Are dietary patterns in childhood associated with IQ at 8 years of age? A population-based cohort study

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ABSTRACT

Background Little is known about the effects of overall diet in childhood and intelligence later in life.

Methods The current study, based on the Avon Longitudinal Study of Parents and Children, uses data on children’s diet reported by parents in food-frequency questionnaires at 3, 4, 7 and 8.5 years of age. Dietary patterns were identified using principal-components analysis and scores computed at each age. IQ was assessed using the Wechsler Intelligence Scale for Children at 8.5 years. Data on a number of confounders were collected, and complete data were available for 3966 children.

Results After adjustment, the ‘processed’ (high fat and sugar content) pattern of diet at 3 years of age was negatively associated with IQ assessed at 8.5 years of age—a 1 SD increase in dietary pattern score was associated with a 1.67 point decrease in IQ (95% CI −2.34 to −1.00; p < 0.0001). The ‘health-conscious’ (salad, rice, pasta, fish, fruit) pattern at 8.5 years was positively associated with IQ: a 1 SD increase in pattern score led to a 1.20 point increase in IQ (95% CI 0.52 to 1.88; p = 0.001).

Conclusion There is evidence that a poor diet associated with high fat, sugar and processed food content in early childhood may be associated with small reductions in IQ in later childhood, while a healthy diet, associated with high intakes of nutrient rich foods described at about the time of IQ assessment may be associated with small increases in IQ.

INTRODUCTION

Studies investigating the long-term effects of nutrition on intelligence are sparse and conflicting. In particular, with the exception of studies of infant feeding, there appears to be little known about the effects of the diet in early childhood on general intelligence later in life.

Several studies have examined the association between breastfeeding and later child intelligence. A meta-analysis of 20 such studies found that breastfeeding was associated with higher cognitive development with an increase of 3.16 points after adjustment for covariates (95% CI 2.35 to 3.98).¹ In addition, several studies have examined the effects of vitamin supplementation on IQ in children with mixed results (see Bellisle² for a review). It has been suggested that micronutrient supplementation is beneficial only to children with poor nutritional status.³ Only one study could be found that examined the effects of general dietary intake on total IQ in childhood: Nelson et al did not demonstrate any association between current diet and total IQ during childhood in a UK study of 227 children aged 7–12 years.⁴ Another study investigated the association between dietary intake and two subtests of the Wechsler Intelligence Scale for Children (WISC-R)⁵; Zhang et al, in a study of 3666 children (6–16 years old) in the USA, showed that lower cholesterol intake and higher polyunsaturated fatty acid intake were associated with higher scores on the digit span, a subtest assessing short-term and working memory.⁶ More recently, Theodore et al examined the intake of specific food groups at 3.5 and 7 years of age.⁷ They reported positive associations between the consumption of margarine, breads/cereals and fish and higher IQ. This study was restricted, however, to children who were born small for gestational age. Additionally, it was cross-sectional in design and did not appear to test for any independent effects of individual food groups, thus ignoring the intercorrelations between groups.

Assessing dietary patterns as opposed to individual foods or nutrients allows us to take into account these intercorrelations, which may otherwise be overlooked. We do not eat foods in isolation, rather consuming combinations of foods in meals and snacks. Principal-components analysis (PCA), the most popular data-driven method of obtaining dietary patterns, uses the correlations between a large number of variables to identifying underlying dimensions in the data. These dimensions can then be used as exposure variables and are complementary to the traditional methods of examining diet—health relationships.

The current study, based on the Avon Longitudinal Study of Parents and Children (ALSPAC), aims to examine the association between dietary patterns obtained using PCA through early and mid-childhood (3 to 8.5 years) and IQ assessed at 8.5 years of age. We hypothesised that a more healthy diet would be associated with increased IQ scores.

METHODS

Sample

ALSPAC is an ongoing longitudinal cohort study that was designed to investigate the determinants of development, health, and disease during childhood and beyond.⁷ Pregnant women with an expected date of delivery between 1 April 1991 and 31 December 1992, resident in the former Avon health authority area in Southwest England, were eligible to participate in the study. A cohort of 14,541 pregnant women was established, resulting in 15,988 children who were alive at 12 months of age. Ethical approval for the study was obtained from the ALSPAC Law and Ethics committee and the three local research-ethics committees.
Measures

Primary data collection was via self-completion questionnaires answered by the primary care givers. From the age of 7 years, all children were invited to attend an annual ‘research clinic’ during which various tests, both physical and psychological, were completed.

IQ

At 8 years of age, a short form of the Wechsler Intelligence Scale for Children (WISC-III), was used to assess IQ. Alternate items from each subtest were administered, with the exception of the coding subtest, which was administered in full. Raw scores were calculated by summing the individual items within each subtest and multiplying by 2 for picture completion, information, arithmetic, vocabulary, comprehension and picture arrangement; multiplying by five thirds for similarities; and multiplying by 3 halves for object assembly and block design. This made the raw scores comparable with those that would have been obtained had the full test been administered (the raw score for the coding subtest was calculated in the standard way as the full subtest was administered). Using look-up tables provided in the WISC-III Manual, age-scaled scores were obtained from the raw scores for each subtest, and total, performance and verbal IQ scores were calculated. A total of 7044 children had complete IQ scores available. The mean age of assessment was 8.5 years (SD 0.3 years).

Diet

Dietary information was collected via food-frequency questionnaire (FFQ) at the ages of 3, 4, 7 and 8.5 years. All four questionnaires contained a set of questions enquiring about the frequency of consumption of a wide range of foods and drinks. The mother or main carer was given the following options to indicate how often her child was currently consuming a variety of food types ‘nowadays’: (1) never or rarely; (2) once in 2 weeks; (3) 1–5 times a week; (4) 4–7 times a week; (5) more than once a day. Mothers were also asked to record the number of cups of tea or coffee, the number of glasses of cola and the number of slices of bread consumed daily. The usual type of bread (white or other) and milk (full-fat or other) usually consumed was also recorded. The data on frequency of consumption were numerically transformed into times consumed per week, in order to apply quantitative meaning to the frequency categories, as follows: (1) 0, (2) 0.5, (3) 2, (4) 5.5 and (5) 10 times per week. All data were standardised by subtracting the mean and dividing by the SD for each variable; this was necessary because tea, coffee, cola and bread were measured on a different scale to the other variables.

The FFQs were adapted from one used to assess maternal diet composition of foods, based on standard portion sizes appropriate to each age.

Potential confounders/mediating factors

A wide variety of factors were considered as potential confounders or mediating factors in the relationship between diet and IQ. The following variables were taken into account: gender; age at WISC assessment; the WISC administrator; the number of stressful life-events experienced by the child; breastfeeding duration (ascertained at 6 months of age), estimated energy intake at each time point, a measure of parenting (HOME score) assessed at 18 months of age, maternal education, housing tenure and social class recorded during pregnancy and maternal age at birth of the study child. Finally, maternal consumption of oily fish during pregnancy was included, as this has been shown to be associated with IQ in this cohort.

Statistical methods

PCA with varimax rotation was performed on the standardised food items. The methods have been described in detail elsewhere. Briefly, the number of components best representing the data at each time point was primarily chosen on the basis of the scree plot and the interpretability of the components. Children were excluded from each PCA if they had more than 10 dietary items missing from the respective questionnaire. If 10 or fewer items were missing, we made the assumption that the child did not consume those items, and they were given a value of 0. The number of food items/groups included in the PCA respectively was 34, 35, 41 and 41 at 3, 4, 7 and 8.5 years of age.

Foods with loadings above 0.5 on a component were considered to have a strong association with that component and were deemed to be the most informative in describing the dietary patterns. Labels were given to each component at each time point. While these do not perfectly describe each underlying pattern, they aid in the reporting and discussion of the results. For each child, a score was created for each component identified at each time point by multiplying the factor loadings by the corresponding standardised value for each food and summing across the food items. All component scores were approximately normally distributed and had a mean of 0 and an SD of 1.

The associations between each dietary pattern at each time point and IQ score were assessed using general linear models. Two models were used for each comparison. The first included adjustment for gender, age at WISC assessment, the WISC administrator and the other dietary pattern scores at that particular time point. The second model made further adjustment for all the potential confounding/mediating factors described above, together with all other dietary pattern scores from all time points. We chose to adjust for other dietary pattern scores at the same point in time, as, although the pattern scores are uncorrelated at a population level, it is possible that an individual could score high or low on more than one pattern. Adjusted parameter estimates and 95% CIs are presented. In each fully adjusted model, complete data were available for 5966 cases. Secondary analyses examined the associations between dietary patterns and performance IQ and verbal IQ separately. All analyses were performed using SPSS for Windows v.15.0 and STATA v.10.0.

RESULTS

Children with IQ data available (n=7044), as compared with the rest of the ALSPAC cohort (n=6944), were more likely to be
girls, to have been breastfed, to have mothers with higher levels of education, to be of a higher social class and to be older (all p < 0.0001, table 1). These children were also more likely to live in owner-occupied housing, to have experienced fewer stressful life-events and to have mothers who consumed oily fish during pregnancy (all p < 0.001). But note that children with IQ data had a lower mean birth weight, as compared with the rest of the cohort (p < 0.0001). The mean (SD) IQ score for the sample was 104 (16).

Three consistent dietary patterns were obtained via PCA at each time point: the ‘processed’, ‘traditional’ and ‘health-conscious’ patterns were stable over time.16–18 The ‘processed’ pattern was described by foods with high fat and sugar content and by processed and convenience foods, while the ‘traditional’ pattern was associated with consumption of meat, poultry, potato and vegetable. Salads, fruit, vegetables, fish, pasta and rice were the foods loading highly on the ‘health-conscious’ pattern. An additional pattern was extracted at 3 years of age: the ‘snack’ pattern that was associated with finger foods such as fruit, biscuits, bread and cakes.

Table 2 presents the associations between the dietary patterns at each age and IQ at 8.5 years of age. It can be seen that, on minimal adjustment, all dietary pattern scores were associated with IQ with the exception of the ‘traditional’ pattern at 4 and 7 years of age. The ‘processed’ patterns were negatively associated with IQ at all ages, while the ‘snacks’ pattern at 3 years and the ‘health-conscious’ pattern at all ages were positively associated with IQ. After adjustment for a wide variety of factors, many associations were lost. However, relationships remained (after full adjustment) for the ‘processed’ pattern at 5 years such that a 1 SD in this score resulted in an almost 2-point decrease in IQ at 8.5 years (95% CI −2.34 to −1.00; p < 0.0001). The ‘snacks’ pattern at 3 years was associated with a 1-point increase (95% CI 0.59 to 1.42; p < 0.0001). Finally, the ‘health-conscious’ pattern at 8.5 years was associated with an increased in IQ of 1.20 points per 1 SD of pattern score (95% CI 0.52 to 1.88; p = 0.001).

Virtually identical patterns were seen with Verbal IQ score (web table 1). Similar associations were evident with Performance IQ (web table 2) after minimal adjustment. However, after full adjustment, the majority of associations between Performance IQ and dietary pattern scores were lost, and those that remained (‘processed’ and ‘snacks’ patterns at 3 years and ‘health-conscious’ patterns at 8.5 years) were markedly attenuated.

DISCUSSION

In this paper, we report weak but novel associations between dietary patterns in early childhood, and current diet, with general intelligence assessed at 8.5 years of age. After adjustment, higher scores on the ‘processed’ pattern at 3 years of age were associated with a lower IQ 5 years later, while higher scores on the ‘health-conscious’ pattern at about the time of IQ assessment were associated with higher IQ scores. After full adjustment, there was no evidence to suggest that dietary patterns measured between these ages were associated with IQ. These results are in line with previous studies we have performed in the ALSPAC cohort: overall dietary patterns in early childhood are associated with both later child behaviour, in particular hyperactivity20 and school performance.21 This suggests that any cognitive/behavioural effects relating to eating habits early in childhood may well persist into later childhood, despite any subsequent changes (including improvements) to dietary intake. To our knowledge, only one other study has examined any longitudinal effects of dietary patterns obtained using PCA on IQ in childhood. Gale et al22 reported that dietary patterns obtained in infants at 6 and 12 months of age had some effect on cognitive development. They found that higher scores on the ‘infant guidelines’ dietary pattern (associated with fruit, vegetables and home prepared foods) were associated with a higher full scale and verbal IQ at the age of 4. These results do not take into account current diet and are on a different time-scale from the data presented here.

There has been some interest in the short- to medium-term effects of dietary intake on cognitive ability and behaviour in children. For example, in short-term experiments, skipping breakfast has been shown to be detrimental23 24 and taking vitamin or iron supplements in malnourished groups can be beneficial.25 Little is known, however, about the long-term effects of nutrition on cognitive abilities in a potentially well-nourished population. It is likely that children scoring highly on...
the ‘processed’ pattern have diets with poorer nutrient content and higher intakes of fat and sugar, as we have shown in the mothers and their partners26 (Northstone K, submitted). Furthermore, high scores on the ‘health-conscious’ patterns in adults were associated with better nutrient profiles26 (Northstone K, submitted). Such dietary habits that have been present from an early age could persist throughout childhood and even into adulthood.

An interesting aspect of the research we have presented is the association evident between dietary patterns at 3 years of age and IQ at 8 years, which is present even after adjustment for diet at later ages. A possible explanation for this is that the brain grows at its fastest rate during the first 3 years of life.27 Studies have shown that head growth during this time is associated with cognitive outcome,28,29 and it is possible that good nutrition during this early period may encourage optimal brain growth.

It is interesting to note that the associations seen with the dietary patterns were stronger for verbal than for performance IQ. Previous studies of vitamin/mineral supplementation have shown improvements in non-verbal intelligence only.28,30 Performance IQ relates to an individual’s innate intellectual ability, while verbal IQ more reflects the impact of education, which in turn is affected by influences such as parenting and environment.31 In comparison with the existing evidence, our results may therefore be somewhat surprising; as Benton explains, ‘Non-verbal tests tap the biologically based functioning that could be expected to reflect the adequacy of the diet.’32 As our results suggest, however, a more long-term effect of diet on the child’s ability to ‘learn,’ this may be partly explained by favourable growth of the brain in early childhood as discussed above.

The strengths of the current study include the large sample size and repeat measures of diet. In addition, a large number of potential confounders have been taken into account. However, given the levels of attrition seen in the effect sizes in the adjusted analyses, we cannot exclude the possibility of residual confounding. The primary limitation is the bias in attrition and the reduction in the number of children with complete data in the fully adjusted models; children included in the study and who had complete data were more socially advantaged than the remainder of the cohort for whom IQ was not measured. It could be argued, however, that we have underestimated any effect sizes as a result Inclusion of children with learning disabilities could also explain the results we have reported: neurological impairment in children is associated with an increased risk of feeding and nutritional problems.33 It is therefore possible that the observed reduction in IQ associated with poor diet might have been due to a relatively large proportion of children with learning disabilities in the sample. We repeated our analyses excluding those children with an IQ score of <70 (n=155); however, the effect sizes were virtually identical. A further potential limitation is the use of a shortened form of the WISC-III. This was done primarily because of the large number of children being tested and to reduce the length of the session. It could be argued that using this shortened version could result in a loss of reliability in the derived IQ measures; however, shortened versions have been used successfully in other studies, and are felt to be a valid substitute.34,35 A further potential limitation of this work is that we could not adjust for maternal intelligence. However, studies have shown that education level, which we did adjust for, is closely associated with intelligence.36,37

The use of dietary patterns obtained using PCA has been criticised for the subjectivity required in identifying the underlying patterns;38 researchers are required to make a number of decisions through the process such as how many patterns to extract, the interpretation of the patterns based on the size of the factor loadings and the labelling of the patterns. It has also been argued that such patterns are population-specific, and therefore cannot be reproduced in other samples. However, the use of dietary pattern scores obtained from PCA is now widely used in nutritional epidemiology and, used as exposures, can provide a different perspective to that using individual nutrients or food groups. Exploiting dietary patterns could help to unravel the complex relationships between the foods we ingest and our

<table>
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<tr>
<th>Table 2</th>
<th>Associations between dietary scores at various ages and IQ at 8 years</th>
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<tr>
<td></td>
<td>Minimally adjusted* model</td>
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<td></td>
<td>Coefficient (95% CI) p Value</td>
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<td>Dietary patterns—3 years</td>
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<tr>
<td>“Processed”</td>
<td>–4.17 (–4.57 to –3.77) &lt;0.0001</td>
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<tr>
<td>“Traditional”</td>
<td>–0.48 (–0.86 to –0.10) 0.014</td>
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<tr>
<td>“Health-conscious”</td>
<td>2.23 (1.85 to 2.60) &lt;0.0001</td>
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<tr>
<td>“Snacks”</td>
<td>1.78 (1.40 to 2.17) &lt;0.0001</td>
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<tr>
<td>Dietary patterns—4 years</td>
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<tr>
<td>“Processed”</td>
<td>–2.53 (–2.94 to –2.12) &lt;0.0001</td>
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<tr>
<td>“Traditional”</td>
<td>–0.15 (–0.55 to 0.25) 0.461</td>
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<tr>
<td>“Health-conscious”</td>
<td>2.46 (2.07 to 2.85) &lt;0.0001</td>
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<td>Dietary patterns—7 years</td>
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<tr>
<td>“Processed”</td>
<td>–3.09 (–3.51 to –2.68) &lt;0.0001</td>
</tr>
<tr>
<td>“Traditional”</td>
<td>–0.34 (–0.75 to 0.06) 0.096</td>
</tr>
<tr>
<td>“Health-conscious”</td>
<td>1.88 (1.46 to 2.26) &lt;0.0001</td>
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<tr>
<td>Dietary patterns—8.5 years</td>
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<tr>
<td>“Processed”</td>
<td>0.87 (0.47 to 1.27) &lt;0.0001</td>
</tr>
<tr>
<td>“Traditional”</td>
<td>–3.13 (–3.54 to –2.72) &lt;0.0001</td>
</tr>
<tr>
<td>“Health-conscious”</td>
<td>1.98 (1.60 to 2.38) &lt;0.0001</td>
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For minimally adjusted models, n varies between 5828 and 6313.
For the fully adjusted model, n=3966.
*Adjusted for gender, age at testing and WISC administrator, dietary pattern scores at that time point.
†As above and breastfeeding duration, energy intake, maternal education, maternal social class, maternal age, housing tenure, life events, HOME score and all other dietary pattern scores.
mental (and physical) well-being. With the exception of breastfeeding, we have not examined diet prior to 3 years in this study. FFQs have been completed for the children at 6 and 15 months and 2 years of age, but we have not established any meaningful dietary patterns owing to the nature of the diet at this age. It is likely that the infant diet, beyond the type of milk consumed, plays an important part in cognitive development, and this will be explored elsewhere.

CONCLUSION
In this population of contemporary British children, a poor diet, associated with increased intake of processed foods, fat and sugar, in early childhood may be associated with lower IQ at the age of 8.5 years. In addition, a concurrent healthy diet may be associated with higher IQ. Dietary patterns between the ages of 4 and 7 years were not predictive. Further research is required to help determine the true effects of early diet on intelligence.

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Competing interests None

Ethics approval Ethics approval was provided by the ALSPAC Law and Ethics committee and the three local research-ethics committees.

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