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Early childhood weight gain: Latent patterns and body composition outcomes

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Abstract

Background: Despite early childhood weight gain being a key indicator of obesity risk, we do not have a good understanding of the different patterns that exist.

Objectives: To identify and characterise distinct groups of children displaying similar early-life weight trajectories.

Methods: A growth mixture model captured heterogeneity in weight trajectories between 0 and 60 months in 1390 children in the Avon Longitudinal Study of Parents and Children. Differences between the classes in characteristics and body size/composition at 9 years were investigated.

Results: The best model had five classes. The "Normal" (45%) and "Normal after initial catch-down" (24%) classes were close to the 50th centile of a growth standard between 24 and 60 months. The "High-decreasing" (21%) and "Stable-high" (7%) classes peaked at the ~91st centile at 12-18 months, but while the former declined to the ~75th centile and comprised constitutionally big children, the latter did not. The "Rapidly increasing" (3%) class gained weight from below the 50th centile at 4 months to above the 91st centile at 60 months. By 9 years, their mean body mass index (BMI) placed them at the 98th centile. This class was characterised by the highest maternal BMI; highest parity; highest levels of gestational hypertension and diabetes; and the lowest socio-economic position. At 9 years, the "Rapidly increasing" class was

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estimated to have 68.2% (95% confidence interval [CI] 48.3, 88.1) more fat mass than the "Normal" class, but only 14.0% (95% CI 9.1, 18.9) more lean mass.

Conclusions: Criteria used in growth monitoring practice are unlikely to consistently distinguish between the different patterns of weight gain reported here.

KEYWORDS

ALSPAC, body composition, childhood, growth, weight

1 | BACKGROUND

Early childhood growth (<5 years) is a key indicator of obesity and disease risk.[1-3] Rapid infant weight gain, defined as upward crossing through one centile band on a United Kingdom (UK) growth chart in the first two years of life, is strongly associated with increased obesity risk.[4,5] This finding has also been observed in studies investigating weight gain beyond infancy and up until 5 years of age.[6,7] Similarly, failure to thrive in early childhood, which is often defined as weight passing downwards through two centile bands,[8] is related to increased risk for thinness or underweight.[9] Even a single weight measurement of a child provides some information about their future body mass index (BMI).[10]

The problem with these types of early childhood growth traits, which are often used in epidemiological research and growth monitoring practice,[11,12] is that they are a crude and potentially misleading summary of a child's pattern of weight gain. This is particularly true given that many infants cross centile bands on a growth chart as part of the normal, innocuous growth assortment that occurs after birth.[13,14] Further, centile crossing between two time points can just reflect differences between the sample under investigation and the source sample used to construct the growth chart. Compared against the WHO Child Growth Standards,[15] for example, the average pattern of weight gain in normal, healthy UK children is characterised by an increase in approximately one centile band between 3-4 and 12-18 months.[16] This is, at least partly, because the WHO source sample comprised exclusively breast-fed infants, who are known to demonstrate slower weight gain.[17]

While simple, easily identifiable traits are unarguably a core and important aspect of growth monitoring, a better understanding of the different patterns of early childhood weight gain that may exist in a population is needed and would be informative for those interested in monitoring the growth of children. Numerous papers have summarised early childhood weight trajectories in terms of individual-level traits,[5,9-11] but we are only aware of seven publications that have analysed early childhood weight data using growth mixture modelling,[18-24] an advanced technique that identifies distinct latent classes of individuals who share similar trajectories.[25] None of these publications included a normal, healthy sample in a high-income country with body composition outcomes. The aim of the present paper was to describe latent patterns of weight gain between 0 and 5 years of age in the UK Avon Longitudinal Study of Parents and Children (ALSPAC) and describe them in terms of length/height growth; maternal, family, and birth characteristics; and body size and composition outcomes at ages 7 and 9 years.

Synopsis

Study question

What are the latent patterns of weight gain between 0 and 5 years of age in a large UK birth cohort? How are these patterns characterised in terms of their length/height growth, sociodemographic and birth characteristics, and their relationship with body size and composition at 7 and 9 years?

What's already known

Despite early childhood weight gain being a key indicator of obesity risk, we do not have a good understanding of the different patterns that exist. Studies have investigated BMI, which has limited clinical utility in early life.

What this study adds

The greatest obesity risk was observed in 3% of children whose weight increased through two centile bands, following mild growth faltering.

2 | METHODS

2.1 | Cohort selection

The ALSPAC is a prospective birth cohort study.[26,27] Pregnant women living in the defunct county of Avon in England with an expected delivery date between April 1991 and December 1992 were invited to take part. The total number of pregnancies is 15 454, representing 15 589 foetuses of which 14 901 were alive at one year of age. Follow-up has included questionnaires, linkage to routine data, and clinics starting at 7 years of age. The children in focus (CiF) group (n = 1432) are a 10% random sample of the ALSPAC cohort who attended frequent clinics across early childhood. The sample for the present paper comprised 1390 singletons, representing 97% of the CiF group, who were alive at age 1 year, had not been withdrawn from the study, and had at least one measurement of weight and length/height in early childhood.

2.2 | Exposure: anthropometric data

Birthweight and length were obtained from obstetric records, birth notifications, or was measured by ALSPAC. Weight was measured at 4, 8, 12, 18, 25, 31, 37, 43, 49, and 61 months of age. Length was measured up until the 18-month sweep, after which height was taken.

2.3 | Outcomes: anthropometric and body composition outcome data

At ages 7 and 9 years, weight and height were measured; BMI was computed as kg/m^2. *Z*-scores according to the WHO 2007 reference were computed for all of these variables.[28] At 9 years, dual-energy X-ray absorptiometry (DXA) scans, using a Lunar prodigy densitometer (GE Healthcare), were performed and whole-body fat and lean masses were derived.

2.4 | Potential confounders

We considered the following as putative confounding variables of the relationship between weight trajectories and outcomes at 7 and 9 years: gestational age, gestational hypertension, diabetes in pregnancy, smoking during pregnancy, alcohol consumption during pregnancy, parity, maternal age at birth of baby, maternal BMI at 12 weeks gestation, parental educational qualifications, parental occupation, household income, and a family adversity index. Further details about the derivation of these variables can be found in Supplementary Material 1.

2.5 | Statistical analysis

A growth mixture model was developed to identify distinct groups of individuals who had similar weight (kg) trajectories between 0 and 60 months of age. Group-based trajectory models (latent class trajectory models) are a type of growth mixture model which are also used for the identification of distinct groups of individuals with similar trajectories. In these models, within-class variability is fixed to zero, meaning all individuals within a class display the same trajectory. This assumption is unrealistic[29] and often results in poorly fitting models which violate key assumptions such as serial independence of residuals. As such, we develop growth mixture models in which within-class variance can be freely estimated, thus meaning individuals within a class are allowed to display different trajectories.

Model development considered several age functions for the trajectory shape, removing default constraints on the growth term variances and covariances, and different specifications of the within-class residual variance structure. Features of the best fitting model include a Berkey-Reed structural growth function[30] and class-specific (once and twice removed) autocorrelated errors.[31] The best class solution was selected based on model fit (eg, Bayesian Information Criterion), quality of classification or separation between the classes (eg, entropy), and plausibility and interpretability of the average trajectories (see Tables S1-S3 for model specification and diagnostics). A figure was produced showing the average fitted trajectories between 0 and 60 months for each class in kg and in *Z*-scores, according to the WHO Standards.[15] To convert the kg trajectories to the *Z*-score trajectories, LMS values averaged across sexes were used.[32] After birth and up until 4 months, *Z*-score trajectories are not plotted because of the lack of data in between these ages.

The early childhood length/height measurements were converted to *Z*-scores according to the WHO Standards, again using sex-averaged LMS values. A multilevel model was developed to describe how mean length/height *Z*-scores change between 4 and 60 months in each class. A figure was produced showing the estimated trajectories and mean values for birth length *Z*-scores, based on observed data.

Descriptive statistics for each potential confounder, and height and BMI *Z*-scores at 7 and 9 years, were produced stratified by class. General linear regression was used to estimate differences between classes in (1) weight, height, and BMI at 7 and 9 years and (2) fat mass and lean mass at 9 years, with adjustment for all potential confounders. Weight and BMI at both ages and fat mass at age 9 years were skewed. To enable comparison of effect sizes across outcomes, the transformation $y = 100\ \ln(x)$ was used for all outcomes, meaning the resulting estimates are symmetric percentage differences.[33] Full details of the mixture modelling and multilevel length/height *Z*-score modelling can be found in Supplementary Material 1.

2.6 | Missing data

Multiple imputation was used to account for missing data, under a missing at random (MAR) assumption, following the guidelines of Sterne et al[34] Evidence to support the MAR assumption is provided in Table S4. Imputation of 100 data sets was performed using chained equations, and imputations were weighted by the posterior probabilities of most-likely class membership (using importance weights). Following imputation, descriptive statistics and regression models were computed using the multiply imputed data, using Rubin's rules to combine estimates across the 100 data sets.[35] Further details about the imputation process can be found in Supplementary material 1.

2.7 | Ethics approval

Ethical approval for the study was obtained from the ALSPAC Ethics and Law Committee and the Local Research Ethics Committees (and conformed to the Declaration of Helsinki). Informed consent for the use of data collected via questionnaires and clinics was obtained from participants following the recommendations of the ALSPAC Ethics and Law Committee at the time. Consent for biological samples has been collected in accordance with the Human Tissue Act (2004). The study website contains details of all the data that is available through a fully searchable data dictionary and variable search tool: http://www.bristol.ac.uk/alspac/researchers/our-data/

3 | RESULTS

Descriptive statistics of the sample are presented in Tables 1 and 2. Missingness was less than 10% for most variables, except for variables relating to maternal anthropometry and socio-economic position (up to 40% missing).

3.1 | Latent weight classes

A mixture model with five classes provided the best representation of the serial weight data and the most plausible solution. Figure 1 shows the average trajectories for each latent class.

- Class 5 comprised 45% of the sample and had an average trajectory just above the 50th centile after 24 months. This class is referred to as "Normal."
- Class 2 comprised 24% of the sample and had an average trajectory characterised by catch-down growth (< −0.67 *Z*-scores) between 0 and 4 months followed by tracking just below the 50th centile after 24 months. This class is referred to as "Normal after initial catch-down."
- Class 4 comprised 21% of the sample and had an average trajectory characterised by the highest mean birthweight, rapid infant weight gain (> +0.67 *Z*-scores) in the first ~ 12 months of life, followed by a gradual decrease in *Z*-scores to approximately the 75th centile at 60 months. This class is referred to as "High-decreasing."
- Class 1 comprised 7% of the sample and had an average trajectory characterised by rapid infant weight gain (> +0.67 *Z*-scores) in the first ~ 12 months of life, followed by stabilisation and tracking at the 91st centile after 24 months. This class is referred to as "Stable-high."
- Class 3 comprised 3% of the sample and had an average trajectory that, following an initial decline in *Z*-score, rapidly increased from below the 50th centile at 4 months to above the 91st centile at 60 months. This class is referred to as "Rapidly increasing."

3.2 | Height Z-score trajectories

The height *Z*-score trajectories are shown in Figure S9. A similar but less extreme pattern, to that observed for weight in Figure 1, was observed. The height *Z*-score trajectory for each class generally fell between the 25 and 75th centiles between 12 and 60 months.

3.3 | Early-life characteristics

The "High-decreasing" and "Stable-high" classes included more males, whereas the "Normal after initial catch-down" and "Rapidly increasing" classes included more females (Table 3). Mothers of children in the "High-decreasing class" had the lowest mean BMI (23.7 kg/m^2) but the second highest mean height (164.7 cm). The "Rapidly increasing" class was characterised by the highest maternal BMI and the lowest maternal age; the highest proportion of women with parity ≥ 3, the highest

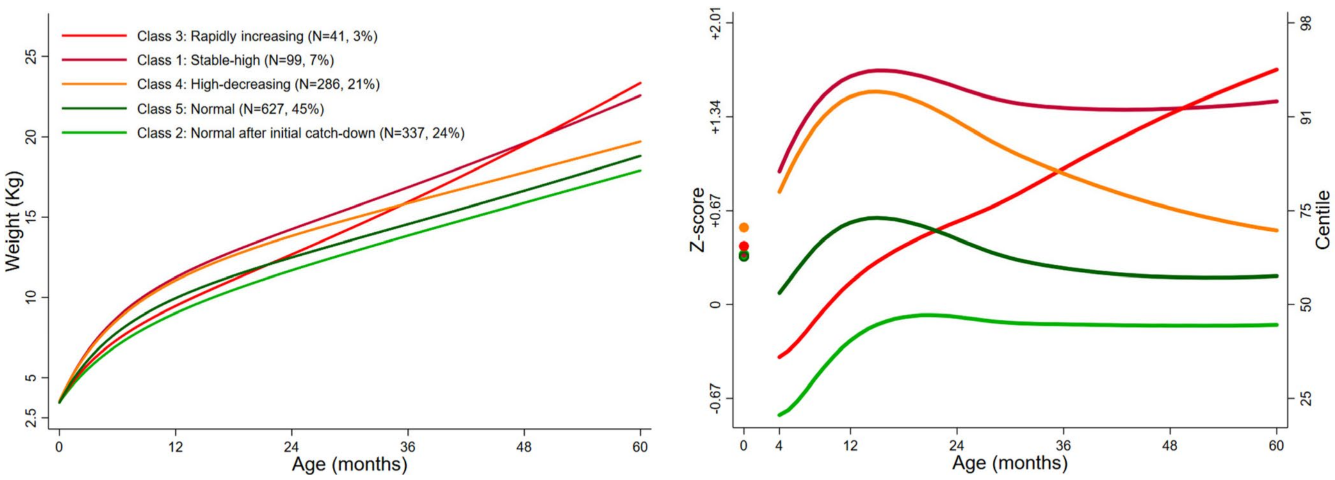

FIGURE 1 Average fitted trajectories from the final mixture model on the original scale (left panel) and expressed relative to the WHO Child Growth Standard (right panel)

TABLE 1 Description of the study sample

			Missing (N [%])
Sex			0
Male	N (%)	753 (54.2)	
Female	N (%)	637 (45.8)	
Ethnicity			86 (6.2)
White	N (%)	1257 (96.4)	
Non-White	N (%)	47 (3.6)	
Parity			54 (3.9)
1	N (%)	624 (46.7)	
2	N (%)	442 (33.1)	
≥3	N (%)	270 (20.2)	
Gestational age (weeks)	Mean (SD)	39.5 (1.6)	0
Gestational hypertension			24 (1.7)
No	N (%)	1168 (85.5)	
Yes	N (%)	198 (14.5)	
Diabetes in pregnancy			69 (5.0)
No	N (%)	1258 (95.2)	
Yes	N (%)	63 (4.8)	
Mother smoked during first 3 mo of pregnancy			38 (2.7)
No	N (%)	1085 (80.3)	
Yes	N (%)	267 (19.7)	
Mother drank alcohol during first 3 mo of pregnancy			51 (3.7)
No	N (%)	1103 (82.4)	
Yes	N (%)	236 (17.6)	
Mother's age	Mean (SD)	28.8 (4.7)	0
Mother's height (cm)	Mean (SD)	164.2 (6.3)	512 (36.8)
Mother's BMI (kg/m^2)	Median (IQR)	23.5 (21.5 26.4)	555 (39.9)
Mother's highest qualification			64 (4.6)
Degree	N (%)	193 (14.6)	
A level	N (%)	336 (25.3)	
O level	N (%)	475 (35.8)	
Vocational	N (%)	130 (9.8)	
CSE	N (%)	192 (14.5)	
Partner's (or mother's if partner's missing) occupation			455 (32.7)
Higher managerial, administrative, and professional occupations	N (%)	146 (15.6)	
Lower managerial, administrative, and professional occupations	N (%)	303 (32.4)	
Intermediate occupations	N (%)	113 (12.1)	
Small employers and own account workers	N (%)	83 (8.9)	
Lower supervisory and technical occupations	N (%)	126 (13.5)	
Semi-routine occupations	N (%)	79 (8.5)	
Routine occupations	N (%)	85 (9.1)	
Weekly family income (£)			505 (36.3)
≥400	N (%)	432 (48.8)	
300-399	N (%)	203 (22.9)	
200-299	N (%)	139 (15.7)	
0-199	N (%)	111 (12.5)	

(Continued)

TABLE 1 (Continued)

			Missing (N [%])
Family adversity index during pregnancy			32 (2.3)
0	N (%)	597 (44.0)	
1	N (%)	353 (26.0)	
2	N (%)	213 (15.9)	
≥3	N (%)	192 (14.1)	

levels of gestational hypertension and diabetes; and the lowest socio-economic position on all indicator variables measured (Table 3).

3.4 | Body size and composition outcomes

Outcomes at age 7 years were similar to those observed at age 9 years and are included in Tables S5 and S6. Table 4 shows mean (95% confidence interval [CI]) values for height and BMI *Z*-scores at 9 years for each class. Estimates based on the observed and imputed data are reported and demonstrate a high degree of agreement. The "High-decreasing" class demonstrated essentially the same mean value for height *Z*-scores and BMI *Z*-scores (using observed or imputed data), whereas the "Stable-high" and "Rapidly increasing" classes did not. For example, using the imputed data, the mean height was 0.75 *Z*-scores (~75th centile) in the "Rapidly increasing" class, but the mean BMI was 2.13 *Z*-scores (~98th centile).

Estimated differences between classes in body size and composition variables at 9 years are presented in Table 5. The "Normal after initial catch-down" class was smaller on all measures compared with the "Normal" class, with the biggest estimate indicating 24.1% (95% CI 15.5, 32.7) less fat mass. The "High-decreasing" class had 3.5% (95% CI 1.7, 5.4) higher lean mass at age 9 years compared with the "Normal" class, with no difference

TABLE 2 Body size and composition data

	Age (y)	Weight (kg)		Length/Height (cm)		BMI (kg/m^2)		Fat mass (kg)		Lean mass (kg)	
Visit	Median (10th & 90th centiles)	N	Mean (SD) or Median (IQR)	N	Mean (SD)	N	Median (IQR)	N	Median (IQR)	N	Mean (SD)
Birth	0 (0, 0)	1379	3.5 (0.5)	1368	50.9 (2.4)						
4 mo	0.31 (0.31, 0.33)	983	6.6 (0.8)	980	62.6 (2.2)						
8 mo	0.67 (0.65, 0.69)	1276	8.8 (1.0)	1275	70.2 (2.4)						
12 mo	1.02 (1.02, 1.06)	1209	10.2 (1.1)	1208	75.6 (2.5)						
18 mo	1.54 (1.50, 1.58)	1129	11.4 (1.3)	1131	81.7 (2.8)						
25 mo	2.08 (2.06, 2.10)	1089	12.7 (1.5)	1016	86.9 (3.0)						
31 mo	2.60 (2.58, 2.62)	1092	14.0 (1.7)	1053	91.6 (3.3)						
37 mo	3.08 (3.07, 3.12)	1037	15.1 (1.8)	1027	95.6 (3.5)						
43 mo	3.60 (3.58, 3.63)	1033	16.3 (1.9)	1025	99.3 (3.7)						
49 mo	4.08 (4.06, 4.12)	1000	17.3 (2.2)	999	103.2 (3.9)						
61 mo	5.15 (5.10, 5.25)	961	19.6 (2.7)	961	110.3 (4.3)						
7 y	7.48 (7.37, 7.67)	940	24.8 (22.7, 27.8)	943	125.6 (5.3)	940	15.8 (14.9, 17.0)				
9 y	9.87 (9.73, 10.13)	890	33.2 (29.6, 38.0)	890	139.2 (6.0)	890	17.2 (15.8, 19.2)	864	7.3 (4.8, 10.9)	864	24.5 (3.1)

TABLE 3 Characteristics of each latent class

	Class 5	Class 2	Class 4	Class 1	Class 3
	Normal	Normal after initialcatch-down	High-decreasing	Stable-high	Rapidly increasing
	Estimates are % or mean (95% CI)				
Sex					
Male	54 (50, 58)	33 (28, 38)	77 (72, 82)	70 (60, 79)	37 (22, 53)
Female	46 (42, 50)	67 (62, 72)	23 (18, 28)	30 (21, 40)	63 (47, 78)
Ethnicity					
White	95 (94, 97)	97 (95, 99)	98 (96, 99)	93 (88, 99)	100
Non-white	5 (3, 6)	3 (1, 5)	2 (1, 4)	7 (1, 12)	0
Parity					
1	49 (45, 53)	38 (32, 43)	54 (47, 60)	54 (44, 65)	27 (12, 41)
2	31 (28, 35)	40 (34, 45)	28 (23, 34)	30 (20, 39)	44 (27, 60)
≥3	20 (16, 23)	22 (18, 27)	18 (13, 23)	16 (8, 23)	30 (15, 45)
Gestational age (weeks)	39.6 (39.5, 39.7)	39.6 (39.4, 39.7)	39.5 (39.3, 39.7)	39.2 (38.8, 39.6)	39.5 (39.2, 39.8)
Gestational hypertension					
No	84 (81, 87)	88 (84, 92)	86 (81, 90)	87 (80, 94)	79 (65, 92)
Yes	16 (13, 19)	12 (8, 16)	14 (10, 19)	13 (6, 20)	21 (8, 35)
Diabetes in pregnancy					
No	95 (93, 97)	94 (91, 97)	97 (95, 99)	95 (90, 100)	90 (80, 100)
Yes	5 (3, 7)	6 (3, 9)	3 (1, 5)	5 (0, 10)	10 (0, 20)
Mother smoked during first 3 months of pregnancy					
No	80 (77, 83)	83 (78, 87)	80 (75, 84)	77 (69, 86)	77 (64, 91)
Yes	20 (17, 23)	17 (13, 22)	20 (16, 25)	23 (14, 31)	23 (9, 36)
Mother drank alcohol during first 3 months of pregnancy					
No	81 (78, 84)	84 (80, 88)	84 (80, 89)	81 (73, 89)	82 (70, 94)
Yes	19 (16, 22)	16 (12, 20)	16 (11, 20)	19 (11, 27)	18 (6, 30)
Mother's age	28.7 (28.3, 29.1)	29.5 (29.0, 30.0)	28.7 (28.1, 29.2)	29.0 (28.2, 29.9)	28.3 (27.1, 29.6)
Mother's height (cm)	163.6 (162.9, 164.2)	163.7 (162.8, 164.6)	164.7 (163.8, 165.7)	166.1 (164.5, 167.7)	164.3 (161.8, 166.9)
Mother's BMI (kg/m^2)	24.0 (23.7, 24.4)	24.7 (24.1, 25.4)	23.7 (23.2, 24.3)	25.7 (24.6, 26.9)	26.5 (24.7, 28.6)
Mother's highest qualification					
Degree	12 (9, 15)	19 (15, 23)	16 (12, 21)	9 (3, 15)	7 (−1, 15)
A level	28 (24, 31)	24 (19, 29)	21 (16, 26)	26 (17, 35)	31 (15, 46)
O level	34 (30, 38)	32 (26, 37)	43 (38, 49)	39 (29, 50)	28 (13, 43)
Vocational	11 (8, 14)	10 (7, 13)	8 (4, 11)	10 (4, 17)	17 (5, 30)
CSE	15 (12, 18)	15 (11, 20)	12 (8, 16)	16 (7, 24)	17 (4, 30)
Partner's (or mother's if partner's missing) occupation					
Higher managerial, administrative, and professional occupations	15 (11, 18)	17 (12, 21)	12 (7, 16)	12 (5, 20)	9 (−1, 18)
Lower managerial, administrative, and professional occupations	27 (23, 31)	32 (26, 39)	28 (22, 34)	39 (27, 52)	25 (10, 40)
Intermediate occupations	11 (8, 14)	10 (6, 14)	15 (10, 20)	11 (3, 20)	18 (5, 32)
Small employers and own account workers	11 (8, 14)	8 (4, 13)	9 (5, 13)	8 (0, 16)	8 (−3, 18)
Lower supervisory and technical occupations	13 (9, 16)	14 (10, 19)	17 (11, 22)	15 (5, 25)	15 (1, 28)
Semi-routine occupations	11 (8, 14)	7 (3, 10)	11 (7, 15)	3 (−3, 10)	15 (1, 28)
Routine occupations	12 (9, 16)	11 (7, 15)	9 (5, 13)	10 (2, 19)	11 (−1, 23)

(Continued)

TABLE 3 (Continued)

	Class 5	Class 2	Class 4	Class 1	Class 3
	Normal	Normal after initialcatch-down	High-decreasing	Stable-high	Rapidly increasing
	Estimates are % or mean (95% CI)				
Weekly family income (£)					
≥400	46 (41, 50)	48 (42, 55)	45 (38, 52)	40 (29, 51)	42 (24, 61)
300–399	23 (19, 27)	21 (15, 26)	26 (20, 32)	19 (9, 28)	17 (1, 33)
200–299	18 (15, 22)	19 (13, 24)	12 (7, 17)	18 (8, 28)	22 (6, 39)
0–199	12 (9, 16)	12 (8, 17)	17 (12, 22)	23 (13, 34)	18 (3, 33)
Family adversity index during pregnancy					
0	43 (39, 47)	44 (38, 49)	51 (45, 57)	35 (25, 45)	41 (24, 57)
1	27 (24, 31)	25 (20, 30)	23 (18, 28)	30 (21, 39)	22 (9, 36)
2	15 (12, 18)	18 (13, 22)	14 (10, 18)	20 (12, 28)	18 (6, 31)
≥3	15 (12, 17)	14 (10, 18)	12 (8, 16)	15 (7, 22)	18 (5, 31)

Note: Results estimated using multiply-imputed data and weighted by posterior probabilities of most-likely class membership.

in BMI or fat mass. Both the "Stable-high" and "Rapidly increasing" classes had higher weight, BMI, and fat mass (and, to a lesser extent, height, and lean mass) at 9 years compared with the "Normal" class. For example, the "Rapidly increasing" class had 25.6% (95% CI 19.0, 32.2) higher BMI and 68.2% (95% CI 48.3, 88.1) higher fat mass, but only a 2.7% (95% CI 1.0, 4.4) height advantage and a 14.0% (95% CI 9.1, 18.9) lean mass advantage. The sensitivity analyses in Tables S7-S9 show similar patterns of results.

4 | COMMENT

4.1 | Principal findings

This paper provides a detailed investigation of latent patterns of early childhood weight gain between 0 and 60 months. We found five distinct classes and described them in terms of maternal, family, and birth characteristics as well as body size and composition outcomes. The highest average BMI and fat mass values at 9 years were observed in the smallest class of children (3% of the sample) who demonstrated rapid weight gain upward through more than two centile bands between 4 and 60 months. This class had all the hallmarks of children most at risk of obesity (eg, highest maternal BMI and lowest maternal education) reinforcing the need for structural interventions that show equal or greater benefit for more disadvantaged socio-economic groups.[36]

4.2 | Strengths of the study

The main strength of the paper lies in the data (eg, DXA-assessed outcomes) and meticulous development of the mixture model. Unlike some

TABLE 4 Height and BMI *Z*-score values at age 9 years for each class, based on observed and imputed data

	Class 5	Class 2	Class 4	Class 1	Class 3
	Normal	Normal after initial catch-down	High-decreasing	Stable-high	Rapidly increasing
	Estimates are mean (95% CI)				
Imputed data					
9 years					
Height Z-score	0.17 (0.09, 0.25)	−0.10 (-0.22, 0.02)	0.43 (0.32, 0.54)	0.93 (0.72, 1.13)	0.75 (0.37, 1.14)
BMI Z-score	0.34 (0.24, 0.43)	0.06 (-0.07, 0.18)	0.44 (0.31, 0.57)	1.56 (1.29, 1.83)	2.13 (1.70, 2.56)
Observed data					
9 years					
Height Z-score (N = 890)	0.19 (0.10, 0.27)	−0.10 (-0.24, 0.03)	0.43 (0.31, 0.55)	0.88 (0.63, 1.12)	0.94 (0.51, 1.37)
BMI Z-score (N = 890)	0.31 (0.20, 0.41)	0.02 (-0.12, 0.16)	0.44 (0.30, 0.57)	1.53 (1.22, 1.83)	2.04 (1.59, 2.49)

Note: Results weighted by posterior probabilities of most-likely class membership. Z-scores according to the WHO 2007 Reference.

TABLE 5 Class differences in body size and composition outcomes at age 9 years

	Class 5	Class 2	Class 4	Class 1	Class 3
	Normal	Normal after initial catch-down	High-decreasing	Stable-high	Rapidly increasing
		s% (95% CI)	s% (95% CI)	s% (95% CI)	s% (95% CI)
9 years					
Weight	0.0 (reference)	−6.7 (-9.4, -4.0)	3.1 (0.3, 6.0)	21.8 (16.8, 26.8)	31.1 (22.7, 39.4)
Height	0.0 (reference)	−1.2 (-1.8, -0.5)	0.8 (0.2, 1.4)	2.9 (1.8, 3.9)	2.7 (1.0, 4.4)
BMI	0.0 (reference)	−4.3 (-6.4, -2.3)	1.5 (−0.6, 3.7)	16.1 (12.2, 20.1)	25.6 (19.0, 32.2)
Fat mass	0.0 (reference)	−24.1 (-32.7, -15.5)	3.3 (−5.6, 12.3)	51.6 (35.3, 67.9)	68.2 (48.3, 88.1)
Lean mass	0.0 (reference)	−2.8 (-4.7, -0.9)	3.5 (1.7, 5.4)	9.3 (6.4, 12.2)	14.0 (9.1, 18.9)

Note: s% estimates are symmetric percentage differences. Results estimated using confounder-adjusted regression models applied to multiply-imputed data and weighted by posterior probabilities of most-likely class membership.

published studies which suffer from modelling trajectories on the *Z*-score (or even centile) scale,[37-40] which distort the mixtures, we considered weight in kg. We believe this is preferable to modelling BMI, as in many other publications,[37,38,41,42] mainly because of the poor clinical utility and interpretability of BMI in early childhood.[43-45] The Berkey-Reed structural growth function is arguably the best model for early childhood growth,[30,46-48] and we present the first published example of a mixture model incorporating this function. We also modelled the random structure resulting from having to constrain the variance-covariance structure,[31] as is normal with these models, something that most (if not all) early childhood growth mixture modelling studies do not consider.[49]

4.3 | Limitations of the data

The ALSPAC cohort is predominantly white British, with low levels of socio-economic deprivation, which may limit generalisability of the findings. ALSPAC is a cohort of individuals born in 1991-1992. Given the increased exposure to and severity of the obesogenic environment experienced by children today, if repeated with a more contemporaneous cohort of children, we may have observed a greater prevalence of children in the "Rapidly increasing" or "Stable-high" BMI trajectories. Alternatively, we may have observed more extreme trajectories (ie, greater increases in the "Rapidly increasing" class or a higher trajectory in the "Stable-high" class). If the latter, then it is likely that associations between these classes and the outcomes would have been stronger. A pragmatic decision was made to analyse data from both sexes together, as had been done elsewhere.[49] There are systematic differences in early childhood growth between boys and girls, but this is not a reason to hypothesise that there should be a different number of latent classes for each sex. Further, stratifying analyses by sex would have led to smaller classes and reduced the precision of our regression models. These outcomes had large amounts of missing data, but results were comparable in the main analysis (which accounted for missing data using multiple imputation) and in a sensitivity analysis in which the outcomes were not imputed.

4.4 | Interpretation

In a recent systematic review, 14 studies had used some form of growth mixture modelling to investigate BMI trajectories starting at birth and another 49 to investigate BMI trajectories starting at some time after birth.[49] We could only, however, find 7 studies which had investigated latent patterns of early childhood body weight trajectories.[18-24] In one publication, a growth mixture model was developed using serial weight *Z*-scores (according to the WHO Standards) between 0 and 36 months in 1364 singleton, term infants.[22,50] The largest class comprised 96% of the sample and had an average trajectory comparable to that of the "Normal" class in the present study, but the other two classes (representing just 4% of the sample) were not comparable to any in the present study.

The two largest classes we observed accounted for nearly 70% of the sample, and both had mean trajectories that tracked close to the 50th centile between 24 and 60 months. The average trajectory for the larger "Normal" class is consistent with previously published cross-sectional estimates of *Z*-scores (according to the WHO Standards) in the CiF group.[16] Compared to this "Normal" class, the smaller "Normal after initial catch-down" class had lower mean values for all body size and composition measures at 7 and 9 years, but with the greatest deficit being for fat mass. It is these children who, therefore, are likely to have the lowest obesity risks, but how they compare to the "Normal" class for other health and wellbeing outcomes warrants investigation.[51] The observed decline in mean weight *Z*-score in the first 4 months of life might seem concerning, but it is not severe enough to be classified as failure to thrive.[8] Less severe, catch-down growth has been viewed as a normal, innocuous aspect of the growth assortment that occurs early in life.[13,14]

The smallest class we found, comprising 3% of the sample, demonstrated a trajectory characterised by weight gain upward through more than two centile bands between 4 and 60 months of age. This class had the worst body composition outcomes at 9 years, with 68% more fat mass than the "Normal" class. This finding is in agreement with the literature linking rapid infant weight gain with increased risk of childhood obesity.[5] Rapid infant weight gain is, however, normally defined as upward crossing through one centile band on a UK growth chart (equivalent to 0.67 *Z*-scores) in the first two years of life.[4,5] Our "Rapidly increasing" class not only demonstrated rapid weight gain in the first two years of life, but also passed upwards through a second centile band between 24 and 60 months. Importantly, this class also showed an initial decline in weight *Z*-score between 0 and 4 months, which might be related to suboptimal early-life nutrition and bottle-feeding,[52] which we know are patterned according to socio-economic position and maternal weight status.[53-55] Indeed, a pattern of early childhood growth faltering relative to the WHO Standards has been well documented in samples that have not been selected on the basis of following the WHO breast-feeding recommendations.[56] The complex pattern of change in the "Rapidly increasing" class means that children demonstrating the most detrimental pattern of weight gain reported in the present study would actually appear to be "Normal" if they were only measured at birth and at some point between 12 and 24 months.

The "Stable-high" and "High-decreasing" classes both had average trajectories that demonstrated rapid infant weight gain between birth and 12-18 months of age, but otherwise these two groups were distinct. The "Stable-high" class had an average weight trajectory just below the 95% centile at 60 months and had estimated mean BMI values at 7 and 9 years that placed them just below the 95th centile. This class, which can be thought of as demonstrating borderline obesity, comprised 7% of the sample. This seems comparable to the 2018-2019 National Child Measurement Programme for England, which reported that 9.7% of 4- to 5-year-olds were obese (43).[57] Conversely, the "High-decreasing" class can be thought of as being constitutionally big. Height demonstrates a high degree of heritability,[58,59] and this class had mothers who were taller than those in the "Normal class," who gave birth to babies who were bigger than those in the "Normal class," who themselves grew to become taller than those in the "Normal" class with greater lean (but not fat) mass at age 9 years. Given the strong evidence that greater childhood height and lean mass are related to better adulthood health and socio-economic outcomes, particularly in the absence of elevated adiposity,[60-62] this class might comprise children with the most optimal pattern of early-life weight gain.

5 | CONCLUSIONS

This study demonstrates the high degree of variability and complexity of early childhood weight gain. The greatest obesity risk in the UK might be observed in a small proportion of children who demonstrate rapid weight gain upward through more than two centile bands, after an initial period of mild growth faltering against the WHO Standards. Conversely, the pattern of weight gain associated with the most favourable body size and composition outcomes may belong to constitutionally big children. Unfortunately, in the first two years of life, these constitutionally big children may be hard to distinguish from children who are unconstitutionally heavy and at high risk for obesity. Criteria used in growth monitoring practice and epidemiological research (eg, for rapid weight gain) are unlikely to consistently distinguish between the different patterns of weight gain reported in this study. To aid practitioners in identifying potentially deleterious patterns of weight gain, we advocate a more extensive measurement schedule during infancy and childhood for the collection of weight measurements at multiple time points. Accordingly, measurements taken at 0, 6 months, and 24 months, and then, further assessment at three or four years is recommended.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section.

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