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Adolescent growth and BMI and their associations with early childhood growth in an urban South African cohort

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Abstract

Objectives: The timing and magnitude of adolescent growth may be influenced by ethnicity and early life factors. We aimed to (a) characterize ethnic differences in the magnitude, timing, and intensity of adolescent growth in height, weight, and BMI; (b) assess the effect of early childhood growth on adolescent growth in black children.

Methods: Data were from the Birth to Twenty Plus cohort (Bt20+) in Johannesburg, South Africa (n = 3273). Height, weight, and BMI were modeled with ethnic comparisons using the SuperImposition by Translation and Rotation for 2089 participants who had data from 7 to 23 years. Relative weight gain and relative linear growth between 0 and 24 months and 24 and 60 months were generated. Multiple regression analyses were used to assess associations between childhood and adolescent growth.

Results: White children were 5 cm (SE: 0.7) taller than black children through adolescence. Black boys had a later timing of adolescent height (0.65 years ±0.12) than white boys, which in black girls was 0.24 years (0.11) earlier than in white girls. Black girls had faster BMI velocity than white girls. Among black children, birth weight and both relative weight gain 0 to 24 and relative linear growth between 3 and 24 months and 24 and 60 months were positively associated with the magnitude of adolescent growth and negatively associated with timing.

Conclusion: Sex dimorphism in ethnic differences in timing of adolescent height growth may reflect some yet unexplained drivers for rapid weight gain and obesity in black females but not black males. Rapid weight gain in early life may contribute to faster adiposity accrual in adolescence.

1 | INTRODUCTION

Puberty is a period of rapid growth with significant changes in height, weight, and body composition. Globally, there is a secular trend toward earlier puberty driven by improving socioeconomic conditions (Ali, Lestrel, & Ohtsuki, 2000; Jones, Griffiths, Norris, Pettifor, & Cameron, 2009a; Jones, Griffiths, Norris, Pettifor, & Cameron, 2009b), both of which are more apparent in transitioning than developed societies (Malina, 2004). In South Africa, a secular change toward earlier puberty as assessed by age at menarche has been observed in black females (Jones et al., 2009a) and by skeletal age particularly in black children (Hawley, Rousham, Norris, Pettifor, & Cameron, 2009). However, black males experience a 6-month delay in skeletal maturity compared to white males, which is not seen in females (Cole et al., 2015). The adolescent growth spurt is a prominent feature of pubertal development and also provides an objective measure of pubertal timing. However, there is a paucity of data describing the adolescent growth spurt of South African children.

Transitioning societies like South Africa are experiencing a double burden of malnutrition (underweight and obesity), and the adolescent growth spurt may contribute to the rise in the prevalence of obesity. Data from the Birth to Twenty Plus (Bt20+) cohort have shown that the incidence of overweight and obesity was the highest between the ages of 11 and 18 years in females (Lundeen, Norris, Adair, Richter, & Stein, 2015), leading to a higher prevalence in black female than male adolescents (Nyati, Pettifor, & Norris, 2019). While changes in adolescent body composition may reflect metabolic changes during puberty (Siervogel et al., 2003), both the timing of puberty (Kindblom et al., 2006; Prentice & Viner, 2012) and body mass index (BMI) gain (Munthali, Kagura, Lombard, & Norris, 2017) are associated with early life growth. Rapid weight gain in early childhood is associated with advanced skeletal maturity (Demerath et al., 2009), earlier age at menarche and advanced Tanner stages (Wang, Dinse, & Rogan, 2012), while faster linear growth in infancy is associated with an earlier age at peak height velocity (APHV) during puberty (Luo, Cheung, He, Albertsson-Wikland, & Karlberg, 2003).

The adolescent growth spurt has been studied largely in relation to height and weight and there are far fewer studies reporting on BMI (adiposity marker) during puberty (Blackwell et al., 2017; Martin & Valeggia, 2018). Thus, the aims of this study were 2-fold (a) to characterize differences between black and white children in the magnitude (size), timing (tempo), and intensity (velocity) of adolescent growth (height, weight, and BMI); and (b) to assess the effect of early life growth on the magnitude, timing, and intensity of adolescent growth in black participants. We hypothesized that there would be ethnic differences in size (large or small relative to the sample mean curve), tempo (early or delayed growth relative to the sample's mean curve), and velocity (steeper or flatter relative to the sample's mean curve) of adolescent growth in height, weight, and BMI. Furthermore, faster growth in early childhood would be associated with an earlier tempo of adolescent growth in height, weight, and BMI.

2 | MATERIALS AND METHODS

2.1 | Participants and settings

Data for this study were obtained from the Bt20+ birth cohort, a longitudinal study of 3273 singleton children born in the Greater Johannesburg region in South Africa between 23 April 1990 and 8 June 1990 (Richter, Norris, & De Wet, 2004; Richter, Yach, Cameron, Griesel, & de Wet, 1995; Yach et al., 1991). Due to the demographics of the population in Johannesburg at the time of enrollment, only a small number of white children were enrolled in the original cohort. This and the greater loss to follow-up of these children in early childhood made it impossible to calculate conditional variables for white children. Thus, we did not include white children in determining the association between early growth events and adolescent growth and development. However, an additional number of white children born during the same period in 1990 were recruited at age 9 years (n = 157), which made it possible to model adolescent growth. For the current study, growth was modeled for 2089 (895 black males; 115 white males; 970 black females; and 109 white females) participants who had data between 7 and 23 years. There was an average of 7.0 (±SD 3.3) observations during this period per child, and the total number of observations per group was 6440 for black males, 674 for white males, 6387 for black females, and 670 for white females. All participants and their guardians provided written informed assent and consent, respectively. Ethics approval was obtained from the University of the Witwatersrand Committee for Research on Human Subjects (M010556).

2.2 | Anthropometric measurements

Anthropometric measurements were collected annually using standard methods (Cameron, 1984). Weight at birth was collected from birth records while from 3 months to 23 years it was measured by field workers. Weight was measured to the nearest 0.1 kg using an electronic scale (Dismed, Miami, Florida). Birth lengths were not routinely measured at delivery and these data were not available. Recumbent length was measured from 3 months to 2 years of age by trained field workers. From 2 to 23 years, standing height was measured without shoes to the nearest 0.1 cm using a Harpenden stadiometer (Holtain, Crymych, UK). BMI was computed from length/height and weight using a standard formula.

2.3 | Sociodemographic variables

In early childhood, mothers or caregivers of the participants completed interviewer-administered structured questionnaires when participants were 6 months, 1 year, and 2 years of age. Data on maternal education, parity, age, and information on physical assets were collected. An index of socioeconomic status (SES) of the household was calculated by summing the main tangible assets owned in the household, such as a television, car, washing machine, refrigerator, and telephone (Pradeilles, Griffiths, Norris, Feeley, & Rousham, 2005).

2.4 | Growth modeling

Height, weight, and BMI from age 7 to 23 years were modeled using the SuperImposition by Translation and Rotation (SITAR; Version 1.0.10 in R version 3.4.2), a shape invariant model with a single fitted curve that summarizes individual growth patterns with three parameters (Cole, Donaldson, & Ben-Shlomo, 2010). The subject-specific random effects (α_i, β_i, and γ_i) correspond to the size (magnitude), tempo (timing), and velocity (intensity) of height, weight, or BMI, and make individual curves as similar in shape as possible. The random effects allow for variation along the x and y axes in the units of the measurement, throughout the period of measurement, that is, 7 to 23 years for the current study. Magnitude refers to a shift on the y-axis, which indicates how large or small an individual is relative to the sample mean curve while timing refers to a shift on the x-axis, which indicates how early or delayed an individual is relative to the sample mean curve. Intensity represents the shrinking or stretching of the age scale affecting the steepness of the curve, giving an indication of how fast or slow an individual is relative to the sample mean curve. Data were cleaned using the plotclean and velout functions in SITAR, which identify outliers with abnormal velocities. Models were fitted at various degrees of freedom, chosen in a decreasing order from the first whole number below the mean number of observations. The Bayesian information criterion (BIC) was used to assess model fit where a lower BIC indicates a better model fit. The best model was rerun after excluding observations with residuals greater than 2 units, which improved model fit. Models for weight and BMI were fitted on a log (y). The results from log-transformed data were interpreted as sympercents (Cole, 2000). Given that we are interested in ethnic differences, that is, differences between black and white participants, models were fitted for males and females separately but black and whites combined. The ethnicity variable was added to the final model to allow for ethnic comparisons, using white participants as a reference.

2.5 | Statistical analysis

Multiple regression analyses were performed using Stata version 13.1 (StataCorp). Using the random effects obtained from the SITAR models, multiple linear regression analyses were performed to assess the effect of early life growth (birth to 5 years) on adolescent growth. Weight-for-age Z-scores (WAZ) were generated using the World Health Organization (WHO) 2006 child growth standards for children between birth and 5 years (de Onis, Garza, Onyango, & Rolland-Cachera, 2009). To address collinearity between the independent variables and to separate out the effects of linear growth and weight gain, standard residuals were obtained (Adair et al., 2013). Relative weight gain between birth and 24 months was obtained by regressing weight at 24 months on current length (24 months) and previous length (12 months) and weight (12 months and birth). Relative weight gain between 24 and 60 months was obtained by regressing weight at 60 months on current length (60 months) and previous length and weight (24, 36, and 48 months). In a similar manner, relative linear growth values between 3 and 24 months and between 24 and 60 months were obtained by regressing on previous length but not weight (Adair et al., 2013). All models were adjusted for maternal education, parity, age, and SES.

3 | RESULTS

The number of participants and observations for each SITAR model are presented in Table 1. The variances explained by the SITAR model were male height 98.9%, female height 98.6%, male weight 94.1%, female weight 92.4%, male BMI 90.5%, and female BMI 92.1%. Unadjusted and SITAR-adjusted individual curves and the sample's mean curves are presented in Figure S1 to demonstrate model fit. Mean distance and velocity curves for height, weight, and BMI, stratified by sex and race, are presented in Figure 1.

3.1 | Ethnic differences in height, weight, and BMI

There were ethnic differences in height, weight, and BMI (Table 2), which are presented as mean differences (SE). Where data were log transformed, data are presented as sympercentages (SE). There were ethnic differences in the magnitude (size), timing (tempo), and intensity (velocity) parameters for height in both males and females. White males and females were 5.5 cm (0.7) and 5.1 cm (0.30) taller than black males and females, respectively ($P < .001$). Peak height velocity was delayed by 0.65 years (0.12) in black compared to white males ($P < .001$) while it was earlier by 0.23 years (0.11) in black than white females ($P = .03$).

TABLE 1 Sample size and outcomes of SITAR model fitting for height, weight, and BMI

	Males			Females		
	Height (cm)	Weight (kg)	BMI (kg/m^2)	Height (cm)	Weight (kg)	BMI (kg/m^2)
No. subjects/observations	1018/7122	1018/7122	1015/7122	1079/7454	1089/7454	1089/7454
Degrees of freedom	6	5	3	6	4	4
Residual SD[a]	0.86	0.04	0.63	0.75	0.04	0.04
Size-tempo correlation	0.19	0.08	0.20	0.31	0.32	−0.13
Size-velocity correlation	0.18	0.22	0.68	0.04	0.24	0.63
Tempo-velocity correlation	−0.67	−0.64	−0.06	−0.61	−0.14	−0.34
Variance explained (%)	99	96	94	99	96	95

Abbreviation: SITAR, SuperImposition by Translation and Rotation.
[a]For height, the residual SD is in cm, while for weight and BMI it is based on log-transformed data.

Ethnic differences in weight were observed among males but not females. Black males were 15% (0.02) lighter than white males. Black males also had lower BMI (−8% ± 0.002) and slower BMI intensity (−27% ± 0.06) than white males. Black females had 16% (SE: 0.06) faster BMI intensity than white females ($P = 0.01$).

3.2 | Associations between early life growth and SITAR random effects timing, magnitude, and intensity

The associations between early life factors and adolescent growth parameters are presented in Table 3; results are presented as $\beta \pm$ SE.

For adolescent height, rapid linear growth between 3 and 24 months (−0.17 years ± 0.06 and −0.14 years ± 0.04) and 24 and 60 months (−0.13 years ± 0.05 and −0.10 years ± 0.04) were associated with an earlier timing of adolescent height in males and females, respectively. Both birth weight *z*-score (∼1.2 cm ± 0.2) and rapid linear growth between 3 and 24 months (∼3.2 cm ± 0.2) and 24 and 60 months (∼2.5 cm ± 0.2) were positively associated with the magnitude of adolescent height while rapid weight gain between 24 and 60 months (∼0.4 cm ± 0.2) was negatively associated with the magnitude of adolescent height in both sexes (Table 3A).

For adolescent weight (Table 3B), relative weight gain between 0 and 24 months (∼−0.3 years ± −0.06) and relative linear growth between 0 and 24 months (∼−0.2 years ± 0.06) in both sexes, as well as relative linear growth between 24 and 60 months (∼ 0.2 years ± 0.05) in females, were associated with an earlier adolescent timing of adolescent weight. Birth weight *z*-score (∼+3-4% ± 0.005), relative weight gain between 0 and 24 months (∼+3-5% ± 0.005) and 24 and 60 months (∼+3-4% ± 0.005), and relative linear growth between 3 and 24 months (∼+5% ± 0.006) and 24 and 60 months (∼+3% ± 0.0065) were all positively associated with the magnitude of adolescent weight in both sexes.

For adolescent BMI (Table 3C), relative weight gain between 0 and 24 months (∼−0.4 years ± 0.1) and 24 and 60 months (∼−0.2 years ± 0.1) in both sexes, and relative linear growth between 3 and 24 months (−0.20 years ± 0.08) in females, were associated with an earlier timing of adolescent BMI. Birth weight *z*-score (∼+2-3% ± 0.006), relative weight gain between 0 and 24 months (∼+3-5% ± 0.006) and 24 and 60 months (∼+4% ± 0.006) were positively associated with the magnitude of adolescent BMI in both sexes.

Between 2.1% and 10.8% of the variance in intensity and between 5.5% and 15.2% of the variance in timing in both sexes for height, weight and BMI could be explained by early childhood growth and confounders (maternal education, parity, age, and SES). The variance explained for magnitude of height, weight, and BMI was greater, ranging from 19.2% to 52.3% for both sexes. Table 4 shows a summary of the regression analyses, which highlight the associations between early childhood growth and earlier timing of adolescent height, weight, and BMI and positive associations with the magnitude of adolescent body size.

4 | DISCUSSION

We set out to assess ethnic differences in the size achieved, the timing and the rate of adolescent growth in height, weight, and BMI, and to test the association between early childhood growth and adolescent growth. We were able to show ethnic differences in all SITAR parameters (ie, magnitude, timing, and intensity) for height, weight, and BMI during puberty. There were

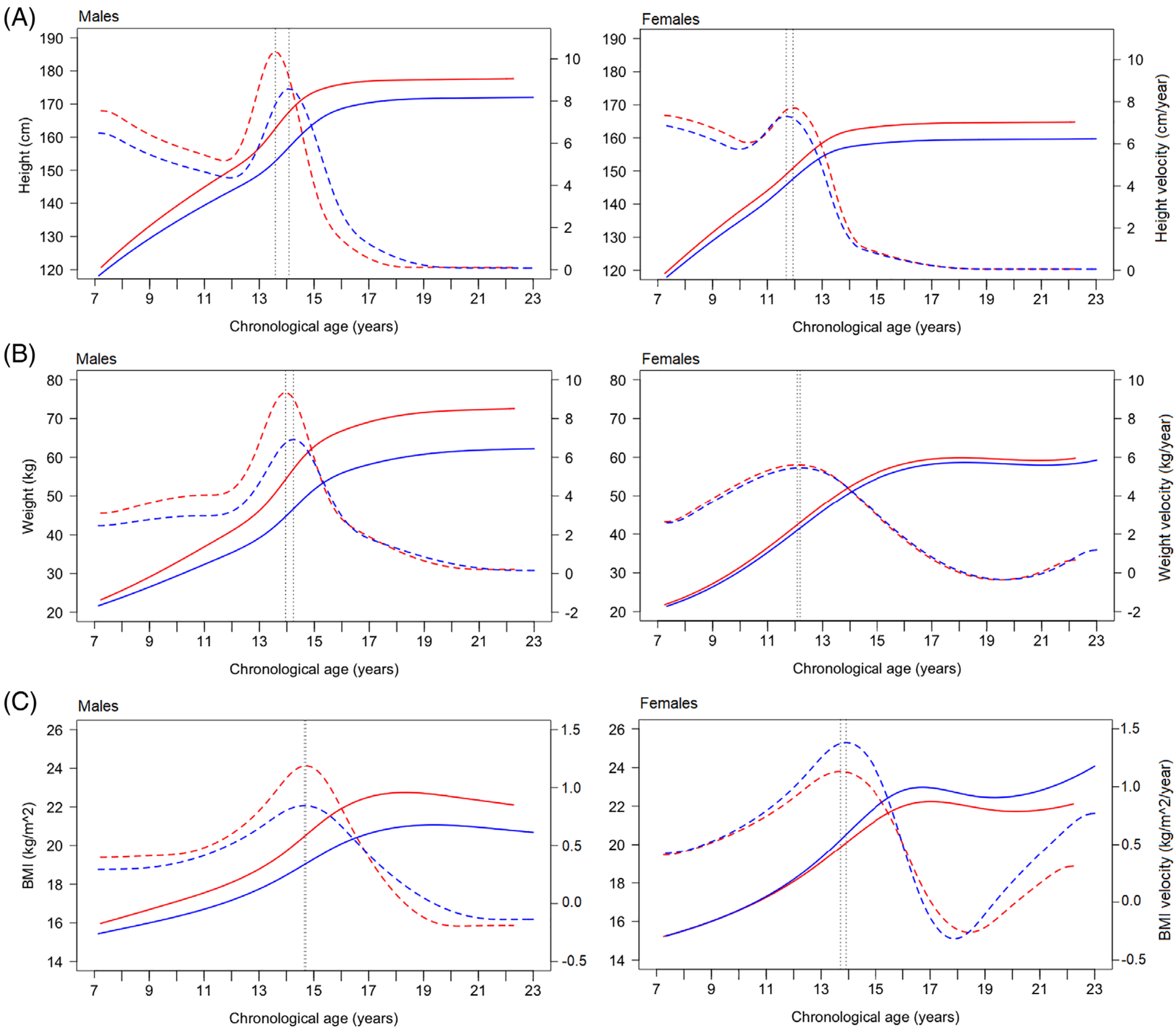

FIGURE 1 Ethnic differences (black = blue and white = red; N = 895 BM, 115 WM, 970 BF, 109 WF) in distance and velocity growth curves for (A) height, (B) weight, and (C) BMI. The vertical lines represent age at peak velocity (APV). APV and peak velocities (PV) are presented for black vs white males and females, respectively: height—males (APV = 14.1 vs 13.6 years and PV = 8.7 vs 10.6 cm/y) and females (APV = 11.7 vs 12.0 years; PV = 7.3 vs 7.7 cm/y); weight—males (APV = 14.2 vs 14.0 years and PV = 6.7 vs 9.0 kg/y) and females (APV = 12.9 vs 12.9 years; PV = 5.5 vs 5.8 kg/y); BMI—males (APV = 14.8 vs 14.5 years and PV = 1.3 vs 2.1 kg/m^2/y) and females (APV = 13.4 vs 13.0 years; PV = 1.3 vs 1.0 kg/m^2/y)
Abbreviations: BM=Black Males; WM=White Males; BF=Black Females; WF=White Females

differences in height (all parameters) in both sexes, weight and BMI (magnitude and intensity) in males, while in females there were only differences in BMI intensity. Historically, South African black children have been shown to be shorter, lighter and have less fat than white children (Chaning-Pearce & Solomon, 1986; Kark & Le Riche, 1944; Smit, 1971). Data from the current study suggest that there has been a positive secular change in weight and BMI in black females but height lags behind. Previous findings in the same cohort have shown that the prevalence of overweight and obesity in black females is nearly double that in white females in late adolescence (27.9% vs 17.1% at 17 years of age) (Nyati et al., 2019). The fact that black females had slower growth velocity in height but similar weight velocity may have contributed to the greater BMI velocity in black than white females and thus to an increased risk of obesity in late adolescence and adulthood. Adult black females have the highest prevalence of overweight and obesity in the country (Puoane et al., 2002).

TABLE 2 Ethnic differences (black and white using white as the reference group) in SITAR parameters for height, weight, and BMI; mean difference (SE)

	Males			Females		
	Height (cm)	Weight (kg)[a]	BMI (kg/m^2)[a]	Height (cm)	Weight (kg)[a]	BMI (kg/m^2)[a]
Size parameter	−5.49 (0.71)***	−0.15 (0.02)[b]***	−0.08 (0.02)[c]***	−5.10 (0.66)***	−0.02 (0.02)	0.03 (0.02)
Tempo parameter	0.65 (0.12)***	0.26 (0.15)	−0.06 (0.30)	−0.23 (0.11)*	0.11 (0.14)	−0.15 (0.24)
Velocity parameter	−0.18 (0.02)***	−0.16 (0.02)[b]***	−0.27 (0.06)[c]***	−0.05 (0.02)**	0.01 (0.03)	0.17 (0.06)[d]**

Note: Magnitude and intensity are in the units of the outcome variable (eg, cm and cm/y for height) and timing is in years.
Abbreviation: SITAR, SuperImposition by Translation and Rotation.
[a]Output based on log-transformed data as specified. For interpretation, mean difference is multiplied by 100 and interpreted as percentage difference.
[b]Model based on log (weight): black males were 15% lighter and 16% slower weight gain than white males.
[c]Model based on log (BMI): black females had 18% faster BMI gain than white females.
[d]Model based on log (BMI): black males had 8% lower BMI and 27% slower BMI gain than white males.
*$P < .05$; **$P < .01$; ***$P < .001$.

We found that APHV was 8 months later in black males than in white males, while it was 3 months earlier in black females than in white females. A similar pattern has been described in Sudanese adolescents, with a delay of 1 year in APHV being observed in Sudanese males compared to their British peers living in the United Kingdom, but not in females (Sukkar, Kemm, Ballal, & Ahmed, 1980). Additionally, the delay in APHV in our cohort is corroborated by the finding in the same cohort of a 6-month delay in skeletal maturity in black males compared to their white peers but not in females during puberty. It was suggested that this delay may be due to male susceptibility to stress (Cole et al., 2015). However, the timing of puberty is associated with obesity (Elks et al., 2010), and it is possible that the sexual dimorphism in ethnic differences in APHV may be related to the rising obesity prevalence in black females.

South African urban black females have experienced a secular trend toward earlier puberty with the age at menarche now being similar in black and white females (Jones et al., 2009a). At the same time, the similarity in weight between black and white females suggests that black females are experiencing a positive secular change in weight, which is not evident in black males. Thus, factors driving the upsurge in obesity in adolescence in black females may also influence the earlier height tempo in black females (Louis et al., 2008).

Puberty is also influenced by environmental factors and its timing is associated with early childhood growth. We found significant associations between early childhood growth and the magnitude, timing, and intensity of adolescent growth in height, weight, and BMI in black children. Generally, rapid weight gain and linear growth in childhood are associated with larger body size, earlier timing (consequently earlier age at peak velocity), and greater intensity of adolescent growth. In both boys and girls, early childhood height and BMI were associated with earlier and faster pubic hair development in the Bt20+ cohort (Lundeen et al., 2016). Previous data also from the Bt20+ cohort showed that rapid weight gain in early childhood was associated with the risk of being in the early-onset obese to morbid obese trajectory (Munthali et al., 2017). In our study in females, linear growth between 3 and 24 months was positively associated with adolescent BMI values and negatively associated with BMI tempo (earlier onset of BMI gain).

The period in early childhood (infancy vs toddler) in which growth failure or rapid growth occurs is significant for later life outcomes. Growth failure between birth and 12 months is a better predictor of short stature than growth failure in the toddler period (Stein et al., 2010). In our study, rapid weight gain between 0 and 24 months was positively associated with pubertal height, weight, and BMI while rapid weight gain between 24 and 60 months was negatively associated with pubertal height but positively associated with weight and BMI, leading to shorter but fatter individuals. Antonisamy and colleagues found that weight gain in early infancy (0-3 months) was positively associated with adult height, while weight gain in childhood through adolescence (6.5-15 years) was negatively associated with adult height (Antonisamy et al., 2016). Similarly, He and Karlberg found negative associations between BMI gain between 2 and 8 years and adolescent height gain. They attributed to the potential adverse effects of adolescent adiposity on GH and IGF-I secretion in that period (Minuto et al., 1988; He & Karlberg, 2001).

Rapid weight gain, which may result from catch up growth in the first few months of postnatal life, is common in early childhood (Cameron, Pettifor, De Wet, &

TABLE 3 The effect of early life growth and environment on the timing, magnitude, and intensity of pubertal height, weight, and BMI change in black children; beta coefficient (SE)

	Males			Females		
(A) Height: Independent variables	**Timing (years)**	**Magnitude (cm)**	**Intensity (cm/y)**	**Timing (years)**	**Magnitude (cm)**	**Intensity (cm/y)**
Birth weight *z*-score	−0.060	1.260***	0.008	0.063	1.334***	−0.000
	(0.051)	(0.206)	(0.006)	(0.037)	(0.186)	(0.006)
Relative weight gain 0 to 24 m	−0.083	0.393	−0.005	−0.166***	0.093	0.022**
	(0.053)	(0.216)	(0.007)	(0.042)	(0.215)	(0.007)
Relative weight gain 24 to 60 m	−0.025	−0.457*	−0.010	−0.092*	−0.521**	0.007
	(0.052)	(0.211)	(0.006)	(0.038)	(0.191)	(0.006)
Relative linear growth 3 to 24 m	−0.175**	3.287***	0.019**	−0.140***	3.219***	0.029***
	(0.056)	(0.225)	(0.007)	(0.041)	(0.208)	(0.007)
Relative linear growth 24 to 60 m	−0.132**	2.668***	0.019**	−0.099*	2.542***	0.017*
	(0.050)	(0.203)	(0.006)	(0.039)	(0.198)	(0.007)
R-squared	0.055	0.520	0.054	0.119	0.523	0.108

	Males			Females		
(B) Weight: Independent variables	**Timing (years)**	**Magnitude (kg)**	**Intensity (kg/y)**	**Timing (years)**	**Magnitude (kg)**	**Intensity (kg/y)**
Birth weight *z*-score	−0.072	0.041***	0.012	0.006	0.033***	−0.003
	(0.056)	(0.005)	(0.008)	(0.049)	(0.006)	(0.007)
Relative weight gain 0 to 24 m	−0.274***	0.033***	0.012	−0.303***	0.054***	0.028***
	(0.059)	(0.006)	(0.008)	(0.056)	(0.007)	(0.008)
Relative weight gain 24 to 60 m	−0.088	0.037***	0.013	−0.105*	0.033***	0.005
	(0.057)	(0.006)	(0.008)	(0.050)	(0.007)	(0.007)
Relative linear growth 3 to 24 m	−0.190**	0.047***	0.006	−0.203***	0.053***	0.015*
	(0.061)	(0.006)	(0.009)	(0.054)	(0.007)	(0.007)
Relative linear growth 24 to 60 m	−0.079	0.033***	0.003	−0.175***	0.027***	0.010
	(0.055)	(0.005)	(0.008)	(0.052)	(0.007)	(0.007)
R-squared	0.088	0.359	0.021	0.152	0.294	0.049

	Males			Females		
(C) BMI: Independent variables	**Timing (years)**	**Magnitude (kg/m^2)**	**Intensity ($kg/m^2/y$)**	**Timing (years)**	**Magnitude (kg/m^2)**	**Intensity ($kg/m^2/y$)**
Birth weight *z*-score	−0.102	0.027***	0.042*	−0.002	0.018**	−0.003
	(0.101)	(0.006)	(0.021)	(0.071)	(0.006)	(0.016)
Relative weight gain 0 to 24 m	−0.390***	0.034***	0.048*	−0.447***	0.053***	0.028
	(0.107)	(0.006)	(0.022)	(0.083)	(0.007)	(0.018)
Relative weight gain 24 to 60 m	−0.233*	0.042***	0.059**	−0.179*	0.040***	0.023
	(0.103)	(0.006)	(0.021)	(0.074)	(0.006)	(0.016)
Relative linear growth 3 to 24 m	−0.071	0.009	0.012	−0.202*	0.012	0.012
	(0.111)	(0.007)	(0.023)	(0.080)	(0.007)	(0.018)
Relative linear growth 24 to 60 m	−0.003	−0.001	0.002	−0.118	−0.005	−0.015
	(0.099)	(0.006)	(0.020)	(0.076)	(0.006)	(0.017)
R-squared	0.059	0.193	0.047	0.100	0.209	0.030

Note: All models were adjusted for maternal education, parity, age, and SES.
***$P < .001$, **$P < .01$, * $P < .05$.

TABLE 4 Summary of associations between early childhood and adolescent growth for (A) males and (B) females

(A) Early childhood	Puberty	Timing	Magnitude	Intensity
Birth weight *Z*-score	Height (cm)	—	↑	—
	Weight (kg)	—	↑	—
	BMI (kg/m^2)	—	↑	↑
Relative weight gain 0 to 24 m	Height (cm)	—	—	—
	Weight (kg)	↓	↑	—
	BMI (kg/m^2)	↓	↑	↑
Relative weight gain 24 to 60 m	Height (cm)	—	↓	—
	Weight (kg)	—	↑	—
	BMI (kg/m^2)	↓	↑	↑
Relative linear growth 3 to 24 m	Height (cm)	↓	↑	↑
	Weight (kg)	↓	↑	—
	BMI (kg/m^2)	—	—	—
Relative linear growth 24 to 60 m	Height (cm)	↓	↑	↑
	Weight (kg)	—	↑	—
	BMI (kg/m^2)	—	—	—
(B) Early childhood	**Puberty**	**Timing**	**Magnitude**	**Intensity**
Birth weight *Z*-score	Height (cm)	—	↑	—
	Weight (kg)	—	↑	—
	BMI (kg/m^2)	—	↑	—
Relative weight gain 0 to 24 m	Height (cm)	↓	—	↑
	Weight (kg)	↓	↑	↑
	BMI (kg/m^2)	↓	↑	—
Relative weight gain 24 to 60 m	Height (cm)	—	↓	—
	Weight (kg)	↓	↑	—
	BMI (kg/m^2)	↓	↑	—
Relative linear growth 3 to 24 m	Height (cm)	↓	↑	↑
	Weight (kg)	↓	↑	↑
	BMI	↓	—	—
Relative linear growth 24 to 60 m	Height (cm)	↓	↑	↑
	Weight (kg)	↓	↑	—
	BMI	—	—	—

Note: Upward arrows indicate significant positive associations, downward arrow indicates significant negative associations while horizontal lines indicate insignificant associations. Magnitude and intensity are in the units of the outcome variable (eg, cm and cm/y for height) and timing is in years.

Norris, 2003; Cole, Singhal, Fewtrell, & Wells, 2016), possibly related to poor birth outcomes (Singhal, 2017). A combination of low birth weight and rapid postnatal growth is associated with greater risk of later obesity. On the contrary, poor birth outcomes with no catch-up growth may contribute to early childhood undernutrition, which is linked to poor health outcomes in later life. Stunting at 2 years is negatively associated with schooling outcomes (Adair et al., 2009). This presents an intervention conundrum as both rapid weight gain and linear growth are associated with increased risk of obesity and poor health outcomes in later life (Adair et al., 2013; Singhal, 2017). Data from five low- and middle-income (LMIC) cohorts including Bt20+ showed that lower birth weight and rapid weight gain irrespective of whether the children were small-for-gestational age or not were associated with poor health outcomes (Adair et al., 2009).

This study provides insight into the biology of adolescent growth in a sample of black and white, male and female, children in an urban community in South Africa, an upper middle-income country. Additionally, it provides insight into the relationship between early life and adolescent growth. Adolescent growth was assessed using SITAR, which has previously been used to model adolescent growth in height, weight, and BMI (Blackwell et al., 2017; Cao, Hui, & Wong, 2018; Cole, 2018; Frysz, Howe, Tobias, & Paternoster, 2018; Martin & Valeggia, 2018; Simpkin, Sayers, Gilthorpe, Heron, & Tilling, 2017). This study however has limitations. Associations between early life and adolescent growth could only be assessed for black children due to a small number of white children in the early childhood years in this study. Thus, the associations between early life and adolescent growth may not be generalizable to other groups.

In conclusion, we found ethnic differences in the magnitude, timing, and intensity of adolescent growth in height, weight, and BMI. White children were taller and had greater height velocity than black children. APHV occurred later in black than white males while earlier in black than white females. Black females also had a faster BMI velocity than white females. Rapid growth in early childhood is associated with an earlier onset and greater magnitude of adolescent growth. Monitoring and managing weight gain in early childhood could assist in curbing the rise in adolescent obesity.

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AUTHOR CONTRIBUTIONS

Lukhanyo Nyati: Conceptualization; data curation; formal analysis; investigation; methodology; writing-original draft; writing-review and editing. **John Pettifor:** Conceptualization; funding acquisition; investigation; methodology; resources; supervision; validation; writing-original draft; writing-review and editing. **Ken Ong:** Conceptualization; formal analysis; funding acquisition; methodology; resources; supervision; validation; writing-original draft; writing-review and editing. **Shane Norris:** Conceptualization; formal analysis; funding acquisition; investigation; methodology; resources; supervision; validation; writing-original draft; writing-review and editing.

CONFLICT OF INTEREST

The authors declare no conflicts of interest.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of this article.

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