the crude (blue) and adjusted (green) models, respectively, while the two vertical arms represent the 95% confidence intervals.
X-axis: Upper limit of age intervals for which the β coefficients are depicted in the Y axis; for example, the β coefficients above 6 months refer to conditional growth between 0 (birth) and 6 months.

Table 2: Association between Human Capital Metrics and Height, Weight, and BMI Gain

	Height gain		**Weight gain**		**BMI gain**	
	Crude model	**Multivariate analysis**	**Crude model**	**Multivariate analysis**	**Crude model**	**Multivariate analysis**
Variables			**Coefficient (95% CI); P value**			
Education (n=1,184, crude model; n=993, multivariate)						
Sex (female vs. male)	0.22 (0.09,0.35); 0.001	0.23 (0.11, 0.35); <0.001	0.22 (0.09, 0.34); 0.001	0.23 (0.11, 0.35); <0.001	0.22 (0.09, 0.34); 0.001	0.24 (0.12, 0.36); <0.001

	Height gain		Weight gain		BMI gain	
	Crude model	**Multivariate analysis**	**Crude model**	**Multivariate analysis**	**Crude model**	**Multivariate analysis**
Variables			**Coefficient (95% CI); P value**			
Birth length	0.13(0.07, 0.19); <0.001	0.09 (0.03, 0.15); 0.005	0.15 (0.09, 0.21); <0.001	0.10 (0.04, 0.16); 0.001	0.11 (0.04, 0.17); 0.001	0.08 (0.02, 0.14); 0.007
	Height gain		Weight gain		BMI gain	
0–6 months	0.21 (0.15, 0.28); <0.001	0.05 (-0.02, 0.11); 0.164	0.24 (0.18, 0.30); <0.001	0.09 (0.03, 0.15); 0.005	0.17 (0.11, 0.23); <0.001	0.08 (0.02, 0.14); 0.006
6–24 months	0.26 (0.20, 0.32); <0.001	0.09 (0.02, 0.15); 0.008	0.25 (0.18, 0.31); <0.001	0.08 (0.02, 0.15); 0.012	0.10 (0.04, 0.17(; 0.001	0.04 (-0.02, 0.10); 0.198
2–5 years	0.08 (0.02, 0.14); 0.011	0.01 (-0.05, 0.07); 0.662	0.01 (-0.05, 0.07); 0.664	-0.05 (-0.11, 0.01); 0.111	-0.06 (-0.13, 0.00); 0.048	-0.07 (-0.13, -0.01); 0.022
5–11 years	0.03 (-0.04, 0.09); 0.404	0.00 (-0.06, 0.06); 0.918	0.10 (0.04, 0.16); 0.001	0.04 (-0.02, 0.10); 0.223	0.18 (0.12, 0.24); <0.001	0.06 (-0.01, 0.12); 0.073
11 years–adulthood	-0.05 (-0.11, 0.02); 0.143	-0.02 (-0.08, 0.04); 0.575	0.02 (-0.05, 0.08); 0.612	0.00 (-0.06, 0.06); 0.988	0.03 (-0.04, 0.09); 0.405	0.00 (-0.06, 0.06); 0.916
Utilization of health services #		0.13 (0.00, 0.26); 0.046		0.12 (-0.01, 0.25); 0.069		0.13 (0.00, 0.26); 0.042
Maternal education		0.15 (0.09, 0.21); <0.001		0.14 (0.08, 0.20); <0.001		0.15 (0.09, 0.21); <0.001
Paternal education		0.22 (0.15, 0.28); <0.001		0.22 (0.15, 0.28); <0.001		0.22 (0.16, 0.29); <0.001
Paternal occupation		0.18 (0.10, 0.27); <0.001		0.17 (0.09, 0.26); <0.001		0.17 (0.09, 0.26); <0.001
Household annual income* (Rs.)		0.04 (-0.10, 0.18); 0.587		0.06 (-0.08, 0.20); 0.410		0.07 (-0.07, 0.22); 0.306
Crowding (members/room)*		-0.06 (-0.21, 0.10); 0.459		-0.07 (-0.22, 0.08); 0.379		-0.06 (-0.21, 0.09); 0.437
Housing		0.03 (-0.04, 0.09); 0.403		0.03 (-0.04, 0.09); 0.438		0.03 (-0.04, 0.09); 0.432
WASH score Ω		0.05 (-0.02, 0.11); 0.188		0.04 (-0.02, 0.11); 0.209		0.04 (-0.03, 0.11); 0.223
Occupation ***(n=672, crude model; n=558, multivariate)***						
Male						
Birth	0.06 (0.01, 0.11); 0.029	0.06 (0.001, 0.11); 0.033	0.06 (0.01, 0.11); 0.021	0.06 (0.00, 0.11); 0.037	0.04 (-0.01,	0.03 (-0.02, 0.08); 0.224

	Height gain		Weight gain		BMI gain	
	Crude model	Multivariate analysis	Crude model	Multivariate analysis	Crude model	Multivariate analysis
Variables			Coefficient (95% CI); P value			
					0.09); 0.160	
0–6 months	0.10 (0.05, 0.15); <0.001	0.04 (-0.02, 0.09); 0.218	0.12 (0.07, 0.17); <0.001	0.06 (0.01, 0.12); 0.018	0.08 (0.03, 0.14); 0.001	0.06 (0.01, 0.11); 0.023
6–24 months	0.14 (0.09, 0.19); <0.001	0.06 (0.01, 0.12); 0.030	0.11 (0.06, 0.16);<0.001	0.05 (0.00, 0.11); 0.057	0.02 (-0.03, 0.07); 0.457	0.01 (-0.04, 0.07); 0.635
2–5 years	0.07 (0.02, 0.12); 0.004	0.05 (0.00, 0.10); 0.050	0.04 (-0.01, 0.09); 0.114	0.01 (-0.05, 0.06); 0.844	-0.03 (-0.08, 0.02); 0.274	-0.04 (-0.09, 0.01); 0.156
5–11 years	0.04 (-0.01, 0.09); 0.118	0.01 (-0.04, 0.07); 0.598	0.06 (0.01, 0.11); 0.028	0.03 (-0.02, 0.08); 0.250	0.09 (0.04, 0.14); 0.001	0.04 (-0.01, 0.09); 0.135
11 years–adulthood	-0.01 (-0.06, 0.04); 0.612	-0.01 (-0.06, 0.04); 0.739	0.01 (-0.04, 0.06); 0.591	0.00 (-0.05, 0.06); 0.854	0.03 (-0.02, 0.08); 0.303	0.01 (-0.04, 0.06); 0.744
Utilization of health services #		0.01 (-0.10, 0.12); 0.823		0.01 (-0.11, 0.12); 0.904		0.02 (-0.09, 0.13); 0.701
Maternal education		0.07 (0.02, 0.12); 0.010		0.07 (0.01, 0.12); 0.012		0.07 (0.02, 0.12); 0.008
Paternal education		0.08 (0.03, 0.14); 0.004		0.08 (0.03, 0.14); 0.004		0.09 (0.03, 0.14); 0.003
Paternal occupation		0.12 (0.05, 0.19); 0.001		0.12 (0.05, 0.19); 0.001		0.12 (0.05, 0.19); 0.001
Household annual income* (Rs.)		-0.04 (-0.16, 0.08); 0.496		-0.04 (-0.16,0.09); 0.573		-0.02 (-0.14, 0.11); 0.797
Crowding (members/ room)*		-0.09 (-0.23, 0.04); 0.173		-0.11 (-0.24, 0.02); 0.099		-0.11 (-0.24, 0.02); 0.110
Housing		-0.01 (-0.07, 0.04); 0.604		-0.02 (-0.07, 0.03); 0.464		-0.02 (-0.08, 0.03); 0.461
WASH score Ω		0.03 (-0.03, 0.09); 0.293		0.03 (-0.03, 0.09); 0.281		0.03 (-0.03, 0.09); 0.268
Material possession score (n=1,184, crude model; n=993, multivariate)						
Sex (female vs male)	-0.38 (-0.64, -0.13); 0.003	-0.40 (-0.65, -0.15); 0.002	-0.38 (-0.63, -0.14); 0.002	-0.39 (-0.63, -0.14); 0.002	-0.38 (-0.64, -0.13); 0.003	-0.39 (-0.64, -0.14); 0.002
Birth length	0.28 (0.16. 0.41); <0.001	0.21 (0.09, 0.34); 0.001	0.30 (0.18, 0.43); <0.001	0.20 (0.08, 0.33); 0.001	0.20 (0.08, 0.33); <0.001	0.13 (0.00, 0.25); 0.046

	Height gain		Weight gain		BMI gain	
	Crude model	Multivariate analysis	Crude model	Multivariate analysis	Crude model	Multivariate analysis
Variables			Coefficient (95% CI); P value			
Height gain			Weight gain		BMI gain	
0–6 months	0.41 (0.28, 0.53); <0.001	0.16 (0.03, 0.30); 0.019	0.47 (0.34, 0.59); <0.001	0.22 (0.10, 0.35); 0.001	0.32 (0.20, 0.45); <0.001	0.17 (0.04, 0.29); 0.008
6–24 months	0.46 (0.33, 0.58); <0.001	0.18 (0.05, 0.32); 0.007	0.43 (0.31, 0.55); <0.001	0.16 (0.03, 0.30); 0.018	0.20 (0.08, 0.33); 0.002	0.06 (-0.07, 0.18); 0.360
2–5 years	0.23 (0.11, 0.36); <0.001	0.11 (-0.02, 0.24); 0.094	0.15 (0.03, 0.27); 0.017	0.09 (-0.04, 0.21); 0.175	-0.03 (-0.16, 0.09); 0.607	-0.01 (-0.14, 0.11); 0.851
5–11 years	0.06 (-0.07, 0.18); 0.386	0.03 (-0.10, 0.15); 0.687	0.27 (0.15, 0.39); <0.001	0.15 (0.02, 0.27); 0.020	0.44 (0.31, 0.57); <0.001	0.23 (0.10, 0.36); <0.001
11 years–adulthood	-0.11 (-0.24, 0.01); 0.079	0.00 (-0.13, 0.13); 0.999	0.31 (0.18, 0.43); <0.001	0.30 (0.17, 0.43); <0.001	0.34 (0.22, 0.47); <0.001	0.29 (0.17, 0.42); <0.001
Utilization of health services #		0.42 (0.16, 0.68); 0.002		0.37 (0.10, 0.63); 0.006		0.38 (0.12, 0.65); 0.004
Maternal education		0.34 (0.22, 0.47); <0.001		0.33 (0.21, 0.45); <0.001		0.34 (0.22, 0.46); <0.001
Paternal education		0.22 (0.09, 0.36); 0.002		0.20 (0.07, 0.34); 0.004		0.21 (0.08, 0.35); 0.002
Paternal occupation		0.40 (0.22, 0.57); <0.001		0.39 (0.21, 0.56); <0.001		0.39 (0.21, 0.56); <0.001
Household annual income* (Rs.)		0.24 (-0.06, 0.53); 0.118		0.25 (-0.04, 0.54); 0.091		0.28 (-0.02, 0.57); 0.063
Crowding (members/ room)*		0.04 (-0.28, 0.37); 0.794		0.03 (-0.29, 0.34); 0.876		0.02 (-0.29, 0.34); 0.892
Housing		0.09 (-0.05, 0.22); 0.204		0.09 (-0.04, 0.22); 0.184		0.09 (-0.04, 0.22); 0.169
WASH score Ω		-0.09 (-0.23, 0.05); 0.204		-0.08 (-0.22, 0.06); 0.261		-0.07 (-0.21, 0.07); 0.305

Source: Authors

Notes: For categorization of other variables refer to Table 1; CI = Confidence interval; WASH = Water, Sanitation and Hygiene.

* Log transformed

Utilization of health services computed as sum of smallpox vaccination and place of delivery.

Ω First principal component score generated from type of toilet, water supply, and toilet and water facilities.

SIMULTANEOUS HEIGHT AND WEIGHT MEASURES

In this model, it was the intention to separate the effects of linear growth and weight gain; height gain refers to present height accounting for previous height and weight (but not present weight) while relative weight is present weight accounting for present height and previous weight and height measures. In the crude model (Table 3, Figure 6*)*, birth length and height gain from 0 to 6 months, and 6 to 24 months had a statistically significantly association with better education (P<0.001), material possession score (P<0.001), and occupation for males (P range 0.029 to <0.001). In addition, height gain from 2 to 5 years had a statistically significantly association with better material possession score (P=0.004) and occupation for males (P=0.01). The coefficients were greater for height gain from 0 to 6 months and 6 to 24 months. On further adjustment for socioeconomic and behavioral covariates (Table 3, Figure 6), these associations were substantially attenuated, and statistical significance (P<0.05) was evident only for the under-two age group as follows: education—significant association with length at birth and height gain from 6 to 24 months; material possession score—significant association with length at birth and height gain from 0 to 6 months and 6 to 24 months age categories; and male occupation—significant association with length at birth.

In the crude model (Table 3, Figure 6*)*, relative weight at birth and subsequent intervals had somewhat different associations with various human capital metrics. Education was positively associated with relative weight at birth (P=0.015) and gain from 0 to 6 months, 6 to 24 months, and 5 to 11 years (P range 0.017 to <0.001). Male occupation was positively associated with relative weight gain from 0 to 6 months (P=0.004). Material possession scores were positively associated (P range 0.021 to <0.001) with relative weight at birth and all age intervals except 2 to 5 years. Except for material possession score, the coefficients were greater for intervals 0 to 6 months and 6 to 24 months. On further adjustment for socioeconomic and behavioral covariates (Table 3, Figure 6*)*, these associations were generally attenuated with statistical significance being restricted to fewer age intervals—education at 0 to 6 months and 6 to 24 months (positive), and 2 to 5 years (negative); male occupation at 0 to 6 months; and material possession score at 0 to 6 months, 5 to 11 years, and 11 years to adulthood.

Table 3: Association between Human Capital Metrics and Conditional Height and Relative Weight Gain

Variables	Crude model	Multivariate analysis
	Coefficient (95% CI); P value	
Education	**(n=1,184)**	**(n=993)**
Sex (female in comparison to male)	0.22 (0.09, 0.34); 0.001	0.23 (0.11,0.35); <0.001
Birth length	0.13 (0.07, 0.19); <0.001	0.09 (0.03, 0.15); 0.004
Height gain		
0–6 months	0.21 (0.15, 0.27); <0.001	0.05 (-0.02, 0.11); 0.139
6–24 months	0.23 (0.17, 0.29); <0.001	0.07 (0.01, 0.14); 0.030
2–5 years	0.05 (-0.01, 0.11); 0.102	0.00 (-0.06, 0.07); 0.888
5–11 years	0.04 (-0.02, 0.10); 0.205	0.02 (-0.04, 0.08); 0.587
11 years–adulthood	-0.02 (-0.08, 0.04); 0.552	-0.02 (-0.08, 0.04); 0.589
Relative weight gain, given height		
Birth	0.08 (0.01, 0.14); 0.015	0.06 (0.00, 0.12); 0.062
0–6 months	0.14 (0.08, 0.21); <0.001	0.08 (0.02, 0.14); 0.012
6–24 months	0.13 (0.07, 0.19); <0.001	0.06 (0.00, 0.13); 0.043
2–5 years	-0.05 (-0.11. 0.02); 0.145	-0.06 (-0.12, 0.00); 0.044
5–11 years	0.07 (0.01, 0.14); 0.017	0.03 (-0.03, 0.09); 0.374
11 years–adulthood	0.02 (-0.04, 0.08); 0.601	0.00 (-0.06, 0.06); 0.975
Utilization of health services #		0.12 (-0.01, 0.25); 0.070
Maternal education		0.14 (0.08, 0.20); <0.001
Paternal education		0.22 (0.15, 0.29); <0.001
Paternal occupation		0.17 (0.08, 0.26); <0.001
Household annual income*(Rs.)		0.05 (-0.09, 0.20); 0.465
Crowding (members/room)*		-0.05 (-0.21, 0.10); 0.497
Housing		0.03 (-0.04, 0.09); 0.403
WASH score Ω		0.04 (-0.03, 0.11); 0.221
Male	***(n=672)***	*(n=558*)
Birth length	0.06 (0.01, 0.11); 0.029	0.06 (0.00, 0.11); 0.032
Height gain		
0–6 months	0.10 (0.05, 0.15); <0.001	0.03 (-0.02, 0.09); 0.239
6–24 months	0.12 (0.07, 0.17); <0.001	0.05 (-0.01, 0.10); 0.104
2–5 years	0.07 (0.02, 0.12); 0.010	0.05 (-0.01; 0.10); 0.083
5–11 years	0.04 (-0.01, 0.09); 0.090	0.02 (-0.03, 0.07); 0.513
11 years–adulthood	-0.01 (-0.06, 0.04); 0.708	-0.01 (-0.06, 0.04); 0.765
Relative weight gain, given height		
Birth	0.03 (-0.02, 0.08); 0.307	0.02 (-0.03, 0.07); 0.471
0–6 months	0.07 (0.02, 0.12); 0.004	0.05 (0.00, 0.10); 0.049
6–24 months	0.04 (-0.01, 0.09); 0.093	0.03 (-0.02, 0.09); 0.218
2–5 years	-0.02 (-0.07, 0.03); 0.550	
5–11 years	0.02 (-0.03, 0.07); 0.504	-0.03 (-0.08, 0.02); 0.308

Variables	Crude model	Multivariate analysis
	Coefficient (95% CI); P value	
11 years–adulthood	0.02 (-0.03, 0.07); 0.430	0.01 (-0.04, 0.06); 0.655
Utilization of health services #		0.01 (-0.11, 0.12); 0.894
Maternal education		0.07 (0.01, 0.12); 0.012
Paternal education		0.09 (0.03, 0.14); 0.003
Paternal occupation		0.12 (0.05, 0.19); 0.001
Household annual income*(Rs.)		-0.04 (-0.16, 0.08); 0.536
Crowding (members/room)*		-0.10 (-0.23, 0.03); 0.145
Housing		-0.02 (-0.07, 0.04); 0.562
WASH score Ω		0.03 (-0.03, 0.09); 0.323
Material possession score	**(n=1,184)**	**(n=993)**
Sex (female in comparison to male)	-0.38 (-0.63, -0.14); 0.002	-0.39 (-0.64, -0.15); 0.002
Birth length	0.28 (0.16, 0.41); <0.001	0.21 (0.08, 0.33); 0.001
Height gain		
0–6 months	0.40 (0.28, 0.52); <0.001	0.18 (0.05, 0.32); 0.007
6–24 months	0.39 (0.27, 0.52); <0.001	0.16 (0.03, 0.29); 0.016
2–5 years	0.18 (0.06, 0.31); 0.004	0.11 (-0.02, 0.23); 0.098
5–11 years	0.07 (-0.05, 0.19); 0.255	0.03 (-0.10, 0.15); 0.667
11 years–adulthood	-0.02 (-0.14, 0.11); 0.779	0.05 (-0.08, 0.17); 0.457
Relative weight gain, given height		
Birth	0.14 (0.02, 0.27); 0.021	0.08 (-0.04, 0.21); 0.191
0–6 months	0.28 (0.16, 0.40); <0.001	0.15 (0.03, 0.27); 0.015
6–24 months	0.24 (0.11, 0.36); <0.001	0.10 (-0.02, 0.23); 0.112
2–5 years	0.02 (-0.11, 0.14); 0.791	0.02 (-0.10, 0.15); 0.707
5–11 years	0.26 (0.14, 0.38); <0.001	0.16 (0.03, 0.29); 0.013
11 years–adulthood	0.31 (0.19, 0.43); <0.001	0.29 (0.16, 0.41); <0.001
Utilization of health services #		0.35 (0.09, 0.61); 0.009
Maternal education		0.32 (0.20, 0.45); <0.001
Paternal education		0.20 (0.06, 0.34); 0.004
Paternal occupation		0.38 (0.21, 0.56); <0.001
Household annual income*(Rs.)		0.22 (-0.07, 0.52); 0.132
Crowding (members/room)*		0.05 (-0.27, 0.37); 0.771
Housing		0.09 (-0.04, 0.22); 0.171
WASH score Ω		-0.08 (-0.22, 0.06); 0.258

Source: Authors

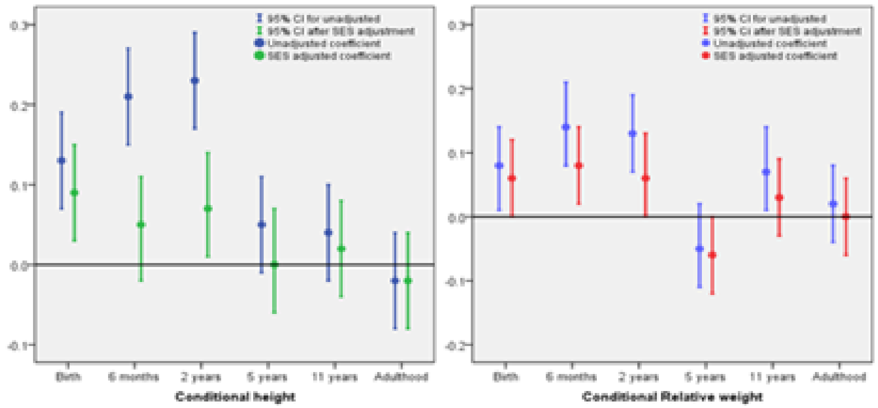
Notes: For categorization of other variables, refer to Table 1 CI = Confidence Interval; WASH = Water, Sanitation and Hygiene.

* Log transformed.

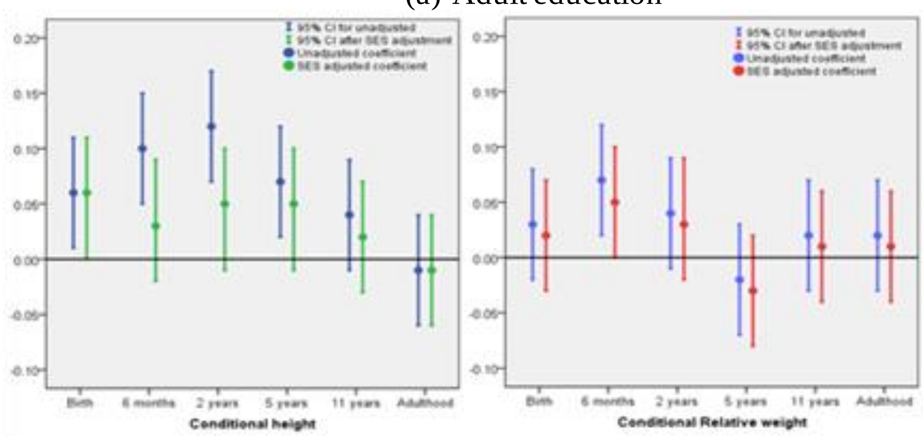
Utilization of health services computed as sum of smallpox vaccination and place of delivery.

Ω First principal component score generated from type of toilet, water supply, and toilet and water facilities.

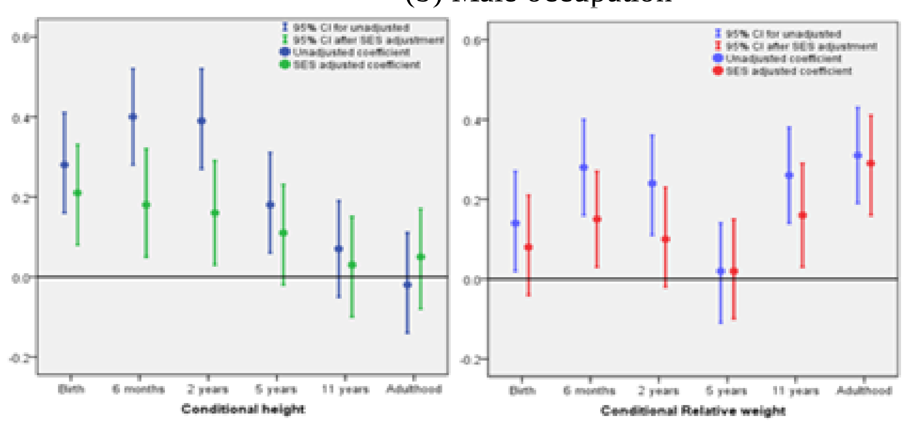
Figure 6: Association of Height (Allowing for Weight) and Relative Weight Gain with (a) Adult Education, (b) Male Occupation, and (c) Material Possession Score



(a) Adult education



(b) Male occupation



(c) Material possession score

Source: Authors

Notes:
Y-axis: β coefficient values (dots) from the crude (blue) and adjusted (green) models, respectively, while the two vertical arms represent the 95% confidence intervals.
X-axis: Upper limit of age intervals for which the β coefficients are depicted in the Y axis; for example, the β coefficients above 6 months refer to conditional growth between 0 (birth) and 6 months.

COMPARATIVE ASSOCIATION OF ADULT HUMAN CAPITAL AND VARIOUS GROWTH MEASURES

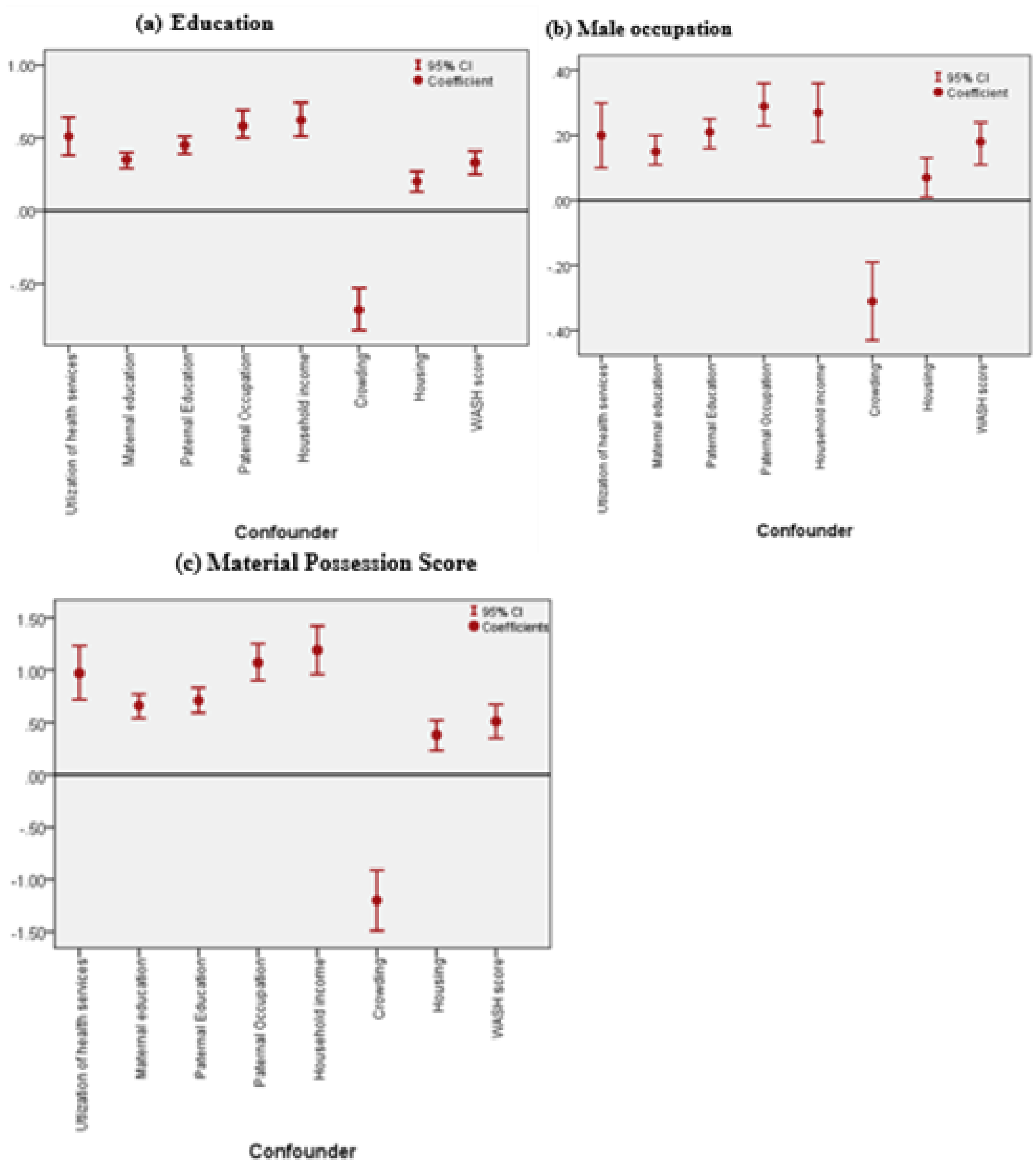
Almost all growth measures at various age intervals had a positive association with one or more of the three human capital metrics (education, male occupation, and material possession score). Adjustment for socioeconomic and behavioral covariates generally attenuated the magnitude and strength of these crude associations. Their statistical significance ($P \leq 0.05$) was mostly restricted to under-five or under-two age intervals except for weight, BMI, and relative weight for material possession scores, where 5 to 11 years and 11 years to adulthood retained significance. However, after adjustment, BMI and relative weight gain from 2 to 5 years had a significant negative association with education. Birth length and height gain from 6 to 24 months had a consistent positive association with all three human capital metrics; in addition, height gain from 0 to 6 months and 2 to 5 years were significant predictors of material possession score and male occupation, respectively. In general, the magnitude of associations was slightly higher for height in comparison to weight, BMI, or relative weight.

COVARIATES ASSOCIATION

In the sex-adjusted analyses, except for a significant inverse association for crowding (members per room), all other socioeconomic and behavioral covariates (utilization of health services, maternal and paternal education, paternal occupation, household income, housing condition, and water and sanitation facilities) had a significant positive association with all adult human capital measures (Figure 7). In all multivariate models, maternal and paternal education and paternal occupation had a consistent positive association with adult education, male occupation, and material possession score. Apart from these, better utilization of health services was also positively associated with higher material possession score.

Gain in height, weight, and BMI until five years of age had a significant positive association with utilization of health care facilities, maternal and paternal education, paternal occupation, household income, and WASH score, but an inverse association with crowding. Height gain from 11 years to adulthood had a significant negative association with paternal occupation and household income, while weight and BMI gain in this age interval had a significant positive association with paternal education. Similar associations were evident for conditional height accounting for weight and relative weight.

Figure 7: Association between Socioeconomic and Behavioral Covariates with (a) Adult Education, (b) Male Occupation, and (c) Material Possession Score



Source: Authors

Notes:
Y-axis: β coefficient values (dots) from the crude (blue) and adjusted (green) models, respectively, while the two vertical arms represent the 95% confidence intervals.
X-axis: Socioeconomic and behavioral covariates. Household income and crowding are log transformed variables.

SENSITIVITY ANALYSES

Sensitivity analyses for the adjusted model for adult human capital metrics using only the available values for the covariates (without any imputation) indicate that the findings were in broad conformity with models using imputed values for the covariates.

Sensitivity analysis for male occupation was done using multinomial logistic regression to explore the possibility that this outcome may not be strictly ordered. The findings were in broad conformity with the models using linear regression analysis. These models provide odds ratio for each individual predictor variable in comparison to the reference category.

We used a simple sum of material possessions to create a composite score for the outcome analysis. However, there is an issue if some of the included items are not monotonically increasing with the underlying latent variable. For example, for two-wheelers to car, the likelihood of ownership of a variable increases at first and then declines as people become richer. Also, some possessions are correlated (one needs to have electricity to have a television, and one needs a television to have cable television). We therefore analyzed the first principal component of the material possessions (~21 percent variance explained) as the outcome variable after dropping electricity and ownership of fan, since all subjects had these possessions (Annex 4). The sum of material possession score and first principal component were strongly correlated ($r=0.735$; $P<0.001$). The observed associations with first principal component were quite similar except that the magnitude and strength of associations was slightly lower. We chose the sum of material possessions for depiction in the main text to keep uniformity with the other two outcomes and also for simplified understanding of the magnitude of change in the dependent variable (outcome). It is also possible that material possessions may change over time. However, the crude and multivariate associations between the mean of material possession score at available adult phases and conditional height and relative weight were also in conformity with the model using the maximum material possession score of the available adult phases.

DISCUSSION

Birth size and growth measures, mostly in the under-five or under-two age intervals, had significant positive associations with one or more human capital metrics (adult education, male occupation, and material possession score). Birth length and height gain from 6 to 24 months were consistently associated with all metrics, while 0 to 6 months and 2 to 5 years height gain also predicted material possession score and male occupation, respectively. Weight, BMI, and relative weight gains from five years onward also significantly predicted material possession scores. While the overall magnitude of associations with growth measures is generally modest, the associations with height were slightly higher. Maternal and paternal education, and paternal occupation also had a consistent positive association with human capital outcomes.

Few studies from LMICs undergoing rapid nutrition and socioeconomic transition have prospectively followed up birth cohorts until adulthood. This urban cohort too had transited from poor socio-demographic and physical growth characteristics during birth and infancy into relative affluence with attendant escalation of cardiometabolic risk factors including diabetes and hypertension in the third and fourth decade of life (Bhargava et al. 2004; Huffman et al. 2011). These analyses provide evidence on some potential beneficial effects (human capital) of early child growth, particularly during the first 1,000 days, in populations that are facing the dual burden of persistent undernutrition and rapidly emerging obesity with cardiometabolic risk factors. Practical measures of adult human capital, connected to livelihoods and income generation, comprised attained educational status, occupation in males, and material possession score as a surrogate for wealth. Limited information is available on the latter two outcomes from LMICs, particularly from India.

The study was population-based; pregnancies and live births were followed up prospectively, and trained personnel collected anthropometric data at frequent intervals during infancy, childhood, and adolescence. As important periods of brain development occur in adolescence and early adulthood (Isaacs and Oates 2008; Wachs et al. 2013), we could examine, probably for the first time from LMICs, the effect of segmental growth faltering after five years of age. Rich longitudinal measurements permitted creation of age intervals (0–6 months, 6–24 months, 2–5 years, 5–11 years and 11 years–adulthood) to meaningfully represent physiological growth phases and current intervention strategies.

This study had several other strengths. Different growth measures (height, weight, and BMI) were compared through independent conditional variables. This removed the phenomenon of regression to the mean and controlled-for common error terms (e.g., measurement error will generate a negative correlation between initial and change values because larger-than-true measurements at baseline will lead to smaller change values, and smaller-than-true initial values will lead to larger change values) (Martorell et al. 2010). We were also able to separate out the effect of linear growth from relative weight gain. Weight gain is a result of linear growth and soft tissue gain (fat mass and fat-free mass); the conditional relative weight variables represent weight change that is separated from change in height (Adair et al. 2013; Osmond and Fall 2017). Conditional relative weight and conditional height variables not being correlated, expressing them in SD units allows direct comparison of coefficients within regression models. These variables therefore have advantages when compared with other representations of growth, and give more nuanced results than those that are based on weight gain alone (Adair et al. 2013). One SD in conditional relative weight at two years corresponded to change in weight-for-age Z score from birth to 2 years that was slightly less than the 0.67 units typically used to define rapid weight gain (Adair et al. 2013; Ong 2007). We were able to control for additional confounders than earlier pooled analyses (Adair et al. 2013; Martorell et al. 2010; Victora et al. 2008), and the choice of all these confounders was justified by observed associations with exposures and outcomes. Use of novel imputation techniques and a variety of sensitivity analyses enhanced the confidence in findings.

Participants came from a population representing all live births within a defined area in urban Delhi. Since only 14.5 percent of the original cohort participated in the present study, the subjects may well be unrepresentative of the cohort as a whole. However, the observed differences in some baseline socio-demographic characteristics, and the mean size at birth and in childhood, though statistically significant, were either small or trivial. Our analysis was based on internal comparisons within the study sample and would be biased only if the association between human capital metrics differed between those who were included in the current study and those who were not. We have no firm evidence to suggest a substantial bias or its direction, if present. Further, apart from refusal of consent, some attrition was inevitable with this follow-up duration, especially because of deaths and out-migration due to demolition of unauthorized construction, marriage, and job opportunities (Bhargava et al. 2004).

Additional limitations merit consideration. Data availability precluded adjustment for some important confounders like educational systems. We could evaluate only three important—

instead of a comprehensive—sets of human capital metrics (Lim et al. 2018). Women's occupation was not evaluated as an outcome because of difficulties in interpreting and quantifying housewives under this category. We did not explore the different domains of cognition and development in the participants, either as children or adults, to gain mechanistic insights. These findings are from a dataset of urban Delhi and might not be directly generalizable to other parts of India or to other LMICs.

The analytic strategy adopted was robust enough to exclude consistent artifactual associations. Larger birth size and higher growth, especially in height in under-five children, was associated with greater adult human capital. Except for positive associations for weight, BMI, and relative weight gain for material possession score, physical growth beyond five years of age was unrelated to education and male occupation. Significant attenuation and persistence of these associations after confounder adjustment suggest causality. However, this cannot be ascertained with certainty by this observational design, particularly due to residual confounding and reverse causality. Similar associations have been documented in pooled analyses from LMICs (including this cohort), with growth exposures largely restricted to under-two or under-five years of age. Birthweight and weight-for-age and height-for-age at two years (positive direction), and undernutrition indexes (negative direction) were associated with attained educational status at adulthood. An inverse association was noted with grade failure (excludes Indian cohort) (Martorell et al. 2010; Victora et al. 2008). Weight gain during the first two years of life had the strongest association with attained education, followed by birthweight and weight gain between two and four years. In nonpooled analyses, most indicators of undernutrition were associated with lower income in Brazil and fewer assets in India, but in Guatemala few associations were significant (Victora et al. 2008). In a subsequent refinement, increased birthweight and linear growth during the first two years of life resulted in gains in schooling. There were no consistent associations with relative weight gain (Adair et al. 2013). In quasi-experimental designs using instrumental variables, increased height-for-age Z scores in preschool age were associated with higher schooling in Guatemala and rural Zimbabwe; and better cognition test scores and per capita household expenditure, and lower probability of living in poverty in adulthood in Guatemala (Alderman, Hoddinott, and Kinsey 2006; Hoddinott et al. 2013a). Upward social mobility measured as a "better" education is shown to result in taller stature, up to the third generation (Koziel et al. 2019). Nutrition intervention in the Guatemalan cohort improved diets and reduced stunting at three years of age (Martorell 1995) with long-term effects on schooling (women), cognitive development (men and women), and wages (men) (Hoddinott et al. 2008; Maluccio et al. 2009; Martorell 2017; Stein et al. 2008). In a recent nonrandomized, single cluster comparison from India, the effects in early adulthood of exposure to nutritional supplement in utero or during the first three years of life through the Integrated Child Development Services (ICDS) were evaluated (Nandi et al. 2018). The 13- to 18-year-old adolescents born in ICDS-intervention villages were taller than control village subjects (Kinra et al. 2008). Later as adults at age 20 to 25, they had improved educational (9 percent more likely to complete secondary school and 11 percent more likely to complete graduate education) and employment (5 percent more likely to be employed or enrolled in higher education) outcomes, and 6 percent lower marriage rates (Nandi et al. 2018). External validation and the two quasi-experimental designs from LMICs provide additional support for a causal effect.

Several hypotheses have been postulated to explain these associations, which are assumed to be causal. Growth failure in early childhood may be a marker of suboptimal nutrients at the cellular level, which have systemic effects on growth and development in general, including brain and neurological development (Martorell et al. 2010). It is also proposed that undersized Indian children represent a combination of intergenerational constraint and maldevelopment (Sachdev 2018). Various components of overall development (e.g., parental education and occupation, socioeconomic status, water supply and sanitation, and health care) could be linked to adult human capital through independent and synergistic pathways including access to quality education and occupation. Significant associations with several of these components in our study lend partial support to this possibility. Other postulated mechanistic pathways include neurological, hormonal, functional isolation, stress, stigma, and infectious disease–related channels (reviewed in Perkins et al. 2017). However, it is unclear whether such factors act as mediators or as precursors to growth failure. In addition, these pathways may dynamically interact with each other. For example, impaired motor development may mediate the relationships between stunting and cognitive development (Larson and Yousafzai 2017). Stunted children with lower motor activity are more likely to be carried for by caregivers, further handicapping motor development and inhibiting cognitive and psychosocial development attained through independent exploration of environments (Perkins et al. 2017). Our study does not permit a scrutiny of these hypotheses. Future work on causal pathways will be important for policy makers trying to identify and support interventions designed to improve child development and human capital (Perkins et al. 2017).

In contrast to education and male occupation, after the age of five, weight, BMI, and relative weight gains but not height gains, predicted significantly greater adult material possession scores. We have no conclusive explanation for this intriguing observation. However, this could simply reflect the tracking and amplification of wealth measures since birth. Relative weight gain, but not height gain, from 5 to 11 years was associated with crude surrogates of wealth at birth, namely, household income (positively) and crowding (negatively). In any case, it would be undesirable to promote interventions resulting in greater BMI and relative weight gains after five years of age because of the attendant risk of cardiometabolic disease (Adair et al. 2013; Bhargava et al. 2004; Fall et al. 2008; Sachdev et al. 2005; Victora et al. 2008).

The economic and public health importance of the magnitude of these observed associations is somewhat debatable, and requires stringent scrutiny under various assumptions to inform policy. In the earlier pooled analysis, one SD increase in birthweight (~0.5 kilograms [kg]) was associated with 0.21 years more schooling; one SD increase in conditional weight gain between 0 and 2 years (~0.7 kg); and 2 and 4 years (~0.9 kg) was associated with 0.43 years and 0.07 years greater schooling, respectively (Martorell et al. 2010). However, their projections were based on the associations with stunting—"*Given the estimate of 0.9 years of schooling lost, we would expect stunting to decrease lifetime income by ~10 percent in the countries included in our analyses*." It is unclear if our observed associations with occupation and material possession score are already captured in these estimates or would be additive. These projections may be overestimates because observational designs generally inflate the effect size, and even if the associations are causal, the benefits may not scale up with nationwide implementation (Nandi et al. 2018). The Lancet Series on Nutrition modeled the population impact of 10 direct nutrition or "nutrient-specific" interventions for 2011 in 34 countries harboring 90 percent of the global burden of stunting (Bhutta et al. 2013). Scaling up of all 10 interventions to 90 percent coverage was associated with only a mean 20.3 percent (range 10.2 to 28.9 percent) reduction in stunting. Evidence also does not support the contention that direct nutrition-mediated effects on height gain persist after short-term interventions have ceased (Devakumar et al. 2016). Further, one SD height increment represents massive effect size, which may require long-term interventions; for example, in the New Delhi Birth Cohort—over one generation in an urban middle-class population whose general living conditions had improved without any programmatic "nutrition-specific interventions" including food supplementation—under-five children became taller by ~1 SD than their parents measured at the same ages (Sinha et al. 2017). Robust benefit-cost estimates incorporating both immediate and longer-term impacts and costs of early-life interventions to improve birth size and under-five growth would thus be crucial to inform public health investments. However, estimating benefit-cost ratios is challenging because of the paucity of information on longer-term benefits that can be causally associated with specific interventions and on relevant costs, all of which tend to vary by context (Nandi et al. 2017). The estimated benefit–cost ratios under several assumptions, for a plausible set of nutritional interventions to reduce stunting, were greater than one in all evaluated countries (Hoddinott et al. 2013b). The authors assumed an uplift in income of 11 percent due to the prevention of one-fifth of stunting and a 5 percent discount rate of future benefit streams. Similarly, in another study, generic estimates of benefit-cost ratios for some relevant interventions, obtained under a range of plausible parameters, also consistently exceeded one, suggesting that the present discounted value of gains exceeds costs. It was therefore contended that early-life health and nutrition should be placed high on the policy agenda (Nandi et al. 2017).

What are the policy implications of our findings against the backdrop of contemporary evidence, particularly about the optimum age intervals and types of growth patterns for enhanced human capital, and whether such growth promotion will necessarily lead to an increase in cardiometabolic disease (Adair et al. 2013)? In conformity with other sparse data from LMICs, larger birth size and faster growth—especially in height in under-two children—were associated with improved adult human capital. However, we also observed occupational benefit with faster height growth from 2 to 5 years. The evidence base, from a human capital perspective thus reinforces the focus on the first 1,000 days (conception to age 2) to promote larger birth size and growth, but there may be an additional opportunity between 2 to 5 years. Earlier pooled analyses show that there are few later adverse cardiometabolic trade-offs of faster growth, especially of height, in the first two years of life (Adair et al. 2013; Victora et al. 2008). Adverse associations with faster growth, especially relative weight gain, were largely observed from mid-childhood, leading to the suggestion of preventing excess weight gain in children older than two years (Adair et al. 2013). However, recent data from Latin America and India suggest that faster growth, even in the first two years of life, may be associated with a later adverse cardiometabolic profile (Ford et al. 2018; Kaur et al. 2015; Ramirez-Silva et al. 2018). Thus, some trade-offs may be inevitable, particularly when there is little clarity regarding factors (Martorell and Young 2012) or interventions that specifically promote faster linear growth without additional weight gain. Optimum growth patterns in early life are therefore likely to lead to the best balance of outcomes with less undernutrition, increased human capital, and reduced risks of obesity and noncommunicable diseases (Adair et al. 2013); the cardiometabolic disease risk escalates with later accelerated growth, particularly after five years of age (Bhargava et al.2004; Fall et al. 2008; Sachdev et al. 2005). "Nutrient-specific" interventions alone will at best have a marginal effect on promoting height growth in early life because quality food intake constitutes one of the many factors that include comprehensive and equitable improvement of living conditions, including health care, socioeconomic status, water supply and sanitation, employment, parental literacy, and educational systems (Sachdev 2018). Our study reaffirms the simultaneous need to invest in such "nutrition-sensitive" interventions to maximize the potential human capital benefits, since the socioeconomic and behavioral covariates were not only significantly associated with these outcomes but also attenuated the adjusted magnitude of effects. The LMICs should also consider monitoring of linear growth in addition to weight gain in under-five children.

Future research on the topic could focus on (i) validation in long-term prospective birth cohorts from South Asian regions including India, which still have a persistent burden of low birthweight and under-five growth failure; (ii) using latent growth analyses or other appropriate techniques to delineate the optimal height and weight growth patterns associated with human capital outcomes, especially in under-five children; (iii) comprehensive set of human capital indicators; (iv) detailed benefit-cost ratio analyses, using these estimates and other relevant evidence; and (v) mechanistic exploration including higher brain functioning and the mediating effect of cardiometabolic disease after the fifth decade of life.

In conclusion, birth size and measures of physical growth (height, weight, and BMI), especially gains in height in children under-five and under-two, had a modest positive association with attainment of one or more of the three adult human capital metrics studied, namely, education, male occupation, and material possession score. Faster weight and BMI gain during 5 to 11 years and 11 years to adulthood had a statistically significant association with material possession scores. Similarly, boys with faster height growth from 2 to 5 years were subsequently employed in occupations requiring higher skills.

This evidence base, from a human capital perspective, thus reinforces the focus on the first 1,000 days (from conception to 2 years) to promote larger birth size and linear growth, but there may be an additional window of opportunity between 2 to 5 years. Optimum growth patterns in early life are also likely to lead to the best balance of outcomes with less undernutrition, increased human capital, and reduced risks of obesity and NCDs. However, birth size and linear growth promotion alone will at best produce modest human capital gains. Several socioeconomic and behavioral characteristics at birth were significantly associated with human capital benefits. Adjusting for these characteristics attenuated the growth promotion effect. Thus, human capital benefits can be boosted considerably by simultaneous investments in parental (especially maternal) literacy, livelihoods, safe water supply and sanitation, access to health care, and enhancing income. These interventions through their “nutrition-sensitive” effect contribute to promoting early life growth.

KEY FINDINGS

Birth size and measures of physical growth—gain in height, weight, and BMI—from birth to adulthood at selected time periods during the life course had a positive association with attainment of one or more of the three adult human capital metrics studied, namely, education, male occupation, and material possession score.

A statistically significant association (P ≤0.05) with adult human capital metrics was documented for growth measures in children under-five years, in particular in children under-two. Faster weight and BMI gain during 5 to 11 years and 11 years to adulthood had a statistically significant association with material possession scores. Adjustment for socioeconomic and behavioral characteristics generally attenuated the magnitude and strength of these crude associations.

Length at birth and height gain from 6 to 24 months had a consistent positive association with all three human capital metrics analyzed. In addition, faster height gain from 0 to 6 month and 2 to 5 years were significant predictors of material possession score and male occupation, respectively. The magnitude of associations with growth measures was generally modest, with the magnitude being slightly higher for height gain in comparison to gains in weight and BMI.

The findings were robust for various sensitivity analyses.

All socioeconomic and behavioral characteristics analyzed (maternal and paternal education, paternal occupation, household income, crowding, housing condition, water and sanitation facilities, and utilization of health services) had a significant association with all adult human capital measures. Maternal and paternal education, and paternal occupation had a consistent positive association with adult education, male occupation, and material possession score.

These findings are significant from a human capital perspective. They reinforce the need to focus on interventions during the first 1,000 days (conception to 2 years) to promote larger birth size and linear growth. They further suggest an additional opportunity between 2 to 5 years to promote growth and contribute to attainment of human capital. The human capital benefits can be boosted considerably by simultaneous investments in parental (especially maternal) literacy, livelihoods and other means to enhance income, safe water supply and sanitation, and access to health care. These interventions through their "nutrition-sensitive" effect contribute to promoting early life growth.

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ANNEX 1
MAP OF NEW DELHI SHOWING LOCATION OF THE NEW DELHI BIRTH COHORT STUDY AREA

ANNEX 2

COMPARISON OF BIRTH ANTHROPOMETRY AND SOCIO-DEMOGRAPHIC CHARACTERISTICS BETWEEN ORIGINAL AND CONDITIONAL GROWTH MEASURES COHORTS

Variables	Original cohort		Conditional growth measures cohort		P Value
	N	n (%)/Mean (SD)	N	n (%)/Mean (SD)	
Birth length (cm)	6,645	48.3 (2.2)	1,184	48.4 (2.1)	**0.032**
Birthweight (kg)	6,809	2.8 (0.4)	1,184	2.8 (0.4)	0.246
Maternal education					
Illiterate	5,768	1968 (34.1)	1,064	300 (28.2)	**0.003**
Primary		946 (16.4)		204 (19.2)	
Middle		902 (15.6)		186 (17.5)	
Matric		1196 (20.7)		227 (21.3)	
College		756 (13.1)		147 (13.8)	
Paternal education					
Illiterate	1,460	124 (8.5)	1,107	90 (8.1)	0.97
Primary		136 (9.3)		102 (9.2)	
Middle		215 (14.7)		164 (14.8)	
High school certificate		415 (28.4)		313 (28.3)	
High school+		159 (10.9)		121 (10.9)	
graduate		285 (19.5)		231 (20.9)	
Professional degree		126 (8.6)		86 (7.8)	
Paternal occupation					
Unemployed, Unskilled manual labor, landless, Semiskilled manual. Rickshaw, army, carpenter, etc.	1,537	194 (12.6)	1,168	138 (11.8)	0.92
Skilled manual, small business/farmer		335 (21.8)		253 (21.7)	
Trained clerical, medium business, mid-level farmer, teacher		764 (49.7)		588 (50.3)	
Professional, big business, Class I, university teacher		244 (15.9)		189 (16.2)	
Utilization of health services					

Variables	Original cohort		Conditional growth measures cohort		P Value
	N	**n (%)/Mean (SD)**	**N**	**n (%)/Mean (SD)**	
No/low health services	5,421	1,577 (29.1)	818	247 (30.2)	
Intermediate		1,627 (30.0)		287 (35.1)	**0.001**
Highest use		2,217 (40.9)		284 (34.7)	
Nuclear family	5,460	4,239 (77.6)	818	574 (70.2)	**<0.001**
Type of housing					
Not-owned thatched hut, Owned thatched hut, Not-owned masonry building, Owned masonry building	5,455	3,716 (68.1)	816	524 (64.2)	**0.007**
Not-owned flat, Owned flat		1,499 (27.5)		265 (32.5)	
Not-owned bungalow, Owned bungalow		240 (4.4)		27 (3.3)	
Household per capita income (Rs.)*^^	5,462	835 (2.1)	817	716 (1.9)	**<0.001**
Crowding	5,452	3.6 (1.8)	816	3.7 (1.9)	0.083
Sanitation					
Open field	5,460	1,238 (22.7)	818	121 (14.8)	
Scavenger cleaned pit		2,172 (39.8)		408 (49.9)	**<0.001**
Flush		2,050 (37.5)		289 (35.3)	
Water supply					
Unprotected	5,461	968 (17.7)	818	89 (10.9)	
Both		498 (9.1)		52 (6.4)	**<0.001**
Protected		3,995 (73.2)		677 (82.8)	

Source: Authors

Notes:

* Geometric mean (SD) from log transformed values.

^^Rs. 835 (1971), constant 2019 Rs. prices = 31,788 (US$454); Rs. 716 (1971), constant 2019 Rs. prices = 27,257 (US$389).

ANNEX 3

ANTHROPOMETRIC COMPARISON AMONG ADULT SUBJECTS IN PHASE I INCLUDED AND EXCLUDED FOR CONDITIONAL GROWTH MEASURES

Age in years	Included in conditional		Not Included in conditional		P value
	N	Mean (SD)	N	Mean (SD)	
Height (cm)					
Birth	1,184	48.4 (2.1)	255	48.5 (2.1)	0.609
0.5	1,184	64.6 (2.5)	294	64.6 (2.6)	0.643
2	1,184	80.5 (3.6)	292	80.2 (4.0)	0.153
5	1,184	101.3 (4.5)	336	101.5 (4.9)	0.592
11	1,184	135.1 (6.5)	279	135.3 (7.1)	0.683
Adulthood	1,184	163.8 (9.5)	352	163.8 (9.7)	0.390
Weight (kg)					
Birth	1,184	2.8 (0.4)	271	2.9 (0.4)	**0.043**
0.5	1,184	6.7 (0.9)	294	6.8 (0.9)	0.667
2	1,184	10.1 (1.3)	287	10.1 (1.3)	0.690
5	1,184	15.2 (1.8)	340	15.3 (1.9)	0.283
11	1,184	28 (4.9)	283	28.4 (5.7)	0.196
Adulthood	1,184	66.2 (14.8)	356	67.4 (16.1)	0.189

Source: Authors
Note: SD = Standard deviation.

ANNEX 4
ASSOCIATION BETWEEN MATERIAL POSSESSION FIRST PRINCIPAL COMPONENT AND HEIGHT, WEIGHT, AND BMI GAIN

	Height gain		**Weight gain**		**BMI gain**	
	Crude model	**Multivariate analysis**	**Crude model**	**Multivariate analysis**	**Crude model**	**Multivariate analysis**
Variables			**Coefficient (95% CI); P value**			
Material possession score (n=1,184, crude model; n=993, multivariate)						
Sex (female vs male)	-0.13 (-0.24, -0.03); 0.014	-0.14 (-0.24, -0.04); 0.008	-0.13 (-0.24, -0.03); 0.012	-0.14 (-0.24, -0.03); 0.009	-0.13 (-0.24, -0.03); 0.014	-0.14 (-0.24, -0.04); 0.009
Birth length/weight/ BMI	0.10 (0.04. 0.15); <0.001	0.06 (0.01, 0.12); 0.016	0.10 (0.05, 0.15); <0.001	0.06 (0.01, 0.11); 0.029	0.06 (0.01, 0.12); <0.016	0.03 (-0.02, 0.08); 0.244
0–6 months	0.18 (0.12, 0.23); <0.001	0.02 (-0.04, 0.07); 0.548	0.20 (0.15, 0.25); <0.001	0.07 (0.02, 0.12); 0.009	0.13 (0.08, 0.19); <0.001	0.07 (0.02, 0.12); 0.008
6–24 months	0.22 (0.17, 0.27); <0.001	0.07 (0.02, 0.13); 0.008	0.22 (0.17, 0.28); <0.001	0.09 (0.03, 0.15); 0.001	0.10 (0.05, 0.16); <0.001	0.05 (-0.00, 0.10); 0.058
2–5 years	0.09 (0.04, 0.15); <0.001	0.03 (-0.02, 0.09); 0.209	0.06 (0.01, 0.11); 0.022	0.03 (-0.02, 0.08); 0.274	0.01 (-0.05, 0.06); 0.845	0.02 (-0.03, 0.07); 0.414
5–11 years	-0.01 (-0.06, 0.05); 0.834	0.01 (-0.06, 0.04); 0.781	0.10 (0.05, 0.15); <0.001	0.05 (-0.00, 0.10); 0.070	0.20 (0.14, 0.25); <0.001	0.09 (0.04, 0.14); 0.001
11 years–adulthood	-0.04 (-0.09, 0.01); 0.147	0.00 (-0.05, 0.06); 0.880	0.13 (0.08, 0.19); <0.001	0.12 (0.07, 0.17); <0.001	0.14 (0.09, 0.19); <0.001	0.11 (0.06, 0.16); <0.001
Utilization of health services #		0.16 (0.06, 0.27); 0.003		0.13 (0.02, 0.24); 0.016		0.14 (0.03, 0.25); 0.013
Maternal education		0.14 (0.09, 0.19); <0.001		0.13 (0.08, 0.18); <0.001		0.14 (0.09, 0.19); <0.001
Paternal education		0.16 (0.10, 0.22); <0.001		0.15 (0.09, 0.20); <0.001		0.15 (0.10, 0.21); <0.001
Paternal occupation		0.22 (0.14, 0.29); <0.001		0.21 (0.14, 0.29); <0.001		0.21 (0.14, 0.29); <0.001
Household annual income* (Rs.)		0.07 (-0.05, 0.19); 0.243		0.07 (-0.05, 0.19); 0.253		0.08 (-0.04, 0.20); 0.210
Crowding (members/room)*		-0.01 (-0.15, 0.12); 0.821		-0.02 (-0.15, 0.11); 0.793		-0.03 (-0.16, 0.10); 0.689

	Height gain		Weight gain		BMI gain	
	Crude model	**Multivariate analysis**	**Crude model**	**Multivariate analysis**	**Crude model**	**Multivariate analysis**
Variables			**Coefficient (95% CI); P value**			
Housing		0.02 (-0.04, 0.07); 0.503		0.02 (-0.03, 0.08); 0.442		-0.02 (-0.03, 0.08); 0.428
WASH score Ω		-0.04 (-0.10, 0.02); 0.202		-0.03 (-0.09, 0.02); 0.265		-0.03 (-0.09, 0.03); 0.295

Source: Authors

Notes: CI = Confidence interval; BMI = Body mass index.

* Log transformed

Utilization of health services computed as sum of smallpox vaccination and place of delivery.

Ω First principal component score generated from type of toilet, water supply, and toilet and water facilities.

Undernutrition begins early in life and has lifelong consequences. The cost of undernutrition both for the individual and the economy are substantial. Analyzing data from an Indian cohort, the New Delhi Birth Cohort, formed between 1969 and 1972, this paper provides evidence on the associations between attained human capital in the third and fourth decade of life and measures of growth from birth to adulthood.

For the purpose of this paper, attained human capital is defined through three metrics: educational status, male occupation, and material possession score. Growth measures (height, weight, body mass index) during five age intervals (0–6 months, 6–24 months, 2–5 years, 5–11 years, and 11 years–adulthood) were related to human capital metrics using multivariate regression models. Sensitivity analyses were also performed to assess the stability of associations.

All three human capital metrics had a significant positive association with birth size and measures of physical growth in children under-five years of age, in particular for children under two years. Length at birth and height gain from 6 to 24 months were consistently associated with all metrics. Faster weight and BMI gain from five years onward significantly predicted material possession scores. Among socioeconomic and behavioral characteristics at birth, maternal and paternal education, and paternal occupation also had a consistent positive association with all three human capital metrics.

The findings reinforce the focus on interventions during the first 1,000 days of life to promote larger birth size and linear growth and suggest an additional window of opportunity between 2 to 5 years to improve human capital. The benefits can be enhanced by simultaneous investments in parental (especially maternal) literacy, livelihoods, safe water supply and sanitation, access to health care, and enhancing incomes. These interventions also have a "nutrition-sensitive" effect to promote early life growth.

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