

TITLE

Ethnic differences in height growth trajectories and early life factors: Findings from the UK Millennium Cohort Study

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ABSTRACT

Background Height growth is an important biomarker for early life exposures which influence later disease risk. Previous studies show that ethnic minority children in the UK tend to be born lighter but experience more rapid infancy growth than White peers. However, whether subsequent childhood-to-adolescence growth differs by ethnic group is insufficiently understood.

Methods We used the data from 15,239 singletons in the UK millennium cohort study and applied mixed-effects cubic growth models to examine ethnic differences in height trajectories between 3y and 14y. Models were adjusted for prenatal factors, birthweight, infant feeding, and socio-economic factors to assess whether these potential explanatory factors could account for any differences in height growth between ethnic groups.

Results Compared with White counterparts, South Asian children had lower birthweight and shorter parents on average, but were slightly taller at 3y by 0.5cm [95% CI: 0.2-0.9] and had comparable childhood and adolescent trajectories, except that girls had a slower growth in adolescence. Height of South Asians relative to White children increased after adjusting for birthweight (e.g. taller by 1.3cm at 3y). Black African-Caribbeans were taller than White children at all ages between 3y and 14y (at 3y boys: 2.2cm, 1.2-2.7; girls: 3.2cm, 2.6-3.8) with height differences widening in childhood and reducing in adolescence. Adjustment for potential explanatory factors did not alter these differences.

Conclusions Despite having lower birthweight, contemporary UK South Asian children had comparable child-to-adolescent growth as White children. Black African-Caribbeans were considerably taller than other ethnic groups. Future research is needed in understanding the role of genetic and other environmental (e.g. diet) factors in these distinct growth patterns across ethnic groups and their health implications.

Keywords: height; growth; ethnicity; early life factors; cohort studies; UK

BACKGROUND

Child growth is influenced by both genetic and environmental factors (Silventoinen, 2003). Despite a great contribution of genetic components to height variation (Silventoinen et al., 2003; Visscher et al., 2006), the extent of genetically determined height potential achieved is shaped by environmental factors such as maternal smoking behaviour in pregnancy, nutrition, childhood illness, psychosocial and family socio-economic circumstances (Cameron, 2012). Height is therefore often considered as a biomarker for early life exposures (Perkins, Subramanian, Davey Smith, & Ozaltin, 2016; Whitley, Gunnell, Smith, Holly, & Martin, 2008). Sub-optimal growth and shorter adult height have been associated with adverse health outcomes (e.g. cardiovascular diseases) (Paajanen, Oksala, Kuukasjarvi, & Karhunen, 2010; Wormser et al., 2012) as well as poor social performance (Meyer & Selmer, 1999; Schultz, 2002).

Limited data are available on growth patterns of ethnic minorities in the UK, which are largely based on cross-sectional studies (Hancock, Bettiol, & Smith, 2016; Lum, Bountziouka, Harding, et al., 2015; Nightingale, Rudnicka, Owen, Cook, & Whincup, 2011; West et al., 2015). There is considerable variation in the reported size and sometimes the direction of the ethnicity-height association. For example, South Asian girls and Indian boys aged 11-13 years were reported to be 2-3 cm shorter than their White counterparts in Harding *et al's* study (Harding, Maynard, Cruickshank, & Teyhan, 2008), while the Healthy Survey for England showed that South Asian children (apart from Bangladeshi girls) aged 2-15 years had a similar mean height as the general population (Sproston & Mindell, 2006). It is possible that these discrepancies were due to ethnic differences in height trajectories, i.e. the pattern of height differences changes with age. Indeed, Fairley *et al* found that UK Pakistani infants were shorter at birth but had more rapid growth in the first two years than White infants (Fairley et al., 2013). However, growth patterns from childhood to adolescence across ethnic groups remains unclear. Furthermore, it is important to understand whether any potential ethnic differences in height growth are attributable to factors in early life, which can be targeted for future public health intervention. To our knowledge, there are no previously published studies examining childhood-to-adolescence height trajectories of contemporary UK children from ethnic minority groups.

Using longitudinal data from the UK Millennium Cohort Study (MCS), we aimed to investigate (1) whether height trajectories between 3 and 14 years differ by ethnic group and (2) whether prenatal factors, birthweight, infant feeding, and family socio-economic circumstances could account for any ethnic differences in height growth observed.

METHODS

Study population

The MCS is a nationally representative study of infants born between September 2000 and January 2002 in the UK. A stratified, clustered sampling design was used to oversample areas with high deprivation and, in England, areas with high proportions of ethnic minorities. Further details are described elsewhere (Connelly & Platt, 2014). The first contact was at 9 months. Children were followed-up at ages 3, 5, 7, 11 and 14 years. Each contact involved interviews with main respondents (usually the mother) at their homes. Ethical approval was obtained from the National Health Service Research Ethics Committee for each survey. Informed consent at each sweep was sought from parents and the children themselves as they grew older. Our analysis used data from all six sweeps via the UK Data Service. Persistent identifiers for these datasets are provided in the acknowledgement.

Outcome

Height was measured to the nearest 0.1 cm at 3, 5, 7, 11 and 14 years (not measured at 9 months) by trained interviewers using the Leicester height Measure Stadiometer (Seca Ltd, Birmingham, UK). Birth length was not collected, therefore, we examined height growth from 3 to 14 years (average four measurements per person).

Exposure

Ethnicity was obtained from parental report and recorded using the 2001 UK Census ethnicity categories. We included six main groups – White, Indian, Pakistani, Bangladeshi, Black African, and Black Caribbean. We further classified Indian, Pakistani and Bangladeshi into ‘South Asian’, and Black African and Black Caribbean into ‘Black African-Caribbean’, due to small sample sizes of these sub-groups.

Potential explanatory factors

A number of potential explanatory factors were examined to establish whether they could account for any ethnic differences in height growth. They were selected *a priori* based on existing literature on their associations with height and with ethnicity, including maternal age (Gulliford, Chinn, & Rona, 1991; Hawkins, Lamb, Cole, & Law, 2008), maternal smoking during pregnancy (Hawkins et al., 2008; Matijasevich et al., 2011), birth order (Gulliford et al., 1991; Hawkins et al., 2008), birthweight (Kelly et al., 2009; Rona, Swan, & Altman, 1978), breastfeeding (Hawkins et al., 2008; Kramer & Kakuma, 2002), introduction to solid foods (Vail et al., 2015), maternal education and family income (Howe, Lawlor, & Propper, 2013; Y. Li & Heath, 2016; Shackleton, Hale, & Viner, 2016).

These factors were collected at baseline (9 months) parental interviews. Maternal age (y) at childbirth was derived using date of birth of the child and that of the mother. Maternal smoking in pregnancy was defined as those smoked >0 cigarette/day at the end of four months of gestation. Birth order was categorised as 'first' and 'second or later' born. Birthweight (g) was obtained from birth registration records through data linkage. In the cases where data linkage was not possible or not successful (32%), maternal report of birthweight was used. A validation study of the MCS has shown a high level of agreement between maternal reports and registration birthweight data (Tate, Dezateux, Cole, Davidson, & Millennium Cohort Study Child Health, 2005). Birthweight was used as a proxy for birth length and was adjusted to explore whether any ethnic differences in later height growth were due to differences in intrauterine growth. Duration of exclusive breastfeeding was classified as 'none', '0-4 months' and '4+ months', according to the recommendations on breastfeeding at the time. Early introduction of solid foods was defined as 'before the age of four months'. Maternal highest educational qualification was categorised as 'degree or higher education diploma', 'A-level', 'GCSE grades A*-C', 'GCSE grades D-G', 'others' (e.g. qualifications obtained overseas that are not in any of the categories) and 'no qualifications'. Family total income was weighted using Organisation for Economic Co-operation and Development scales to take into account family size, and divided into quintiles.

Statistical Analyses

After a rapid growth during infancy, the velocity of height growth decreases gradually in childhood before increasing markedly in adolescence (Cameron, 2012). We explored third-order fractional polynomial functions with random effects to capture the non-linear trends for height growth between 3 and 14 years. The Akaike Information Criterion and Bayesian Information Criterion statistics of the best-fitting fractional polynomial models were only marginally better than cubic models. Therefore, we adopted mixed effects cubic models for the present analysis. There are known sex differences in height growth during this age period (Cole, Freeman, & Preece, 1998). Hence, all models were fitted for boys and girls separately. We allowed random coefficients for age and age². Including random effects for the extra age term led to convergence issues. Deviance, Akaike Information Criterion and Bayesian Information Criterion statistics were used to compare models. Interactions between ethnicity and age terms were included as fixed effects to estimate ethnic differences in height growth trajectories (model 1). White children were the largest ethnic group and used as the reference group. The assessment of model residuals is provided in supplementary material table S1. The models were then adjusted for potential explanatory factors from each life stage, first for prenatal factors (model 2), then for birthweight (model 3), further for infant feeding (model 4) and family socio-economic circumstances (SEC) (model 5).

A total of 19 517 children participated in the MCS. Our analysis included children who were singletons with at least one height measurement and from White, South Asian or Black African-Caribbean backgrounds ($n=16\ 138$, total eligible sample). We excluded those who were not living with either of their natural parents ($n=41$) because they were unlikely to have information on their natural parents' characteristics. After exclusion of cohort members who had missing data on the covariates ($n=858$), a total of 15 239 children with 60 202 height measurements were included in the main analysis (94% of eligible sample).

We repeated the analyses using the maximum available sample for each model, the results were similar for those based on complete cases. Hence, the latter are presented here. As a sensitivity analysis to assess the effect of parental height (as a proxy for genetic influence) on ethnic differences in offspring height growth, we repeated model 5 with additional

adjustment for mid-parental height ($n = 15\ 214$). Maternal and paternal height (mm) were self-reported or reported by their partner, and converted to internal standard deviation scores (SDS). Mid-parental height SDS was calculated as the average height SDS of natural parents. Height SDS of one parent (usually the mother) was used as mid-parental height SDS when height of the other parent was not available (17%). We also performed a sensitivity analysis adjusting for measures of pubertal development (such as age at menarche, voice change, available for ~60% of children) (supplementary materials Appendix A).

All analyses were conducted in Stata V.15.1 (Stata Corp., College Station, TX, USA).

RESULTS

The characteristics of the study sample (88.0% White, 8.8% South Asian, and 3.2% Black African-Caribbean children) are summarised in Table 1. Compared with White children, ethnic minority children were less likely to be first-borns and born to a mother who smoked during pregnancy. They had a lower mean birthweight (e.g. 3.1 kg for South Asians and 3.4 kg for White children), were more likely to have been exclusively breastfed and have a mother with a lower educational qualification and live in a low income family. On average, South Asians had shorter parents (e.g. mothers by nearly 5cm) and younger mothers, while Black African-Caribbeans had shorter fathers but older and taller mothers (Table 1).

Differences in height trajectories between South Asian and White children

Figure 1 shows estimated mean height trajectories by ethnic group. Height differences between ethnic groups at 3, 5, 7, 9, 11 and 14 years were estimated and provided in supplementary materials Table S2 with 95% confidence interval (CI). Compared with White children, South Asians were slightly taller at age 3 years by 0.5 cm (95% CI 0.2, 0.8), had similar trajectories during childhood and adolescence with small (≤ 0.5 cm) or no height difference. However, South Asian girls appeared to have a slower growth in adolescence than their White counterparts, with a height deficit of 0.6 cm (0.1, 1.2) at 11 years increasing to 3.2 cm (2.6, 3.7) at 14 years. These height differences were largely unchanged when adjusting for prenatal factors. The height of South Asian relative to White children increased when further adjusting for birthweight and remained similar when adding infant feeding and

family SEC in the models. Figure 2 shows the pattern of changes in estimated ethnic height differences at ages 3, 7, 11 and 14 years, after adjusting for covariates in stages.

Differences in height trajectories between Black African-Caribbean and White children

The pattern of differences in height trajectories between Black African-Caribbean and White children was different from that between South Asian and White children. Black African-Caribbean children had distinctly higher height trajectories than other ethnic groups (Figure 1). Compared with White children, they were taller at 3 years, grew more rapidly in childhood but slower in adolescence: the mean estimated height difference in boys was 2.1 cm (1.6, 2.6) at 3 years, increased to 3.6 cm (2.7, 4.5) at 11 years, and reduced to 2.8 cm (1.7, 3.9) at 14 years. Similar but more evident pattern was found in girls: height difference increased from 3.2 cm (2.6, 3.7) at 3 years to 5.4 cm (4.5, 6.2) at 11 years, and reduced to 2.3 cm (1.4, 3.2) at 14 years. Height differences were largely unaltered with adjustment for prenatal factors, increased slightly when further adjusting for birthweight, and remained similar with additional adjustment for infant feeding and family SEC (Figures 2C and 2D).

Sensitivity analysis

We further adjusted for mid-parental height SDS as a sensitivity analysis to examine the role of potential genetic influence in ethnic differences in height growth. South Asians' relative height to White children increased, while the estimated height differences between Black and White children remained similar to those from model 5 (supplementary material Table S2). Results from sensitivity analysis with adjustment for measures of puberty were largely unaltered (supplementary materials Appendix A - Table S3).

DISCUSSION

In a nationally representative cohort study, we found South Asian children had comparable childhood and adolescence growth with White children, except that South Asian girls had a slower growth and were shorter in adolescence. Height of South Asians relative to White children increased when adjusting for birthweight and further for mid-parental height. Black African-Caribbean children were the tallest ethnic group. The difference (relative to White

children) increased in childhood and slightly reduced in adolescence. Adjustment for early life factors did not alter these differences.

To our knowledge, this is the first study to investigate ethnic differences in height trajectories from pre-school years to adolescence in contemporary UK children and whether differences could be accounted for by prenatal and early life factors. We applied mixed effects cubic models to capture the non-linear age trends for height during this growth period. The models take into account within-individual correlations and allow individuals with different numbers and timing of height measures (Singer & Willett, 2003). However, limitations exist. Despite the over-sampling of ethnic minorities, the numbers of children in ethnic subgroups are still small. Hence we used broader ethnic categories. Additional analyses show some variations in height between specific sub-groups, although the patterns of ethnic differences remained unchanged compared with those using broader ethnic groups (data not shown). The MCS is an ongoing cohort study and cohort members are still in their adolescence. Data on birth length and their final achieved height are not available to examine the complete height trajectory from birth to adulthood. Additionally, only crude measures of pubertal development were collected in the MCS which did not capture the stage of maturity when height was measured, e.g. parental rating of children's growth spurt and secondary sexual characteristics development as 'has definitely started' 'has barely started' or 'has definitely not started' at 11 years and children's self-rating at 14 years. There are high proportions of missing data in puberty measures in our analysis sample (nearly 40%). Therefore, we were not able to further investigate the role of timing of pubertal maturation in explaining ethnic differences in adolescent height growth – i.e. why a height deficit for South Asian girls started to emerge and height differences between Black and White children reduced noticeably in adolescence.

Comparison with existing research is hindered by the lack of longitudinal studies that investigated height growth trajectories by ethnic groups, possibly owing to that few cohorts have sufficient sample sizes for ethnic minorities and follow-ups (L. Li & Pearce, 2016). A previous study by Fairley *et al* (Fairley *et al.*, 2013) found that Pakistani children, despite being born shorter and lighter, experienced a rapid growth in height and weight during infancy and were taller than their White counterparts at 2 years by 0.6 cm (0.02, 1.21) in

boys and 1.1 cm (0.48, 1.64) in girls. Similarly in our study, South Asians were on average about 320 g lighter at birth, had greater weight gain between birth and 3 years (data not shown) and were slightly taller at 3 years by 0.5 cm. Adjusting for birthweight increased South Asians' height relative to White children, which suggests that South Asians may have also experienced greater height growth in infancy, as seen in Fairley *et al's* study. However, our study further shows that they maintained a comparable childhood and adolescence growth trajectories to White children, except that South Asian girls were shorter than White girls. South Asian children had noticeably shorter parents. Additional adjustment for parental height in the sensitivity analysis further increased their height relative to White children, indicating that contemporary South Asian children in the UK may have experienced a great intergenerational height gain. Although parental height is commonly used as an indicator of height potential of offspring, it reflects both genetic influence and parents' own growth environment (Karlberg & Luo, 2000). Therefore, the greater intergenerational height gain in South Asians could be explained by improvement in growth environment, i.e. South Asian parents may have sub-optimal growth experience. Parental height may therefore underestimate growth potential for children of ethnic minority parents who experienced sub-optimal growth environments.

A social gradient in height was repeatedly reported by previous studies with people from more advantageous socio-economic backgrounds being taller (Kuh, Power, & Rodgers, 1991; Shackleton *et al.*, 2016). Although the socio-economic gradient in achieved adult height has narrowed across generations (L. Li, Manor, & Power, 2004), socio-economic inequalities still exist among today's children (Ballon *et al.*, 2018; Howe *et al.*, 2012). However, ethnic differences in height observed in our study of contemporary UK children were not explained by family SEC, such as family income and maternal education.

Consistent with results from cross-sectional studies (Hancock *et al.*, 2016; Lum, Bountziouka, Sonnappa, *et al.*, 2015), we found that Black African and Caribbean children were taller than White and South Asian from childhood into adolescence, with height differences widening in childhood and reducing in adolescence. We repeated the analyses using z-scores (data not presented) and conclusions are largely unchanged, except that the finding of increasing height difference with age in childhood is less evident. We considered a number of early life

factors, which did not appear to explain these ethnic differences. Additionally, the parents of Black children had similar height to White parents. Further research in understanding genetic and other environmental (e.g. diet) factors in ethnic differences in height growth is needed. Rapid height growth is often accompanied by with rapid weight gain (Bécares, Kelly, Montgomery, & Sacker, 2016). Given the association between accelerated early growth and later health (Scientific Advisory Committee on Nutrition, 2011), and the greater risk of type 2 diabetes and coronary heart diseases among UK South Asians (McKeigue, Shah, & Marmot, 1991; Smith, Chaturvedi, Harding, Nazroo, & Williams, 2000), it would be informative for future research to understand whether ethnic differences in cardio-metabolic health outcomes are attributable to differences in early growth patterns.

CONCLUSION

There are differences in childhood-to-adolescence height growth trajectories between ethnic groups in the UK. Despite having much shorter parents and a lower mean birthweight, South Asian children had comparable childhood and adolescent height growth to White British children, suggesting contemporary UK South Asian children may have experienced a greater intergenerational height gain. Black children were the tallest ethnic group, which was not explained by the prenatal and infancy factors explored in this study. Future research of following this cohort into adulthood and understanding health implications of different growth patterns experienced across ethnic groups is warranted.

Abbreviations

CI: confidence interval; MCS: Millennium Cohort Study; SA: South Asian; SD: standard deviation; SDS: standard deviation score; SEC: socioeconomic circumstances; UK: United Kingdom; US: United States.

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COMPETING INTERESTS

None declared.

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Table 1: Description of participant characteristics by ethnic group (total $n=15\ 239$ singletons)*

Characteristics	White ($n=13\ 405$)	South Asian† ($n=1\ 375$)	Black African/ Caribbean† ($n=504$)
Maternal age at childbirth (y), mean(SD)	28.5(5.9)	26.9(5.2)	30.1(6.2)
First born, n(%)	5 799(43.2%)	475(35.4%)	158(32.1%)
Maternal smoking (>0 cigarette/day), n(%)	3 491(26.0%)	45(3.4%)	49(10.0%)
Birthweight (kg), mean(SD)	3.41(0.56)	3.09(0.56)	3.30(0.60)
Duration of exclusive breastfeeding, n(%)			
None	4 852(36.2%)	271(20.2%)	40(8.1%)
Less than 4 months	8 146(60.8%)	997(74.3%)	433(88.0%)
4 months or more	407(3.0%)	74(5.5%)	19(3.9%)
Early introduction to solid foods (<4 months), n(%)	5 147(38.4%)	188(14.0%)	76(15.4%)
Maternal education, n(%)			
Higher education	3 512(26.2%)	198(14.8%)	140(28.5%)
A-level	1 337(10.0%)	111(8.3%)	36(7.3%)
GCSE grades A*-C	4 866(36.3%)	280(20.9%)	104(21.1%)
GCSE grades D-G	1 486(11.1%)	117(8.7%)	36(7.3%)
Others	179(1.3%)	145(10.8%)	34(6.9%)
No qualification	2 025(15.0%)	491(36.6%)	142(28.9%)
Household income quintiles, n(%)			
Lowest	2 778(20.7%)	525(39.1%)	220(44.7%)
Second lowest	2 744(20.5%)	478(35.6%)	117(23.8%)
Middle	2 754(20.6%)	158(11.8%)	61(12.4%)
Second highest	2 677(20.0%)	97(7.2%)	49(10.0%)
Highest	2 452(18.3%)	84(6.3%)	45(9.2%)
Mid-parental height SDS‡, mean(SD)	0.07(0.77)	-0.57(0.81)	0.10(0.94)
Paternal height‡ (cm)	178.3(7.1)	173.5(7.8)	176.1 (8.1)
Maternal height‡ (cm)	164.0(6.9)	159.4(6.7)	165.1(7.7)

* Cell values are mean(SD) or frequency(%). SD: standard deviation. SDS: standard deviation score.

† All characteristics differed between each ethnic group and Whites: $p \leq 0.001$ for t-tests for continuous variables and Chi-squared tests for categorical variables, except the difference in mid-parental height SDS between Black African/Caribbean and White groups ($p=0.354$).

‡ Examined in a sensitivity analysis.

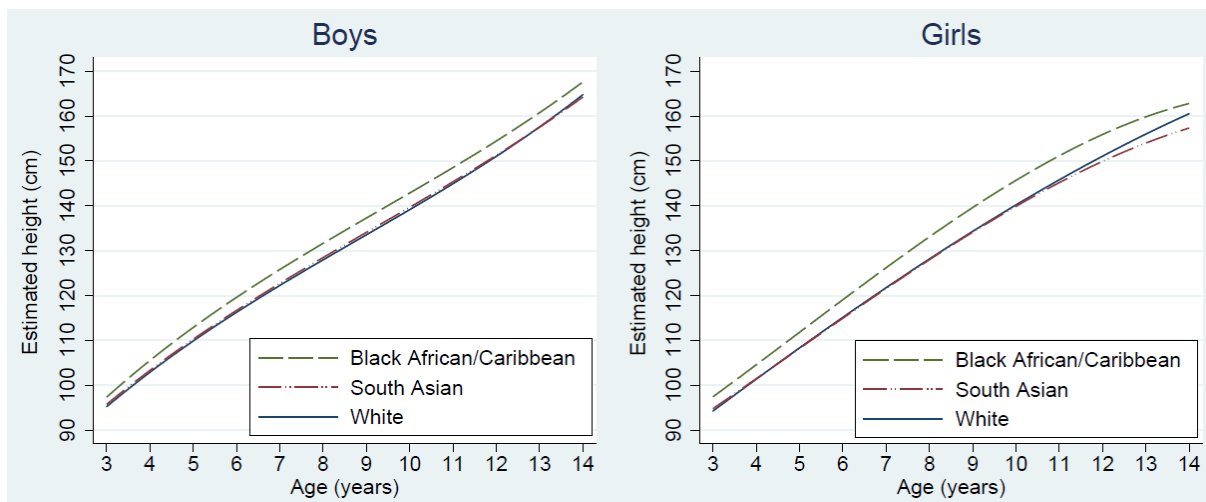


Figure 1: Estimated mean height trajectories (3-14y) for boys and girls by ethnic group, from unadjusted mixed effects cubic models.

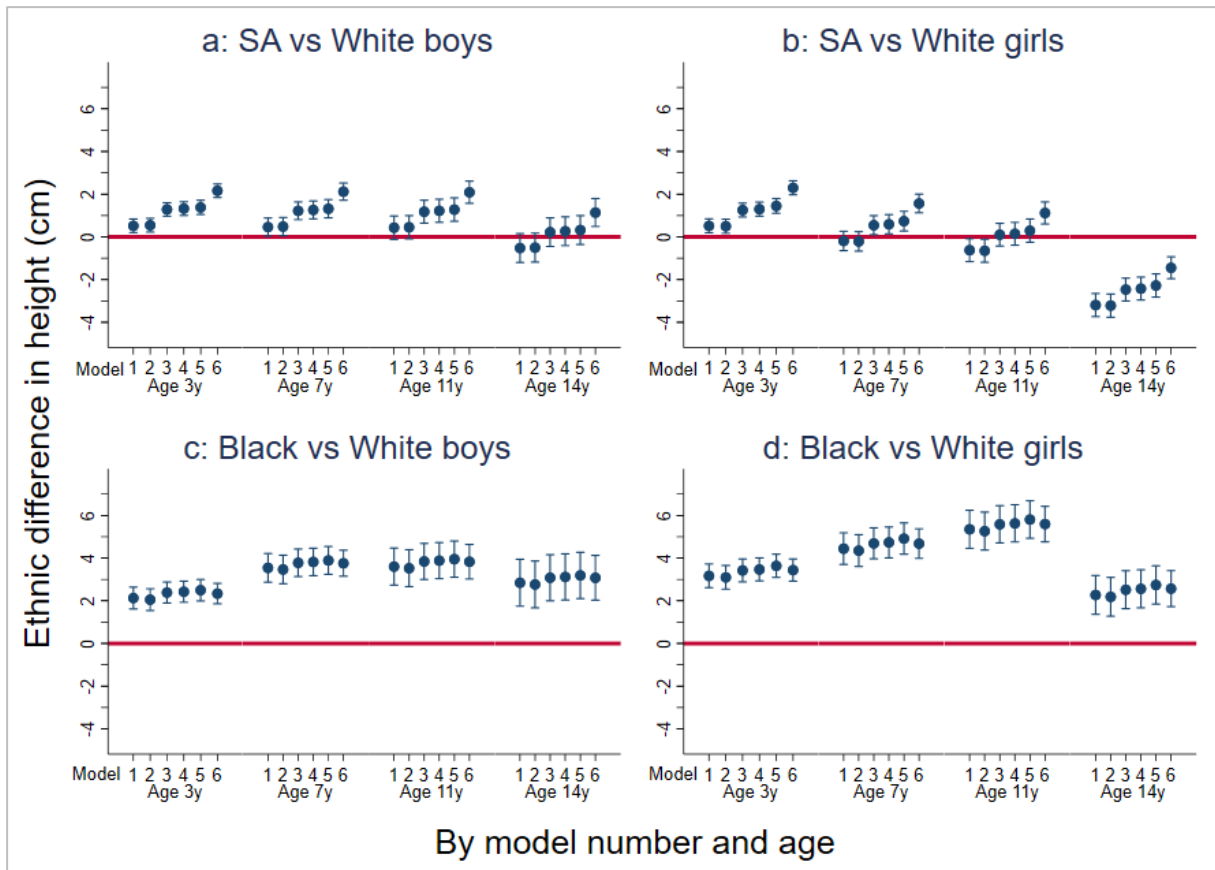


Figure 2: Differences in mean height between each ethnic minority group and White for models 1-5, at ages 3, 7, 11 and 14 years.

● are estimated differences with 95% confidence interval from mixed effects cubic models. — reference line, indicate no height difference between ethnic groups. SA: South Asian. Black: Black African/Caribbean.

Model 1: unadjusted model

Model 2: model 1 + prenatal factors (maternal age, smoking during pregnancy, birth order)

Model 3: model 2 + birthweight

Model 4: model 3 + infant feeding (breastfeeding, early introduction to solid foods)

Model 5: model 4 + family SEC (maternal education, family income)