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Longitudinal comparisons of dietary patterns derived by cluster analysis in 7- to 13-year-old children

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Abstract

Little is known about changes in dietary patterns over time. The present study aims to derive dietary patterns using cluster analysis at three ages in children and track these patterns over time. In all, 3 d diet diaries were completed for children from the Avon Longitudinal Study of Parents and Children at 7, 10 and 13 years. Children were grouped based on the similarities between average weight consumed (g/d) of sixty-two food groups using *k*-means cluster analysis. A total of four clusters were obtained at each age, with very similar patterns being described at each time point: Processed (high consumption of processed foods, chips and soft drinks), Healthy (high consumption of high-fibre bread, fruit, vegetables and water), Traditional (high consumption of meat, potatoes and vegetables) and Packed Lunch (high consumption of white bread, sandwich fillings and snacks). The number of children remaining in the same cluster at different ages was reasonably high: 50 and 43 % of children in the Healthy and Processed clusters, respectively, at age 7 years were in the same clusters at age 13 years. Maternal education was the strongest predictor of remaining in the Healthy cluster at each time point – children whose mothers had the highest level of education were nine times more likely to remain in that cluster compared to those with the lowest. Cluster analysis provides a simple way of examining changes in dietary patterns over time, and similar underlying patterns of diet at two ages during late childhood, that persisted through to early adolescence.

Key words: **Dietary patterns: Children: Cluster analysis: Avon Longitudinal Study of Parents and Children: Adolescence: Diet diaries: Tracking**

Dietary intake is associated with many health outcomes. When investigating these associations, particularly with health outcomes occurring in adulthood, it is important to consider the effect of diet over the whole life course[1]. Diet may have a cumulative effect and there may be critical periods during which diet is particularly important. In addition, the effects of later diet may be influenced or confounded by previous dietary intakes. Therefore, longitudinal modelling of the development and change of diet throughout life may be useful, particularly if started during childhood.

Dietary patterns have emerged as an effective way of describing and quantifying diet in nutritional epidemiological studies[2]. These methods recognise that foods and drinks are consumed in combination and enable the study of the whole diet, rather than individual foods or nutrients. Cluster analysis is one such method for deriving dietary patterns, which combines individuals into non-overlapping groups based on similarity of dietary intakes. Meaningful dietary patterns derived using cluster analysis among children have been shown in diverse settings, including Australia[3], Germany[4], Great Britain[5,6], Finland[7], South Korea[8,9] and the USA[10,11]. The majority of these have used data collected from diet diaries, although some used 24 h recalls[9,10] and FFQ[6].

Despite the diverse cultures represented in the published literature, similar patterns of dietary intake have been identified across studies. Two dichotomous patterns have often been described in adult studies[12–15]. These have been labelled either as 'prudent' or 'healthy', being related to high intakes of fruit, vegetables, cereals and low-fat dairy products, or 'less healthy', being related to high intakes of meat, processed

Abbreviations: ALSPAC, Avon Longitudinal Study of Parents and Children; PCA, principal components analysis.

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meats and added sugar. It is quite likely that an individual's adult diet is heavily influenced by their childhood diet, and it would therefore be important to examine any change in dietary patterns over time prior to adulthood. Such changes, during childhood and from childhood into early adulthood, have been investigated with principal components analysis (PCA)[16,17], but we are not aware of any studies that have examined them using dietary patterns obtained from cluster analysis.

Newby & Tucker[2] note that the 'reproducibility of patterns over time may either represent instability of the measurements or actual changes in dietary intakes'. It is therefore unclear whether observed changes are due to the underlying patterns themselves changing or whether it is the individuals in that population who are changing their diet over time[17]. Therefore, the purpose of the present study is to derive cross-sectional dietary patterns using cluster analysis from diet diary data collected from children aged between 7 and 13 years, and to examine whether these patterns, or the individuals, change over time.

Subjects and methods

The Avon Longitudinal Study of Parents and Children (ALSPAC) is a population-based birth cohort study investigating environmental, genetic and other influences on development and health[18]. Pregnant women living in the Avon health authority area (South West England), with expected dates of delivery between April 1991 and December 1992, inclusive, were eligible to participate. The present study includes children in the core ALSPAC sample, consisting of 14 541 pregnancies together with children from an additional 542 eligible pregnancies that were invited to participate at a later date. There were 14 535 children alive at 1 year of age, comprising the baseline sample. Further details can be obtained from the ALSPAC website (http://www.bristol.ac.uk/alspac). Ethical approval was obtained from the ALSPAC Law and Ethics Committee and the Local Research Ethics Committees.

Children were invited to attend hands-on research clinics when they were 7, 10 and 13 years of age. The mean age at attendance was 7 years 7 months (SD 4 months), 10 years 8 months (SD 3 months) and 13 years 10 months (SD 2 months), respectively. Prior to each clinic visit, the subjects were sent a 3 d diet diary for care-giver completion at 7 years and child completion at 10 and 13 years, recording all food and drink consumed over two weekdays and one weekend day. At each clinic visit, a nutritionist conducted an interview to clarify portion sizes and any omitted foods and drinks. The 24 h recalls were conducted if the child did not bring a completed diary to the clinic with them (<10 % at each time point). Further details on the recording and coding of the dietary data can be found elsewhere[19,20]; briefly, the completed diaries were entered into the DIDO (Diet In Data Out) computer program[21], which generated a weight for every food consumed by each child based on the description given in the diary. For the purposes of the present study, the average weight of each food consumed over the 3 d was used. Foods were allocated to sixty-two groups, which were based primarily on the food groups used in FFQ administered to the same subjects[6,17,22]; additional groups were included to allow for foods not covered by the FFQ (such as salty flavourings and sauces). The average weights (g/d) consumed in each group were used as input variables for cluster analysis.

Statistical methods

Cluster analysis combines individuals into non-overlapping groups according to the similarity of foods consumed between individuals. Here, similarity between children was measured by the sum of squares of differences in standardised average weights (g/d) of foods consumed in each of the sixty-two food groups. Cluster solutions are sensitive to extreme values, therefore outliers were removed at that time point (not from other time points, unless they too were outliers); these were defined as children with at least one intake being more than 5 SD higher than the mean, where the mean and SD were calculated from non-zero intakes. The standardisation method used was subtraction of the mean and division by the range[23], as there are potential drawbacks of standardisation by subtracting the mean and dividing by the SD when performing cluster analysis[24].

The cluster analysis used the *k*-means algorithm, the most common method used in dietary studies[2]. This method minimises the sum of squares of differences between each child and the mean of his/her cluster. The standard *k*-means algorithm can give incorrect cluster solutions[24] and it was therefore run 100 times, with different starting positions, to find the solution with the smallest sum of squares differences. To examine the stability of the final solution, the data were randomly split and analyses performed on separate halves. The number of children allocated to a different cluster gave a measure of stability of the solution. This procedure was repeated five times.

We examined two- to six-cluster solutions at each time point: several factors influenced the choice of the number of clusters to retain, including stability of the cluster solutions and the size and interpretation of each cluster. At each time point, the four-cluster solution was found to be the most interpretable and was also the most reliable (with less than 10 % misclassified at each time point; see Results for further details). ANOVA and the Tukey–Kramer method aided interpretation of clusters by testing for differences in the means of each food item according to cluster. We chose to give labels to the clusters to assist with reporting; these labels were subjective and based on the foods that were most highly associated with each cluster. The characteristics of children with dietary data were compared with the whole cohort at baseline using χ^2 tests and the following characteristics were considered: child ethnicity (white if both parents were white, non-white otherwise), maternal age at delivery, highest level of maternal education, housing tenure and whether the mother had ever smoked. These characteristics were reported by the mother via self-completion questionnaires administered during pregnancy. Changes in dietary patterns over time were assessed by cross-tabulating cluster solutions at different ages and calculating the proportion of children remaining in the same cluster between each pair of ages. A sequence index plot[25] was also used to illustrate the changes in cluster membership over time. Logistic regression was used to assess the associations between the characteristics mentioned earlier and a child consistently belonging to a particular cluster over time. We chose these variables as we have previously shown that they are associated with dietary patterns cross-sectionally. All analyses were performed in Stata v11.0 (Stata Corp LP).

Results

At age 7 years, 8299 children attended the clinic with 7285 (88 %) providing diet diaries. Of these, 6837 (94 %) children were available for analysis after outlier removal. At age 10 years, 7563 children attended, 7473 (99 %) provided diaries and 6972 (93 %) were available after outlier removal. At age 13 years, 6147 children attended, with 6105 (99 %) providing diaries and 5661 (93 %) remaining after outlier removal. Dietary data were more likely to be available for girls, white children, children with older, higher educated and non-smoking mothers, and those living in homes that were owned or mortgaged. These inequalities were similar across the three ages (data not shown).

A four-cluster solution provided stable clusters with similar interpretations at each age. In stability testing, consisting of five sets of split-sample testing, at most 573 (the maximum from the five sets) children were allocated to different clusters at age 7 years, at most 460 were reallocated at age 10 years and at most 581 were reallocated at age 13 years. Tables 1–3 present the sizes of each cluster and the mean consumption of each food, according to those clusters that were retained at ages 7, 10 and 13 years, respectively. The mean amount of each food consumed within each cluster differed between ages, generally increasing as the children got older. However, the patterns of foods consumed, and the foods in each cluster with higher and lower than average consumptions, were similar at each age.

The largest cluster at each age, which we chose to label as Processed, had higher mean consumption of processed meat, pies and pasties, coated and fried chicken and white fish, pizza, chips, baked beans and tinned pasta, chocolate, sweets, sugar and diet and regular fizzy drinks compared to the other clusters. The second-largest cluster at each age, which we chose to label as Healthy, had higher mean consumption of non-white bread, reduced fat milk, cheese, yoghurt and fromage frais, butter, breakfast cereal, rice, pasta, eggs, fish, vegetable and vegetarian dishes, soup, salad, legumes, fruit, crackers and crispbreads, high-energy-density sauces (e.g. mayonnaise), fruit juice and water. The third cluster had higher mean consumption of red meat, poultry, potatoes, vegetables, starch-based products (e.g. Yorkshire pudding), low-energy-density sauces (e.g. gravy), puddings, tea and coffee. This cluster was given the label ‘Traditional’, in line with a traditional British diet. The final cluster had higher mean consumption of white bread, margarine, ham and bacon, sweet spreads (e.g. honey), salty flavourings (e.g. yeast extract), crisps, biscuits, diet squash, tea and coffee. This cluster was labelled as ‘Packed Lunch’, because in school-aged children these foods are often eaten in packed lunches.

Table 4 shows the cluster membership at 10 and 13 years of age, tabulated against cluster membership at 7 years. It also shows the proportion of children who remained in each cluster between the ages. The highest proportions staying in the same cluster were seen for the Healthy cluster: 54 % of children in this cluster at age 7 years remained in it at age 10 years and 50 % were still in it at age 13 years. Of those in the Healthy cluster at age 10 years, 50 % remained there at age 13 years. The Processed cluster at age 7 years also showed reasonable stability over time: 43 and 46 % of children in this cluster at 7 years were still in it at 10 and 13 years, respectively, while 43 % in it at 10 years remained there at 13 years. The Traditional and Packed Lunch clusters were less stable, with 25–34 % remaining in those clusters over time. The proportion of children who stayed in the same cluster at all three ages was 20 %; for individual clusters, the greatest stability was seen for the Healthy cluster at 33 %, with the processed cluster second at 22 %. Fig. 1 illustrates the tracking of cluster membership over time and shows that the most consistent cluster membership over time was for the Healthy cluster, followed by the Processed cluster.

Given that the Healthy and Processed clusters showed greater stability and could be considered to represent the two extremes of diet, we carried out our association analyses on these clusters only. It can be seen in Table 5 that mothers with the highest level of education had children who were nearly nine times more likely to be in the Healthy cluster at all three time points compared to the lowest level of education (adjusted OR 8·83; 95 % CI 4·58, 17·01). This compared to an adjusted OR of 4·39 (95 % CI 3·05, 6·35) for being in the Healthy cluster at any two time points. Girls were also more likely to remain in the Healthy cluster, as were children whose mothers were aged over 30 years at delivery and who lived in rented/other accommodation. Staying in the Processed cluster at all three ages was much more likely in children who were non-white and who had mothers with the lowest levels of education.

Discussion

In the present study, four meaningful dietary patterns were consistently identified using cluster analysis among children at 7, 10 and 13 years of age: Processed, with higher consumption of processed, convenience and snack foods; Healthy, with higher consumption of high-fibre, low-fat foods, fruit and vegetables; Traditional, with higher consumption of meat and vegetables; and Packed Lunch, with higher consumption of white bread, sandwich fillings and snacks. Although the mean amounts of each food consumed changed slightly over time, the relative intakes were similar at each age. Therefore, the underlying dietary patterns were comparable at the different ages. Although some children changed between clusters at later ages, the most stable clusters were the Healthy cluster followed by the Processed cluster, and continued membership of both was highly associated with maternal education level (although in opposite directions).

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Table 1. Weight (g/d) of foods consumed across clusters for 6837 children aged 7 years
(Mean values and standard deviations)

	Processed (*n* 1991)		Healthy (*n* 1709)		Traditional (*n* 1558)		Packed lunch (*n* 1579)	
Food item	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Full-fat milk	132·3[b]	174·5	132·9[b]	179·7	149·6*[a]	198·3	80·0†[c]	132·4
Reduced-fat milk	97·6†[b]	143·1	143·6*[a]	178·7	106·7[b]	148·5	132·4[a]	167·6
Cheese	6·7†[d]	10·7	16·2*[a]	16·2	8·5[c]	11·8	14·2[b]	16·5
Yoghurt, fromage frais	28·1†[c]	39·9	47·2*[a]	50·2	34·4[b]	43·8	37·0[b]	44·9
Butter, animal fat	2·0[b]	5·5	4·5*[a]	8·1	2·4[b]	5·9	1·0†[c]	4·3
Margarine	5·8†[c]	5·2	6·7[b]	6·5	7·2[b]	6·3	15·7*[a]	7·1
Vegetable oil	0·1[b]	0·5	0·1*[a]	0·7	0·1†[b]	0·4	0·1[b]	0·5
High-fibre bread	5·9[c]	15·2	25·7*[a]	33·1	10·1[b]	20·1	4·2†[c]	13·9
Low-fibre bread	43·9[b]	28·1	39·6†[c]	31·8	45·2[b]	31·3	94·2*[a]	33·3
Special bread	1·1[b]	6·8	2·5*[a]	9·8	1·0[b]	5·6	1·0†[b]	6·2
Other starch-based products	5·2†[b]	12·9	7·3[b]	16·3	9·7*[a]	16·5	6·6[b]	14·6
Breakfast cereal	29·6[b]	20·8	37·3*[a]	25·8	31·4[b]	22·3	25·6†[c]	20·7
Rice	4·1†[c]	12·5	9·1*[a]	20·6	5·6[b]	14·8	4·6[b,c]	13·7
Pasta	9·2†[c]	19·5	27·0*[a]	32·9	11·9[b]	22·6	13·1[b]	24·5
Baked beans, tinned pasta	42·9*[a]	47·3	22·6[b,c]	34·3	21·2†[c]	29·9	25·8[b]	34·4
Pizza	12·7*[a]	25·3	11·2[a]	23·6	6·9†[b]	18·1	8·8[b]	21·3
Eggs	7·3[b]	15·8	9·8*[a]	16·8	6·4†[b]	13·7	7·1[b]	14·7
Coated and fried chicken	15·6*[a]	21·4	6·8†[c]	14·5	7·2[c]	14·7	9·2[b]	17·0
Poultry	11·0†[c]	18·6	14·9[b]	21·4	25·2*[a]	27·5	12·8[c]	18·9
Ham, bacon	5·6†[c]	9·6	7·7[b]	11·1	7·9[b]	11·7	10·6*[a]	14·1
Red meat	18·6†[c]	27·5	24·4[b]	32·0	33·7*[a]	35·9	22·2[b]	29·1
Meat pies, pasties	6·7*[a]	17·0	3·6†[c]	11·0	6·1[a,b]	16·4	5·3[b]	14·3
Processed meat	22·4*[a]	24·8	10·0†[c]	15·0	14·4[b]	19·8	14·2[b]	19·7
Coated and fried white fish	11·1*[a]	17·8	6·4†[b]	13·5	6·6[b]	13·9	6·8[b]	14·4
White fish, shellfish	1·9[b]	10·2	3·1*[a]	12·6	2·4[a,b]	12·6	1·7†[b]	9·0
Tuna, oily fish	2·5†[b]	9·8	6·2*[a]	13·8	3·5[b]	10·4	3·4[b]	10·3
Vegetarian products	1·4†[b]	11·2	4·3*[a]	23·2	2·4[b]	19·5	1·6[b]	10·5
Chips	52·9*[a]	32·8	17·3†[d]	21·6	20·7[c]	22·2	26·2[b]	25·9
Roast potatoes	11·5[c]	19·6	8·1†[d]	15·7	40·9*[a]	33·0	14·8[b]	22·2
Other potatoes	23·2†[c]	30·7	33·1[b]	34·7	38·3*[a]	38·3	25·0[c]	30·8
Root vegetables	1·1†[c]	4·4	1·8[b]	5·5	3·5*[a]	8·8	1·2[c]	4·4
Carrots	6·3†[d]	9·9	11·5[b]	14·2	24·8*[a]	18·8	9·0[c]	11·6
Green leafy vegetables	3·3†[d]	6·9	7·1[b]	11·0	17·9*[a]	17·0	4·6[c]	8·7
Peas, broad beans, sweet corn	7·8†[c]	12·7	11·3[b]	14·8	15·4*[a]	18·1	8·6[c]	13·7
Other cooked vegetable dishes	6·1†[b]	13·7	11·3[a]	20·0	12·5*[a]	19·0	6·5[b]	13·6
Salad, tomatoes	7·0†[c]	15·5	24·1*[a]	29·5	9·8[b]	18·4	10·7[b]	19·1
Legumes	0·2†[c]	2·0	1·1*[a]	6·7	0·5[b]	4·3	0·4[b]	4·0
Soup	4·9[b]	21·6	6·8*[a]	24·1	4·8†[c]	19·1	5·1[b,c]	20·9
Nuts, seeds, peanut butter	1·3[b]	4·8	2·7*[a]	6·9	1·3†[b]	4·4	1·4[b]	4·8
Fresh fruit	47·5†[c]	54·1	121·7*[a]	84·7	69·1[b]	65·3	67·1[b]	63·2
Other fruit	2·7†[c]	11·6	6·4*[a]	17·6	5·0[b]	15·7	3·4[c]	13·8
Puddings	10·3[c]	22·2	12·5[b]	24·2	17·7*[a]	27·9	9·7†[c]	21·0
Dairy puddings	39·8[b]	41·7	35·2†[c]	36·5	48·2*[a]	43·8	36·6[b,c]	37·9
Cakes	23·5[b]	25·2	29·1[a]	29·2	29·5*[a]	28·0	22·9†[b]	25·5
Chocolate	12·6*[a]	15·9	8·6†[c]	12·4	10·1[b]	12·8	12·0[a]	15·4
Sweets	8·6*[a]	12·4	5·5†[c]	9·1	6·9[b]	10·3	6·4[b,c]	9·9
Sugar	2·9*[a]	4·9	1·9†[c]	3·3	2·7[a,b]	4·3	2·5[b]	4·4
Sweet spreads	4·2†[d]	7·7	6·3[b]	9·3	5·1[c]	8·2	7·7*[a]	11·6
Biscuits	26·8[b]	20·8	20·6†[d]	16·8	22·8[c]	17·7	28·9*[a]	20·4
Crackers, crispbreads	1·7[a,b]	5·1	2·1*[a]	5·2	1·4†[b]	4·1	2·0[a]	5·6
Crisps	18·0[b]	13·5	12·6†[d]	10·9	16·2[c]	12·8	23·7*[a]	13·5
Low-energy-density sauce	9·3†[c]	11·3	10·2[c]	12·0	26·4*[a]	16·9	12·2[b]	12·6
High-energy-density sauce	0·6†[c]	2·6	1·7*[a]	4·3	0·8[b,c]	2·6	0·9[b]	2·7
Salty flavouring	0·2†[c]	0·9	0·4[b]	1·1	0·3[b,c]	1·0	0·6*[a]	1·6
Water	99·2†[c]	135·1	206·3*[a]	215·4	156·5[b]	187·0	109·4[c]	160·8
Fizzy drinks	54·7*[a]	112·1	29·7[b]	69·3	32·4[b]	76·6	28·5†[b]	72·3
Diet fizzy drinks	123·1*[a]	164·1	40·6†[d]	81·7	82·6[c]	127·5	100·7[b]	145·1
Squash	79·1*[a]	142·3	67·5†[b]	124·7	75·5[a,b]	134·5	69·9[a,b]	131·4
Diet squash	203·1[b]	222·6	119·2†[d]	169·5	177·8[c]	208·2	285·4*[a]	277·3
Fruit juice	64·5†[c]	109·4	134·6*[a]	156·4	76·9[b]	119·7	69·9[b,c]	113·5
Flavoured milk drinks	18·1*[a]	49·7	13·0†[b]	41·2	13·3[b]	42·2	13·3[b]	44·6
Tea, coffee	39·8[a]	90·5	18·8†[b]	58·0	37·5[a]	82·5	41·4*[a]	92·4

[a,b,c,d] Mean values within a row with unlike superscript letters were significantly different between clusters ($P < 0·05$; Tukey–Cramer method).
* Highest mean value in the row.
† Lowest mean value in the row.

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Table 2. Weight (g/d) of foods consumed across clusters for 6972 children aged 10 years
(Mean values and standard deviations)

	Processed (*n* 2078)		Healthy (*n* 1980)		Traditional (*n* 1489)		Packed lunch (*n* 1425)	
Food item	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Full-fat milk	73·8*[a]	138·9	48·2†[c]	114·2	57·7[b,c]	123·1	60·5[b]	125·4
Reduced-fat milk	86·3†[c]	117·9	173·0*[a]	176·9	125·6[b,c]	148·2	111·7[b]	140·9
Cheese	7·5†[c]	12·1	16·7*[a]	18·6	9·1[b,c]	13·4	16·0[a]	19·9
Yoghurt, fromage frais	22·1†[d]	40·2	45·5*[a]	58·0	28·3[c]	44·2	34·5[b]	49·1
Butter, animal fat	2·8[b]	6·7	4·0*[a]	8·0	2·5[b]	6·2	1·1†[c]	4·8
Margarine	5·4†[d]	5·5	7·0[c]	7·1	7·9[b]	7·2	19·8*[a]	8·7
Vegetable oil	0·7*[a]	1·4	0·5†[b]	1·0	0·5[b]	1·2	0·5[b]	1·2
High-fibre bread	7·4[b,c]	19·6	24·5*[a]	35·0	9·4[b]	22·2	6·2†[c]	18·9
Low-fibre bread	46·6[c]	34·2	42·7†[d]	35·4	51·2[b]	36·9	107·2*[a]	40·8
Special bread	2·3[b]	10·5	4·6*[a]	14·8	2·8[b]	10·1	1·9†[b]	8·8
Other starch-based products	6·1†[c]	14·5	7·2[c]	16·1	14·3*[a]	21·8	9·2[b]	19·1
Breakfast cereal	24·1[c]	20·5	31·6*[a]	24·8	26·3[b]	21·6	22·1†[d]	21·0
Rice	9·6[b]	26·7	15·2*[a]	31·3	10·3[b]	26·5	8·9†[b]	25·2
Pasta	17·5†[c]	37·0	44·5*[a]	54·5	23·8[b]	41·8	21·5[b]	38·8
Baked beans, tinned pasta	48·4*[a]	65·7	25·9†[c]	43·9	26·4[c]	44·2	32·0[b]	50·3
Pizza	23·0*[a]	43·3	18·2[b]	35·9	12·3†[c]	30·9	16·0[b]	34·1
Eggs	7·7†[c]	17·3	10·9*[a]	20·6	7·8[b,c]	16·6	9·4[a,b]	19·3
Coated and fried chicken	17·0*[a]	27·5	5·7†[c]	14·8	7·1[b,c]	16·2	9·1[b]	18·6
Poultry	18·6†[b]	31·2	21·2[b]	31·7	32·1*[a]	35·3	20·4[b]	31·3
Ham, bacon	8·4†[c]	13·1	8·7[b,c]	13·4	9·8[b]	13·5	15·8*[a]	18·7
Red meat	25·3†[c]	40·6	34·7[b]	45·4	45·9*[a]	48·5	28·4[c]	40·2
Meat pies, pasties	9·2*[a]	24·0	6·0†[b]	18·6	9·0[a]	21·9	6·5[b]	18·5
Processed meat	24·3*[a]	28·0	11·9†[d]	18·4	15·1[c]	21·2	20·2[b]	25·5
Coated and fried white fish	9·8*[a]	21·1	6·2[b]	15·1	4·5†[c]	12·9	5·6[b,c]	15·4
White fish, shellfish	2·0[a,b]	11·8	2·7*[a]	11·8	2·0[a,b]	11·7	1·5†[b]	9·1
Tuna, oily fish	3·0†[c]	11·4	7·1*[a]	16·7	4·3[b]	12·4	4·4[b]	13·8
Vegetarian products	1·5[b]	13·3	4·5*[a]	21·9	1·9[b]	14·4	1·2†[b]	8·1
Chips	69·7*[a]	48·0	19·7†[d]	26·1	26·0[c]	31·2	33·9[b]	36·1
Roast potatoes	12·0[c]	22·4	9·5†[d]	18·9	61·1*[a]	43·9	15·5[b]	25·4
Other potatoes	23·6†[b]	37·9	37·0[a]	44·2	37·9*[a]	47·3	34·4[a]	45·4
Root vegetables	1·0†[d]	4·5	2·5[b]	7·8	4·1*[a]	9·9	1·8[c]	6·7
Carrots	6·1†[d]	11·5	12·4[b]	16·1	32·9*[a]	24·4	9·6[c]	14·3
Green leafy vegetables	3·4†[d]	9·2	8·1[b]	14·5	21·5*[a]	23·0	5·7[c]	11·8
Peas, broad beans, sweet corn	9·6†[c]	17·5	13·4[b]	19·6	19·6*[a]	24·0	10·1[c]	17·3
Other cooked vegetable dishes	6·4†[b]	16·0	13·7[a]	22·6	15·4*[a]	21·9	7·8[b]	17·5
Salad, tomatoes	9·6†[c]	20·6	30·2*[a]	37·7	12·2[b]	22·3	14·5[b]	24·8
Legumes	0·4[b]	3·6	1·9*[a]	10·0	0·7[b]	5·5	0·3†[b]	3·3
Soup	5·6†[b]	24·3	11·1*[a]	33·9	7·1[b]	26·6	7·1[b]	29·2
Nuts, seeds, peanut butter	1·0†[c]	4·3	2·3*[a]	6·4	1·2[b,c]	4·5	1·6[b]	6·0
Fresh fruit	35·9†[c]	49·8	102·6*[a]	84·9	62·4[b]	66·3	60·1[b]	68·1
Other fruit	3·2†[c]	13·3	6·1*[a]	16·1	4·9[a,b]	15·5	3·7[b,c]	14·3
Puddings	8·9[c]	22·6	11·6[b]	25·0	19·9*[a]	33·6	7·6†[c]	20·7
Dairy puddings	33·8[b]	41·4	32·1[b]	36·9	49·2*[a]	48·2	27·7†[c]	35·3
Cakes	21·6†[c]	27·2	30·4*[a]	32·2	25·6[b]	29·4	23·0[b,c]	27·6
Chocolate	15·0*[a]	19·6	11·1†[c]	15·0	13·4[b]	17·4	12·4[b,c]	16·1
Sweets	9·5*[a]	15·5	5·8†[c]	10·8	7·9[b]	12·7	8·2[b]	13·6
Sugar	3·6[a]	5·2	2·8†[b]	4·4	3·7*[a]	5·5	3·4[a]	5·3
Sweet spreads	4·2†[c]	8·2	5·8[b]	9·2	5·4[b]	8·8	7·3*[a]	11·5
Biscuits	24·4[b]	23·2	20·7†[c]	18·2	23·5[b]	20·6	28·8*[a]	22·8
Crackers, crispbreads	1·2†[b]	4·4	2·5*[a]	6·4	1·4[b]	4·5	2·1[a]	6·1
Crisps	20·9[b]	16·6	13·4†[d]	12·2	18·1[c]	14·1	23·8*[a]	15·3
Low-energy-density sauce	11·4†[c]	14·6	14·9[b]	17·1	35·7*[a]	21·7	13·8[b]	15·2
High-energy-density sauce	1·2†[c]	3·8	2·5*[a]	5·3	1·4[b,c]	3·8	1·6[b]	4·0
Salty flavouring	0·2†[c]	0·8	0·3[b]	1·0	0·3[b,c]	1·0	0·8*[a]	1·9
Water	118·5†[c]	183·2	245·8*[a]	276·1	177·6[b]	238·8	146·6[d]	215·8
Fizzy drinks	113·6*[a]	175·5	46·7†[c]	94·4	61·1[b]	118·1	68·9[b]	133·8
Diet fizzy drinks	88·3*[a]	159·2	39·5†[c]	101·0	71·6[b]	139·4	82·4[a,b]	154·1
Squash	58·3[a]	106·7	61·0*[a]	113·3	58·0†[a]	112·4	58·5[a]	110·9
Diet squash	137·7[b]	167·1	87·9†[b]	137·6	133·3[b]	166·5	185·7*[a]	199·8
Fruit juice	82·9†[c]	125·5	176·0*[a]	179·4	108·4[b]	142·8	95·5[b,c]	135·3
Flavoured milk drinks	23·9[a]	68·4	21·3†[a]	58·7	23·4[a]	67·0	25·1*[a]	70·0
Tea, coffee	44·1[b]	98·2	37·0†[b]	90·6	56·5[a]	121·0	61·6*[a]	126·8

[a,b,c,d] Mean values within a row with unlike superscript letters were significantly different between clusters ($P<0·05$; Tukey–Cramer method).
* Highest mean value in the row.
† Lowest mean value in the row.

Table 3. Weight (g/d) of foods consumed across clusters for 5661 children aged 13 years
(Mean values and standard deviations)

Food item	Processed (*n* 1813)		Healthy (*n* 1728)		Traditional (*n* 1108)		Packed lunch (*n* 1012)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Full-fat milk	47·6*[a]	133·8	29·5†[c]	101·9	32·7[bc]	105·6	41·7[a,b]	118·1
Reduced-fat milk	109·1†[c]	141·7	182·4*[a]	190·8	160·6[b]	184·5	142·9[b]	172·8
Cheese	10·0†[b]	16·1	20·3*[a]	21·5	11·6[b]	16·2	19·9[a]	23·9
Yoghurt, fromage frais	18·1†[c]	41·4	37·1*[a]	60·1	28·9[b]	52·4	20·0[c]	41·7
Butter, animal fat	3·3[a]	7·5	3·8*[a]	8·3	3·5[a]	7·4	2·3†[b]	8·2
Margarine	4·8†[b]	5·9	6·5[b]	7·7	6·6[b]	7·7	19·5*[a]	10·9
Vegetable oil	0·0†[b]	0·3	0·2*[a]	0·8	0·1[b]	0·5	0·1[b]	0·6
High-fibre bread	12·5[c]	25·3	44·2*[a]	43·9	22·2[b]	32·9	9·0†[d]	24·1
Low-fibre bread	46·7[b]	37·1	30·0†[c]	33·8	45·0[b]	41·5	124·3*[a]	50·5
Special bread	4·4[b]	14·2	8·7*[a]	20·7	4·4†[b]	14·4	4·4[b]	16·2
Other starch-based products	6·9[b]	19·2	6·5†[b]	17·8	14·7*[a]	23·3	7·7[b]	19·7
Breakfast cereal	22·8†[c]	25·5	36·6*[a]	33·6	29·4[b]	28·8	25·6[c]	28·0
Rice	15·1†[b]	38·2	22·5*[a]	42·1	14·2[b]	33·5	17·0[b]	40·7
Pasta	20·3†[c]	40·9	65·8*[a]	73·5	25·4[b,c]	44·6	28·7[b]	52·7
Baked beans, tinned pasta	41·1*[a]	66·7	25·0[c]	48·7	23·8†[c]	46·7	32·7[b]	61·7
Pizza	32·0*[a]	57·4	18·6[b,c]	41·9	16·7†[c]	39·3	23·4[b]	52·9
Eggs	8·0†[b]	19·8	11·2*[a]	23·5	8·3[b]	20·1	10·3[a]	22·6
Coated and fried chicken	13·4*[a]	30·9	3·8†[c]	14·5	5·0[b,c]	16·8	6·8[b]	19·1
Poultry	27·5†[b]	42·2	29·4[b]	40·5	44·3*[a]	47·3	30·9[b]	44·0
Ham, bacon	10·1†[b]	15·4	11·2[b]	16·7	11·7[b]	16·8	20·5*[a]	24·0
Red meat	37·0†[b]	57·8	38·3[b]	56·5	50·3*[a]	61·4	41·3[b]	57·3
Meat pies, pasties	13·7*[a]	32·1	6·8†[c]	20·2	11·1[a,b]	26·1	9·4[b,c]	25·0
Processed meat	23·4*[a]	34·8	10·4†[c]	20·2	13·6[b]	23·3	20·6[a]	30·5
Coated and fried white fish	8·4*[a]	22·9	4·3[b]	14·4	4·2†[b]	14·1	5·1[b]	16·0
White fish, shellfish	2·7[b]	14·3	4·2*[a]	16·6	2·0[b]	10·6	1·8†[b]	9·9
Tuna, oily fish	5·9[b]	19·0	10·1*[a]	22·7	5·8†[b]	16·1	7·5[b]	21·1
Vegetarian products	2·3[b]	18·2	6·1*[a]	24·1	3·3[b]	22·0	2·2†[b]	15·5
Chips	66·7*[a]	61·8	16·3†[d]	28·9	23·7[c]	34·3	33·6[b]	42·6
Roast potatoes	7·9[c]	20·0	7·0†[c]	18·3	70·5*[a]	51·8	14·3[b]	27·9
Other potatoes	32·0†[b]	51·5	41·7[a]	52·2	41·8*[a]	55·2	37·8[a]	51·9
Root vegetables	1·2†[c]	4·9	3·1[b]	8·9	7·2*[a]	17·2	2·0[c]	7·7
Carrots	6·4†[c]	13·2	11·6[b]	17·9	38·4*[a]	30·3	9·6[b]	16·9
Green leafy vegetables	3·3†[c]	9·3	8·2[b]	15·6	24·6*[a]	26·1	6·6[b]	14·2
Peas, broad beans, sweet corn	9·6†[c]	18·1	12·2[b]	20·8	20·6*[a]	26·5	10·4[c]	20·3
Other cooked vegetable dishes	11·4[b]	26·4	22·8*[a]	35·6	21·8[a]	33·8	11·2†[b]	24·8
Salad, tomatoes	14·4[c]	26·1	42·5*[a]	47·0	15·2†[c]	25·8	20·3[b]	33·6
Legumes	0·6[b]	6·2	3·3*[a]	14·0	0·5†[b]	5·0	0·7[b]	6·3
Soup	8·3†[b]	32·3	12·0*[a]	37·2	9·0[a,b]	32·4	9·6[a,b]	38·6
Nuts, seeds, peanut butter	0·7†[c]	3·7	2·6*[a]	7·9	1·6[b]	6·3	1·4[b]	6·3
Fresh fruit	39·2†[c]	60·5	122·2*[a]	108·5	68·7[b]	82·0	64·5[b]	79·7
Other fruit	4·5[b]	23·2	10·3*[a]	33·9	6·5[b]	29·9	4·0†[b]	21·7
Puddings	7·1†[c]	22·1	9·3[b]	23·6	16·0*[a]	32·5	7·7[b,c]	22·5
Dairy puddings	20·7†[c]	36·5	24·2[b]	37·4	31·9*[a]	46·6	24·8[b]	40·3
Cakes	19·7†[c]	30·0	25·7[b]	34·0	29·9*[a]	37·0	22·6[b,c]	32·2
Chocolate	13·4[a]	21·7	9·2†[b]	15·8	13·6*[a]	19·8	11·8[a]	19·2
Sweets	6·5*[a]	15·3	4·1†[c]	10·8	5·1[b,c]	13·1	5·7[a,b]	15·0
Sugar	3·1[a]	5·8	2·1†[b]	4·5	3·1[a]	5·7	3·4*[a]	6·4
Sweet spreads	2·4†[b]	6·5	4·3[b]	8·6	4·1[b]	8·7	6·0*[a]	12·5
Biscuits	19·5†[c]	24·1	21·3[b,c]	22·2	23·6[b]	25·1	26·6*[a]	26·0
Crackers, crispbreads	1·3†[b]	5·0	2·4*[a]	6·9	1·6[b]	5·1	2·2[a]	6·5
Crisps	16·4[b]	16·5	11·3†[d]	12·9	13·7[c]	13·8	19·6*[a]	16·9
Low-energy-density sauce	13·8†[d]	19·3	22·3[b]	27·0	43·4*[a]	30·3	17·7[c]	21·5
High-energy-density sauce	1·7†[c]	4·7	3·6*[a]	6·9	1·9[b,c]	4·9	2·5[b]	6·6
Salty flavouring	0·2†[b]	0·7	0·4[b]	1·2	0·3[b]	1·2	0·6*[a]	1·9
Water	442·3†[d]	379·8	711·9*[a]	498·2	552·9[c]	438·5	645·6[b]	484·8
Fizzy drinks	144·2*[a]	219·8	49·8†[c]	110·1	87·9[b]	169·0	96·4[b]	175·0
Diet fizzy drinks	103·0*[a]	199·7	36·1†[c]	101·9	60·2[b]	139·4	72·1[b]	150·5
Squash	70·0*[a]	150·3	62·0†[a]	134·6	58·0[a]	134·1	66·1[a]	160·9
Diet squash	126·2†[c]	204·8	132·1[b,c]	238·6	154·4[b]	254·2	233·0*[a]	319·6
Fruit juice	112·0†[d]	163·3	189·2*[a]	204·7	162·0[b]	192·4	131·9[c]	185·3
Flavoured milk drinks	29·7*[a]	85·3	16·8†[b]	55·1	23·2[a,b]	65·7	22·4[b]	67·9
Tea, coffee	68·7[b]	138·2	62·5†[b]	139·3	88·0*[a]	168·1	87·3[a]	164·0

[a,b,c,d] Mean values within a row with unlike superscript letters were significantly different between clusters ($P < 0·05$; Tukey–Cramer method).
* Highest mean value in the row.
† Lowest mean value in the row.

Several studies have extracted dietary patterns in children using cluster analysis, although to our knowledge none has examined longitudinal changes in cluster interpretation or membership. Dietary patterns can be population dependent and the underlying patterns may differ between studies. However, there are many similarities between the patterns we have described here and those in the literature. A study of British children aged between 1 and 4 years identified three clusters[5]. One described a diet with high consumption of prepared meat products, chips and soft drinks, similar to our Processed cluster. A second had a high consumption of wholegrain cereals, low-fat dairy products, fruit and vegetables, similar to our Healthy cluster. The final pattern was identified as a traditional diet and is similar to our Traditional pattern. The lack of a Packed Lunch pattern is most likely due to the children being of a pre-school age. A study of British adults based on 7 d diet diaries found four clusters after stratification by sex[26]. One cluster described a dietary pattern with, in men, high consumption of meat products, chips and beer and, in women, high consumption of convenience foods. A second pattern was identified as a traditional British diet. These are similar to our Processed and Traditional patterns, respectively. The remaining two clusters were similar to our Healthy pattern. A study based on an FFQ administered to adults in Ireland[27] found three clusters, a pattern with high consumption of meat products, chips and alcohol, a pattern with high consumption of pasta, rice, brown bread, poultry, fish, fruit and vegetables and a pattern identified as a traditional Irish diet. These are similar (taking into account cultural differences) to our Processed, Healthy and Traditional patterns, respectively. It is also worth noting that a comprehensive review of empirically derived dietary patterns reported that Healthy, Traditional and Less-healthy/Processed patterns were the most commonly reproduced across fifty-four studies[2].

We have previously extracted three dietary patterns from ALSPAC children aged 7 years based on FFQ data, using cluster analysis[6]. These patterns described a diet with high consumption of processed foods, a plant-based and a traditional British pattern. The Packed Lunch pattern was not evident in the FFQ cluster analysis, and this is most probably explained by the fact that foods typically found in packed lunches were not identified separately in the FFQ. Cluster analysis of the diet diary data, which provide much greater detail in dietary intakes and specific foods consumed, thus provided better separation of foods compared to the FFQ.

Examining cluster membership over time showed that, while children do change their diet, they are more likely to continue following the same dietary pattern as they did at an earlier age: about half of the children continued to follow the same pattern at a later age. This helps to quantify the extent to which dietary patterns are formed in childhood and continue into adolescence, demonstrating that establishing healthy eating habits as early as possible is important. Further research is necessary to quantify the extent to which dietary patterns established in childhood and adolescence are maintained in adulthood. Other studies of British and Irish adults report similar patterns to those observed in the present study[12,15], suggesting that the underlying dietary patterns are similar between children and adults, and healthy or less healthy eating patterns track from childhood. Not surprisingly,

Table 4. Cross-tabulations between cluster membership at different ages
(Number of participants and percentages)

	Processed		Healthy		Traditional		Packed lunch		Total	
	n	%	*n*	%	*n*	%	*n*	%	*n*	%
	Cluster at 7 years									
Cluster at 10 years										
Processed	649	43	215	16	307	25	321	27	1492	28
Healthy	276	18	735	54	318	26	233	19	1562	30
Traditional	302	20	217	16	393	32	238	20	1150	22
Packed lunch	278	18	191	14	203	17	411	34	1083	21
Total	1505		1358		1221		1203		5287	
	Cluster at 10 years									
Cluster at 13 years										
Processed	623	46	309	21	326	30	288	29	1546	31
Healthy	277	21	751	50	261	24	236	24	1525	31
Traditional	242	18	272	18	283	26	174	17	971	20
Packed lunch	199	15	167	11	203	19	306	30	875	18
Total	1341		1499		1073		1004		4917	
	Cluster at 7 years									
Cluster at 13 years										
Processed	532	43	236	20	275	27	318	33	1361	31
Healthy	252	20	592	50	296	29	247	26	1387	32
Traditional	245	20	207	17	280	27	153	16	885	20
Packed lunch	206	17	152	13	173	17	241	25	772	18
Total	1235		1187		1024		959		4405	

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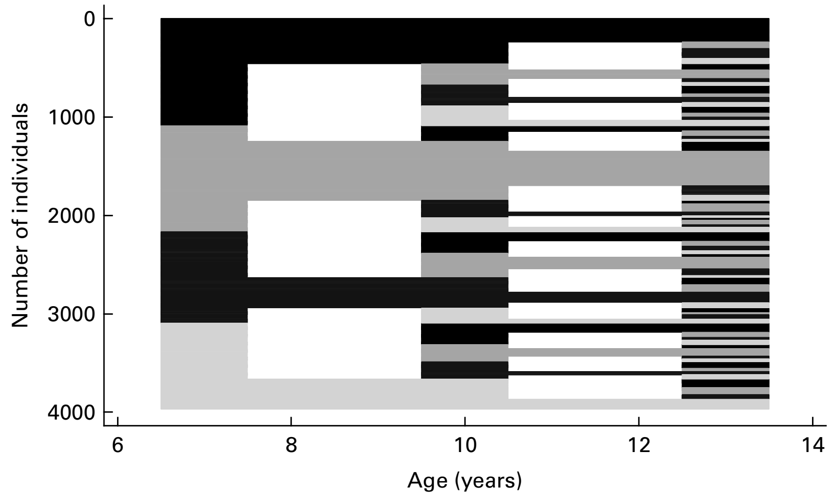

Fig. 1. Sequence index plot illustrating changes in cluster membership over time. Pattern: ■, Processed; ■, Healthy; ■, Traditional; ■, Packed Lunch.

children who remained in the Healthy cluster for at least two out of the three time points were more likely to have higher educated and older mothers. This is similar to the associations we have repeatedly shown with children scoring higher on a 'Health conscious' dietary pattern obtained using PCA[22,28]. The same is true of the processed pattern, which by both methods is consistently associated with lower maternal education.

A particular advantage of the present study is the large sample size. While, the sample is biased towards higher socioeconomic status, it also has the advantage of multiple time points that allowed longitudinal examination of the data. Furthermore, the dietary data were collected from diet diaries, which are considered to be the gold standard for self-reported dietary assessment. Given that we observed some differences in the patterns reported here and those derived using FFQ data, our next steps are to repeat the present study using FFQ data. Similar work in other populations and age groups are needed to better understand the tracking of dietary patterns from a life-course perspective.

Another popular method of obtaining dietary patterns is PCA. However, cluster analysis has a potential advantage over PCA when examining longitudinal changes in dietary patterns. Specifically, while both methods can identify changes in the

Table 5. Adjusted* associations between maternal characteristics and cluster membership over time (each group compared to all other combinations of cluster membership; *n* 1975)

(Odds ratios and 95 % confidence intervals)

	Processed cluster at all three time points (*n* 240)		Processed cluster at any two time points (*n* 692)		Healthy cluster at any two time points (*n* 353)		Healthy cluster at all three time points (*n* 714)	
	OR	95 % CI	OR	95 % CI	OR	95 % CI	OR	95 % CI
Sex								
Boys (*n* 1874)	1·00		1·00		1·00		1·00	
Girls (*n* 2100)	1·25	0·94, 1·67	1·07	0·89, 1·28	1·51	1·25, 1·83	1·45	1·12, 1·87
Ethnicity								
White (*n* 3575)	1·00		1·00		1·00		1·00	
Non-white (*n* 109)	2·28	1·11, 4·68	1·24	0·70, 2·19	1·38	0·81, 2·36	0·94	0·45, 1·97
Maternal age								
≤ 24 years (*n* 292)	1·00		1·00		1·00		1·00	
25–30 years (*n* 1157)	0·99	0·64, 1·53	1·00	0·75, 1·35	1·29	0·88, 1·91	1·42	0·75, 2·70
30+ years (*n* 1240)	0·73	0·46, 1·15	0·91	0·67, 1·23	1·94	1·32, 2·85	3·35	1·80, 6·22
Maternal education†								
< O level (*n* 616)	1·00		1·00		1·00		1·00	
O level (*n* 1324)	0·94	0·65, 1·35	0·80	0·62, 1·02	1·83	1·25, 2·69	2·33	1·16, 4·70
> O level (*n* 1786)	0·51	0·33, 0·77	0·67	0·52, 0·86	4·39	3·05, 6·35	8·83	4·58, 17·01
Maternal smoking								
Never (*n* 2238)	1·00		1·00		1·00		1·00	
Ever (*n* 1501)	0·96	0·71, 1·30	1·00	0·83, 1·21	1·05	0·86, 1·27	1·02	0·78, 1·34
Housing tenure								
Owned/mortgaged (*n* 3240)	1·00		1·00		1·00		1·00	
Council/housing association (*n* 215)	1·06	0·60, 1·88	1·32	0·92, 1·91	0·69	0·37, 1·31	0·39	0·09, 1·65
Rented/other (*n* 258)	0·89	0·48, 1·64	1·12	0·77, 1·64	1·43	0·97, 2·09	2·43	1·51, 3·92

* Each factor adjusted for all other factors in the table.
† O levels are examinations achieved at the age of 16 years.

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underlying patterns, cluster analysis can more clearly demonstrate dietary changes within individuals even when the patterns themselves change over time. For example, it is highly likely in the ALSPAC population that the Packed Lunch pattern will not persist into adulthood. Using cluster analysis, we will be able to identify what happens to the diet of those young adults who belonged to the Packed Lunch cluster in childhood. As far as we are aware, this is the only example of a longitudinal study that has examined dietary patterns over time using cluster analysis. The tracking of childhood diets may be an important factor in the development of adult-onset disease, and we intend to perform a similar analysis on the dietary patterns obtained using PCA. Such additional studies are needed to continue moving the literature forward.

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