International Journal of Obesity (2013), 1–9

www.nature.com/ijo

ORIGINAL ARTICLE

Q1

Social class variation in the predictors of rapid growth in infancy and obesity at age 3 years

R Layte[1], A Bennett[2], C McCrory[3] and J Kearney[2]

OBJECTIVE: To examine the extent to which early child nutrition, maternal antenatal lifestyle behaviours and child diet and lifestyle explain social class inequalities in the risk of rapid weight gain between birth and 3 years and obesity at age 3 years.
DESIGN: A longitudinal and prospective birth cohort study.
SUBJECTS: Nationally representative sample of 11 134 children and their parents followed from 9 months of age to until 3 years. Child weight and maternal height and weight were measured at 9 months and 3 years and child birth weight was extracted from hospital records. Other predictors of child growth and obesity were collected by maternal report at 9 months and 3 years.
RESULTS: Although born lighter on average, children of unskilled manual parents were 274 g heavier than children of professional parents by 3 years of age. The fully adjusted model of rapid growth from birth to 3 years of age and obesity at 3 years of age accounted for all social class differentials. Breastfeeding and age at the introduction of solids were associated with the largest average reduction (41%) in the odds ratio (OR) of rapid growth in the first 9 months of life for each class relative to the professional class. In the period from 9 months to 3 years of age, the class differential in rapid growth was reduced most by measures of the child's diet and lifestyle. However, the impact of the groups of predictors varied by social class. For early life growth, among the non-manual classes the proportionate reductions are largest when adjusted for early infant nutrition, whereas maternal prenatal smoking is more important for the manual social classes.
CONCLUSION: Preventative interventions to reduce levels of childhood obesity should be multi-dimensional but different dimensions should be given more or less significance depending on socio-economic group.

International Journal of Obesity accepted article preview 27 August 2013; doi:10.1038/ijo.2013.160

Keywords: child obesity; rapid weight gain; social class; social gradient

INTRODUCTION

There is now strong evidence that the prevalence of overweight and obesity among school-age children and adolescents has increased in recent decades across all countries for which data are available.[1,2] Obesity is one of the leading causes of preventable morbidity and mortality worldwide,[3] and is reported to track from childhood into adulthood.[4,5] Evidence shows that obesity is associated with serious short- and long-term effects on quality of life, psycho-social well-being, risk of chronic illness and increased health and social care costs.[5,6] Systematic reviews of current therapeutic interventions for childhood obesity have found that there is weak evidence for their efficacy;[7,8] as such, primary prevention of obesity appears to be a more effective policy option.

After some initial uncertainty in early research,[9] socio-economic status (SES) has been found to be strongly related to the risk of obesity among children,[10,11] with children and adolescents from lower income and social class households significantly more likely to be obese. Recent research has also shown that although the increase in obesity rates among higher SES groups may have moderated, rates among lower SES groups are still increasing.[12–14] Given the association between obesity and chronic disease, a widening of SES differentials in child obesity would, holding all else constant, imply widening health inequalities between SES groups over time.

Studies have identified a number of risk factors for rapid weight gain and early child obesity. These include birth weight, extent of breastfeeding, age at weaning, maternal smoking in pregnancy, consumption of alcohol in pregnancy, parental weight status, maternal weight gain in pregnancy, child's dietary quality and child physical exercise.[15–20] This research has provided important data on how different factors independently influence patterns of growth and risk of obesity. However, no research, as far as we are aware, has examined the role of these factors in explaining socio-economic variation in the risk of rapid growth and childhood obesity. Depending on the distribution of different risk factors across social class groups, it is possible that the observed patterns of growth and obesity are the result of different processes. For example, smoking in pregnancy is far more prevalent among manual working class mothers than among white collar mothers and as such may be a more important factor among manual working class groups. It is also possible that different factors are important in the early period of 'catch-up' or 'catch-down' growth than growth in later infancy.

Using data from a large nationally representative, longitudinal observational survey of children from the Republic of Ireland, we model the predictors of rapid growth between birth and 3 years of age and child obesity at age 3 years. Crucially, we model the velocity of child growth in two phases, the first from birth to 9 months and the second from 9 months to 3 years of age in order

Q2
Q3

[1]Economic and Social Research Institute, Dublin 2, Ireland; [2]Dublin Institute of Technology and [3]Trinity College Dublin, Dublin, Ireland. Correspondence: Professor R Layte, Economic and Social Research Institute, Whitaker Square, Sir John Rogerson's Quay, Dublin 2, Ireland.
E-mail: Richard.layte@esri.ie
Received 17 April 2013; revised 15 July 2013; accepted 8 August 2013

to understand how the effect of predictors can vary by child age. To examine whether the predictors of growth and obesity vary by socio-economic position, we decompose the effect of groups of predictors across social class groups.

Given the prevailing distribution of risk factors across social class groups, we hypothesise that the extent of breastfeeding and age at weaning will be the predominant risk factors for rapid growth in infancy and obesity at age 3 years among non-manual groups, whereas antenatal smoking, and to a lesser extent of alcohol consumption, will be the primary factors among the children of manual and unclassified social class groups.

Q4

SUBJECTS AND METHODS

Sample

The wave one sample was selected from the Child Benefit Register for the Republic of Ireland, which was provided by the Department of Social Protection. Of 16 136 mothers selected from the sampling frame, 11 134 agreed to take part in the study, a response rate of 69%. Fieldwork was carried out over 7 months, extending from September 2008 to end of April 2009. Children were selected so as to be 9-month old at the time of interview; consequently, eligible children were all those born between the 1 December 2007 and 30 June 2008.

The sampling frame for the study was the Child Benefit Register for the Republic of Ireland. The sample was selected on a systematic basis, pre-stratifying by marital status, county of residence, nationality and number of children (where child is defined as <16 years of age) in the household, using a random start and constant sampling fraction. The completed sample was statistically grossed or reweighted on the basis of external population estimates to ensure that it was wholly representative of all children aged 1 year or less in Ireland.

Parents were re-contacted as their child approached its third birthday and 9738 agreed to take part in the second wave, a response rate of 88%.

Physical measures

Birth weight from birth records was linked to each infant's survey record. The infant's height at 3three years was measured using a Leicester portable height stick. The child's weight at both time points was measured using a Class III medically approved SECA 835 portable electronic scales. Children's body mass index (BMI) at 3 years of age was indexed using the IOTF cutoffs for children aged 36 months.[21]

Q5

Maternal weight measurements were recorded at both time points to the nearest 0.5 kg using a Class III medically approved SECA 761 flat mechanical scale.

Calculations

Our measure of weight trajectory is calculated in two steps following the process used in Ong *et al*.[22] First, a weight *z*-score at both birth and 9 months of age is calculated (child weight – mean sample weight/sample standard deviation). Second, trajectory or change in weight *z*-score (SDS) is calculated by partitioning the change in *z*-score between the two ages with a change of less than −0.67 denoting a 'slow' trajectory, change between −0.67 and 0.67 denoting 'stable' and >0.67 denoting rapid change. The use of 0.67 is significant as this is equivalent to the distance between adjacent centile lines drawn on standard growth curves (that is, 2nd, 9th, 25th, 50th, 75th, 91th and 98th centiles).

Child BMI at 3 years of age was calculated in the usual manner (child weight in kg/child height in m^2). International Obesity Task Force thresholds were used to define child overweight and obesity at age 3 years. Maternal BMI was divided into underweight (BMI <18.5), healthy weight (BMI 18.5–25), overweight (BMI 25–29) and obese (BMI 30+).

Dependent variables

Three dependent variables are used: rapid weight gain from birth to 9 months of age; rapid weight gain from 9 months to 3 years of age and child obesity at 3 years of age.

Independent variables

A large number of measures was collected from the child's mother at first interview when the child was 9 months of age. These included child parity (first child, second or higher), child sex and gestational age (in weeks) at birth as well as maternal country of origin (Irish, UK, other EU, African and other). Retrospective information concerning maternal health and behaviours during pregnancy were also collected at the time of the first interview when the child was 9 months of age. These include average number of cigarettes smoked daily during pregnancy (none, <5, 6–10, 11+ daily) and units of alcohol consumed each week (none, light, moderate, heavy) plus maternal weight gain in pregnancy (<12, 12–14.9 and 15 kg+).

Maternal report was used to establish when solid foods were introduced (divided into five groups: <3 months, <4 months, 4–5 months, 5–6 months and 6+ months) and extent of breastfeeding (none, <3 months, <6 months and 6+ months). Our measure of breastfeeding included complementary feeding.

Family socio-economic position is represented by household social class. This was measured using the Irish Central Statistics Office's social class schema and coded using the International Standard Classification of Occupations 1988 (ISCO88). Household social class is established using a dominance procedure. This meant that in two-parent families where both members of the household were economically active, the family's social class group was assigned as the higher of the two. Where the individual is currently not in employment their previous job is used. Where there is no previous job the person is categorised as 'unclassified'.

The quality of the child's diet was measured at age 3 years by parental questionnaire using a modified version of the Sallis-Amherst Food Frequency Questionnaire.[23] Parents were asked whether the child had consumed each of 20 foods in the last 24 h and if so, if this was once or more than once. Responses were scaled into a dietary quality index using principle components analysis with responses weighted by factor scores and summed before being divided in to three tertiles (low, medium and high dietary quality).

Parent's reported the child's average daily number of minutes watching television or DVDs at interview when the child was aged 3 years. This was divided into three groups (< 1 h, <2 h and 2 h+).

Missing cases analysis

Cases missing weight measures at birth, 9 months or 3 years of age are excluded from the analysis (478). Overall, the degree of missing data was small for most covariates. However, maternal BMI was missing for 343 cases and prenatal alcohol consumption was missing for 264 cases. Analysis showed that these cases were not missing at random so rather than exclude them, a missing category is used in analysis. Together with cases missing on the independent variables, this reduces the sample for analysis from 9738 to 9057 cases.

Analyses

Univariate and multivariate logistic regression were used to analyse the relative odds of rapid weight gain (change in *z*-score >0.67) between birth and 9 months and between 9 months and 3 years of age. Logistic regression was also used to analyse the child's odds of obesity at age 3 years. To establish the contribution of different factors to child weight gain and risk of obesity, predictors were divided into three groups:

- Early infant nutrition (breastfeeding and weaning behaviours);
- Maternal prenatal behaviours (prenatal smoking and alcohol consumption);
- Child diet and lifestyle (child dietary quality, maternal weight status and child television (TV) viewing).

Logistic regression models were used to establish the effect of each group on risk of rapid weight gain and child obesity for each social class relative to a base model, which adjusts for maternal age, child sex, gestation, birthweight, birth order, weight gain in pregnancy and multiple status. The proportionate reduction in each social class coefficient is taken as a measure of the effect of each group of variables on the risk of that class. The effect of each group of variables is tested both with and without adjustment for the other groups of variables.

RESULTS

Analysis of mean child weight by age (birth, 9 months and 3 years; Figure 1) shows that children from manual working class or unclassified households are lighter than their peers from non-manual and particularly professional households at birth. For

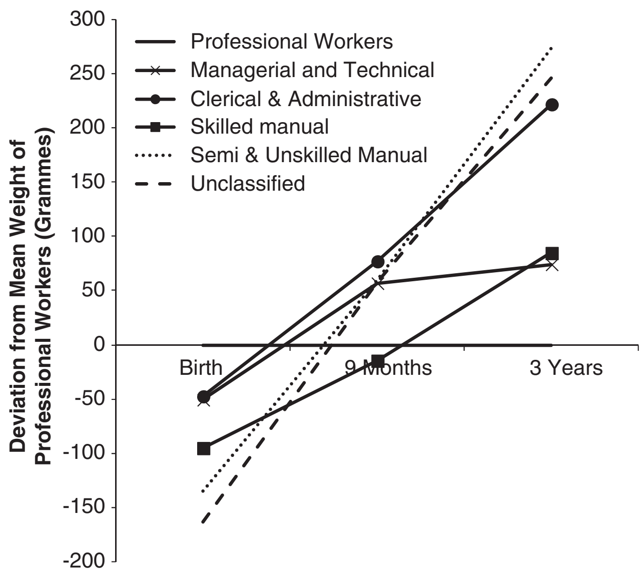

Figure 1. Mean child weight by household social class and age measured as deviance from mean weight of children from professional households at each age.

example, children from semi- and unskilled manual households are 135 g lighter at birth than children from professional households. However, Figure 1 also shows that by 9 months, the mean weight of children from lower social class groups have equalled or exceeded the mean of the professional group. By 3 years of age, children from semi- and unskilled manual households are 274 g heavier than their professional class peers. Analysis of child height shows no significant class differences in length/height at 9 months or 3 years of age with the consequence that children from lower social class groups have a higher mean BMI at 9 months and 3 years of age and a higher risk of obesity.

Rapid growth from birth to 3 years of age

Table 1 shows that the odds of experiencing rapid growth both between birth and 9 months and between 9 months and 3 years of age are higher for all other social class groups relative to professional workers. The odds for rapid growth are higher for all class groups in the first period compared with the second, as are the levels of significance. For example, semi- and unskilled manual groups are 64% more likely to experience rapid growth in the first period compared with 25% more likely in the second period (relative to professional groups). There is also a significant and pronounced social class gradient in the risk of child obesity at age 3 years in Table 1. In unadjusted analyses, children from skilled manual households are 95% more likely to become obese at 3 years of age.

Table 1 shows that in unadjusted analyses, child birth weight and gestation are important predictors of rapid growth, particularly in the earlier period: children born before 33 weeks are 24 times more likely to grow rapidly before 9 months compared with children born at term (OR: 24; $P<0.001$). The odds fall to 4.1 in the second period (OR: 4.1, $P<0.001$). Children of low birth weight (<2500 g) are over 11 times more likely (OR: 11.2, $P<0.001$) to grow rapidly in the first period compared with children of 3–3.5 kg and 89% more likely in the second period (OR: 1.89, $P<0.001$).

Breastfeeding and age at weaning also appear to be associated strongly with growth velocity. Children breastfed for 6 months or more are 52% less likely to grow rapidly in the first 9 months (OR: 0.48, $P<0.001$), yet are 34% more likely to grow rapidly in the period from 9 months to 3 years of age (OR: 1.34, $P=0.002$). Earlier weaning is linearly associated with rapid growth in the first period but earlier weaning appears to be associated with slower growth in the second period. Similarly, there is a significant dose–response relationship between smoking in pregnancy and rapid growth in the first period but this relationship almost disappears in the second period.

Higher child dietary quality, lower maternal BMI and lower levels of TV viewing are all significantly associated with a lower odds of rapid weight gain (Table 1), but the relationship is far stronger in the second period from 9 months, although the pattern for dietary quality is more stable.

Table 2 shows that in adjusted analyses short gestation and low birth weight remain significant and powerful predictors of rapid weight gain in the first 9 months (although both are attenuated), but that birth weight becomes insignificant as a predictor for rapid growth between 9 months and 3 years of age once we adjust for other factors in the model. The role of breastfeeding in the first period is attenuated after adjustment but breastfeeding for 6+ months remains a predictor (OR: 0.7, $P<0.001$). In the same way, the role of breastfeeding in promoting velocity in the second period also remains after adjustment (OR: 1.5, $P<0.001$). Both earlier weaning onto solid foods and prenatal smoking remain significant predictors of rapid growth before 9 months but appear to have no role after this. Following adjustment, the odds for maternal overweight and child obesity at age 3 years remain almost unaltered. Child dietary quality now becomes marginally insignificant but is largely unattenuated.

Child obesity at age 3 years

In unadjusted analyses (Table 1), high birth weight, lower levels of breastfeeding, earlier weaning and maternal smoking in pregnancy, poorer dietary quality, higher levels of TV watching and higher maternal BMI are all significantly associated with a higher odds of obesity at age 3 years. Children born weighing >4.5 kg are 4.3 times more likely to become obese (OR: 4.29, $P<0.001$) compared with children at the mean birth weight. Children breastfed for more than 6 months are 58% less likely to become obese (OR: 0.42, $P<0.001$) and there is a linear increase in odds for children weaned before 6 months of age. Children consuming a diet of high quality at 3 years of age are 35% less likely to be obese (OR: 0.65, $P=0.002$) and children watching 2 or more hours of TV on an average per day are 38% more likely to be obese (OR: 1.38, $P=0.017$).

In adjusted analyses (Table 2), higher birth weight, less breastfeeding, prenatal smoking and maternal BMI remain significant, although attenuated, predictors of a higher risk of obesity at age 3 years. The odds associated with a child weighing >4.5 kg at birth becoming obese at age 3 years remain almost unchanged (OR: 4.3, $P<0.001$), despite adjustment. Maternal BMI remains a very strong predictor with maternal obesity associated with an odds of 2.8 ($P<0.001$).

Does the contribution of variables differ across classes?

The first panel of Table 3 gives the reduction in class coefficients for rapid growth before 9 months associated with three different groups of predictors. Across all classes our full model reduces the class coefficients by 76% over the base model with all coefficients rendered insignificant. The full model reduces the manual and unclassified coefficients the most with the skilled manual coefficient being reduced to zero. The average reduction in class coefficients is largest for the early infant nutrition model (41%) but the impact of the groups of predictors varies by social class. Among the non-manual classes the proportionate reductions are largest when adjusted for early infant nutrition, whereas maternal prenatal behaviours are more important for the manual social classes, particularly among the unclassified.

The second panel shows that adjustment for early nutrition actually increases the class coefficients (because breastfeeding

Table 1. Sample distribution and unadjusted odds of rapid growth birth to 9 months (rapid1), rapid growth from 9 months to 3 years (rapid2) and child obesity at age 3 years

	N	%	OR rapid1	P-value	OR rapid2	P-value	OR obesity	P-value
HH social class								
Professional workers	1738	13.2	1.00		1.00		1.00	
Managerial and technical	2898	34.9	1.24	0.004	0.99	0.947	1.13	0.484
Clerical and administrative	1506	17.9	1.31	0.002	1.14	0.229	1.28	0.19
Skilled manual	1185	14.5	1.31	0.003	1.24	0.067	1.95	<0.001
Semi- and unskilled manual	790	9.7	1.64	<0.001	1.25	0.106	1.65	0.02
Unclassified	940	9.8	1.75	<0.001	1.33	0.031	2.22	<0.001
Maternal nationality								
Irish	7606	86.3	1.00		1.00		1.00	
UK	174	1.8	1.05	0.805	0.81	0.41	0.31	0.03
EU14	766	6.6	1.17	0.072	1.30	0.024	1.20	0.425
African	235	2.4	2.04	<0.001	1.81	0.003	1.34	0.323
Other	276	2.8	0.67	0.015	1.75	0.001	1.43	0.227
Maternal age (years)	9057	100.0	0.98	<0.001	1.00	0.671	0.99	0.215
Child sex								
Male	4593	51.0	1.00		1.00		1.00	
Female	4464	49.0	0.51	<0.001	1.73	<0.001	1.23	0.059
Gestation								
Very early (<33 weeks)	114	1.5	24.01	<0.001	4.12	<0.001	1.00	0.997
Somewhat early (<36 weeks)	442	5.0	7.15	<0.001	1.59	0.001	0.86	0.545
On time (37–41 weeks)	7477	81.8	1.00		1.00		1.00	
Late birth (42+ weeks)	1024	11.8	0.63	<0.001	0.99	0.923	1.31	0.096
Birth weight (kg)								
<2.5	474	5.5	11.23	<0.001	1.89	<0.001	0.53	0.095
2.5–3	1008	11.6	2.22	<0.001	1.20	0.12	0.71	0.115
3–3.5	2962	32.8	1.00		1.00		1.00	
3.5–4	3194	34.6	0.50	<0.001	0.94	0.467	1.25	0.109
4–4.5	1155	12.5	0.22	<0.001	0.81	0.078	1.62	0.006
>4.5	264	2.9	0.11	<0.001	1.17	0.46	4.29	<0.001
Birth order								
Second or higher	5478	59.8	1.00		1.00		1.00	
First child	3579	40.2	1.36	<0.001	1.19	0.01	0.85	0.165
Weight gain in pregnancy								
Low	2649	29.3	1.00	0.987	1.06	0.512	0.98	0.888
Medium	3156	34.9	1.00		1.00		1.00	
High	2023	22.3	0.90	0.076	1.12	0.172	1.30	0.052
Missing	1229	13.6	1.17	0.443	1.01	0.976	1.65	0.124
Multiple status								
Singleton	8780	96.9	1.00		1.00		1.00	
Non-singleton	277	3.1	9.60	<0.001	1.27	0.179	0.32	0.03
Breastfeeding								
None	4743	57.1	1.00		1.00		1.00	
<3 Months	386	4.3	0.88	0.041	0.89	0.203	0.84	0.208
<6 Months	543	5.6	0.69	<0.001	1.11	0.313	0.83	0.294
6+ Months	870	8.8	0.48	<0.001	1.34	0.002	0.42	<0.001
Month weaned								
<4 Months	1336	15.8	1.42	<0.001	0.70	0.001	1.63	0.004
<5 Months	2920	34.0	1.34	<0.001	0.91	0.248	1.47	0.007
<6 Months	2083	22.5	1.26	0.001	0.76	0.004	1.13	0.469
6 Months+	2718	27.7	1.00		1.00		1.00	
Smoking in pregnancy								
Never	7319	78.7	1.00		1.00		1.00	
1–5 Daily	703	8.4	1.49	<0.001	1.04	0.782	1.50	0.033
6–10 Daily	467	5.9	1.61	<0.001	1.33	0.055	1.83	0.006
11+ Daily	304	3.9	2.28	<0.001	1.04	0.843	1.58	0.055
Missing	264	3.1	1.33	0.043	1.34	0.13	1.13	0.72

Table 1. (Continued)

	N	%	OR rapid1	P-value	OR rapid2	P-value	OR obesity	P-value
Alcohol in pregnancy								
None	7096	78.9	1.00		1.00		1.00	
Light	1390	14.6	0.75	<0.001	0.93	0.488	0.65	0.008
Moderate	250	2.7	0.91	0.544	1.04	0.846	0.63	0.239
Heavy	57	0.7	1.20	0.531	0.87	0.738	1.19	0.767
Missing	264	3.1	1.16	0.301	1.29	0.188	0.93	0.834
Child dietary quality		3.1						
Low	3018	31.7	1.00		1.00		1.00	
Medium	3015	32.9	0.88	0.037	0.92	0.303	0.86	0.25
High	3024	35.4	0.84	0.004	0.83	0.028	0.65	0.002
Maternal body mass index								
Healthy	4646	51.0	1.00		1.00		1.00	
Overweight	2639	28.7	0.96	0.501	1.32	0.001	1.56	0.001
Obese	1429	16.4	1.08	0.252	2.02	<0.001	3.47	<0.001
Missing	343	4.0	0.88	0.339	1.34	0.106	3.00	<0.001
Daily TV time								
<Hour daily	2446	25.6	1.00		1.00		1.00	
<2 h Daily	1195	13.5	1.04	0.637	1.06	0.634	0.95	0.79
2+ Hours daily	3622	42.2	1.14	0.029	1.21	0.028	1.38	0.017
Missing	1794	18.7	1.00	0.973	1.22	0.051	1.07	0.683

Q8 Abbreviations: OR, odds ratio; TV, television; UK, United Kingdom.

increases the probability of rapid growth after 9 months–see Tables 1 and 2). However, the reduction in class differences is largest for all classes when adjusting for child diet and lifestyle after 9 months. The coefficients for the semi- and unskilled and unclassified classes remain significantly different from the professional groups even after adjustment for early nutrition and prenatal behaviours showing that these have less effect on growth in the second period.

The third panel of Table 3 shows that child diet and lifestyle also reduce class differences in risk of obesity more than either early nutrition or maternal prenatal behaviours although class differences remain significant for the semi- and unskilled manuals relative to the professional class when adjusting for each group individually.

These results are conditional in the sense that Table 3 does not control for variables other than those in the base model. Using forward step-wise entry of each group of variables in the presence of the other two, we found a similar pattern of results. In the model of rapid growth from birth to 9 months, the addition of the early nutrition variables into the model led to the largest improvement in model fit (49.5 reduction in deviance for 6 degrees of freedom; $P<0.001$). However, in the model of rapid growth from 9 months to 3 years of age, the child's diet and lifestyle had a far larger effect, a pattern replicated in the model of obesity at age 3 years.

DISCUSSION

Child height and weight have long served as leading indicators of physical health and development, but it is becoming increasingly apparent that the period from infancy extending through early childhood is a critical one for growth and development[24] and an emerging body of research suggests that early growth patterns may have implications for health and development over the life-course.[25] The higher risk of child obesity among lower socio-economic groups has life-time implications for health, well-being and life-expectancy. Indeed, if current research is correct in finding that the risk of obesity has plateaued among higher socio-economic groups while continuing to rise among lower groups[12,14] then this could be expected to increase social class inequalities in a number of chronic conditions and overall mortality in the years to come. Q6

Research suggests that the SES gradient in the prevalence of child obesity develops at a young age although this appears to vary across countries. Data from the UK Millennium Cohort Study show that the gradient does not emerge until after age 3 years but before 5 years,[26] whereas it had emerged by age 3 years in an Irish cohort study.[27] Either ways it is clear that the gradient emerges in early life. A growing body of literature[28–31] suggests that rapid post-natal growth may contribute to the risk of child obesity; as such, analysis of the SES patterning of predictors of rapid growth in infancy may shed light on modifiable risk factors.

It is well understood that children born with relatively small or large birth weights will demonstrate either 'catch-up' or 'catch-down' growth, respectively. In doing so, they grow more rapidly or more slowly than their age peers, resulting in convergence with their genetic potential and overall regression to the mean in child weights in the post-natal period. However, some children demonstrate unexpectedly rapid growth[32] in weight relative to length, which can mean that their weight overshoots the healthy weight target leading to an increased risk of childhood obesity.

Ong *et al.*[22] have shown that 'rapid growth' in infancy is strongly associated with childhood obesity. They define 'rapid growth' in infancy and early childhood as a change in the child's population centile position measured as a *z*-score of 0.67 within the first 2 years of life. This change represents one centile band, that is, the distance from the 10th to the 25th percentile or from the 25th to the 50th percentile. Research suggests that centile crossing among infants is relatively common in the first 2 years of life.[20,33] Indeed, centile crossing is actually significantly more common among children than subsequent obesity, particularly at younger ages, suggesting that the relationship between the two is not simple. For example, Taveras *et al.*[20] found that over 64% of their sample crossed two or more centile bands in the first 24 months of life yet only 11.6% were classified as obese at age 5 years. However, the child's starting position is important. In the Taveras *et al.*[19] study, a child under the 25th percentile at birth who crossed two bands in the first 6 months had an obesity risk of

Table 2. Adjusted OR and significance: rapidity of growth birth to 9 months, 9 months to 3 years and obesity at age 3 years

	Model 1 *Rapid growth birth to 9 months*		*Model 2* *Rapid growth 9 months to 3 years*		*Model 3* *Obesity at age 3 years*	
	OR	*P-value*	*OR*	*P-value*	*OR*	*P-value*
HH social class						
Professional workers	1.00		1.00		1.00	
Managerial and technical	1.10	0.31	0.97	0.80	1.01	0.95
Clerical and administrative	1.07	0.56	1.09	0.47	0.96	0.82
Skilled manual	0.96	0.77	1.17	0.22	1.32	0.18
Semi- and unskilled manual	1.12	0.43	1.13	0.42	1.05	0.82
Unclassified	1.04	0.81	1.24	0.17	1.43	0.12
Maternal nationality						
Irish	1.00		1.00		1.00	
UK	1.34	0.29	0.78	0.34	0.31	0.04
EU14	1.34	0.02	1.13	0.37	1.28	0.32
African	1.91	0.00	1.29	0.25	0.98	0.94
Other	0.70	0.11	1.63	0.01	1.96	0.03
Maternal age						
Years	0.99	0.28	1.02	0.03	1.01	0.31
Child sex						
Male	1.00		1.00		1.00	
Female	0.37	<0.001	1.74	<0.001	1.44	0.00
Gestation						
Very early (<33 weeks)	4.10	<0.001	3.50	<0.001	3.12	0.06
Somewhat early (<36 weeks)	2.00	<0.001	1.40	0.04	1.63	0.10
On time (37–41 weeks)	1.00		1.00		1.00	
Late birth (42+ weeks)	0.72	0.01	0.97	0.77	1.02	0.92
Birth weight (kg)						
<2.5	6.69	<0.001	1.26	0.20	0.34	0.02
2.5–3	2.01	<0.001	1.13	0.32	0.65	0.06
3–3.5	1.00		1.00		1.00	
3.5–4	0.48	<0.001	0.96	0.61	1.31	0.06
4–4.5	0.21	<0.001	0.85	0.20	1.75	0.00
>4.5	0.10	<0.001	1.11	0.63	4.29	<0.001
Birth order						
Second or higher	1.00		1.00		1.00	
First child	1.11	0.15	1.29	0.00	1.01	0.93
Weight gain in pregnancy						
Low	0.91	0.26	1.02	0.87	1.02	0.88
Medium	1.00		1.00		1.00	
High	0.97	0.77	1.24	0.02	1.25	0.12
Missing	1.05	0.64	0.97	0.77	1.92	0.07
Multiple status						
Singleton	1.00		1.00		1.00	
Non-singleton	2.48	<0.001	0.79	0.22	0.46	0.19
Breastfeeding						
None	1.00		1.00		1.00	
<3 Months	1.03	0.70	0.93	0.48	0.96	0.79
<6 Months	0.91	0.37	1.23	0.07	0.97	0.87
6+ Months	0.70	<0.001	1.47	<0.001	0.51	<0.001
Month weaned						
<4 Months	1.50	<0.001	0.81	0.08	1.28	0.18
<5 Months	1.34	0.00	1.02	0.84	1.25	0.16
<6 Months	1.37	0.00	0.83	0.06	1.05	0.80
6 Months+	1.00		1.00		1.00	
Smoking in pregnancy						
Never	1.00		1.00		1.00	
1–5 Daily	1.32	0.02	1.05	0.72	1.59	0.02
6–10 Daily	1.14	0.36	1.32	0.08	1.93	0.01
11+ Daily	1.85	<0.001	0.97	0.89	1.50	0.13
Missing	1.28	0.73	1.28	0.68	2.44	0.37
Alcohol in pregnancy						
None	1.00		1.00		1.00	
Light	0.92	0.39	1.01	0.93	0.72	0.05
Moderate	0.61	0.01	1.08	0.74	0.62	0.23
Heavy	1.00	1.00	0.76	0.57	0.92	0.89
Missing	0.78	0.72	0.95	0.94	0.41	0.38

Table 2. (Continued)

	Model 1 Rapid growth birth to 9 months		Model 2 Rapid growth 9 months to 3 years		Model 3 Obesity at age 3 years	
	OR	*P-value*	*OR*	*P-value*	*OR*	*P-value*
Child dietary Quality						
Low	1.00		1.00		1.00	
Medium	0.94	0.47	0.96	0.65	0.98	0.89
High	1.01	0.93	0.85	0.06	0.78	0.08
Maternal body mass index						
Healthy	1.00		1.00		1.00	
Overweight	1.08	0.29	1.31	0.00	1.39	0.02
Obese	1.09	0.40	2.08	<0.001	2.83	<0.001
Missing	1.06	0.75	1.35	0.10	2.68	<0.001
Daily TV time						
< Hour Daily						
<2 h Daily	1.15	0.31	1.13	0.41	1.03	0.89
2+ Hours daily	1.17	0.23	1.25	0.12	1.23	0.36
Missing	1.10	0.50	1.28	0.11	1.07	0.79
Deviance	8094.997		7456.405		3568.396	
pseudo R^2	0.1933		0.0446		0.0787	
N	9057		9057		9057	

Q9 Abbreviations: OR, odds ratio; TV, television; UK, United Kingdom.

Table 3. % Reduction in class Coefficients by model and predictor group relative to the base model[a]

	Early infant nutrition (%)		*Maternal prenatal behaviours (%)*		*Child diet and lifestyle (%)*		*Full model (%)*	
Models of rapid growth from birth to 9 months								
Professional workers	–		–		–		–	
Managerial and technical	18.8	NS	12.1	NS	11.6	NS	33.3	NS
Clerical and administrative	43.3	NS	21.2	NS	16.6	NS	63.7	NS
Skilled manual	74.9	NS	61.1	NS	38.2	NS	100.0	NS
Semi- and unskilled manual	32.4	NS	36.0	NS	14.6	NS	65.1	NS
Unclassified	35.3	NS	59.0	NS	15.9	NS	85.3	NS
Models of rapid growth from 9 months to 3 years								
Professional workers	–		–		–		–	
Managerial and technical	0	NS	0	NS	0	NS	0	NS
Clerical and administrative	−23.4	*	9.1	NS	62.3	NS	37.8	NS
Skilled manual	−11.0	NS	7.0	NS	50.0	NS	40.3	NS
Semi- and unskilled manual	−19.2	*	13.5	*	60.1	NS	45.3	NS
Unclassified	−10.8	*	11.5	*	48.5	NS	41.2	NS
Models of rapid obesity at age 3 years								
Professional workers	–		–		–		–	
Managerial and technical	40.1	NS	21.4	NS	55.0	NS	93.1	NS
Clerical and administrative	52.5	**	30.9	**	67.9	*	100.0	NS
Skilled manual	26.0	NS	22.3	NS	42.5	NS	67.7	NS
Semi- and unskilled manual	34.3	***	37.7	**	55.2	**	92.6	NS
Unclassified	25.2	***	31.1	**	43.3	**	71.0	NS
N	9057		9057		9057		9057	

Abbreviation: NS, not significant. *$P<0.05$; **$P<0.01$; ***$P<0.001$. [a]Base model adjusts for child sex, birth weight, gestation, birth order, parity, multiple status and maternal nationality, age and weight gain in pregnancy.

11.5% but this rose to 33% for an infant who was above the 75th percentile at birth and who subsequently crossed two or more centile bands.

Our analyses of the odds of rapid growth in the first 3 years of life showed the familiar pattern of catch-up and catch-down growth for children with short/long gestation and low/high birth weight. Adjusting for birthweight and gestational age, our models showed that early child nutrition was an important determinant of rapid growth velocity in the first 9 months of life. After this, age at weaning loses significance and level of breastfeeding becomes a positive predictor of growth rate.

Even adjusting for child birth weight and gestation, children of mothers who smoked heavily (11+ cigarettes daily) were 85% more likely to grow rapidly in the first 9 months of life. Antenatal smoking will influence child growth primarily through its impact on birth weight for which it is the most important determinant in developed countries after length of gestation.[34] Birth weight became an insignificant driver of growth velocity in the second period from 9 months yet maternal smoking continued to exert an effect. This could be because of residual confounding of factors correlated with prenatal smoking but the finding would also support previous research,[35] which suggests that smoking impacts on growth patterns through the impact of antenatal nicotine exposure on the catecholaminergic neurotransmitter system in the brain and the subsequent appetite and impulse control of the child.[35–37]

As hypothesised, the extent to which the groups of variables explained social class differentials in rapid growth and risk of obesity at age 3 years varied across social class groups. Whereas level of breastfeeding and age at weaning were the most important explanatory factors among non-manual class groups for rapid growth before 9 months of age, antenatal smoking and alcohol consumption were more important among the children of manual and unclassified class groups. Antenatal smoking is far more common among mothers from these groups[38] as is exclusive formula feeding[39] but our analyses suggest that antenatal smoking may be relatively more important in early growth patterns for these groups. After 9 months of age, child diet and lifestyle were found to be more important determinants of growth for all classes and these factors also had a larger impact on overall risk of obesity, even when adjusting for other predictors.

Our study has a number of limitations. First, a number of our measures including prenatal smoking, alcohol consumption, breastfeeding and weaning behaviours are retrospectively self-reported by the mother. It is possible that this introduces recall error, although research suggests that this will be minimal at 9 months.[40] Our expectation is that the latter bias will be equal across groups meaning that the absolute coefficient may be biased upward (because lower reported levels of smoking will be associated with larger absolute effects) but that this effect will be uniform across the sample.

This study has further advanced our understanding of the factors predictive of, or associated with, obesity at age 3 years. The patterns reported suggest that preventative interventions to reduce levels of child obesity should be multi-dimensional but that different dimensions should be given more or less importance depending on socio-economic group. Among manual working class groups, smoking cessation during pregnancy will be important, but this should be accompanied by interventions to increase breastfeeding rates and to delay weaning until 6 months or more. Among non-manual groups breastfeeding and weaning behaviours are more salient. Child dietary quality and level of physical activity are important among all groups. The role of public health nurses in positively influencing breastfeeding duration[41] and timing of weaning[42] has been recognised. Further training of such health-care professionals to enable them to provide more tailored advice to their patients may be of benefit. These findings provide valuable direction for future strategies aimed at preventing overweight and obesity in infants and children.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

ACKNOWLEDGEMENTS

The Growing Up in Ireland data have been funded by the Government of Ireland through the Department of Children and Youth Affairs; have been collected under the Statistics Act, 1993, of the Central Statistics Office. The project has been designed and implemented by the joint ESRI-TCD Growing Up in Ireland Study Team. In addition to the funders, we thank the entire Growing Up in Ireland Project and Study teams, and the children and families who participated in the study.

REFERENCES

1 Wang Y, Lobstein T. Worldwide trends in childhood overweight and obesity. *Int J Pediatr Obes* 2006; **1**: 11–25.
2 Popkin BM, Conde W, Hou N, Monteiro C. Is there a lag globally in overweight trends for children compared with adults? *Obesity* 2006; **14**: 1846–1853.
3 WHO. *Reducing Risks, Promoting Healthy Life*. World Health Organistion: Geneva, 2002.
4 Serdula MK, Ivery D, Coates RJ, Freedman DS, Williamson DF, Byers T. Do obese children become obese adults? A review of the literature. *Prev Med* 1993; **22**: 167–177.
5 Power C, Lake JK, Cole TJ. Measurement and long-term health risks of child and adolescent fatness. *Int J Obes Relat Metab Disord* 1997; **21**: 507–526.
6 World Health Organisation. *Global Strategy on Diet, Physical Activity and Health*. World Health Organisation: Geneva, 2004.
7 Summerbell CD, Ashton V, Campbell KJ, Edmunds L, Kelly S, Waters E. Interventions for treating obesity in children. *Cochrane Database Syst Rev* 2003; **3**: CD001872.
8 Oude Luttikhuis H, Baur L, Jansen H, Shresbury VA, O'Malley C, Stolk RP *et al*. Interventions for treating obesity in children (Review). *Cochrane Database Syst Rev* 2009; **1**: 1–175.
9 Sobal J, Stunkard AJ. Socioeconomic status and obesity: a review of the literature. *Psychol Bull* 1989; **105**: 260–275.
10 Wang Y, Zhang Q. Are American children and adolescents of low socioeconomic status at increased risk of obesoty? Changes in the association between overweight and family income between 1971 and 2002. *Am J Clin Nutr* 2006; **84**: 707–716.
11 Stamatakis E, Primatesta P, Chinn S, Rona R, Falascheti E. Overweight and obesity trends from 1974 to 2003 in english children: what is the role of socio-economic factors? *Arch Dis Childhood* 2005; **90**: 999–1004.
12 Stamatakis E, Wardle J, Cole TJ. Childhood obesity and overweight prevalence trends in England: evidence for growing socio-economic disparities. *Int J Obes* 2010; **34**: 41–47.
13 Ogden CL, Carroll MD, Kit BK, Flegal KM. Prevalence of obesity and trends in body mass index among US children and adolescents, 1999-2010. *J Am Med Assoc* 2012; **307**: 483–490.
14 Olds T, Maher C, Zumin S, Peneau S, Lioret S, Cestetbon K *et al*. Evidence that the prevalence of childhood overweight is plateauing: data from nine countries. *Int J Paediatr Obes* 2011; **6**: 342–360.
15 Danielzik S, Czerwinski-Mast M, Langnase K, Dilda B, Muller MJ. Parental overweight, socio-economic status and high birth weight are major determinants of overweight and obesity in 5-7 y-old children: baseline data of the Kiel Obesity Prevention Study (KOPS). *Int J Obes* 2004; **28**: 1494–1502.
16 Von Kries R, Toschke A, Koletzko B, Slikker W. Maternal smoking during pregnancy and childhood obesity. *Am J Epidemiol* 2002; **156**: 954–961.
17 Griffiths LJ, Smeeth L, Hawkins SS, Cole TJ, Dezateaux C. Effects of infant feeding practice on weight gain from birth to 3 years. *Arch Childhood Dis* 2009; **94**: 577–582.
18 Reilly JJ, Armstrong J, Dorosty AR, Emmett M, Ness A, Rogers I *et al*. Early life risk factors for obesity in childhood: cohort study. *Br Med J* 2005; **300**: 1357–1359.
19 Oken E, Taveras EM, Kleinman KP, Rich-Edwards JW, MW GIllman. Gestational weight gain and child adiposity at age 3 years. *Am J Obstetr Gynecol* 2007; **196**: 322.
20 Taveras EM, Rifas-Shiman SL, Sherry B, Oken E, Haines J, Kleinman K *et al*. Crossing growth percentiles in infancy and risk of obesity in childhood. *Arch Pediatr Adolesc Med* 2011; **165**: 993–998.
21 Cole TJ, Belizzi MC, Flegal KM, Dietz WH. Establishing a standard definition for child overweight and obesity worldwide: international survey. *Br Med J* 2000; **320**: 1–6.
22 Ong KK, Ahmed ML, Emmett PM, Preece MA, Dunger DB. Association between post-natal catch-up growth and obesity in childhood: prospective cohort study. *Br Med J* 2000; **320**: 967–971.
23 Sallis AF, Taylor AH, Dowda M, Freedson PS, Pate RR. Correlates of vigorous physical activity for children in grades 1 through 12: comparing parent reported and objectively measured physical activity, 2001. Q7
24 Cameron N. Growth patterns in adverse environments. *Am J Hum Biol* 2007; **19**: 615–621.
25 Singhal A, Fewtrell M, Cole TJ, Lucas A. Low nutrient intake and early growth for later insulin resistance in adolescents born preterm. *Lancet* 2003; **361**: 1089–1097.
26 Griffiths LJ, Dezateux C, Hill A. Is obesity associated with emotional and behavioural problems in children? Findings from the Millennium Cohort Study. *Int J Pediatr Obes* 2010; **6**: 1–10.
27 DCYA. Growing Up in Ireland: Infant Cohort (at 3 years). In. *The Health of 3 Years Olds*. Department of Children and Youth Affairs: Dublin, 2012.

28 Baird J, Fisher D, Lucas P, Kleijnen J, Roberts H, Law C. Being big or growing fast: systematic review of size and growth in infancy and later obesity. *Br Med J* 2005; **331**: 929–931.
29 Monteiro PO, Victoria CG. Rapid growth in infancy and childhood and obesity in later life: a systematic review. *Obes Rev* 2005; **6**: 134–154.
30 Taveras EM, Rifas-Shiman SL, Belfort MB, Kleinman KP, Oken E, GIllman MW. Weight status in the first six months of life and obesity at 3 years of age. *Pediatrics* 2009; **123**: 1177–1183.
31 GIllman MW. Early infancy as a critical period for development of obesity and related conditions. In: Lucas A, Makrides M, Ziegler E (eds) *The Importance of Growth for Health and Development*. Nestle Nutrition Institute Workshop: Boston, MA, 2010, pp 13–24.
32 Cameron N, Pettifer J, De Wet T, Norris S. The relationship of rapid weight gain in infancy to obesity and skeletal maturity in childhood. *Obes Res* 2003; **1**: 457–460.
33 Mei Z, Grummer-Strawn LM, Thompson D, Dietz WH. Shifts in percentiles of growth during early childhood: analysis of longitudinal data from the California Child Health and Development Study. *Pediatrics* 2004; **113**: 617–627.
34 Kramer MS. Determinants of low birth weight: methodological assessment and meta-analysis. *Rev Analyses* 1987; **65**: 663–737.
35 Beyerlein A, Ruckinger S, Toschke M, Schaffrath Rosario A, Von Kries R. Is low birth weight in the causal pathway of the association between maternal smoking in pregnancy and higher BMI in the offspring? *Eur J Epidemiol* 2011; **26**: 413–420.
36 Toschke A, Ehlin AG, Von Kries R, Ekbom A, Montgomery SM. Maternal smoking during pregnancy and appetite control in offspring. *J Perinatal Med* 2003; **31**: 251–256.
37 Ong KK, Preece MA, Emmett PM, Ahmed ML, Dunger DB. Size at birth and early childhood growth in relation to maternal smoking, parity and infant breast-feeding: longitudinal birth cohort study and analysis. *Pediatr Res* 2002; **52**: 863–867.
38 McCrory C, Layte R. Prenatal exposure to maternal smoking and childhood behavioural problems: a Quasi-experimental approach. *J Abnorm Child Psychol* 2012; **40**: 1277–1288.
39 McCrory C, Layte R. Breastfeeding and risk of overweight and obesity at nine-years of age. *Soc Sci Med* 2012; **75**: 323–330.
40 Kenkel DS, Lillard DR, Mathios AD. Accounting for misclassification error in retrospective smoking data. *Health Econ* 2004; **13**: 1031–1044.
41 Tarrant RC, Younger KM, Sheridan Periera M, Kearney JM. Factors associated with breastfeeding in ireland: potential areas for improvement. *J Hum Lact* 2011; **27**: 262–271.
42 Tarrant RC, Younger KM, Sheridan-Pereira M, White M, Kearney JM. Factors associated with weaning practices in term infants: a prospective observational study in Ireland. *Br J Nutr* 2010; **104**: 1544–1554.

