RESEARCH PAPER

Childhood Head Growth and Educational Attainment in an Indian Cohort

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Background: There is minimal information about the association of head growth at different stages of childhood with cognitive ability.

Objective: To determine the relationship of newborn head size and head growth during infancy, childhood and adolescence with attained education, a proxy for cognitive ability.

Study design: Prospective birth cohort study.

Setting: Married women living in South Delhi between 1969 and 1973.

Participants: The New Delhi Birth Cohort study followed up 8030 newborns born in 1969-1973 with head circumference, weight and height measurements at birth and 6-12 monthly until adulthood. Of these, 1526 men and women were followed up at the age of 26-32 years.

Outcomes: Association between years of schooling, as an indicator of cognitive ability, and newborn head circumference and conditional measures of head growth during infancy,

childhood and adolescence.

Results: In unadjusted analyses, newborn head size was positively associated with years of education [(β (95% Cl)=0.30 (0.14 to 0.47) years per SD head circumference], as was head growth from birth to 6 months [β (95% Cl)=0.44 (0.28 to 0.60) years per SD conditional head growth], 6 months to 2 years [β (95% Cl)=0.31 (0.15 to 0.47) years per SD conditional head growth] and 2 to 11 years [β (95% Cl)=0.20 (0.03 to 0.36) years per SD conditional head growth]. There were similar findings for height and body mass index (BMI). In the adjusted model containing all growth measures, gestational age, and socioeconomic status (SES) at birth as predictors, only SES was positively associated with educational attainment.

Conclusion: Educational attainment in this population is positively associated with socioeconomic status and its influence on inter-related early life (fetal, infant and childhood) factors like nutritional status and brain growth.

Keywords: New Delhi birth cohort, Head circumference, Educational attainment, Cognitive development.

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ead circumference during fetal life and childhood correlates with brain size and brain weight [1]. Moreover, it has been shown that head circumference correlates with total brain volume in pre-pubertal children [2-4]. Head circum-ference is approximately 65% of adult values at birth and 94% at 5 years [5], while the equivalent values for brain volume are 36% and >95%, respectively [6,7]. Popu-lation based studies and some cross-sectional studies have shown that both head circumference and brain volume in children and young adult correlate with cognitive ability [3,4,7-15].

Findings suggest that infant brain growth may be more critical for cognitive ability than fetal or later childhood brain growth [16]. It is not clear whether only head growth, or overall nutrition predicts cognitive function. Large European studies [10,15] have shown that the head circumference at birth and at 5-years of age were positively associated with later cognitive scores, independent of concurrent weight and height.

We used the conditional analysis method to investigate associations of head size at birth and head growth during specific periods in infancy and childhood with educational attainment, as a proxy for cognitive ability, in the New Delhi Birth Cohort [18].

Invited Commentary: Pages 11-12.

METHODS

During 1969-73, 20755 married women living in South Delhi were recruited, of whom 9169 became pregnant, resulting in 8030 singleton live newborns, forming the New Delhi Birth Cohort [18]. The enrolled women were followed up every two months. The exact gestational age, occipito-frontal head circumference, weight and length of the babies born to them were recorded within 72 hours of birth, and at ages 3, 6, 9 and 12 months, and 6-12 monthly thereafter until age 21 years. Head circumference was measured using steel measuring tapes to the nearest 0.1 cm. Height and weight

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were measured using standardized procedures. Follow-up was interrupted between 1980 and 1983 due to a lack of funding, and removal of unauthorized housing, which led to a large drop in cohort numbers [18]. Socioeconomic indicators (both parents' education, household size, type of housing, household income, toilet facilities, drinking water source and use of health facilities) were collected during pregnancy or within 3 months post-delivery.

Between 1999-2002, 2584 men and women, then aged 26-32 years, were retraced and 1526 participated in a study of cardio-metabolic risk markers in relation to early life growth [18].Participants' educational attainment was recorded in seven categories from no schooling to a professional qualification. Paternal occupation at the time of the cohort member's birth was recorded at this follow-up. Head circumference, height and weight were re-measured.

Statistical analysis: We converted head circumference measurements (Suppl. Table I) to SD scores using Royston method [19], based on a cubic spline fit to the head measurements and assuming the head measurements are symmetrical at the defined ages, and used linear interpolation to estimate head circumference SD scores at the exact ages of 6 months, 2 years and 11 years, provided that genuine measurements were made within 6 months, 1 year and 2 years, respectively. The 6-month measurements were made in 98% within 2 weeks of that age, 80% of 2-year measurements were made within one month, and 76% of 11year measurements were made within 6 months. We backtransformed the SD scores to provide estimates of head circumference at these ages in cm. We followed similar procedures for height and body mass index (BMI). The ages chosen define clinically important stages of human growth: newborn size as a summary of fetal growth; six months as the end of predominant breast-feeding; two years as the end of infancy, completion of weaning and growth hormone becoming the main endocrine regulator of growth; eleven years as the approximate end of prepubertal growth; and young adulthood reflecting the completion of adolescent growth.

We calculated sex-specific conditional growth variables for head circumference, height and BMI. These are the standardized residuals resulting from regression of the SD score for the body measurement at a particular age on the SD scores for the same measurement at preceding ages [9,20]. For example, conditional head growth from 6 months to 2 years is the standardized residual from the regression of head SD score at 2 years on the SD scores for head size at birth and 6 months. These growth measures, which were calculated for birth-6m (early infancy), 6 month to 2 year (late infancy), 2-11 year (childhood) and 11 year-adult (adolescence) are, by construction, uncorrelated, and

represent growth during specific age periods, independent of earlier growth. Further details about conditional growth variables are provided as Supplementary Methods.

Educational attainment was converted from the original seven categories into years of education, from none (0 years) to a professional qualification (17 years). Socioeconomic status (SES) is a potential confounder of the association between childhood growth and educational attainment. We created a combined measure of SES at birth by standardizing the individual variables and deriving the first principal component.

Using all recorded measurements, we used multiple imputation to generate values for missing entries of head circumference, height and BMI at birth, 6 months, 2 years, 11 years and adulthood; and SES components and gestational age at birth.

The association between growth and educational attainment was assessed initially by unadjusted univariate analysis, followed by multiple models of multivariate regression analysis, taking head circumference, height and BMI separately (Model 1), and then in combination (Model 2). We adjusted for gestational age and the combined SES variable (Model 3) and finally, replaced the combined SES variable with its individual components (Model 4). We report pooled analyses, adjusted for sex. We present the multiple imputation-based results for the full study sample (all who had educational attainment ascertained in young adulthood, N=1526), while the results from the complete case analysis (participants with complete growth, SES and gestational age data, N=558) are shown in supplementary material.

To check the representativeness of our sample, we used independent sample *t*-tests to compare newborn and infant measurements between those studied as adults and included in this analysis and the remainder of the original cohort, and (among those studied as adults) between those with complete growth, SES, and education data (complete case sample) and the remainder. Analyses were conducted using SPSS version 20 and STATA version 14.

RESULTS

Table I shows the cohort's childhood head circumference, height, weight and educational attainment and **Table II** shows their SES data. Eighty-four percent of the men and 92% of the women were educated to secondary school level or above while 52% of men and 64% of women were graduates. Compared with the remainder of the original cohort, participants studied as adults were longer at birth, and shorter and lighter at age 11 years, but these differences were small [birth length (95% CI) 0.15 (0.02 to 0.28) cm; 11-year height (95% CI) 0.77 (0.29 to 1.24) cm; 11-

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Parameters		Full samp	ole, n=15	26		Comp	lete case :	sample, n=558
		Male (n=886)		Female (n=640)		Male (n=322)		Female (n=236)
	n	mean (SD)	п	mean (SD)	n	mean (SD)	n	mean (SD)
At birth								
Gestational age (weeks)	791	38.7 (2.6)	588	39.1 (2.5)	322	38.7 (2.4)	236	39.2 (2.3)
Head circumference(cm)	851	33.7 (1.3)	612	33.2 (1.1)	322	33.7 (1.3)	236	33.2 (1.0)
Height (cm)	820	48.6 (2.1)	590	48.1 (1.9)	322	48.6 (2.1)	236	48.3 (1.9)
Weight (kg)	834	2.9 (0.4)	592	2.8 (0.4)	322	2.8 (0.4)	236	2.7 (0.4)
Body mass index (kg/m ²)	820	12.0 (1.2)	590	11.9 (1.2)	322	12.1 (1.3)	236	11.8 (1.2)
At 6 months								
Head circumference (cm)	869	42.1 (1.2)	629	40.9 (1.2)	322	42.1 (1.2)	236	41.0 (1.0)
Height (cm)	836	65.3 (2.4)	613	63.7 (2.4)	322	65.3 (2.4)	236	63.6 (2.1)
Weight (kg)	836	7.0 (0.9)	613	6.4 (0.9)	322	7.1 (0.8)	236	6.3 (0.8)
Body mass index (kg/m ²)	836	16.4 (1.6)	613	15.7 (1.6)	322	16.5 (1.6)	236	15.7 (1.5)
At 2 years								
Head circumference (cm)	838	46.9 (1.3)	606	45.7 (1.2)	322	46.8 (1.3)	236	45.7 (1.2)
Height (cm)	840	81.1 (3.6)	609	79.6 (3.6)	322	80.9 (3.4)	236	79.4 (3.4)
Weight (kg)	834	10.3 (1.3)	609	9.8 (1.2)	322	10.3 (1.2)	236	9.7 (1.2)
Body mass index (kg/m ²)	833	15.8 (1.2)	604	15.4 (1.2)	322	15.8 (1.2)	236	15.3 (1.2)
At 11 years								
Head circumference (cm)	832	52.1 (1.4)	603	52.2 (1.5)	322	52.1 (1.4)	236	52.1 (1.5)
Height (cm)	831	135.9 (5.7)	607	134.2 (7.4)	322	135.4 (5.6)	236	134.0 (6.9)
Weight (kg)	834	28.4 (4.7)	608	27.6 (5.4)	322	27.9 (4.1)	236	27.3 (5.2)
Body mass index (kg/m ²)	830	15.3 (1.7)	606	15.2 (1.8)	322	15.2 (1.5)	236	15.1 (1.7)
Adult								
Head circumference (cm)	884	56.6 (1.8)	640	53.8 (1.7)	322	56.6 (1.7)	236	53.8 (1.7)
Height (cm)	886	169.7 (6.4)	638	154.9 (5.7)	322	169.7 (6.2)	236	154.5 (4.9)
Weight (kg)	886	71.8 (14.0)	640	59.2 (13.4)	322	71.5 (14.0)	236	58.2 (12.9)
Body mass index (kg/m ²)	886	24.9 (4.3)	638	24.6 (5.1)	322	24.7 (4.2)	236	24.3 (5.1)
Years of education (n %)	886		638		322		236	
No education (0 y)		10 (1.1)		10(1.6)		1 (0.3)		1 (0.4)
Primary school (3 y)		29 (3.3)		14 (2.2)		14 (4.3)		5 (2.1)
Middle school (8 y)		99 (11.2)		25 (3.9)		32 (9.9)		8 (3.4)
Secondary school (12 y)		150 (16.9)		82 (12.8)		46 (14.3)		36 (15.3)
Secondary school $+(13.5 \text{ y})$		138 (15.5)		99 (15.5)		59 (18.3)		34 (14.4)
Graduate (15 y)		354 (40.0)		312 (48.8)		135 (41.9)		121 (51.3)
Professional (17 y)		106 (12.0)		98 (15.3)		35 (11.0)		31 (13.1)

 Table I Anthropometry and Educational Attainment of the Cohort Members, at Birth, Childhood and At Adult Follow-up (N= 2084)

The 'complete case analysis' (N=558) included participants with no missing data. They had all 15 body measurements recorded from birth to young adulthood, plus all 10 early life socio-economic status variables, plus gestational age at birth. The 'full sample' (N=1,526) refers to all participants whose educational attainment was recorded in young adulthood during phase 5 of the New Delhi Birth Cohort follow-up, but were missing one or more of the above 26 variables.

year BMI (95% CI) 0.21 (0.07 to 0.34) kg/m²] (**Supp. Table II**). Compared with the remainder of those studied as adults, the complete case sample had a lower BMI at age 11 years (0.22 kg/m², 95% CI 0.03 to 0.40) but there were no significant differences for the other measurements.

In the unadjusted model, head size at birth and head growth at 0-6 month, 6 month -2 year and 2-11 year were positively associated with years of attained education

(Model 1 in **Fig. 1** (*a*), **Table III** and **Supp. Table III**). The strongest association was with head growth from birth to 6 month; one SD increase in head growth between birth and 6 months was associated with a 0.44 year increase in education. There were similar findings for height and BMI. There was a significant interaction of birth head circumference with head growth from birth to 6 months in relation to educational attainment (P=0.02). The positive association of 0-6 months conditional head growth with

Variables	Full sample (n=1526)	Complete case sample $(n=558)$	<i>Correlation</i> ^a
Maternal education (y) , $n=1366$			0.78
Illiterate (0 y) Completed primary school (3 y) Completed middle school (7 y) Matriculation (10 y) College (12 y)	386 (28.3) 264 (19.3) 236 (17.3) 293 (21.4) 187 (13.7)	178 (31.9) 105 (18.8) 114 (20.4) 120 (21.5) 41 (7.3)	
Type of housing, $n=1055$			0.47
Thatched hut (rented) Thatched hut (owned) Masonry build (rented) Masonry build (owned) Flat (rented) Flat (owned) Bungalow (rented) Bungalow (owned)	5 (0.5) 4 (0.4) 135 (12.8) 539 (51.1) 175 (16.6) 165 (15.6) 8 (0.8) 24 (2.2) (00 (450, 1200)) (00 (450, 120	$\begin{array}{c} 0(0) \\ 1(0.2) \\ 58(10.4) \\ 283(50.7) \\ 105(18.8) \\ 94(16.8) \\ 5(0.9) \\ 12(2.2) \end{array}$	0.70
Household income $(INR)^a$, $n=1056$	690 (459, 1200)	696 (456,1200)	0.79
Unemployed Unskilled manual labor Semi-skilled manual labor Skilled manual labor Clerical Professional or running a large business	3 (0.2) 28 (1.9) 161 (10.7) 328 (21.8) 741 (49.3) 243 (16.2)	11 (2.0) 62 (11.1) 124 (22.2) 286 (51.3) 75 (13.4)	0.20
Health service usage ^b , n=1057	1057 (69.3)		0.59
No/low health services use Intermediate use Highest use	336 (31.8) 366 (34.6) 355 (33.6)	163 (29.2) 201 (36.0) 194 (34.8)	
Sanitation, n=1057 No household toilet Non-flush toilet Flush toilet	179 (16.9) 495 (46.9) 383 (36.2)	66 (11.8) 275 (49.3) 217 (38.9)	0.63
Water supply, n=1057			0.60
No piped water Shared piped water Sole use piped water Crowding index (people/room), ^{<i>a</i>} n=1055 Child dependency. ^{<i>a</i>} n=1057	124 (11.7) 540 (51.1) 393 (37.2) 4 (3,6) 1 0 (0 7, 2 0) $10 (0 7, 2 0)$	54 (9.7) 277 (49.6) 227 (40.7) 4 (3,5.5) 1.0 (0.6, 1.6)	-0.72 -0.56
Paternal years of schooling, $n=1430$			
Illiterate (0 y) Completed primary school (3 y) Completed middle school (8 y) High school certificate (12 y) High school+ (13.5 y) Graduate (15 y)	123 (8.6) 132 (9.2) 211 (14.8) 404 (28.3) 155 (10.8) 280 (19.6)	2 (0.4) 19 (3.4) 40 (7.2) 82 (14.7) 93 (16.7) 256 (45.9) $66 (41.7)$	0.31

Table II Socioeconomic Characteristics of Cohort Members at Birth (N= 2084)

Data presented no. (%) or ^amedian (IQR). ^bCombination score of any health-promotion or preventative health service utilization during the antenatal and postnatal period (e.g. antenatal care, child immunization). The 'complete case analysis' (N=558) included participants with no missing data. They had all 15 body measurements recorded from birth to young adulthood, plus all 10 early life socioeconomic status variables, plus gestational age at birth. The 'full sample' (N=1526) refers to all participants whose educational attainment was recorded in young adulthood during phase 5 of the New Delhi Birth Cohort follow-up, but were missing one or more of the above 26 variables. Crowding index (-0.72), child dependency (-0.56) and paternal years of schooling (0.31). Correlation of various variables with socioeconomic status score; maternal education (0.78), type of housing (0.47), household income (0.79), water supply (0.60).







Footnote: Model 1: Head circumference (a), height (b) or BMI (c) separately; Model 2: Head circumference, height and BMI included together in the model; Model 3: Additionally adjusted for gestational age and the combined SES variable; Model 4: Replacing the combined SES variable with its individual components. Associations are statistically significant where the confidence intervals exclude 0.

Fig. 1 Change in years of attained education per SD change in head circumference, height and body mass index at birth, and conditional growth in head circumference, height and BMI during infancy, childhood and adolescence.

attained education was significant in all four quartiles of birth head circumference, but stronger in the smallest quartile at birth (β =0.875 years of education per SD 0-6 month head growth, *P*<0.001) compared with the 2nd, 3rd and 4th quartiles (β =0.467, *P*=0.002; β =0.464, *P*=0.02; and β =0.328, *P*=0.04, respectively).

The positive associations of head size were not significant after adjusting for height and BMI (Model 2). In this joint model, height growth 0-6 month and 6 month - 2year, and BMI gain 6 month-2 year remained positively associated with attained education. Gestational age was unrelated to educational attainment, while higher SES (the first principle component and individual components) was strongly positively associated with both educational attainment and childhood growth (Model 3, Supp. Tables IV and V). After adjusting for gestational age and SES (models 3 and 4) there were no associations with childhood head, height or BMI growth. Model 4 had a better overall fit than Model 3. The body size/growth measurements explained approximately 8% of the variability in attained education and SES a further 16%. Similar results were obtained in the complete case sample (Supp. Table III) except for a positive association of BMI gain from 6 month to 2 year with educational attainment.

DISCUSSION

Newborn head size and head growth up to 11 years were positively associated with years of education, which we used as a proxy for cognitive ability. The strongest associations were with early head growth (birth to 2 years). Height growth up to 2 years, and BMI at birth and BMI gain from 6 month-2 year were also positively associated with educational attainment. The associations of head size and growth with attained education were not significant after adjusting for height and BMI during the same age intervals. None of the associations of body size with educational attainment were significant after further adjustment for SES at birth, which was strongly positively related to attained education.

The positive association between newborn head circumference and attained education is consistent with previous literature. While some studies have shown positive associations between head circumference at birth and later cognitive ability, assessed by psychometric testing or achieved education [9-15], others found no association [13-15]. Similar to our results, other studies showing positive effects have also reported modest effects of head circumference on cognitive scores [9,12]. We found that the association was not significant after adjusting for newborn length and BMI, suggesting that overall prenatal growth, rather than specifically brain growth, was related to later educational attainment. Though many previous

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Predictor	Model 1: Unad	ljusted	Model 4: Adjuste	ed ^a
(Standardized score)	β (95% CI)	P value	β (95% CI)	P value
Head circumference (cm)				
Birth	0.30 (0.14 to 0.46)	< 0.001	0.15 (-0.05 to 0.34)	0.1
Birth-6 mo	0.44 (0.28 to 0.60)	< 0.001	0.14 (-0.03 to 0.31)	0.1
6 mo-2 y	0.30 (0.14 to 0.46)	< 0.001	0.03 (-0.13 to 0.19)	0.6
2 y-11y	0.20 (0.04 to 0.38)	0.01	0.03 (-0.14 to 0.20)	0.7
11 y-adult	0.15 (-0.02 to 0.33)	0.07	0.08 (-0.10 to 0.26)	0.3
Height				
Birth	0.31 (0.14 to 0.48)	< 0.001	0.01 (-0.18 to 0.20)	0.9
Birth-6 mo	0.49 (0.33 to 0.66)	< 0.001	0.00 (-0.17 to 0.17)	0.9
6 mo-2 y	0.68 (0.52 to 0.85)	< 0.001	0.11 (-0.08 to 0.28)	0.2
2 y-11 y	0.24 (0.08 to 0.40)	0.003	0.09 (-0.07 to 0.24)	0.2
11 y-adult	-0.01 (-0.17 to 0.16)	0.9	0.10 (-0.06 to 0.25)	0.2
Body mass index				
Birth	0.27 (0.09 to 0.44)	0.004	0.14 (-0.04 to 0.33)	0.1
Birth-6m	0.44 (0.27 to 0.62)	< 0.001	0.13 (-0.04 to 0.30)	0.1
6m-2y	0.31 (0.14 to 0.48)	< 0.001	-0.02 (-0.20 to 0.15)	0.8
2y-11y	0.35 (0.19 to 0.51)	< 0.001	-0.03 (-0.18 to 0.13)	0.7
11y-adult	0.13 (-0.04 to 0.29)	0.1	-0.00 (-0.17 to 0.17)	0.9

Table III Association of Head Circumference, Height and Body Mass Index at Birth and Growth During Childhood With Years of Education

 R^2 for model 1 for head circumference, height, and socioeconomic status were 0.5, 0.09 and 0.05, respectively. R^2 for model ¹ for socioeconomic status was 0.24. ^aModel 4 Adjusted for SES components and gestation.

studies have reported that, newborn head circumference along with birthweight and length were positively related to later cognitive performance [10-12], only one, a large Swedish study [10] demonstrated that head circumference remained a significant predictor, even after adjusting for weight and length.

Our findings of the unadjusted analyses, showing strong association with head growth between birth and 6 months are consistent with previous studies [9,11,13,15,16]. The association of early infancy head growth with educational attainment was stronger among participants in the lowest quartile of birth head circumference, possibly reflecting severe intrauterine growth restriction followed by relatively favorable conditions in infancy. We did not find any studies with longitudinal follow-up measures of head growth through adolescence, highlighting the importance of the New Delhi cohort growth data. In our study, head growth after 11 years was not significantly related to attained education. MRI studies have shown that brain volume peaks before the onset of puberty, after which the correlation between head circumference and brain size becomes weaker [2,7].

In our study, infant and childhood head growth was not related to attained education after adjustment for concurrent height and BMI gain, which independently of head growth, predicted higher attained education, thus reestablishing the fact that good overall nutrition, freedom from illness, enabling exploration and play, are important contributors to neuro-development [22].The 1970 UK birth cohort study found that head growth, independent of weight and height, was associated with cognitive scores at 10 years [15]. Many studies have reported that infant weight and length gain are positively related to later cognitive scores [11,16,17]. A meta-analysis of data from five cohorts from low- and middle-income countries (LMICs) showed that height gain from birth to 2 years is positively associated with attained schooling, a stronger association than was found for later height gain, or for weight gain during either period [22].

SES at birth was an independent predictor of attained education in this study, probably explained by its effect on multiple parameters including nutrition, exposure to childhood illness, availability of playthings and learning materials, quality of parental stimulation, and quality of education [24,25]. SES is thus likely to be both a confounder of the association between head size/growth and education, and an 'upstream' factor determining head growth and brain development.

The main strengths of the study were the frequent longitudinal body measurements from birth to adulthood, and detailed early life SES indicators. A limitation was that educational attainment, though frequently used in

WHAT IS ALREADY KNOWN?

 Previous studies have shown positive associations of head circumference of newborns, infants and children with later cognition.

WHAT THIS STUDY ADDS?

 Newborn head circumference and head growth in infancy, when adjusted for various parameters, do not have any association with educational attainment. Socio-economic status is the only factor predicting educational attainment in this population.

epidemiological studies, is a fairly crude measure of cognitive ability. In high income countries, cognitive function and years of education are strongly correlated [21], but may be less so in India, where access to education is influenced by family wealth and other socio-cultural factors. Nevertheless, it constitutes a practical metric for improving human capital in LMICs. Another limitation was cohort attrition, resulting in a final sample which was 19% of the original birth cohort. However, early life head size was similar between the analysis sample and the original cohort.

In conclusion, higher socioeconomic status predicted greater educational attainment in this urban Indian population, possibly through its influence on overall nutrition, somatic growth and other related factors. The findings support measures to reduce socioeconomic inequalities, promote maternal health and support infant nutrition and nurturing, for optimal neurodevelopment.

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Contributors: SKB has led the New Delhi Birth Cohort Study since the cohort's inception in 1969. The current study was designed by SP, HPSS, SKB, CHDF and CO. Data analysis was carried out by SP, CO, ND, SS and HPSS. The manuscript was drafted by SP, CHDF and CO, and critically modified by ND, ZSP, SS, SKB and HPSS. All authors approved the final version of manuscript, and are accountable for all aspects related to the study.

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Note: Supplementary matter related to this article is available at *www.indianpediatrics.net*

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Age				Centiles (cm)			
(7)	3%	10%	25%	50%	75%	90%	97%
Males							
0	31.37	32.10	32.85	33.68	34.50	35.25	35.98
0.25	36.86	37.63	38.41	39.28	40.14	40.92	41.69
0.5	39.69	40.48	41.27	42.16	43.04	43.84	44.63
1	42.12	42.91	43.71	44.61	45.50	46.30	47.10
2	44.48	45.26	46.05	46.93	47.81	48.60	49.39
3	45.76	46.53	47.31	48.18	49.05	49.83	50.60
4	46.64	47.41	48.19	49.06	49.92	50.70	51.47
5	47.39	48.16	48.95	49.83	50.70	51.49	52.27
6	48.00	48.80	49.61	50.51	51.41	52.22	53.02
7	48.48	49.30	50.14	51.06	51.98	52.82	53.64
8	48.89	49.71	50.55	51.47	52.40	53.24	54.06
9	49.15	49.99	50.83	51.77	52.79	53.55	54.39
10	49.29	50.15	51.02	51.99	52.96	53.83	54.69
11	49.37	50.27	51.18	52.19	53.20	54.11	55.00
12	49.48	50.41	51.36	52.41	53.46	54.40	55.33
13	49.70	50.66	51.62	52.70	53.78	54.75	55.71
14	50.08	51.04	52.02	53.10	54.19	55.17	56.13
15	50.56	51.52	52.49	53.57	54.65	55.62	56.58
16	51.05	52.00	52.97	54.03	55.10	56.06	57.01
17	51.50	52.44	53.40	54.46	55.52	56.47	57.41
18	51.88	52.82	53.77	54.83	55.88	56.83	57.77
19	52.16	53.11	54.07	55.14	56.20	57.12	58.14
20	52.40	53.41	52.36	53.31	54.26	55.11	55.96
21	50.64	51.49	52.34	52.40	54.25	55.11	55.95
26-33	50.55	51.49	52.44	53.49	54.54	55.49	56.43
34-39	50.96	51.97	53.00	54.14	55.28	56.31	57.32

Supplementary Table I Head Circumference Centile Values in the New Delhi Birth Cohort

Contd..

Table continued from pre page

Females							
0	31.13	31.81	32.49	33.25	34.00	34.69	35.36
0.25	36.05	36.78	37.51	38.33	39.14	39.88	40.60
0.5	38.70	39.44	40.18	41.02	41.85	42.59	43.33
1	41.09	41.83	42.58	43.42	44.25	45.00	45.74
2	43.29	44.07	44.86	45.75	46.63	47.42	48.20
3	44.71	45.48	46.26	47.13	48.00	48.79	49.56
4	45.81	46.55	47.31	48.15	48.99	49.74	50.49
5	46.56	47.32	48.08	48.94	49.79	50.55	51.31
6	47.29	48.06	48.85	49.72	50.59	51.37	52.14
7	47.96	48.74	49.52	50.40	51.27	52.06	52.83
8	48.24	49.03	49.83	50.72	51.61	52.41	53.20
9	48.46	49.29	50.14	51.07	52.01	52.85	53.68
10	48.85	49.75	50.66	51.67	52.68	53.59	54.49
11	49.32	50.29	51.28	52.37	53.47	54.46	55.43
12	49.80	50.83	51.88	53.04	54.21	55.25	56.29
13	50.19	51.25	52.33	53.52	54.72	55.80	56.86
14	50.43	51.48	52.54	53.71	54.89	55.95	57.00
15	50.56	51.56	52.57	53.69	54.82	55.83	56.83
16	50.61	51.56	52.52	53.58	54.64	55.60	56.54
17	50.65	51.55	52.46	53.47	54.49	55.40	56.30
18	50.66	51.53	52.41	53.39	54.37	55.25	56.12
19	50.68	51.52	52.38	53.34	54.30	55.16	56.01
20	50.62	51.50	52.36	53.31	54.26	55.11	55.96
21	50.64	51.49	52.34	53.30	54.25	55.11	55.95
26-33	50.55	51.60	52.44	53.49	54.54	55.49	56.43
34-39	50.96	51.97	53.00	54.14	55.28	56.31	57.32

Supplementary Table II Representativeness of the study sample: a) Comparison of newborn and childhood growth data between those included in the current study and the remainder of the original cohort; and b) Comparison of newborn and infant data between (among those studied as adults) those who had the full set of size, SES and educational attainment measures and those who did not

p- value	0	0.9	0.8	0.7		0.4	0.5	0.2		0.6	0.2	0.3		0.9	0.1	0.02
Gender-adjusted Regression coefficient (95% CI) {Adult Phase-Complete case analysis) v Complete case (N=558)		0.01 (-0.12 to 0.13)	-0.02 (-0.24 to 0.20)	0.02 (-0.11 to 0.15)		-0.05 (-0.18 to 0.07)	0.08 (-0.17 to 0.33)	-0.11 (-0.27 to 0.05)		0.03 (-0.10 to 0.17)	0.23 (-0.15 to 0.61)	0.07 (-0.06 to 0.20)		0.01 (-0.15 to 0.16)	0.55 (-0.14 to 1.24)	0.22 (0.03 to 0.40)
p- value	0	0.06	0.02	0.2		0.2	0.1	0.05		0.2	0.2	0.6		0.08	0.002	0.002
Gender-adjusted Regression coefficient (95% CI) (Original Cohort-Adult Phase) v Adult Phase		-0.07 (-0.14 to 0.01)	-0.15 (-0.28 to -0.02)	-0.05 (-0.12 to 0.03)		-0.05 (-0.12 to 0.03)	-0.10 (-0.26 to 0.05)	-0.10 (-0.19 to -0.00)		0.05 (-0.03 to 0.13)	0.15 (-0.09 to 0.39)	-0.02 (-0.10 to 0.06)		0.09 (-0.01 to 0.19)	0.77 (0.29 to 1.24)	0.210.07 to 0.34)
Total members in Adult Phase		1463	1457	1457		1498	1464	1439		1444	1410	1324		1435	1431	1426
Total number of members in the original cohort		7034	6940	6934		7295	7125	7050		5300	5202	4890		3235	3233	3233
Body size at birth, growth variables and SES components	At birth	Head circumference (cm)	Height(cm)	Body mass index(kg/m ²)	At age 6 months	Head(cm)	Height(cm)	Body mass index(kg/m ²)	At age 2 years	Head (cm)	Height (cm)	Body mass index(kg/m ²)	At age 11 years	Head (cm)	Height (cm)	Body mass index(kg/m ²)

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h and Growth During	
ody Mass Index at Biri	
rence, Height and Bo	llysis)
ns of Head Circumfe	(Complete Case Ana
Table III Association	Years of Education
Supplementary	Childhood with

Predictor (Standardized score)	Model I: Unadjusted		Model 2: Mutually adjusted f body measurem	or other ents	Model 3: Further adjusted for gestation	SES and	Model 4: Further adjusted f components and ge	or SES station
	β (95% CI)	p-value	β (95% CI)	p-value	β (95% CI)	p-value	β (95% CI)	p-value
Head								
Birth	0.32 (0.06 to 0.57)	0.01	0.22 (-0.11 to 0.55)	0.1	0.22 (-0.09 to 0.53)	0.1	0.18 (-0.12 to 0.49)	0.2
Birth-6m	0.50 (0.24 to 0.77)	< 0.001	0.13 (-0.18 to 0.43)	0.4	0.16 (-0.12 to 0.44)	0.2	0.13 (-0.15 to 0.41)	0.3
6m-2y	0.17 (-0.09 to 0.43)	0.2	-0.20 (-0.49 to	0.1	-0.12 (-0.39 to	0.3	-0.12 (-0.38 to	0.3
2y-11y	0.09 (-0.16 to 0.35)	0.4	-0.08 (-0.35 to	0.5	-0.00 (-0.26 to	0.9	-0.03 (-0.28 to	0.8
11y-adult	0.11 (-0.14 to 0.36)	0.3	-0.02 (-0.29 to	0.8	-0.01 (-0.25 to	0.9	-0.00 (-0.24 to	0.9
R-square	0.05							
Height								
Birth	0.18 (-0.08 to 0.44)	0.1	-0.05 (-0.36 to	0.7	-0.09 (-0.38 to	0.5	-0.08 (-0.37 to	0.5
Birth-6m	0.46 (0.20 to 0.72)	0.001	0.37 (0.09 to 0.66)	0.01	-0.03 (-0.30 to	0.8	-0.07 (-0.34 to	0.6
6m-2y	0.54 (0.30 to 0.79)	<0.001	0.59 (0.30 to 0.88)	<0.001	0.06 (-0.22 to 0.35)	0.6	0.08 (-0.20 to 0.36)	0.5
2y-11y	0.32 (0.07 to 0.58)	0.01	0.25 (-0.03 to 0.53)	0.08	0.08 (-0.18 to 0.34)	0.5	0.07 (-0.19 to 0.33)	0.5
11y-adult	-0.15 (-0.40 to	0.2	-0.10 (-0.37 to	0.4	0.01 (-0.24 to 0.26)	6.0	0.02 (-0.23 to 0.26)	0.9
R-square	0.08							
Body Mass Index								
Birth	0.17 (-0.09 to 0.43)	0.2	0.09 (-0.20 to 0.39)	0.5	0.11 (-0.16 to 0.38)	0.4	0.07 (-0.20 to 0.34)	0.6
Birth-6m	0.51 (0.27 to 0.75)	< 0.001	0.32 (0.03 to 0.60)	0.03	0.20 (-0.06 to 0.46)	0.1	0.21 (-0.05 to 0.47)	0.1
6m-2y	0.49 (0.24 to 0.74)	< 0.001	0.55 (0.28 to 0.83)	<0.001	0.33 (0.07 to 0.59)	0.01	0.36 (0.10 to 0.61)	0.006
2y-11y	0.27 (0.01 to 0.53)	0.04	0.06 (-0.25 to 0.37)	0.7	-0.09 (-0.37 to	0.5	-0.05 (-0.33 to	0.7
11y-adult	0.11 (-0.14 to 0.36)	0.3	0.09 (-0.17 to 0.34)	0.5	0.07 (-0.17 to 0.31)	0.5	0.05 (-0.19 to 0.28)	0.6
Socio-economic		-	1	-	1.41 (1.13 to 1.68)	<0.001		
Gestational age		1	ı		0.09 (-0.16 to 0.33)	0.4	0.04 (-0.20 to 0.28)	0.7
R-square	0.07		0.13		0.25		0.29	
The complete case i	analysis is limited to pa	articipants	with complete measu	ements for	all variables (N=558). Missing (lata: Years of attained	education
was available for 1,:	526 men and women. O	of the 15 bo	dy size variables: head	circumfer	ence, length or height a	and BMI at	birth, 6 months, 2 year	s, 11 years
and in young adulth	ood, data were complet	te for 958 ((53%). A further 352 (2)	3%) were n	nissing up to three of th	ne 15 measi	arements. Socio-econo	mic status
data was complete f	or 962 of the 1,526 (63	%); a furth	er 88 (6%) were missi	ng only on	e socio-economic stati	us variable.	See supplementary Ta	able VI for
frequency of missin,	g data for each variable							

Supplementary Table IIIa Associations of Head Circumference, Height and Body Mass Index at Birth and Growth During Childhood with Years of Education (Data Used to Generate Fig. 1)

Predictor	Model 1:Unadji	usted	Model 2:Mutually ad other body measur	justed for ements	Model 3.Further adju SES, gestation	sted for	Model 4:Further adji SES components and _l	tsted for zestation
(Standardised score)	β (95% CI)	p-value	β (95% CI)	p-value	β (95% CI)	p- value	β (95% CI)	p-value
Head circumference								
Birth	0.30 (0.14 to 0.46)	< 0.001	0.10 (-0.12 to 0.32)	0.3	0.32 (0.06 to 0.58)	0.01	0.15 (-0.05 to 0.34)	0.1
Birth-6m	0.44 (0.28 to 0.60)	<0.001	0.14 (-0.05 to 0.33)	0.1	0.18 (-0.04 to 0.40)	0.1	0.14 (-0.03 to 0.31)	0.1
6m-2y	0.30 (0.14 to 0.46)	<0.001	-0.06 (-0.24 to	0.5	-0.05 (-0.26 to 0.17)	0.6	0.03 (-0.13 to 0.19)	0.6
2y-11y	0.20 (0.04 to 0.38)	0.01	0.07 (-0.12 to 0.25)	0.4	0.05 (-0.17 to 0.27)	0.6	0.03 (-0.14 to 0.20)	0.7
11y-adult	0.15 (-0.02 to 0.33)	0.07	0.05 (-0.14 to 0.23)	0.6	0.04 (-0.20 to 0.27)	0.7	0.08 (-0.10 to 0.26)	0.3
R-square	0.05							
Height								
Birth	0.31 (0.14 to 0.48)	<0.001	0.16 (-0.06 to 0.37)	0.1	-0.05 (-0.31 to 0.21)	0.7	0.01 (-0.18 to 0.20)	0.9
Birth-6m	0.49 (0.33 to 0.66)	<0.001	0.38 (0.20 to 0.56)	<0.001	-0.02 (-0.25 to 0.21)	0.8	0.00 (-0.17 to 0.17)	0.9
6m-2y	0.68 (0.52 to 0.85)	<0.001	0.69 (0.50 to 0.88)	<0.001	0.10 (-0.13 to 0.34)	0.3	0.11 (-0.08 to 0.28)	0.2
2y-11y	0.24 (0.08 to 0.40)	0.003	0.13 (-0.05 to 0.31)	0.1	0.04 (-0.18 to 0.25)	0.7	0.09 (-0.07 to 0.24)	0.2
11 y-adult	-0.01 (-0.17 to	0.9	0.05 (-0.13 to 0.22)	0.6	0.10 (-0.10 to 0.31)	0.3	0.10 (-0.06 to 0.25)	0.2
R-square	60.0							
Body Mass Index								
Birth	0.27 (0.09 to 0.44)	0.004	0.15 (-0.05 to 0.35)	0.1	0.13 (-0.10 to 0.37)	0.2	0.14 (-0.04 to 0.33)	0.1
Birth-6m	0.44 (0.27 to 0.62)	<0.001	0.17 (-0.03 to 0.36)	0.08	0.03 (-0.19 to 0.24)	0.8	0.13 (-0.04 to 0.30)	0.1
6m-2y	0.31 (0.14 to 0.48)	<0.001	0.37 (0.19 to 0.55)	<0.001	0.12 (-0.10 to 0.34)	0.2	-0.02 (-0.20 to 0.15)	0.8
2y-11y	0.35 (0.19 to 0.51)	<0.001	0.13 (-0.06 to 0.32)	0.1	-0.11 (-0.35 to 0.13)	0.3	-0.03 (-0.18 to 0.13)	0.7
11y-adult	0.13 (-0.04 to 0.29)	0.1	0.06 (-0.11 to 0.23)	0.5	0.02 (-0.19 to 0.23)	0.8	-0.00 (-0.17 to 0.17)	0.9
Gestational age				-	-0.09 (-0.30 to 0.13)	0.4	-	
Socio-economic status			,		1.55 (1.33 to 1.77)	<0.001		
R-square	0.05		0.08		0.10		0.24	

Supplementary Table IV Associations of (a) Head Circumference, (b) Height and (c) Body Mass Index at Birth and Growth During Childhood With

Individual SES Components	and the First Principl	e Component			
SES Variables (SD scores)	(a) HEAD (JIRCUMFERENCE (cms) ((GENDER ADJUSTED RE	GRESSION COEFFICIEN	T (95% CI))
	Birth	Conditional growth Birth-6m	Conditional growth 6m-2v	Conditional growth 2v-11v	Conditional growth 11v-adult
1 st principle component					>
Maternal education	-0.02 (-0.10 to 0.06)	0.13 (0.05 to 0.21)	0.10 (0.03 to 0.18)	0.04 (-0.04 to 0.12)	0.06 (-0.02 to 0.14)
Type of Housing	0.01 (-0.07 to 0.08)	0.05 (-0.02 to 0.12)	-0.04 (-0.11 to 0.04)	-0.05 (-0.12 to 0.02)	-0.02 (-0.09 to 0.05)
Income	-0.05 (-0.13 to 0.02)	0.11 (0.04 to 0.19)	$0.11 \ (0.03 \ to \ 0.18)$	0.07 (-0.01 to 0.14)	0.07 (-0.01 to 0.14)
Parental occupation	0.08 (-0.00 to 0.16)	0.18 (0.10 to 0.26)	0.08 (-0.01 to 0.16)	0.09 (0.01 to 0.17)	0.01 (-0.08 to 0.09)
Utilities	-0.02 (-0.10 to 0.06)	0.11 (0.03 to 0.20)	0.12 (0.04 to 0.20)	0.03 (-0.05 to 0.11)	0.03 (-0.05 to 0.11)
Sanitation	-0.05 (-0.02 to 0.12)	0.07 (-0.00 to 0.14)	0.02 (-0.05 to 0.10)	-0.02 (-0.10 to 0.05)	0.04 (-0.03 to 0.11)
Water	0.04 (-0.04 to 0.11)	0.03 (-0.05 to 0.11)	0.01 (-0.07 to 0.09)	0.04 (-0.04 to 0.12)	-0.06 (-0.13 to 0.02)
Crowding Index	0.00 (-0.08 to 0.09)	-0.07 (-0.16 to 0.01)	-0.14 (-0.22 to -0.05)	-0.12 (-0.20 to -0.04)	-0.03 (-0.11 to 0.06)
Child dependency ratio	0.06 (-0.03 to 0.15)	-0.12 (-0.21 to -0.03)	-0.09 (-0.18 to 0.01)	-0.05 (-0.14 to 0.04)	-0.08 (-0.17 to 0.01)
Paternal years of schooling	0.02 (-0.07 to 0.10)	0.12 (0.03 to 0.21)	0.10 (0.01 to 0.18)	0.06 (-0.03 to 0.14)	0.05 (-0.03 to 0.14)
SES Variables (SD scores)	(q)	HEIGHT (cms) (GENDEI	R ADJUSTED REGRESSIG	ON COEFFICIENT (95% C	((t)
	Birth	Conditional growth Birth-6m	Conditional growth 6m-2y	Conditional growth 2y-11y	Conditional growth 11y-adult
<i>Ist principle component</i>					
Maternal education	0.05 (-0.04 to 0.13)	0.23 (0.15 to 0.31)	0.29 (0.22 to 0.37)	0.12 (0.04 to 0.20)	-0.12 (-0.20 to -0.05)
Type of Housing	0.03 (-0.05 to 0.11)	0.02 (-0.05 to 0.10)	0.04 (-0.03 to 0.11)	0.01 (-0.07 to 0.08)	-0.02 (-0.09 to 0.06)
Income	0.00 (-0.08 to 0.08)	0.20 (0.12 to 0.27)	0.29 (0.22 to 0.36)	0.12 (0.04 to 0.20)	-0.10 (-0.17 to -0.02)
Parental occupation	0.07 (-0.02 to 0.16)	0.20 (0.12 to 0.29)	0.20 (0.12 to 0.28)	0.15 (0.06 to 0.23)	-0.09 (-0.17 to -0.01)
Utilities	-0.05 (-0.13 to 0.04)	0.14 (0.06 to 0.23)	0.17 (0.09 to 0.25)	0.10 (0.02 to 0.18)	-0.12 (-0.20 to -0.04)
Sanitation	0.03 (-0.05 to 0.10)	0.08 (0.01 to 0.16)	0.10 (0.03 to 0.18)	0.06 (-0.02 to 0.13)	-0.05 (-0.13 to 0.02)
Water	0.09 (0.02 to 0.17)	0.13 (0.05 to 0.21)	0.08 (0.01 to 0.16)	0.08 (-0.00 to 0.16)	-0.04 (-0.12 to 0.04)
Crowding Index	0.00 (-0.09 to 0.09)	-0.13 (-0.22 to -0.05)	-0.32 (-0.39 to -0.24)	-0.21 (-0.29 to -0.12)	0.06 (-0.03 to 0.14)
Child dependency ratio	0.08 (-0.02 to 0.17)	-0.16 (-0.25 to -0.07)	-0.28 (-0.36 to -0.19)	-0.07 (-0.16 to 0.02)	0.05 (-0.04 to 0.14)
Paternal years of schooling	-0.01 (-0.10 to 0.09)	0.29 (0.21 to 0.38)	0.24 (0.15 to 0.32)	0.09 (0.00 to 0.18)	-0.09 (-0.17 to 0.00)
SES Variables				IV 7030/ TRADiadaOO N	
(sources)		DINI (KZ/M) (UENDEN	ADJUSTED REURESUU	V CUEFFICIENT (97% CL	
	DITIN	Conditional growin Birth-6m	Conautonat growin 6m-2y	Conational growin 2y-11y	Conautonat growth 11y-adult
I^{st} principle component					
Maternal education	0.03 (-0.05 to 0.12)	0.14 (0.07 to 0.22)	0.10 (0.02 to 0.18)	0.23 (0.15 to 0.31)	0.07 (-0.01 to 0.15)
Type of Housing	0.05 (-0.03 to 0.12)	0.03 (-0.04 to 0.10)	0.09 (0.02 to 0.16)	0.02 (-0.06 to 0.09)	-0.03 (-0.10 to 0.04)
Income	-0.08 (-0.16 to 0.00)	0.08 (0.01 to 0.15)	0.04 (-0.03 to 0.12)	0.23 (0.15 to 0.30)	0.05 (-0.03 to 0.12)
Parental occupation	0.09 (0.00 to 0.17)	0.14 (0.06 to 0.22)	0.03 (-0.05 to 0.12)	0.12 (0.03 to 0.21)	0.04 (-0.04 to 0.13)
Utilities	-0.07 (-0.15 to 0.02)	0.09 (0.01 to 0.17)	0.11 (0.03 to 0.19)	0.17 (0.08 to 0.25)	0.05 (-0.03 to 0.13)
Sanitation	0.07 (-0.01 to 0.14)	0.09 (0.02 to 0.16)	0.05 (-0.03 to 0.12)	0.04 (-0.03 to 0.12)	0.02 (-0.06 to 0.09)
Water	0.11 (0.03 to 0.19)	0.07 (-0.01 to 0.14)	0.02 (-0.06 to 0.10)	0.07 (-0.01 to 0.15)	0.02 (-0.06 to 0.09)
Crowding Index	0.06 (-0.03 to 0.15)	-0.07 (-0.15 to 0.01)	-0.09 (-0.17 to 0.00)	-0.18 (-0.27 to -0.09)	-0.06 (-0.14 to 0.02)
Child dependency ratio	0.14 (0.05 to 0.24)	-0.22 (-0.30 to -0.13)	-0.09 (-0.18 to 0.00)	-0.11 (-0.20 to -0.01)	-0.04 (-0.13 to 0.05)
Paternal years of schooling	0.01 (-0.09 to 0.10)	0.12 (0.04 to 0.21)	0.09 (0.00 to 0.18)	0.15 (0.06 to 0.24)	0.12 (0.03 to 0.21)