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Associations between dietary patterns, eating behaviours and body composition and adiposity in 3-year old children of mothers with obesity

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Abbreviations:

ALSPAC: Avon Longitudinal Study of Parents and Children

BIA: bio-electrical impedance analysis

BMI: body mass index

CEBQ: Childhood Eating Behaviour Questionnaire

FFQ: Food frequency questionnaire

IOTF: International Obesity Task Force

UPBEAT: UK Pregnancy Better Eating and Activity Trial

SWS: Southampton Women's Survey

WHO: World Health Organisation

Abstract

Background: The relationships between eating habits, behaviours and the development of obesity in pre-school children is not well established.

Objective: As children of mothers with obesity are themselves at risk of obesity, we examined these relationships in a cohort of 482 three-year-old children of mothers with obesity from the UPBEAT study.

Method: Dietary patterns were derived using factor analysis of an 85-item food frequency questionnaire (FFQ). Eating behaviours were assessed using the Children's Eating Behaviour Questionnaire (CEBQ). Measures of body composition included age-specific BMI cut-offs, WHO z-scores, sum of skinfolds, waist and arm circumferences and body fat percentage. Using adjusted regression analysis, we examined associations between dietary patterns, eating behaviours and measures of body composition.

Results: Three distinct dietary patterns were defined; "healthy/prudent", "African/Caribbean" and "processed/snacking". The "processed/snacking" pattern was associated with greater odds of obesity; OR 1.53 (95%CI: 1.07 to 2.19). The "African/Caribbean" and the "healthy/prudent" patterns were associated with a lower arm circumference (β=-0.23cm (-0.45 to -0.01)) and sum of skinfolds (β=-1.36cm (-2.88 to -0.37)), respectively. Lower enjoyment of food and food responsiveness, and greater slowness in eating and satiety, were associated with lower arm and waist circumferences, WHO z-scores and obesity (all $p<0.05$).

Conclusion: In children of mothers with obesity, those who had higher scores on a "processed/snacking" dietary pattern had greater odds of obesity. In contrast slowness in eating was associated with lower measures of body composition. These novel findings highlight modifiable behaviours in high-risk pre-school children which could contribute to public health strategies for prevention of childhood obesity.

Introduction: Recent figures from the National Child Measurement Programme in England suggest that nearly a quarter of pre-school children have overweight or obesity[1], with one in 40 children being affected by severe obesity. Obesity in early life is a predictor for adolescent and adulthood obesity [2–4], with a recent meta-analysis of 37 studies reporting that children classified as having obesity using body mass index (BMI) were five-times more likely to have obesity as adults compared to their healthy weight counterparts [5]. Worldwide, there is intense focus on reducing rates of childhood obesity [6,7]. The UK government recommend creating healthier food environments in schools, local areas and providing parents with information on healthy food choices for their families with the aim of halving rates of childhood obesity by 2030 [6].

Several studies have independently suggested a relationship between eating behaviours [8–11] or dietary intake [12,13] and body composition in childhood. Associations between weight status in early life and food approach eating behaviours, such as food responsiveness and emotional overeating and consumption of energy dense foods have consistently been reported. Longitudinal studies suggest that eating habits and food choices established in childhood are likely to persist into adulthood [14–18]. Therefore, the early years provide a unique opportunity to develop and establish healthy eating habits and behaviours.

Since current guidelines for prevention of childhood obesity recommend identification of populations at risk and early engagement [6,7], we have addressed relationships between dietary habits and behaviours and childhood adiposity in children born to mothers with obesity. As recently reported by ourselves in a contemporary cohort [19], and previously in many mother-child cohort studies, children of mothers with obesity are at high-risk of developing obesity themselves [20].

The primary aims of this study were to investigate 1) associations of childhood dietary patterns with measures of body composition and 2) associations between child's eating behaviours and measures of body composition in the 3-year old children born to mothers from inner city settings and ethnically diverse backgrounds (UK Pregnancy Better Eating and Activity Trial, UPBEAT). The role of socio-economic deprivation in these relationships was also examined.

Methods: UPBEAT was a multicentre randomised controlled trial which explored the effect of an intensive 8-week antenatal diet and physical activity intervention in 1555 women with a BMI ≥30kg/m^2 [21]. The intervention focused on improving insulin sensitivity through reducing dietary glycaemic load, saturated fat intake, and increasing physical activity in comparison to standard antenatal care. The participants were from UK inner-city settings of ethnic diversity and high socioeconomic deprivation. Details of the intervention inclusion and exclusion criteria have been published previously [21,22]. Research Ethics Committee approval was obtained in all participating centres, UK Integrated Research Application System; reference 09/H0802/5 (South East London Research Ethics Committee). All participants provided written informed consent.

The intervention had no effect on the primary outcomes of gestational diabetes and large for gestational age infants. However, it was effective at improving maternal dietary intake, reducing gestational weight gain and sum of skinfolds and increasing self-reported physical activity by 36 weeks' gestation (all $p \leq 0.04$). In the infants at 6 months of age we have reported that the intervention was associated with a reduction in a measure of adiposity [23]; as a cohort analysis in these infants, we have also shown positive associations between measures of appetite, assessed by the Baby Eating Behaviour Questionnaire, and body fat percentage, weight and growth [24].

Between August 2014 and October 2017 participants in the UPBEAT study were invited to attend a 3-year post-delivery visit with their children. The study design and protocol of the follow-up were approved by the NHS Research Ethics Committee (UK Integrated Research Application System; reference 13/LO/1108). The children were included in this analysis if they had 1) attended the follow-up visit at 3-years of age; 2) had eating behaviour and food frequency questionnaires completed by the main caregiver; and 3) had body composition data recorded during the 3-year

visit. Children were excluded if they were suffering from severe illness or if they were born before 34 weeks' gestation.

Child Variables

Food Frequency Questionnaire

The child's diet was assessed using an 85-item Food Frequency Questionnaire (FFQ). The list of food and drink items were compiled from the 80-item validated Southampton Women's Survey FFQ [25]. In addition, three questions were extended to include culturally appropriate options, e.g. "Rice-boiled & fried" extended to "Rice-boiled & fried jollof, rice and peas". Five extra food items were included which were culturally appropriate for the non-white ethnic subgroups in the UPBEAT cohort (Black – including Afro Caribbean and African) (Supplementary Table 1). The FFQ asked how often in the last three months the child had consumed each item with response options including: never, less than once per month, 1-3 times per month, number of times per week (1-7) or more than once per day. If the item was consumed more than once a day, the number of times was recorded. Food and drink items consumed more than once a week which were not included in the FFQ were recorded as additional items. Type of milk consumed as a drink or added to cereal and sugar added to drinks and cereal was also collected.

Dietary patterns of the children were derived using factor analysis. Food and drink items listed in the FFQ were categorised into 39 groups based on similar nutritional composition. On the basis of frequency consumption, three items recorded as additional foods were also included: porridge/shredded wheat, fast food (McDonalds, Burger King and KFC) and cereals bars (Supplementary Table 1). Factor analysis with orthogonal varimax rotation was performed to derive the patterns using the children's weekly standardised frequency of each of the 39 food groups. The

number of factors retained was chosen using the scree plot of eigenvalues. Within each factor, food groups with a factor loading coefficient ≥ ± 0.22 were chosen (Supplementary Table 2); this cut-off was selected so that each dietary pattern had equal distribution of food groups. Food groups with a factor loading coefficient ≥ ±0.32 were considered to have a strong association with that factor. Derived dietary pattern labels were selected based on foods with the highest factor loadings (≥ ±0.32).

Child Eating Behaviour Questionnaire

The Child Eating Behaviour Questionnaire [26] (CEBQ) is a validated parent-reported psychometric method to assess child's eating style and behaviour [27]. The questionnaire consists of 35 items divided into eight eating behaviours, further sub-divided into food approach and food avoidance questions rated on a 5-point Likert scale (Never=1, Rarely=2, Sometimes=3, Often=4, Always=5) Seven questions were reverse scored. Food approach behaviours include food responsiveness, emotional over-eating, enjoyment of food and desire to drink; food avoidance behaviours were satiety responsiveness, slowness in eating, emotional under-eating, and food fussiness. Higher scores indicate a higher level for the respective eating style.

Anthropometric measures and body fat percentage

The outcomes of interest for the offspring were measures of body composition and adiposity assessed by sum of skinfold thicknesses (addition of triceps, bicep, subscapular, suprailiac and abdominal skinfolds, measured in triplicate by trained research staff using children's Holtain skinfold callipers), mid-upper arm and waist circumferences, body fat percentage assessed by ImpediMed Imp SFB7 bioelectrical impedance analysis (BIA) and weight, height and BMI z-scores derived using the World Health Organisation (WHO) reference data [28]. Childhood obesity was defined by

International Obesity Task Force (IOTF) sex-specific centiles (boys obesity = 98.9th centile and girls obesity = 98.6th centile) [29].

Maternal variables

We also addressed relationships between maternal social and demographic variables (maternal age at trial entry, ethnicity, socioeconomic status, years in full-time education and early-pregnancy BMI) and offspring eating habits.

Statistical analysis

In this secondary analysis of the UPBEAT study there was no effect of the intervention on offspring eating patterns or behaviours, therefore the data was treated as a cohort. Demographic results were expressed as mean ± standard deviation, median and interquartile range or percent and number as appropriate. Depending on the outcome of interest, unadjusted and adjusted linear, logistic or quantile regression were used. Unadjusted regression (model 1) was performed to analyse the relationship between maternal social and demographic factors and dietary patterns at age 3-years, followed by adjusted regression (model 2) to investigate the relationship of the derived dietary patterns and the eight CEBQ subscale scores with the nine measures of body composition at age 3-years. For model 2 confounding variables were selected due to their association with dietary intake and body composition and included the minimisation variables from the main trial (maternal BMI at trial enrolment, parity and ethnicity), smoking status at baseline, maternal age, years spent in full time education, infant birthweight, child's age at follow-up, sex and randomisation arm. Coefficients or odds ratios were presented with 95% confidence intervals. Data was analysed using Stata software, version 15.0 (StataCorp, College Station, Texas).

Results: Figure 1 shows a flow chart of participants through the study. 514 children (33.0% of the original UPBEAT cohort) were followed up at age 3 years (3.5±0.28 years). 490 (95%) provided complete dietary data (FFQ and CEBQ), eight children were excluded as they were either born ≤34 weeks gestation or were suffering from severe illness, therefore the study population comprised of 482 children. Data for the majority of measures of anthropometry had less than 5% missingness except for BIA (20%) and sum of skinfolds (23%). Of the 482 included children, 243 (50%) were female and 234 (49%) were born to mothers who were randomised to the UPBEAT intervention arm. Mean maternal age was 31.2±5.2 years; 68% were White, 23% were Black African/Caribbean and 9% were from Asian or other ethnic backgrounds. 76% were from the index of multiple deprivation quintiles 4 and 5 (most deprived). 165 of the children (34%) were overweight or had obesity, and 6% were morbidly obese (defined using the IOTF sex specific centiles [29]). For the WHO z-scores, the average height-for-age, weight-for-age and weight-for-height were above the mean of the reference population 0.38±1.1, 0.83±1.0 and 0.90±1.0, respectively (Table 1).

Dietary pattern analysis

Factor analysis identified three dietary patterns in the children, summarised in Supplementary Figure 1 with the full list of factor loadings shown in Supplementary Table 2. The first dietary pattern was labelled 'healthy/prudent' due to high loadings (≥0.32) on brown bread, boiled and baked potatoes, rice and pasta, fish, vegetables, beans and pulses, fruit (fresh, tinned and dried) and nuts. The second dietary pattern was characterised as a diet high in white bread, crisps and savoury snacks, roast potatoes (including chips), processed foods, quiche and pizza, confectionary, desserts, cakes, biscuits and low and high sugary drinks and this pattern was termed 'processed/snacking'. The third pattern, 'African/Caribbean' was characterised by yam/cassava/plantain, red meat, chicken and turkey, soups (including African and Caribbean soups) and rice/pasta, fish and offal and was low in cheese, yoghurts and spreads.

175

176 *Maternal demographics*

177 In a univariate analysis (model 1) different maternal social and demographic characteristics were
178 associated with the three childhood dietary patterns. A higher number of years in full time education
179 and a higher maternal age were associated with the child having a higher score on a healthy/prudent
180 dietary pattern. Fewer years in full time education, lower maternal age and having a White mother
181 were associated with the child having a higher score on a processed/snacking dietary pattern.
182 Having a Black mother and a greater deprivation defined by index of multi-deprivation were
183 associated with the child having a high score on an African/Caribbean dietary pattern
184 (Supplementary Table 3, all $p<0.05$).

185

186 *Dietary patterns and anthropometric measures and body fat percentage*

187 In the adjusted regression model (model 2), the healthy/prudent dietary pattern was associated with
188 a -1.76cm (95% confidence interval -3.30 to -0.14, $p=0.03$) lower sum of skinfolds. The
189 processed/snacking pattern was associated with a higher odds of obesity [(BMI ≥30kg/m^2), defined
190 using the IOTF gender-specific cut-odds [29]] (OR =1.53 (1.07 to 2.19) $p=0.04$). The African/Caribbean
191 pattern was associated with a lower arm circumference (-0.23cm (-0.45 to -0.01), $p=0.04$) (Table 2).
192 No other dietary pattern-body composition associations were found.

193

194 *Eating behaviour and body composition*

195 There were no differences in the CEBQ scores according to gender or mode of infant feeding
196 (Supplementary Table 4 & 5). For the food approach scales, following adjustment for confounders,
197 lower enjoyment of food and food responsiveness were associated with lower arm and waist
198 circumferences, weight-for-age, weight-for-height and BMI z-scores and obesity (all $p<0.006$, Figure

199 2 & Figure 3). For the food avoidance scales, greater slowness in eating and satiety responsiveness
200 were associated with a lower BMI z-score, a lower odds of obesity, weight-for-age, weight-for-height
201 and height-for-age z-scores and arm and waist circumferences (all $p<0.009$, Figures 2 & 3). Food
202 fussiness was associated with a lower BMI, odds of obesity and weight-for-height z-score (all
203 $p<0.002$, Figures 2 & 3). Emotional under eating was not associated with any measures of body
204 composition or adiposity; emotional overeating was only associated with weight-for-height z-score
205 ($p=0.02$). Body fat percentage and sum of skinfolds were not associated with any of the eating
206 behaviour sub scales (data not shown).

207

208 Grouping the children by BMI class, an obese BMI (IOTF BMI centile cut-off equivalent to ≥30kg/m^2)
209 vs healthy, after adjustment for confounders, the children with obesity showed higher food
210 approach scales scores for food responsiveness ($p=0.001$), enjoyment of food ($p=0.02$) and desire to
211 drink ($p=0.03$). In contrast, the food avoidance scale, slowness in eating, and satiety responsiveness
212 ($p<0.008$) were inversely associated with obesity (Table 3, Supplementary Figure 2).

213

214 **Discussion**: This study uniquely explores associations between dietary patterns and eating
215 behaviours with BMI and measures of adiposity in 3-year-old children born to mothers with obesity
216 from high social deprivation and ethnically diverse backgrounds.

217

218 Children with obesity had higher scores on a processed/snacking dietary pattern defined as a diet
219 high in confectionary, crisps, processed foods, cakes and biscuits and greater food approach and less
220 food avoidance eating behaviours. Dietary intake and body composition analyses in children have
221 hitherto focused on specific food groups, such as sugar-sweetened beverages [30], high sugar/fat
222 snacks [31] or fruit and vegetable intake [32]. However, dietary patterns reduces dietary data into fewer
223 variables by combining highly correlated food groups, therefore they may better define an
224 individual's habitual diet as they attempt to describe the whole diet rather than description of
225 specific nutrients or foods [33]. Whilst several studies have addressed relationships between dietary
226 patterns and obesity in older children [34], we are unaware of previous reports addressing dietary
227 patterns and adiposity in three-year olds even though at this age the children may already be on a
228 trajectory to development of later life obesity [35]. Arguably, prevention at this age through
229 appropriate dietary intervention may have particular gain in terms of prevention of adult obesity, as
230 previous studies have reported that dietary patterns track from early childhood to later life [36]. A
231 report of dietary patterns in the UK ALSPAC cohort of children described 'healthy', 'traditional' and
232 'processed' dietary patterns in children at 3-years of age [37], whilst the healthy and processed
233 patterns are similar to the present study, other differences may reflect ethnic diversity of the
234 UPBEAT cohort. Comparison in relations to body composition is not possible as the ALSPAC study did
235 not include measurement of adiposity, although there was no association between dietary patterns
236 at 3-years and body mass index when measured at age 7-years [38].

237

Our findings support those from the CHASE cohort who described that UK Black/African 9-10-year-old children benefit from maintaining a traditional African/Caribbean diet. This was evident from the observed association of high scores on an African/Caribbean dietary pattern with a lower arm circumference despite the Black women having a higher index of multi-deprivation. CHASE showed that a traditional African/Caribbean diet in late childhood was associated with an improved lipid profile, and compared to a White-European diet the overall nutrient content was lower in total fats and higher in carbohydrates [39], and lower in processed foods, which might explain the relationship with the lower measure of adiposity.

We have previously reported the maternal dietary patterns of 1023 women obtained during the UPBEAT study [40] in which four distinct patterns were identified, “snacks”, “processed”, “fruit and veg” and “African/Caribbean”. Whilst only three patterns were identified in this analysis of the diets of their children they were broadly similar to those of their mothers three years previously, highlighting commonality of diet within families, as reported previously in the UK Southampton Women’s Survey [41].

Similarly to dietary patterns, eating behaviours developed in early life track through childhood [42]. The validated CEBQ questionnaire has greatly facilitated studies of relationships between appetite traits and body composition [18,26,43]. Using this questionnaire, food responsiveness and enjoyment of food were associated with higher arm and waist circumferences, weight-for-age, weight-for-height and BMI z-scores and higher odds of obesity. In contrast slowness in eating and satiety responsiveness were inversely associated with the same measures of body composition, suggesting that these traits are protective against an obesogenic environment. Importantly, slower eating is a modifiable eating style which may reduce excessive weight gain in childhood. The associations between enjoyment of food and food responsiveness and increased body composition and rates of

obesity, are consistent with previous studies suggesting that children with overweight or obesity are more responsive to food cues [44–46], but amongst these the only report of children at a similar age to this study was from an Australian cohort of 2-5 year old children, although the results were based on parent reported measurements [46].

In agreement with BASELINE, an observational study in 1189 2-year old children from Ireland [43] we did not find associations between emotional under/over eating and desire to drink and measures of body composition. This could be because the children were too young to display emotion in relation to eating habits. Although, in older children a similar lack of an association has been found. [47] This may imply that these three measures from the CEBQ do not have a major impact on body composition and adiposity compared to the other sub-scales.

The offspring of mothers with obesity are particularly at risk of obesity and this is the first study to address dietary patterns and eating behaviours associated with obesity in such children. As previously described by ourselves [19] and others, there is a striking relationship between maternal obesity and offspring risk of obesity [20,48]. Whether this arises from shared familial environment, shared genes or the maternal *in-utero* environment or a combination of all three is not established. Animal models and some of the human cohort studies however have argued for a major contribution of *in-utero* determinants through persistent effects on the developing fetus, including modification of the pathways of energy balance at the level of the hypothalamus [49,50]. This is supported by the recent finding of an association between perinatal methylation of the SLC6A4 gene implicated in appetite regulation and obesity in later childhood [51]. Whether the relationships between food approach and food avoidance variables with measures of childhood adiposity in these children are a direct result of the *in-utero* environment cannot be established from this study, although future comparisons of the strength of these relationships within cohorts of children from

mothers of a healthy BMI, with appropriate adjustment for confounders, could shed light on the aetiology of these relationships.

Strengths and limitations

Strengths of the study include the rich UPBEAT dataset which provides comprehensive information on the eating habits and behavioural origins of early childhood obesity and multiple determinants of childhood body composition and adiposity. The sample of the mothers and their offspring included are ethnically diverse and of low socio-economic status. To our knowledge this the only study which has combined dietary patterns and eating behaviours in the same study of childhood obesity at any age. Limitations include loss to follow-up of the study population which may result in selection bias; however, there were no differences in the maternal population who completed the 3-year follow-up compared to those who did not, except for a higher proportion of white women returning for the 3-year visit. The CEBQ is a parent reported measure and is subject to recall bias and the main care giver's own interpretation of eating behaviours, however the CEBQ is validated and previous trials have reported high internal validity. The dietary patterns, derived using factor analysis, involve a number of arbitrary decisions including consolidation of food items into groups, the number of factors to extract, rotation method and naming of the factors. FFQs are also associated with recall bias from the child's main caregiver [52]. The measures of body composition utilised in this study have limitations. BMI standardised cut-offs, z-scores, BIA and sum of skinfolds which was used to define obesity and adiposity in the children are indirect measures of fat mass; future studies should consider validating measures of body composition with DEXA, which is widely recognised as a good measure of adiposity [53]. Lastly, our study was observational, so causality of the associations cannot be assumed.

In summary, we found that food approach eating behaviours and a diet high in processed and snacking foods were associated with obesity and measures of body composition at 3 years of age in

313 children of mothers with obesity. Conversely slower eating, a “healthy/prudent” or a traditional
314 “African/Caribbean” diet were associated with lower rates of obesity or adiposity. This study
315 provides evidence for potentially modifiable determinants and adds credence to the view that
316 promoting healthy food alternatives and eating behaviours should be considered for assimilation
317 into public health strategies in high-risk children at risk of obesity in early life.

Conflict of Interest: KMG reports other from Nestle Nutrition Institute, grants from Nestec, outside the submitted work; In addition, KMG has a patent Phenotype prediction issued, a patent Predictive use of CpG methylation issued, a patent Maternal Nutrition Composition pending, and a patent Vitamin B6 in maternal administration for the prevention of overweight or obesity in the offspring issued. LP is part of an academic consortium that has received research funding from Abbott Nutrition and Danone. The other authors declare no conflict of interest.

Authors contribution: The authors responsibilities were as follows – PTS, ALB, KMG and LP conceptualised and designed the study. KVD, ACF, MOK and PTS drafted and carried out the analyses. KVD, ACF, MOK and LP had overall responsibility for the manuscript. KVD, ACF, PTS, ALB, MOK, KMG and LP critically reviewed the manuscript, and approved the final manuscript as submitted.

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Supplementary Figure 2: Associations between measures of the CEBQ and childhood obesity at 3-years of age

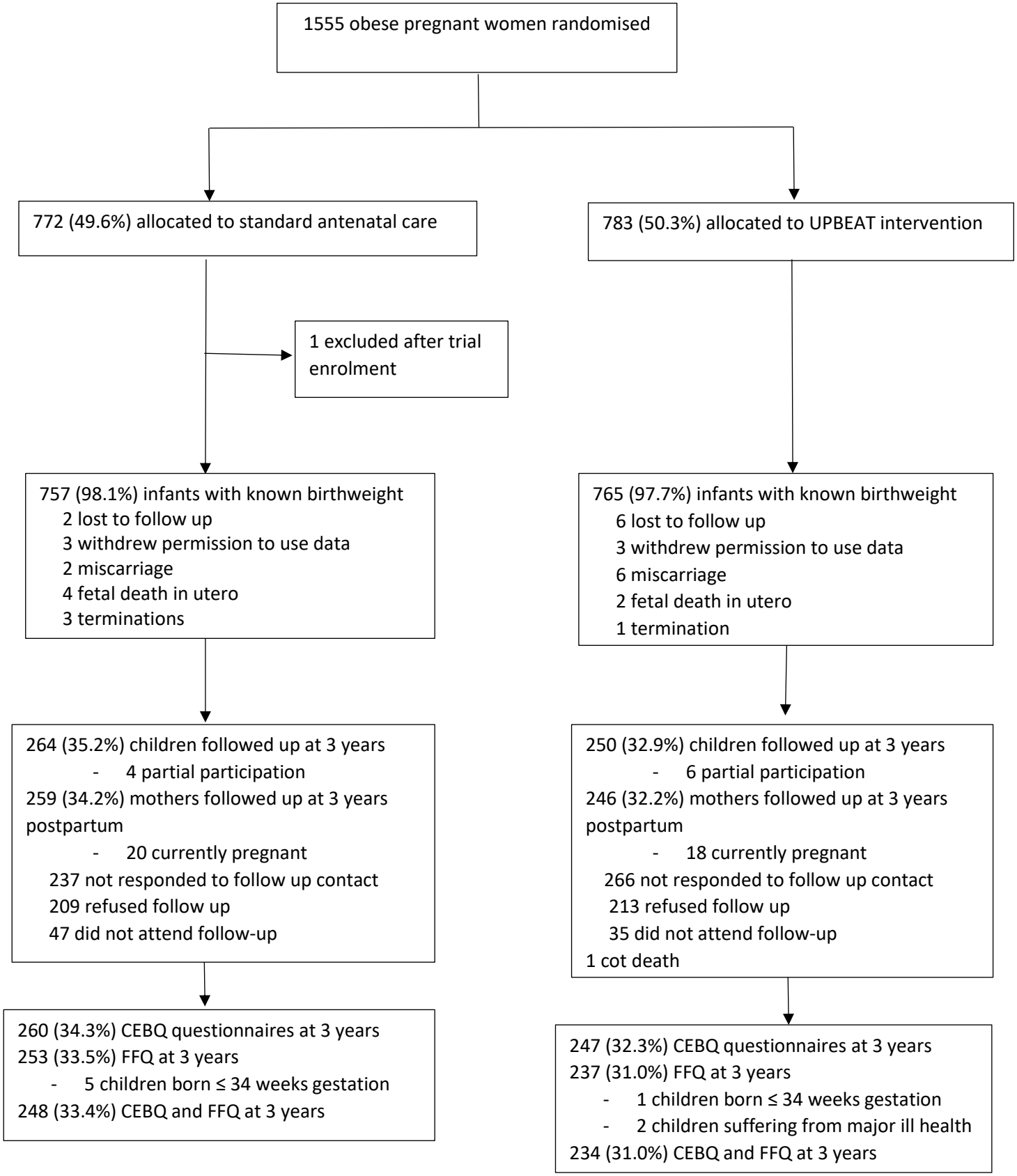

Figure 1: Consort diagram of participants enrolled in the UPBEAT trial at 3 years postpartum

Table 1: Maternal and offspring demographics of the analysed sample (n=482)

Maternal demographics	Mean (SD)/Median (IQR)/N (%)	
Pre-pregnancy		
Age (years)		31.2 (5.2)
Ethnicity	*White*	329 (68)
	Black	110 (23)
	Asian	20 (4)
	Other	23 (5)
Years in full time education		15.0 (2.8)
Maternal BMI (kg/m^2) [a]		34.7 (32.5 to 37.9)
Nulliparous		229 (50)
Index of Multiple Deprivation Quintiles [b]	*1 (least deprived)*	30 (6)
	2	31 (6)
	3	55 (12)
	4	172 (36)
	5 (most deprived)	191 (40)
Maternal antenatal and neonatal demographics		
Mother assigned to UPBEAT Intervention		234 (49)
Gestational diabetes mellitus [c]		116 (25)
Birthweight (g)		3499 (499)
Large for gestational age >90th centile [d]		61 (12)
Small for gestational age <10th centile [d]		34 (7)
Child 3-year follow-up demographics		
Age (years)		3.5 (0.28)
Female		243 (50)
Mother living with a partner		387 (80)
Mother a current smoker		47 (9)
Mode of infant feeding at 4 months	*Breastfed*	135 (52)
	Formula fed	105 (41)
	Mixed fed	18 (7)
BMI z-score [d]	472	0.88 (1.0)
Height-for-age z-score [d]	477	0.38 (1.1)
Weight-for-age z-score [d]	477	0.83 (1.0)
Weight-for-height z-score [d]	472	0.90 (1.0)
International Obesity Task Force gender specific cut-offs BMI categorises [e]	*Underweight (< 18.5 kg/m^2)*	15 (3)
	Healthy (18.5-24.9 kg/m^2)	292 (62)
	Overweight (25.0-29.9 kg/m^2)	125 (26)
	Obese (30.0-34.9 kg/m^2)	14 (3)
	Morbidly obese (≥35.0 kg/m^2)	26 (6)
Sum of skinfolds (mm) [a, f]	371	41.3 (34.0 to 50)
Percentage body fat (%)	382	22.3 (6.5)
Arm circumference (cm)	462	17.7 (1.8)
Waist circumference (cm)	466	53.0 (4.3)

[a] Median (interquartile range); [b] Scores were calculated for the region of residence, by fifths of the population. UK-wide scores were developed from English and Scottish data relating to employment and income domains; [c] Gestational diabetes diagnosed using the International Association of Diabetes in Pregnancy Group's criteria at 24–28 weeks' gestation; [d] World Health Organisation (2007) z-score; [e] IOTF International cut-off as BMI references [f] sum of triceps, biceps, subscapular, suprailiac and abdominal skinfold thicknesses (mm).

Table 2: Adjusted associations between offspring dietary patterns at age 3-years and body composition

		Healthy		Processed and Snacking		African and Caribbean	
		Coefficient/ Odds ratio[+] (95% CI)		**Coefficient/ Odds ratio[+] (95% CI)**		**Coefficient/ Odds ratio[+] (95% CI)**	
BMI z-score [a, d]	472	-0.01 (-0.12 to 0.09)	P=0.82	0.06 (-0.04 to 0.16)	P=0.23	-0.08 (-0.21 to 0.04)	p=0.20
Body fat percentage (%)	382	-0.10 (-0.92 to 0.71)	P=0.80	0.66 (-0.10 to 1.43)	P=0.09	-0.64 (-1.41 to 0.48)	p=0.33
Height-for-age z-score [a, d]	477	0.02 (-0.08 to 0.13)	P=0.65	0.02 (-0.08 to 0.12)	P=0.69	0.07 (-0.05 to 0.21)	P=0.24
Height-for-weight z-score [a, d]	472	-0.02 (-0.12 to 0.08)	p=0.72	0.08 (-0.01 to 0.18)	p=0.09	-0.08 (-0.21 to 0.04)	p=0.18
Weight-for-age z-score [a, d]	477	-0.01 (-0.12 to 0.09)	P=0.75	0.05 (-0.04 to 0.15)	P=0.28	-0.007 (-0.13 to 0.12)	p=0.91
Arm (cm)	462	-0.1 (-0.29 to 0.08)	P=0.28	0.15 (-0.03 to 0.33)	P=0.10	-0.23 (-0.45 to -0.01)	P=0.04
Waist (cm)	466	0.06 (-0.39 to 0.51)	P=0.79	0.10 (-0.33 to 0.52)	P=0.66	-0.45 (-0.98 to 0.08)	P=0.09
Sum of skinfolds (mm) [b]	371	-1.76 (-3.30 to -0.14)	P=0.03	0.63 (-1.59 to 2.86)	P=0.57	-0.89 (-3.12 to 1.33)	p=0.43
Obese (IOFT cut off) [c, d]	472	1.07 (0.73 to 1.56)	P=0.70	1.53 (1.07 to 2.19)	P=0.002	0.61 (0.37 to 1.01)	p=0.056

IOTF: International Obesity Task Force, gender specific BMI cut-offs; [a] Z-scores calculated using the WHO growth standards (2007); [b]sum of triceps, biceps, subscapular, suprailiac and abdominal skinfold thicknesses (mm); [c] Odds ratio. [+]Adjusted for maternal ethnicity, socio-economic status, smoking and BMI at baseline (15-18 weeks' gestation), years spent in full time education, maternal age, parity, infant birthweight, age at follow-up and sex and randomisation arm. [d] was not adjusted for infant sex or age at follow-up. Children were excluded if they were born ≤ 34 weeks gestation or suffering from major ill health.

Table 3: Adjusted association between offspring dietary patterns at 3-years of age and eating behaviour

	Underweight		**Overweight**		**Obese**	
	Coefficient (95% CI)		**Coefficient (95% CI)**		**Coefficient (95% CI)**	
Food approach scales	(n=15)		(n=125)		(n=38)	
Food responsiveness	-0.25 (-0.68 to 0.18)	P=0.25	0.27 (0.09 to 0.44)	P=0.003	0.47 (0.19 to 0.74)	P=0.001
Emotional overeating	-0.21 (-0.47 to 0.03)	P=0.096	0.05 (-0.04 to 0.15)	P=0.29	0.07 (-0.09 to 0.23)	P=0.39
Enjoyment of food	-0.62 (-1.09 to -0.16)	P=0.008	0.20 (0.02 to 0.399)	P=0.02	0.34 (0.05 to 0.64)	P=0.02
Desire to drink	0.20 (-0.40 to 0.81)	P=0.508	0.10 (-0.14 to 0.35)	P=0.418	0.42 (0.03 to 0.83)	P=0.03
Food avoidance scales						
Emotional under eating	0.008 (-0.49 to 0.50)	P=0.94	-0.07 (-0.27 to 0.13)	P=0.48	-0.20 (-0.52 to 0.11)	P=0.213
Slowness in eating	0.46 (0.005 to 0.93)	P=0.047	-0.08 (-0.27 to 0.09)	P=0.36	-0.40 (-0.70 to -0.11)	P=0.007
Food fussiness	0.71 (0.22 to 1.21)	P=0.005	0.02 (-0.18 to 0.22)	P=0.83	-0.28 (-0.60 to 0.03)	P=0.08
Satiety responsiveness	0.19 (-0.20 to 0.58)	P=0.34	-0.21 (-0.37 to -0.05)	P=0.009	-0.461 (-0.71 to -0.20)	P<0.001

Adjusted for maternal ethnicity, socio-economic status, smoking and BMI at baseline (15-18 weeks' gestation), years spent in full time education, maternal age, parity, infant birthweight, sex age at follow-up and randomisation arm. Children were excluded if they were born ≤ 34 weeks gestation and suffering from major ill health.

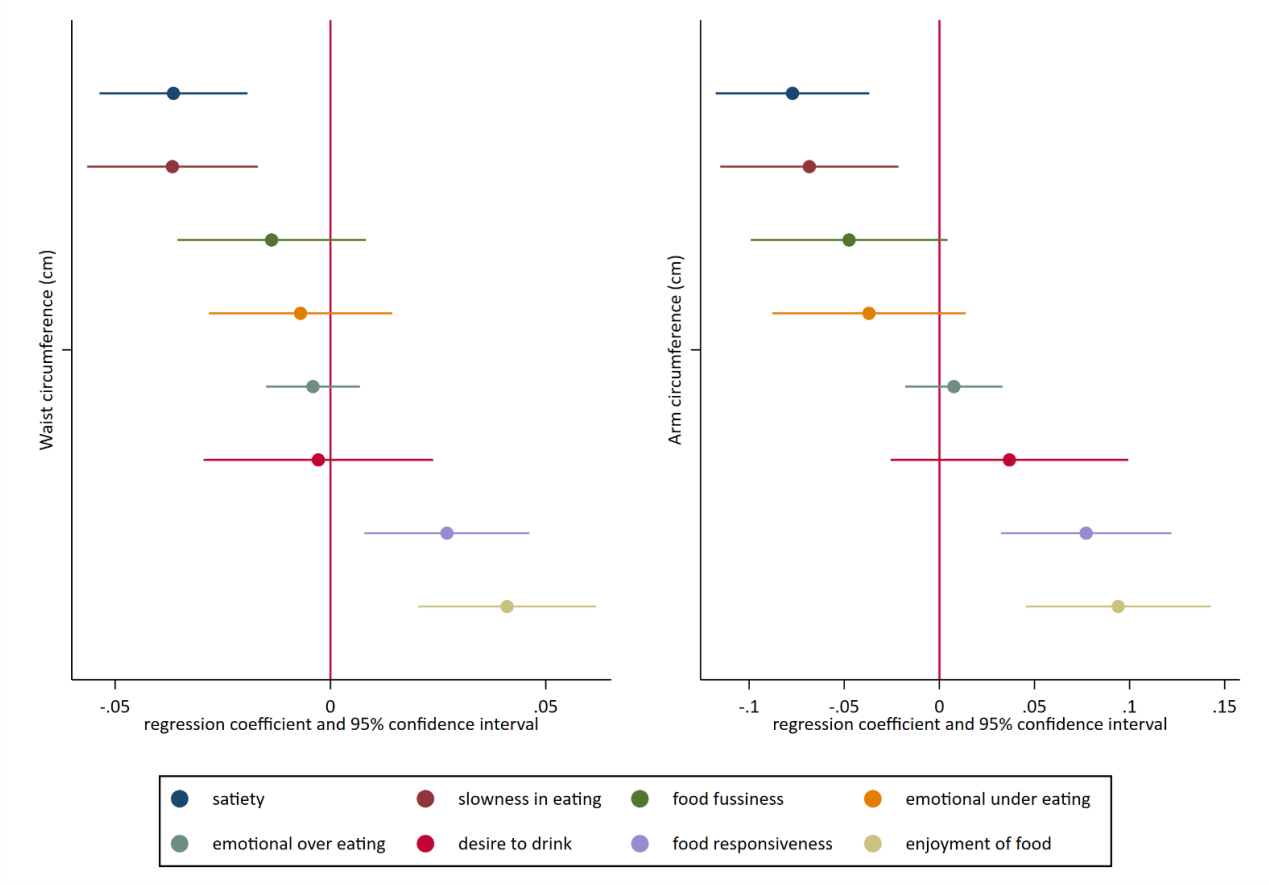

Figure 2: Associations between measures of the Children's Eating Behaviour Questionnaire (CEBQ) and waist and arm circumferences in children at 3 years of age

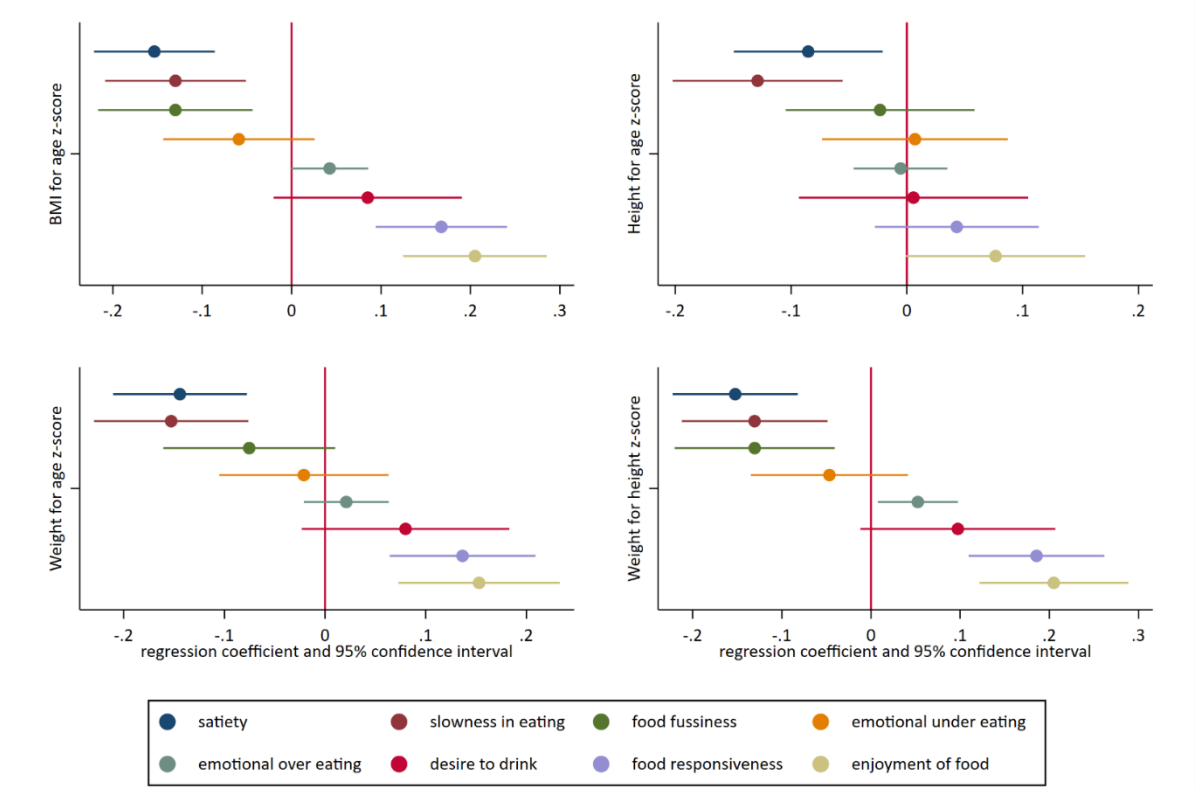

Figure 3: Associations between measures of the Children's Eating Behaviour Questionnaire (CEBQ) and the WHO *z* scores in children at 3 years of age

Supplementary Table 1: List of the 39 food groups derived from the 88 items in the food frequency questionnaire

1. White bread	White bread Hard dough, African bread*
2. Brown bread	Brown and wholemeal bread
3. Crisps and savoury snacks	Crackers, cheese biscuits and breadsticks Crisps and savoury snacks
4. Low sugar cereals	Weetabix -Porridge/ Shredded Wheat¥
5. Medium & high sugar cereals	>5g/100g of sugar -cereal bars¥
6. Boiled and baked potatoes	Boiled and baked potatoes
7. Fried and roasted potatoes	Chips, waffles and potatoes shapes Roasted potatoes
8. Rice and pasta	Pasta - boiled & tinned Rice - boiled, fried, jollof, rice and peas∞
9. Chicken and turkey	Chicken and turkey - roasted in batter or breadcrumbs or fried Chicken and turkey - casseroles, curries, African/Caribbean soup∞
10. Red meat	Beef, pork, lamb and goat - roast meats Beef burgers Beef, pork, lamb and goat - casseroles, curries, African/Caribbean soup∞
11. Offal	Liver, kidney and faggots
12. Processed meat	Bacon & gammon Ham & processed cold meats Sausages Meat pies, sausage rolls and patties Including McDonalds/Burger King¥
13. Fish	Fish in batter or breadcrumbs Oily fish - fresh and tinned Other white fish
14. Quiche and pizza	Quiche and savoury flans Pizza
15. Vegetarian dishes/food	Vegetarian burgers, sausages and nuggets
16. Eggs	Eggs
17. Yam, cassava, plantain	Yam, cassava, fufu, kenkey, green banana and plantain*
18. Vegetables	Tinned vegetables Carrots Salad Peas and green beans Tomatoes Cabbage spring greens, spinach, kale and brussels sprouts Broccoli, cauliflower, courgettes and marrow Sweetcorn and mixed veg
19. Root vegetables	Parsnip, turnip, swede and sweet potato
20. Beans and pulses	Baked beans Other beans, lentils and pulses: e.g chickpeas, black eyed, gunga∞
21. Cooked and tinned fruit	Tinned fruit Cooked/stewed fruit

22. Fresh fruit	Apples and pears Bananas Oranges, satsumas and grapefruit Plums, cherries and grapes strawberries, raspberries, mango, kiwi, pineapple and papaya peaches, nectarines and melon
23. Dried fruit	Dried fruit
24. Nuts	Nuts
25. Cheese and cottage cheese	Cheese Cottage cheese
26. Soup	African/Caribbean fish/shrimp soups* Soup - fresh, canned, packet African/Caribbean vegetable soups eg. Okra, aubergine, tomatoes, spinach* African/Caribbean groundnut/peanut soups*
27. Sauces and salad dressing	Savoury white sauce Tomato pasta sauce Sauces and salad dressings
28. Yoghurt	Yoghurt and fromage frais
29. Desserts and puddings	Other readymade desserts in pots Ice-cream Other puddings eg. Rice and semolina Ice-lollies Custard and sweet white sauce
30. Cakes and biscuits	Cakes, buns and pastries Chocolate and digestive biscuits Other biscuits
31. Confectionary	Chocolate Sweets
32. Spreads	Marmite and Bovril Peanut butter Butter and margarine
33. Sweet spreads	Jam and sweet spreads
34. Hot drinks	Tea & coffee
35. Milky drinks	Milk and malt drinks
36. Low sugar soft drinks	Low calorie/sugar free squash eg. Robinsons No added sugar Low calorie/diet fizzy drinks
37. High sugar soft drinks	Fruit drinks eg. Fruit shoots, Rubicon, smoothies Ribena, high juice blackcurrant squash Squash Fizzy drinks
38. Fruit juice	Pure fruit juice
39. Water	Water

[∞]Food items extended from the original SWS questionnaire, * additional food items included which were culturally appropriate for the UPBEAT cohort [¥]additional items consumed more than once a week which were not included in the main FFQ and were included with the factor analysis due to frequency of consumption in the whole cohort.

Supplementary Table 2: Factor loadings (≥±0.1) of items in the three dietary patterns identified

	Factor 1	Factor 2	Factor 3
1. White bread	-0.207	**0.3813**	
2. Brown bread	**0.3278**		-0.1675
3. Crisps and savoury snacks	0.11	**0.3782**	
4. Low sugar cereals	**0.264**	-0.1016	-0.1776
5. Medium & high sugar cereals	-0.2023	0.2123	0.1104
6. Boiled and baked potatoes	**0.352**	0.2178	-0.1422
7. Fried and roasted potatoes		**0.5194**	0.1203
8. Rice and pasta	**0.271**		**0.348**
9. Chicken and turkey	0.217	**0.2482**	**0.4132**
10. Red meat	**0.2351**	**0.2457**	**0.4761**
11. Offal			**0.2915**
12. Processed meat		**0.4992**	
13. Fish	**0.4234**		**0.3178**
14. Quiche and Pizza	0.146	**0.3099**	
15. Vegetarian dishes/food	0.1706		
16. Eggs	0.1864	0.1312	0.1219
17. Yam, cassava, plantain			**0.5508**
18. Vegetables	**0.6854**		0.1698
19. Root vegetables	**0.6555**		
20. Beans and pulses	**0.375**	0.1225	
21. Cooked and tinned fruit	**0.2346**	0.1656	0.16
22. Fresh fruit	**0.2803**		0.1188
23. Dried fruit	**0.2572**		
24. Nuts	**0.2321**		0.1005
25. Cheese and cottage cheese	0.1859	0.1494	**-0.2553**
26. Soup	0.1381		**0.4044**
27. Sauces and salad dressing	**0.3233**	0.1161	
28. Yoghurt		**0.2568**	**-0.2256**
29. Desserts and puddings		**0.4421**	0.1775
30. Cakes and biscuits		**0.4484**	0.1066
31. Confectionary	-0.1073	**0.5544**	
32. Spreads	**0.2335**	**0.3233**	**-0.2722**
33. Sweet spreads	0.2096	0.1746	
34. Hot drinks			
35. Milky drinks			-0.1132
36. Low sugar soft drinks		**0.2842**	-0.2094
37. High sugar soft drinks		**0.2426**	
38. Fruit juice	0.1462	0.1337	
39. Water		-0.1578	**0.2546**

Supplementary Table 3: Association between offspring dietary patterns at 3-years of age and maternal social and demographic factors (n=482)

	Healthy pattern		**Processed and Snacking pattern**		**African and Caribbean pattern**	
	Coefficient/ Odds ratio (95% CI)		**Coefficient/ Odds ratio (95% CI)**		**Coefficient/ Odds ratio (95% CI)**	
Maternal BMI (kg/m^2)	0.19 (-0.30 to 0.68)	p=0.44	0.02 (-0.42 to 0.47)	p=0.91	0.30 (-0.18 to 0.78)	p=0.23
Years in full time education (years)	0.41 (0.12 to 0.70)	p=0.005	-0.56 (-0.82 to -0.30)	p<0.001	-0.17 (-0.46 to 0.10)	p=0.22
Maternal age (years)	0.63 (0.09 to 1.17)	p=0.02	-0.63 (-1.12 to -0.14)	p=0.012	-0.19 (-0.72 to 0.34)	p=0.48
White vs black [a]	1.11 (0.86 to 1.43)	p=0.41	1.46 (1.14 to 1.86)	p=0.002	0.13 (0.09 to 0.21)	p<0.001
IMD Quintile	-0.1 (-0.22 to 0.01)	P=0.07	-0.01 (-0.12 to 0.09)	P=0.79	0.23 (0.11 to 0.35)	p<0.001

[a] Odds ratio; BMI, maternal age and years in full time education recorded at 15-18 weeks gestation. IMD quintiles are calculated for the region of residence, by fifths of the population. UK wide-scores were developed by reconciling Scottish data to English norms. Children were excluded if they were born ≤ 34 weeks gestation or suffering from major ill health.

Supplementary table 4: UPBEAT 3-year follow-up: Descriptive statistics for the whole sample and stratified by gender for the subscales of the Children's Eating Behaviour Questionnaire (CEBQ)

	All (n=507)	**Female (n=259)**	**Male (n=248)**
	Mean (SD)	**Mean (SD)**	**Mean (SD)**
Food responsiveness	2.12 (0.84)	2.12 (0.85)	2.12 (0.82)
Emotional overeating	1.41 (1.41)	1.38 (0.47)	1.43 (0.52)
Emotional under eating	2.68 (0.96)	2.62 (0.93)	2.73 (0.98)
Slowness in eating	3.13 (0.86)	3.14 (0.87)	3.13 (0.85)
Enjoyment of food	3.57 (0.90)	3.60 (0.89)	3.53 (0.91)
Desire to drink	2.79 (1.20)	2.73 (1.17)	2.85 (1.24)
Food fussiness	2.91 (0.94)	2.84 (0.95)	2.99 (0.94)
Satiety responsiveness	3.12 (0.75)	3.13 (0.79)	3.10 (0.71)

Abbreviations: SD: standard deviation

Supplementary table 5: UPBEAT 3-year follow up: Univariate analysis of child eating behaviour at 3 years of age stratified by mode of early feeding in offspring born to obese women (n=271)

	Breastfeeding n=140	**Formula feeding n=111**	**Mixed feeding n=20**	**p-value**
	Mean (SD)	***Mean (SD)***	***Mean (SD)***	
Food responsiveness	2.18 (0.84)	2.04 (0.76)	2.12 (0.86)	0.39
Emotional overeating	1.44 (0.54)	1.42 (0.47)	1.3 (0.35)	0.53
Emotional undereating	2.78 (0.93)	2.63 (1.04)	2.86 (0.81)	0.39
Slowness in eating	3.00 (0.86)	3.14 (0.92)	3.19 (0.83)	0.26
Enjoyment of food	3.65 (0.84)	3.59 (0.86)	3.63 (0.90)	0.82
Desire to drink	2.62 (1.10)	2.70 (1.27)	2.2 (1.13)	0.22
Food fussiness	2.96 (0.90)	2.92 (1.06)	2.88 (0.89)	0.91
Satiety responsiveness	3.08 (0.70)	3.11 (0.77)	3.26 (0.66)	0.60

Supplementary Figure 1: Radar graphs with factor loadings ≥ ±0.22 for each identified dietary pattern

Supplementary Figure 2: Assocations between measures of the CEBQ and childhood obesity at 3-years of age