

# Investigating socioeconomic inequalities in BMI growth rates during childhood and adolescence

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## Abstract

**Background:** Many countries report socioeconomic inequalities in childhood obesity, but when they develop is not well-characterised. Studies rarely isolate BMI growth rates from overall BMI, perhaps overlooking an important precursor to the observed inequalities in obesity. The objective of this study was to determine the age at which inequalities in BMI growth rates develop in children and whether they are similar across the BMI spectrum.

**Methods:** Using the Longitudinal Study of Australian Children ( $n = 9024$ ), a cohort study, we measured socioeconomic inequalities in annual BMI growth from age 2 to 17 years by age, sex and weight status. We fit a linear model using generalised estimating equations (GEE) to estimate simultaneously the effects of age and weight status on inequalities in BMI growth rate.

**Results:** The slope (SII) and relative (RII) indexes of inequality for annual BMI growth were greatest in middle childhood (age 4–11 years) (SII 0.25, RII 1.83 (boys) 1.78 (girls)) and were moderate during adolescence (age 10–17 years) (SII 0.11, RII 1.16 [boys] 1.15 [girls]). In early childhood, there was little evidence of inequality in annual BMI growth except in children with obesity. In middle childhood and adolescence, inequalities were greater at higher weight status. The GEE indicated that both weight status ( $P < 0.001$ ) and age period ( $P < 0.001$ ) affected inequalities in BMI growth rates.

**Conclusions:** Inequalities in annual BMI growth were strongest in middle childhood, and widest in children at the upper end of the BMI spectrum. This could signify a key age bracket to intervene clinically and at a public health level and improve inequalities in childhood obesity.

## KEYWORDS

BMI growth rate, children, inequalities, socioeconomic

## 1 | INTRODUCTION

In Australia, 19% of children aged from 5 to 14 years living in high socioeconomic areas have overweight or obesity, but in low

socioeconomic areas, the prevalence is much higher at 33%.<sup>1</sup> Associations between low socioeconomic position (SEP) and higher weight status,<sup>2–4</sup> BMI or BMI z-scores<sup>4–6</sup> have been well-established in children in high-income countries. Longitudinal studies have

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shown that low SEP is a risk factor for persistent overweight or high BMI trajectories<sup>7-11</sup> and, in a variety of settings, have described a widening of socioeconomic inequalities in adiposity measures as children age<sup>4,10,12-14</sup> and across time.<sup>12,15</sup> Moreover, a UK study found that inequalities were wider in the upper quintiles of BMI than they were in the lower.<sup>16</sup> Conversely, in most high-income countries, the evidence shows that there is either no socioeconomic patterning in birthweight<sup>17</sup> or a positive association between socioeconomic position and birthweight.<sup>18-20</sup> Therefore, it can be inferred that the inversion of this socioeconomic patterning after birth stems from inequalities in rates of BMI growth during childhood.

Despite this, only a few studies have sought to characterise socioeconomic inequalities in rates of BMI growth specifically.<sup>5,10,14</sup> A study of child growth trajectories in South-West England found that BMI loss was faster in children of degree-educated mothers in the early years.<sup>14</sup> Another in Australian children that classified patterns of growth trajectories using latent class analysis found that children at low SEP were at higher risk of persistent and late-onset overweight.<sup>10</sup> Finally, a study conducted in the United States showed that children from households with higher compared to lower socioeconomic deprivation, had faster BMI growth for most of childhood and delayed plateauing of BMI growth in later years.<sup>5</sup>

In a prominent systematic review<sup>21</sup> and analysis of a large cohort study in the UK,<sup>22</sup> excessive weight gain in infancy has been found to be one of the key modifiable risk factors of childhood obesity. The review identified it as the only post-birth factor with strong evidence.<sup>21</sup> Correspondingly, interventions to prevent childhood obesity,<sup>23</sup> tend to focus on primary prevention (i.e., slowing BMI growth) rather than secondary prevention (promoting weight loss) – with the aim of shifting BMI trajectories towards sustained healthy weight for age. Therefore, pinpointing the timing and extent of inequalities in BMI growth could be valuable for devising approaches to prevent inequalities in obesity from developing.

The Longitudinal Study of Australian Children (LSAC), in which height, weight and socioeconomic position have been repeatedly measured over 12 years in two cohorts of children, provides a unique opportunity to examine socioeconomic inequalities in rates of BMI growth. The aim of this study was to use LSAC to explore these inequalities descriptively. Specifically, the aim was to determine the timing of socioeconomic inequalities in BMI growth rates and whether the inequalities differ across the BMI spectrum.

## 2 | METHODS

### 2.1 | Study sample

LSAC tracks two cohorts of children: one recruited at age 0–1 year, the Birth or B cohort, and the second recruited at age 4–

5 years, the Kindergarten or K cohort.<sup>24</sup> Two-stage clustered sampling from the Medicare Australia enrolment database was used to recruit a nationally representative sample of each age group. A sample of 5107 children for the B cohort and 4983 children for the K cohort were recruited between March and November 2004 and were found to be comparable in key characteristics to national statistics of each age group.<sup>24</sup> Each participant and their caregivers were interviewed every two years. There were seven waves and 12 years of follow-up available at the time of this study, with the most recent wave of data collected between April 2016 and July 2017. Both cohorts and all waves except for wave 1 of the B cohort, as height was not measured for children under 2 years, were used in this analysis. Where possible, data from both cohorts within age groups were pooled: for example, analyses in 4–5 year old children included data from wave 3 of the B cohort and wave 1 of the K cohort. All observations where BMI, age, sex, and SEP had been recorded were included in the study.

### 2.2 | Variables

The outcomes in the analyses were annual BMI growth and BMI. Children's direct anthropometric measurements were converted to BMI and annual BMI growth ( $\text{kg}/\text{m}^2/\text{year}$ ) was calculated as the difference between BMI measurements in consecutive waves divided by the exact number of years between interviews, accurate to the day.

The primary explanatory variable was socioeconomic position (SEP). A variable provided by the LSAC that combined measures of the parent's education status, occupation, and income into a single z-score<sup>26</sup> was used. These measures were collected at every wave at the same time BMI was collected. The SEP z-score was categorised into quintiles, with quintile 1 representing the lowest and quintile 5 representing the highest SEP group. Socioeconomic inequality was primarily measured by the slope index of inequality (SII) which is calculated by fitting a regression model between the outcome and the proportion in each SEP group.<sup>27</sup> SII is taken as the difference in the predicted outcome between Quintile 1 and 5 according to the regression model. In this study, the SII is interpreted as the absolute difference in either mean annual BMI growth (in  $\text{kg}/\text{m}^2/\text{year}$ ) or mean BMI (in  $\text{kg}/\text{m}^2$ ) between individuals in the highest and lowest socioeconomic quintile, adjusted for the distribution in the whole population. An SII of 0 indicates no inequality,  $\text{SII} < 0$  indicates faster BMI growth or higher BMI in low SEP, and an  $\text{SII} > 0$  indicates the reverse. SII was selected as the primary measure of inequality, instead of a relative measure, as it is easier to interpret and not as sensitive to small and potentially clinically insignificant differences in a health outcome. However, the SII can be sensitive to population level shifts in health status so the relative index of inequality (RII) was also calculated for an analysis to determine if this affected the conclusions. The RII was calculated as the ratio between the predicted

annual BMI growth in the lowest SEP quintile and that in the highest SEP quintile in the same regression models used to calculate SII. An RII of 1 indicates no inequality in BMI growth rate,  $RII > 1$  indicated faster BMI growth in low SEP, and  $RII < 1$  indicates faster BMI growth in high SEP. SIIs and RIIs were considered significant at  $P < 0.05$ .

Sex, age, weight status, indigenous status, and primary language spoken to child (as a proxy for ethnicity) were stratifying or controlling variables in these analyses. Sex was provided as a binary variable (boys/girls). Age was provided in years, accurate to the day, and used as a categorical variable. To classify weight status categories, height, weight, sex and age of the child were first converted into a BMI z-score based on World Health Organisation (WHO) growth standards.<sup>28,29</sup> Observations where BMI z-scores were less than  $-5$  or above  $5$  were excluded as such scores are biologically implausible.<sup>30</sup> Non-missing BMI z-score were then categorised into three groups: healthy weight and underweight ( $BMIz \leq 1$ ), overweight ( $1 < BMIz \leq 2$ ) and obesity ( $BMIz > 2$ ). Indigenous status (Indigenous/Not indigenous) and primary language spoken to child (English/Language other than English) as collected in the first and second waves of LSAC in the K and B cohorts respectively, were categorised as binary variables.

### 2.3 | Statistical analyses

All analyses were conducted in boys and girls separately and were conducted using STATA version 16.0,<sup>31</sup> unless otherwise mentioned.

### 2.4 | Timing of inequalities

First, the timing of socioeconomic inequalities in annual BMI growth and mean BMI were examined. In the initial analysis, age was categorised into two-year age groups that corresponded to the age of the child participants at each wave: 2–3, 4–5, 6–7, 8–9, 10–11, 12–13, 14–15 and 16–17 years. SEP quintiles were calculated within each age group. The mean annual BMI growth ( $\text{kg}/\text{m}^2/\text{year}$ ) for each age interval at the highest and lowest SEP quintile of the earlier age group and the corresponding SII were then calculated. For example, the mean annual BMI growth between 2–3 and 4–5 years was presented by highest and lowest SEP quintile at age 2–3 years. Age and sex specific mean BMI were presented similarly by highest and lowest SEP quintile.

Second, age was categorised into three periods based on the patterns of BMI growth identified in the initial analysis and corresponding approximately to three stages of child development: early childhood (from 2–3 years to 4–5 years), middle childhood (from 4–5 years to 10–11 years) and adolescence (from 10–11 years to 16–17 years). Annual BMI growth was then calculated from the earliest and latest BMI measurement for each participant within each age period; the intermediate measurements were not used. SEP quintiles were calculated for the earliest age for each age period. Annual BMI

growth in each age period was presented for all quintiles of SEP and SIIs and RIIs were calculated.

### 2.5 | Inequalities in annual BMI growth across the BMI spectrum

Next, inequalities across the BMI spectrum were examined by stratifying BMI growth results by weight status (healthy weight, overweight and obesity) and age period. Again, annual BMI growth was calculated using the earliest and last BMI measurement for each participant within each age period. SEP quintiles were calculated within the earlier age of each period. Annual BMI growth was then plotted by weight status and SEP quintile (highest and lowest) and SIIs were calculated for each age period.

### 2.6 | Timing of inequalities and differences across the BMI spectrum

To simultaneously analyse the timing of inequalities in BMI growth and differences across the BMI spectrum, while controlling for primary language spoken to child (as a proxy for ethnicity) and indigenous status, a linear model was fitted using generalised estimating equations (GEE) with a compound symmetry working correlation matrix. GEE adjusts standard errors to account for repeated measures in individual participants. Boys and girls were combined in this analysis. The outcome was annual BMI growth between each wave of measurement. The exposure was SEP quintile at the earlier wave, and the other covariates were age period (early childhood, middle childhood or adolescence), weight status at the earlier wave, sex, indigenous status and primary language spoken to child. The latter two variables were included to control for the potentially confounding effect of ethnicity. To assess the timing of inequalities in rates of BMI growth and any differences across the BMI spectrum, interaction terms between SEP quintile and weight status, and SEP quintile and age period were added. An interaction term between weight status and age period was also added to allow for the observed opposite effect of weight status on annual BMI growth in early childhood when compared to the two other age periods. Interactions were considered significant if the *Wald* chi-squared values, calculated using the *testparm* command on Stata, had a *P*-value less than 0.01. The models were used to calculate adjusted annual BMI growth by age period, SEP quintile, and weight status using the *margins* command on STATA, as a way of visualising all trends examined in this study while controlling for all covariates.

### 2.7 | Sensitivity analysis

To assess the impact of analysing each cohort alone and accounting for clustered sampling on the conclusions, the descriptive analyses

were repeated in each cohort alone using population survey weights provided by the LSAC.<sup>32</sup>

Data from LSAC were used with approval from the University of Sydney Human Research Ethics Committee (Project Number 2018/726).

### 3 | RESULTS

#### 3.1 | Study sample and characteristics

For each age group, BMI, annual BMI growth, weight status and sex had similar means and proportions in the B and K cohorts (Table 1). Overall, data for 9024 children and 80,826 person-years of follow-up were used. Of all interviews conducted, this study used 94% of the observations in the B cohort and 97% in the K cohort (Table S1) due to missing SEP and missing or implausible values recorded for BMI. Participants lost to follow-up were more likely to be in the lower SEP quintiles (Table S2) and slightly more likely to have obesity (Table S3) than participants that remained in the study.

#### 3.2 | Timing of inequalities

Mean annual BMI growth by sex, age and highest and lowest SEP quintile are presented in Figure 1. In both boys and girls, between ages 2–3 and 4–5 years (early childhood) mean annual BMI growth was negative indicating that children generally lost BMI during this period. Between ages 4–5 years to 10–11 years (middle childhood), annual BMI growth rose steadily in both sexes but from 10–11 years to 16–17 years (adolescence) it plateaued in boys and peaked, then decreased in girls. Patterns in inequalities in BMI growth were consistent between boys and girls. There was no indication of socioeconomic inequality in mean annual BMI growth in early childhood (SII = 0.02,  $P = 0.17$ ), but the inequality developed between ages 4–5 years and 6–7 years (SII = 0.20 in boys and 0.24 in girls,  $P < 0.001$ ). This means that, on average, boys and girls in the lowest SEP quintile have 0.20 kg/m<sup>2</sup>/year and 0.24 kg/m<sup>2</sup>/year greater annual BMI growth than boys and girls in the highest SEP quintile, respectively. This inequality in growth rate persisted, and even increased, during middle childhood, but it attenuated during adolescence (after age 10–11 years) (SIIs from 0 to 0.19).

TABLE 1 Size and characteristics of the study sample

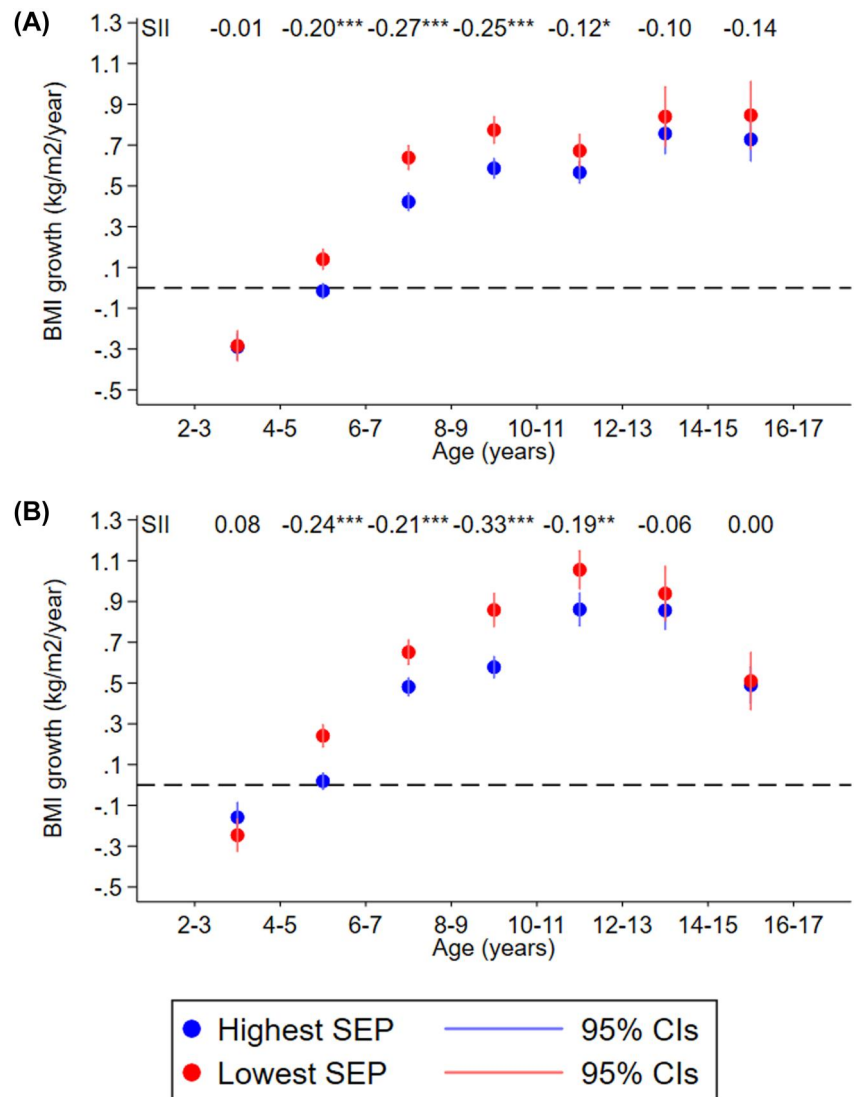
	Age (years)							
	2–3	4–5	6–7	8–9	10–11	12–13	14–15	16–17
<b>B cohort</b>								
Wave	2	3	4	5	6	7		
Observations used (n) <sup>a</sup>	4486	4292	4144	3946	3530	2685		
Female	2196 (49)	2096 (49)	2014 (49)	1926 (49)	1725 (49)	1296 (48)		
BMI, mean (SD)	16.8 (0.02)	16.3 (0.03)	16.5 (0.03)	17.6 (0.04)	18.8 (0.06)	20.3 (0.07)		
Annual BMI gain, mean (SD)	-	-0.25 (0.70)	0.1 (0.71)	0.52 (0.75)	0.67 (0.85)	0.80 (0.90)		
Healthy Weight <sup>b</sup>	2521 (56)	2820 (66)	2967 (72)	2689 (68)	2348 (67)	1810 (67)		
Overweight	1373 (31)	1088 (25)	803 (19)	817 (21)	777 (22)	624 (23)		
Obesity	592 (13)	384 (9)	374 (9)	440 (11)	405 (11)	251 (9)		
<b>K cohort</b>								
Wave		1	2	3	4	5	6	7
Observations used (n) <sup>a</sup>		4898	4389	4269	3968	3760	3239	2328
Female		2412 (49)	2154 (49)	2086 (49)	1927 (49)	1834 (49)	1560 (48)	1137 (49)
BMI, mean (SD)		16.3 (0.02)	16.5 (0.03)	17.6 (0.04)	19 (0.06)	20.5 (0.06)	21.9 (0.07)	23.1 (0.09)
Annual BMI gain, mean (SD)		-	0.08 (0.58)	0.56 (0.74)	0.7 (0.81)	0.75 (0.95)	0.82 (1.02)	0.66 (1.00)
Healthy Weight <sup>b</sup>		3326 (68)	3170 (72)	2844 (67)	2576 (65)	2534 (67)	2264 (70)	1638 (70)
Overweight		1146 (23)	844 (19)	916 (21)	890 (22)	810 (22)	655 (20)	444 (19)
Obesity		426 (9)	375 (9)	509 (12)	502 (13)	416 (11)	320 (10)	246 (11)

Note: All cells are presented as count (percentage) unless otherwise indicated.

<sup>a</sup>i.e. data complete and plausible for BMI and SEP.

<sup>b</sup>includes children who are underweight.

**FIGURE 1** Socioeconomic inequalities in annual BMI growth in (A) boys and (B) girls from ages 2–3 to 16–17 years. Means and 95% confidence intervals for the highest and lowest SEP quintiles are presented. A reference line is placed at 0 kg/m<sup>2</sup>/year representing no change in BMI. Slope Index of Inequality values, in kg/m<sup>2</sup>/year, are presented for each age group \**p* < 0.05 \*\**p* < 0.01 \*\*\**p* < 0.001. BMI, body mass index; SEP, socioeconomic position



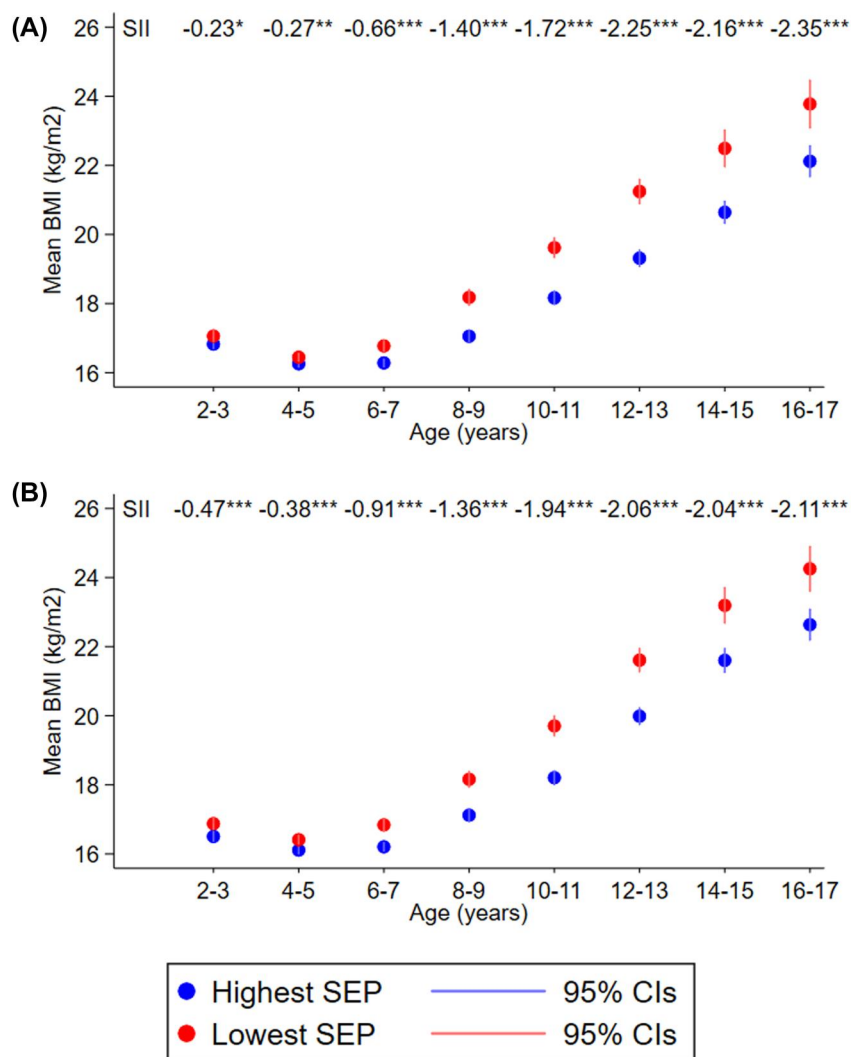
These trends in inequalities in BMI growth were reflected in the trends in inequalities in mean BMI (Figure 2). Between ages 2–3 and 4–5 years, the inequality in BMI barely changed in boys (SII 0.23–0.27 kg/m<sup>2</sup>) and girls (SII 0.47–0.38 kg/m<sup>2</sup>), consistent with the minimal inequality in annual BMI growth observed between these ages. Between 4–5 and 6–7 years, however, the SII for mean BMI had more than doubled in both sexes and grew until 12–13 years (SII 2.25 kg/m<sup>2</sup> in boys and 2.06 kg/m<sup>2</sup> in girls, *P* < 0.001) but then remained relatively stable until age 16–17 years.

The absolute and relative inequalities in annual BMI growth over three age periods are presented in Figure 3. In both boys and girls, absolute inequality was very low in early childhood (SII 0.01 kg/m<sup>2</sup>/year in boys and 0.08 kg/m<sup>2</sup>/year in girls), strongest in middle childhood (SII 0.25 in both sexes), and weaker but still present in adolescence (SII 0.11 in both sexes). Similarly, relative inequality was greatest in middle childhood and lower but still present in adolescence. In boys and girls, the RIIs of 1.83 and 1.78 in middle childhood meant that the annual BMI growth in those at the lowest SEP quintile were 1.83 and 1.78 times that of those in

the highest SEP quintile, respectively. These RIIs decreased to 1.16 in boys and 1.15 in girls in adolescence. As with absolute inequality, relative inequality in annual BMI change (a BMI loss at this time) was small in early childhood for boys; an RII of 0.96 means that BMI loss was similar across all SEP quintiles. In girls, however, the relative inequality was 1.42, reflecting an overall slower BMI loss in those with higher SEP.

### 3.3 | Inequalities across the BMI spectrum

In early childhood, there was no evidence of growth inequality between children in healthy weight and overweight (Figure 4). Boys and girls with obesity at low SEP had slower BMI loss than those with obesity at high SEP but the SIIs were non-significant. In middle childhood, SEP inequalities were present (SII *P* < 0.01) in all weight status groups and both sexes but were greatest at higher weight status. In adolescence, the SII was significant only in those with obesity for both sexes (*P* < 0.05).



**FIGURE 2** Socioeconomic inequalities in BMI in (A) boys and (B) girls from ages 2–3 to 16–17 years. Means and 95% confidence intervals for the highest and lowest SEP quintiles are presented. Slope Index of Inequality values, in kg/m<sup>2</sup>, are presented for each age group. \* $p < 0.05$  \*\* $p < 0.01$  \*\*\* $p < 0.001$ . SEP, socioeconomic position

### 3.4 | Timing of inequalities and differences across the BMI spectrum

The results of the GEE are presented in Table S4 and Figure 5 and are consistent with the descriptive analyses. The interactions between SEP quintile and weight status ( $\chi^2_6 = 103.44$ ,  $P < 0.001$ ) and SEP quintile and age period ( $\chi^2_6 = 27.24$ ,  $P < 0.001$ ) were significant, showing that both weight status and age period affected the level of inequality. The trends identified from these models, and visualised in Figure 5, show that the slope of annual BMI growth by SEP quintile was steepest in middle childhood and in those with obesity. They also show that BMI loss during the early childhood period for those with obesity is greater with higher SEP. Neither indigenous status ( $P = 0.27$ ) nor primary language spoken to child ( $P = 0.14$ ) were significantly associated with annual BMI growth.

### 3.5 | Sensitivity analysis

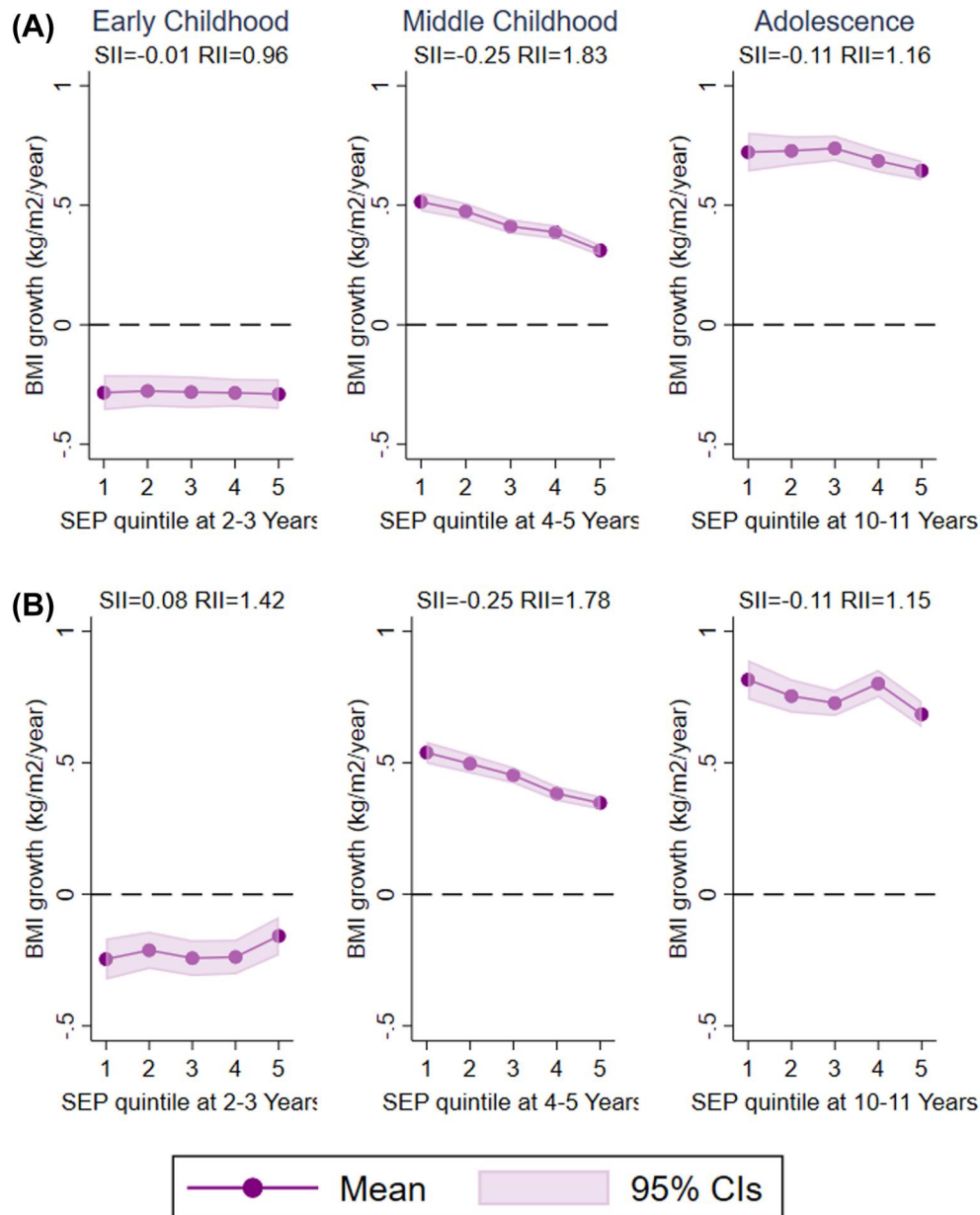
All results remained qualitatively the same in analyses separating the cohorts and applying survey weights (Tables S5–S8). In general, the

largest inequalities (highest SIIs and RIIs) for annual BMI growth were in middle childhood (Tables S5 and S7) and at higher weight status (Table S8).

## 4 | DISCUSSION

In this study of 9024 children and 80,826 person-years of follow-up from the Longitudinal Study of Australian Children, the timing, extent and distribution of socioeconomic inequalities in rates of BMI growth were examined. Inequalities in annual BMI growth were found to be strongest in middle childhood and start to attenuate in adolescence, preventing further widening of inequality in BMI. Furthermore, inequalities in annual BMI growth were found to be dependent on child weight status, with greater SEP inequality in annual BMI growth for children experiencing overweight or obesity compared to those at healthy weight. In early childhood, there was no discernible inequality in BMI growth for children in healthy or overweight, but, those with obesity had greater BMI loss at higher SEP.

This study is one of few in the literature on socioeconomic inequalities in childhood obesity to hone into BMI growth rates, and



**FIGURE 3** Annual BMI growth by baseline SEP quintile in early childhood (2–3 to 4–5 years), middle childhood (4–5 to 10–11 years) and adolescence (10–11 to 16–17 years) in (A) boys and (B) girls. Means and 95% confidence intervals for all SEP quintiles are presented. BMI, body mass index; SEP, socioeconomic position; SII, Slope Index of Inequality RII, Relative Index of Inequality

the first to consider the impact of both age and weight status on inequalities in BMI growth rates. These results are consistent with existing work examining inequalities in other obesity metrics. A number of studies,<sup>4,10,12–14,33</sup> have found widening inequality in BMI/BMI z-score with increasing age in children. Three longitudinal studies<sup>10,13,14</sup> identified that inequalities in BMI or weight status emerged by early childhood (age 4 years) which is comparable to the small, but significant inequalities identified in mean BMI in age 2–3 years and 4–5 years (Figure 2) in this study. An additional finding of the current study was that inequality in *annual BMI growth* emerged in middle childhood before considerable inequalities in BMI developed in adolescence.

Another study, examining the 2001 Millennium Cohort Study in the UK,<sup>12</sup> found that inequalities in BMI continued to widen in adolescence rather than stabilising as in the present study. The SIIs for BMI they calculated were considerably smaller than in this study at similar ages. The difference in timing and magnitude of inequality between the two studies may be due to contextual differences between Australian and UK children. This UK study<sup>12</sup> was also the only other which investigated the magnitude of inequalities in BMI across the BMI spectrum and similarly found widening socioeconomic inequalities with increasing BMI quintile.

This study's findings describing socioeconomic inequalities in annual BMI growth could be plausibly explained by intermediary

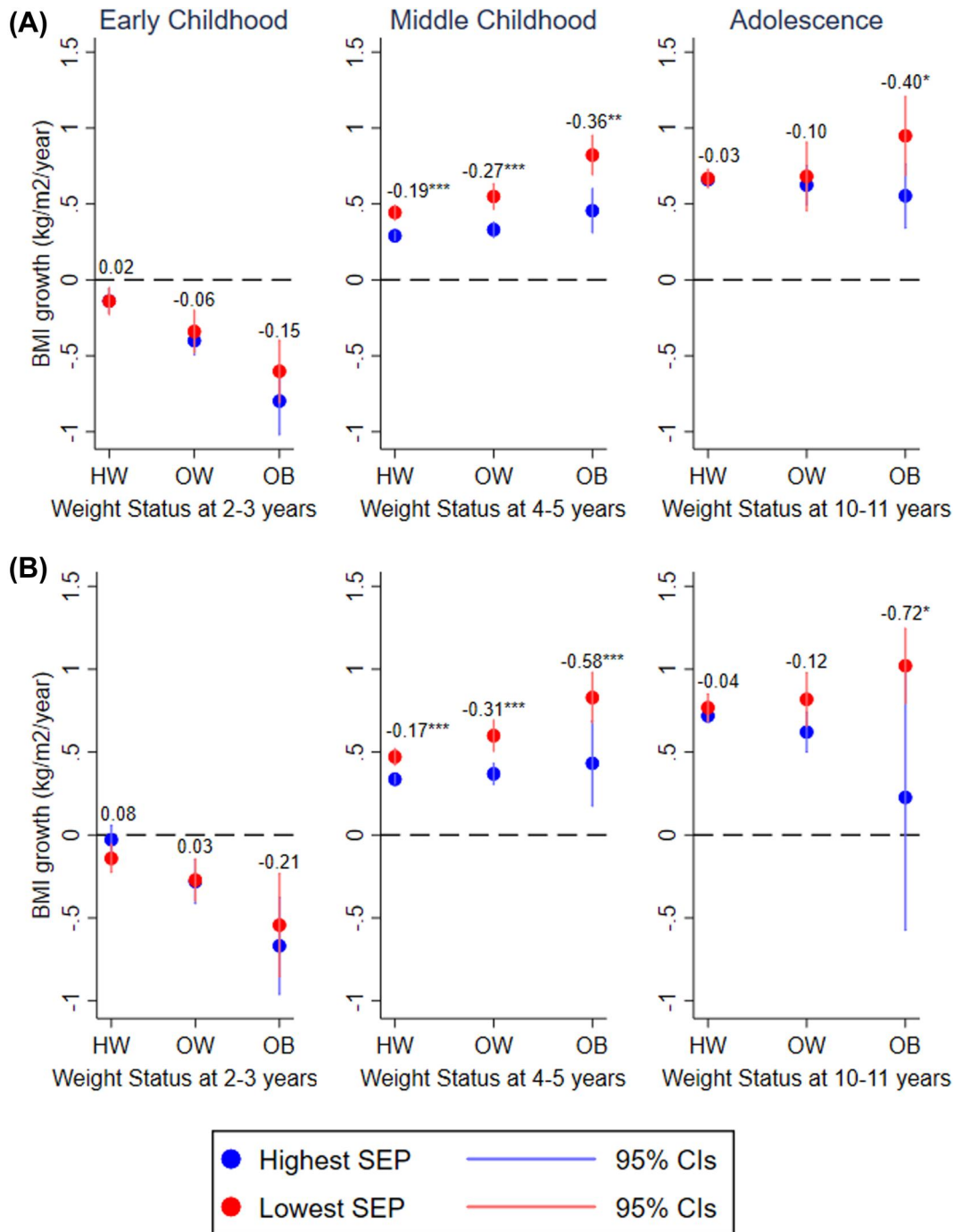


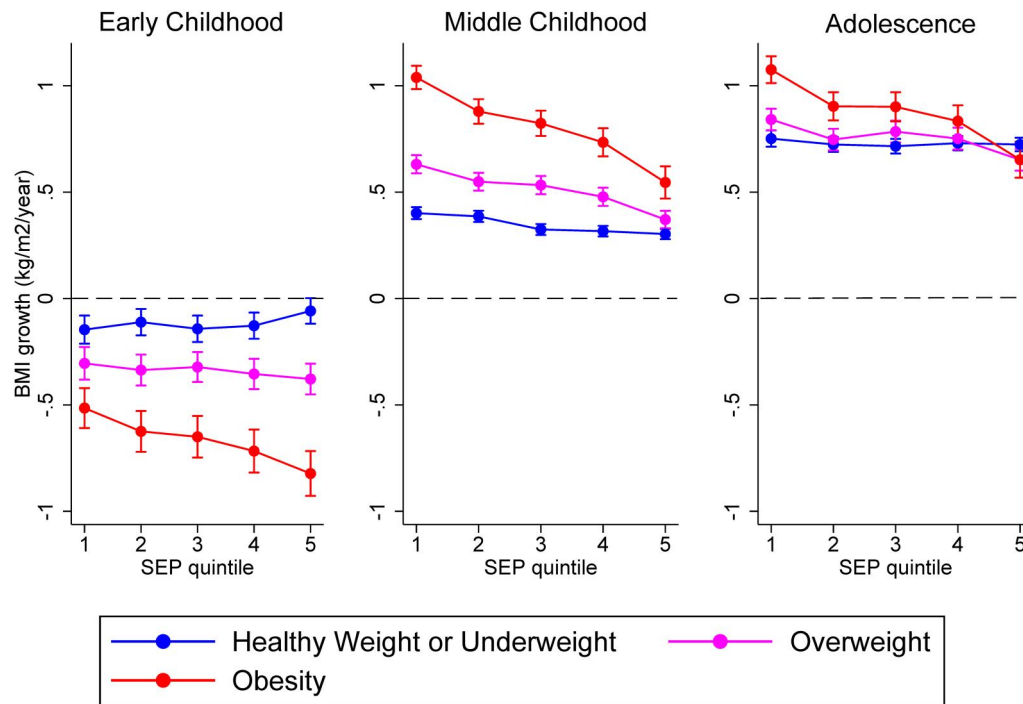
FIGURE 4 Annual BMI growth at the highest and lowest SEP quintiles by baseline weight status in three age periods in (A) boys and (B) girls. Mean BMI growth and 95% confidence intervals are presented for highest and lowest quintiles of SEP. Slope Index of Inequality values are presented for each weight status group. \* $p < 0.05$  \*\* $p < 0.01$  \*\*\* $p < 0.001$ . BMI, body mass index; SEP, socioeconomic position

factors that are socioeconomically patterned. For example, there is strong evidence that poor diet quality<sup>34-36</sup> and insufficient physical activity<sup>37-39</sup> is income and education related in many countries. Socioeconomic influences on these obesity-related behaviours may be particularly impactful during middle childhood where rapid physical changes coincide with sudden environmental changes as children start primary school. It is also possible that children from low SEP in this study's sample experience an earlier adiposity rebound than

those at high SEP, which would explain the faster BMI growth in middle childhood. This would be consistent with findings from two recent European studies.<sup>40,41</sup> As the GEE analyses showed that ethnicity did not have major effect on annual BMI growth, it is unlikely that potential ethnic differences between SEP groups could explain the trends identified.

There are many strengths of this analysis. A large, nationally representative dataset with repeated, direct measurements of BMI





**FIGURE 5** Adjusted mean annual BMI growth by age period, SEP quintile and weight status. Mean annual BMI growth is determined from a GEE model adjusting for sex, indigenous status, primary language spoken at home and for interactions between SEP and age period, SEP and weight status and weight status and age period, are presented for those with healthy weight, overweight and obesity. BMI, body mass index; GEE, generalised estimating equations; SEP, socioeconomic position

and up to 12 years of follow-up for each participant equating to over 80,000 person-years of follow-up was used. This allowed for an analysis of changes in the *rate* of BMI growth—an indicator that would not be measurable in cross-sectional or single time point studies. This also facilitated an examination of the direction of effect; the relationship between SEP quintile and weight status at the *start* of a time period on annual BMI growth over a subsequent two years period could be investigated. Although not definitive, this provides stronger evidence towards causal relationships than cross-sectional studies. Furthermore, these analyses used contemporary data with the most recent measurements collected in 2017 ensuring that our findings are relevant to a context of rising obesity rates that are attributed to environmental factors.<sup>42-44</sup> This is also the first Australian study to consider the differences in socioeconomic inequalities across the weight spectrum and is one of the largest studies to do so internationally.

There are also some limitations to consider. Firstly, data from two cohorts that overlapped only from ages 4 to 12 years were combined, and meant that survey weights that accounted for the complex sampling strategy of LSAC could not be applied. However, the cohorts (each including the observations of over 4000 children) had similar characteristics (Table 1) indicating that it was appropriate to combine them. Moreover, the results of the sensitivity analysis separated by cohort and applying survey weights supported the primary conclusion that middle childhood was the key period in which inequalities in annual BMI growth form. These results were also consistent with the finding that inequalities were wider at

higher weight status. Also, loss to follow-up and missing or implausible measurements of BMI and SEP over the decade (or more) of follow-up may have resulted in bias. These losses did not appear to be random; the lost participants were more likely to have obesity and were of lower socioeconomic position than those that remain (Tables S2 and S3) which, if anything, means the results are likely conservative. Finally, except for the aforementioned comparison with the UK, the generalisability of the findings to other countries are unknown and likely dependent on contextual factors such as the level of economic inequality and lifestyle. As such, further research is needed in other contexts to understand the similarities and differences in inequalities in BMI growth rates across countries.

## 5 | CONCLUSIONS AND IMPLICATIONS

This study provides strong evidence that socioeconomic inequalities in BMI growth rates differ in early childhood, middle childhood and adolescence. While inequality is present in those with obesity in early childhood, they strengthen in all weight status groups throughout middle childhood with some attenuation during adolescence. There is evidence of wider inequality in children with overweight or obesity than children with healthy weight. This is the first study, to the best of our knowledge, to examine inequalities in BMI growth rates across both age and the weight spectrum and the only Australian study to examine the latter of these.

In the context of limited resources, the findings of this study suggest that targeting weight gain prevention efforts to middle childhood, to children already suffering from overweight and obesity and to those at lower socioeconomic position has the potential to reduce socioeconomic inequalities in obesity. Clinical and public health intervention tools could be employed for this. For example, at a clinical level, general practitioners and paediatricians could provide tailored weight management support for at-risk children within this age and socioeconomic group. At a public health level, structural obesity prevention interventions, which are often the most effective but also the most expensive, could be targeted to low socioeconomic areas instead of the whole population. Another option would be to provide interventions, such as directed physical activity sessions, to primary schools in low socioeconomic areas. While further research is needed in this area, targeting interventions to the relevant subgroups could offer an affordable and sustainable approach to addressing inequalities in childhood obesity.

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### CONFLICTS OF INTEREST

None of the funders had any role in the design and conduct of the study. None of the authors have conflicts of interest to disclose.

### AUTHOR CONTRIBUTIONS

Anagha Killedar conducted analyses and wrote the initial draft of the manuscript. Anagha Killedar, Alison Hayes and Thomas Lung contributed to the study design, interpreted analyses and made revisions to manuscript drafts.

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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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