Growth in early life and childhood IQ at age 11 years: the Newcastle Thousand Families Study

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Background It has been suggested that in addition to genetic factors, fetal and post-natal growth influence childhood cognition, although it is unclear whether such an effect continues throughout childhood. This study aimed at investigating the potential relationships between childhood IQ at age 11 years and birth weight and height at the ages of 9 and 13 years, after adjusting for the confounding factors available to this investigation.

Methods The Newcastle Thousand Families study, a prospectively followed cohort, originally consisted of all 1142 births in the city of Newcastle in May and June 1947. Using data on 733 members of this cohort, we investigated the associations between IQ at age 11, and birth weight and height at ages 9 and 13 years.

Results Birth weight showed no association with childhood IQ. However, height at age 9 years was a significant predictor of childhood IQ after adjusting for socio-economic status (standardized regression coefficient $b = 2.6$, $95\%$ CI 1.6–3.6, $P < 0.0001$). Height at age 13 was also a significant predictor of IQ after adjusting for socioeconomic status ($b = 3.4$, $95\%$ CI 2.3–4.4, $P = 0.001$), and explained an additional 2.5% of the variation in IQ scores to that already explained by socioeconomic status and height at age nine.

Conclusions These results suggest a continuing effect of post-natal growth on childhood cognition beyond the age of 9 years. Post-natal growth, which may be influenced by genetic factors and nutrition and socioeconomic circumstances in childhood, may be more important than fetal growth in terms of childhood cognition.

Keywords Cognition, child, birth weight, growth, fetal origins hypothesis, height

Risk of chronic disease in middle life has been suggested to be ‘programmed’ by impaired development in utero due to suboptimal fetal nutrition.1 Although cognitive ability has a heritable component, environmental influences also play a substantial role. Nutritional status in utero, for which birth weight is often used as an indicator, is one such environmental influence that may affect brain development,2 although an association with birth weight may be equally mediated by genetic factors.3 It follows that cognitive function, both in childhood and in later life may be also be ‘programmed’ by in utero development.

While it is acknowledged that very low birth weight babies are less well developed in terms of cognitive function by the age of 11 years,4,5 more recent research has suggested that there is also a positive association, although probably of a small magnitude, between birth weight and childhood intelligence, even in the normal range of birth weights in term births.6 However, not all studies have been also able to take into account possible confounding factors, such as socioeconomic status.7 Further, not all have had complete information on gestational age,8,9 limiting the ability to view birth weight as an indicator of fetal growth.

Although genetic influences on birth weight and height at all ages are well accepted,10 a number of environmental influences, such as diet,11 illness,12 stress,13 and socioeconomic status14 have also been suggested to influence height in childhood.
Given that these factors are likely to be socially distributed, childhood height is commonly used in chronic adult disease epidemiology as a marker for childhood adversity.

Height in adulthood has been consistently related to IQ in adulthood.9,15 Little is known regarding the relationship between IQ and height in childhood, although height in childhood has been shown to be positively associated with cognitive ability.9,16 However, it is unclear whether such a relationship exists throughout childhood, or whether it diminishes with age. As is the case for birth weight, any investigation of a relationship between childhood height and IQ at a similar age should take account of possible confounding factors.

This study, using prospectively recorded data from the Newcastle Thousand Families Study, aimed to investigate the relationships between childhood IQ at age 11 years and birth weight and height at the ages of nine and 13 years, after adjustment for potential confounding factors.

Materials and methods
Participants in this investigation were members of the Newcastle Thousand Families cohort, into which all 1142 births to mothers resident in the city of Newcastle upon Tyne in May and June 1947 were recruited.14,17,18 All families who agreed to take part and remained resident in the city were visited regularly by a team of health visitors. Information on a number of factors, including birth weight, gestational age, maternal age, parity, growth, social class, and childhood intelligence was recorded prospectively for all study members and abstracted from the original records. Birth weights were standardized for gestational age and gender.19 Socioeconomic status (I (the most advantaged) II, III, IV, and V) at birth was derived prospectively from the contemporary United Kingdom Registrar General’s Standard Occupational Classification using paternal occupation.20 After the seventh year of the study, the school health service was used to prospectively record information including height at ages 9 and 13 years. Heights at both ages were standardized for age and gender.

The liaison with schools also enabled the collection of information on educational performance. In 1958, study members took the 11-plus examination, consisting of written papers involving tests of verbal reasoning (Moray House tests 57 and 58) and two standardized tests of English and arithmetic ability.18 The total IQ score was derived as the average of the four test results. At that time in England, the 11-plus examination was a standard test used in educational establishments at the age of 11 years, often to determine the type of secondary school at which a child was to continue their education.

Statistical analysis
Gender differences in IQ at age 11 years were tested using the Wilcoxon rank sum test. Fourteen twins were excluded from all analyses. The representativeness of the participants in this study in relation to the original cohort was tested using the Wilcoxon rank sum test for birth weight and chi-squared tests for the categorical variables. A measure of the extent of growth in height by age 13 years, taking account of height at age 9 years, was estimated by the residuals from a linear regression of height at age 13 years on height at age nine. Relationships between childhood IQ and explanatory variables were estimated using multiple linear regression. Standardized regression coefficients \(b\), denoting the increase in the number of IQ score points for a standard deviation increase in the explanatory variable, are presented with accompanying 95% confidence intervals (95% CI). Social class and parity were treated as continuous ordinal variables [with the first level denoting social class I (the most advantaged) and first-born children and so on]. Maternal age was treated as a continuous variable. Fractional polynomials were used to assess non-linear effects. Study members with missing data were included in all analyses for which they contributed complete data (i.e. complete data for all variables included in a particular model), although to allow a comparison between models, hierarchical models determining proportions of variance attributable to explanatory variables were restricted to only those study members with complete data for the variables included in the final model. All statistical analyses used the Stata statistical software package, version 8.0 (StataCorp, College Station, TX).

Results
Of the original 1142 study members, 967 were followed-up through until the end of their first year, 847 to the end of the fifth year and 763 until the end of their 15th year. A total of 49 children died before the age of 15. The main reason for loss to follow-up was families moving out of the city (316 children had left Newcastle before their 15th birthdays).

Information from the 11-plus examination was available for 733 (67% of the 1088 members of the original cohort alive at age 11 years) study members (365 boys and 368 girls). Additional data were complete for birth weight and parity, but 114 study members were missing data on at least one of social class at birth and standardized heights at ages 9 and 13 years. The study sample did not differ significantly from those members of the original cohort who were not included in this analysis (but still alive at age 11) for gender (\(P = 0.37\)) or standardized birth weight (\(P = 0.22\)). However, children born into the more advantaged social classes and at lower parities were more likely to have left the study before the 11-plus examinations took place than other children (\(P < 0.0001\)) (Table 1).

Descriptive statistics for all explanatory variables are given in Tables 1 and 2. No difference in IQ was seen between boys and girls (\(P = 0.20\)). Social class at birth was significantly associated with standardized heights at both 9 and 13 years (\(P < 0.0001\), lesser heights with less advantaged social classes), but not with standardized birth weight (\(P = 0.86\)).

There was no significant association between IQ at age 11 years and standardized birth weight (\(P = 0.95\)). Significant associations were seen between IQ and social class at birth and standardized heights at age 9 and 13 years (Table 3), which remained after adjustment for parity, maternal age, birth weight and for the height variables, further adjusting for social class at birth. There were no significant interactions between standardized birth weight and height at either 9 or 13 years. Increased growth between the ages of 9 and 13 years was significantly associated with higher IQ at age 11 years (\(P = 0.002\)). The association between standardized height at age 13 years and childhood IQ remained highly significant (\(P = 0.001\)) after adjustment for social class and standardized height at age 9 years, accounting for an additional 2.5% of the variation in IQ score to that already
explained by social class and height at age nine. The model of social class at birth and heights at ages 9 and 13 years explained 16% of the variation in IQ scores at age 11. Social class at birth alone, excluding indirect effects possibly mediated through later height, explained 7.4% of the variation in IQ scores. After adjustment for social class, height at age 9 years explained 3.3% of the variation in IQ scores, although after including the later height measure this fell to less than 0.01%, suggesting that the effect of height at age 9 years was also detectable through the later height measure. There was no association between maternal age and childhood IQ (P = 0.6).

Discussion

Principal findings

In this cohort of children born in 1947, no significant relationship was seen between birth weight and IQ at age 11 years. There were significant positive associations between IQ and standardized height at ages 9 and 13 years. These relationships remained after adjustment for social class at birth, parity, and gender. Height at age 13 remained highly significant after additional adjustment for the earlier height, suggesting that growth between 9 and 13 years may be related to cognitive ability.

Comparisons with other studies

Birth weight

In contrast to the results of this investigation, a number of previous studies have shown a positive relationship between birth weight and childhood intelligence,21–24 implying that brain growth in utero may have an effect on childhood intelligence. However, a recent systematic review has concluded that there are very few good quality studies on this topic and that any such effect of birth weight, at least in terms of term births in the normal range of birth weights, on childhood IQ is likely to be of a very small magnitude.6

The influence of social class at birth is consistent with previous studies that have shown a stronger effect of socioeconomic status on childhood cognition than that seen for birth weight.22,23,25 No social class effect gradient for birth weight was seen for this cohort, which may reflect the reduced variation in maternal nutrition due to post-war rationing, or may be the result of smoking patterns at the time which saw women from the more advantaged social classes more likely to smoke than less-advantaged women. Although this may explain

Table 1 Comparison of the study sample with the original cohort

<table>
<thead>
<tr>
<th>Variable</th>
<th>Original cohort</th>
<th>Alive at age 11 years</th>
<th>Study sample</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
<td>%</td>
<td>n</td>
</tr>
<tr>
<td>Gender</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>583</td>
<td>51</td>
<td>552</td>
</tr>
<tr>
<td>Female</td>
<td>559</td>
<td>49</td>
<td>536</td>
</tr>
<tr>
<td>Social class at birth</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I</td>
<td>32</td>
<td>2.8</td>
<td>32</td>
</tr>
<tr>
<td>II</td>
<td>93</td>
<td>8.1</td>
<td>90</td>
</tr>
<tr>
<td>III</td>
<td>602</td>
<td>53</td>
<td>588</td>
</tr>
<tr>
<td>IV</td>
<td>172</td>
<td>15</td>
<td>166</td>
</tr>
<tr>
<td>V</td>
<td>163</td>
<td>14</td>
<td>153</td>
</tr>
<tr>
<td>Unknown</td>
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<td>7.0</td>
<td>59</td>
</tr>
<tr>
<td>Parity</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>1st born</td>
<td>868</td>
<td>76</td>
<td>814</td>
</tr>
<tr>
<td>2nd born</td>
<td>162</td>
<td>14</td>
<td>162</td>
</tr>
<tr>
<td>3rd born</td>
<td>65</td>
<td>5.7</td>
<td>65</td>
</tr>
<tr>
<td>&gt;3rd born</td>
<td>47</td>
<td>4.1</td>
<td>47</td>
</tr>
<tr>
<td>Total</td>
<td>1142</td>
<td>100</td>
<td>1088</td>
</tr>
</tbody>
</table>

Table 2 Descriptive statistics for continuous variables

<table>
<thead>
<tr>
<th>Variable</th>
<th>n</th>
<th>Mean (SD)</th>
<th>Median (IQR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>11-plus examinations</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IQ</td>
<td>733</td>
<td>99.4 (14.0)</td>
<td>100 (87–110)</td>
</tr>
<tr>
<td>Birth weight (kg)</td>
<td>726</td>
<td>3.4 (0.5)</td>
<td>3.4 (3.1–3.7)</td>
</tr>
<tr>
<td>z-scorea</td>
<td>726</td>
<td>−0.1 (0.1)</td>
<td>−0.2 (−0.8–0.5)</td>
</tr>
<tr>
<td>Maternal age (years)</td>
<td>727</td>
<td>29.0 (5.8)</td>
<td>28.0 (25.0–33.0)</td>
</tr>
<tr>
<td>Height at age 9 years (cm)</td>
<td>709</td>
<td>127.7 (7.2)</td>
<td>128.2 (124.4–132)</td>
</tr>
<tr>
<td>z-scoreb</td>
<td>709</td>
<td>−0.5 (1.1)</td>
<td>−0.5 (−1.2–0.2)</td>
</tr>
<tr>
<td>Height at age 13 years (cm)</td>
<td>654</td>
<td>149.8 (7.8)</td>
<td>149.8 (144.7–154.9)</td>
</tr>
<tr>
<td>z-scoreb</td>
<td>654</td>
<td>−1.2 (1.2)</td>
<td>−1.2 (−2.0 to −0.3)</td>
</tr>
</tbody>
</table>

a Standardized for gestational age and gender.

b Standardized for age and gender.

Table 3 Standardized regression coefficients (and corresponding 95% confidence intervals) relating IQ at age 11 years to explanatory variables

| Explanatory variable       | Unadjusted | Adjusted for standardized birth weight, parity, maternal age, and social class at birth |
|---------------------------|------------|-------------------------------------------------------------------------------------------------
|                           | $b$  | 95% CI    | $P$     | $b$  | 95% CI    | $P$     |
| Standardized birth weight | −0.04 | −1.1–1.0  | 0.95     | 0.01 | −0.98–1.0 | 0.99     |
| Parity                    | −1.0  | −2.0–0.01 | 0.05     | −0.8 | −1.8–0.28 | 0.15     |
| Maternal age              | 0.2   | −0.77–1.3 | 0.63     | 0.3  | −0.76–1.32| 0.60     |
| Social class at birth     | −4.5  | −5.5 to −3.5 | <0.001 | −4.4 | −5.4 to −3.4 | <0.001 |
| Standardized height at age 9 years | 3.4  | 2.4–4.4  | <0.001 | 2.7  | 1.7–3.7  | <0.001 |
| Standardized height at age 13 years | 4.0  | 2.9–5.0  | <0.001 | 3.4  | 2.4–4.4  | <0.001 |

Standardized regression coefficients are based on changes in IQ score at age 11 years due to an SD change in the explanatory variable.
the lack of an association between birth weight and IQ in this cohort, this is not consistent with the results of the Scottish Mental Survey 1932 which showed independent associations between social class and birth weight on IQ at 11 years, but like the present study showed no correlation between birth weight and social class.23

It is also not possible to exclude any programming effect that may have been shown had data been available on alternative measures of fetal growth, such as the ponderal index, head circumference, or placental to fetal weight ratio. Information was not available on head size, either at birth or at the time of the height assessments. Similar positive associations have been shown between head size during childhood and childhood IQ as seen in this study for height.26

**Childhood height**

Our results for childhood height suggest that in the Thousand Families Cohort, the effect of growth on IQ continued beyond the age of 9 years, independently of social class. Combined with the lack of an effect of birth weight, these results suggest, in this cohort at least, that post-natal growth may be more influential in terms of cognitive ability than fetal growth.

Linear growth retardation, particularly in the first 3 years of life, has been associated with poor development and deficits in cognition in childhood and adolescence.27 It has also been suggested that catch-up growth in height to normal adult stature may lower the risk of intellectual impairment for those babies born very small for gestational age.28 Our findings of positive associations between IQ and standardized heights at age 9 and 13 years are consistent with previous findings suggesting a continued effect of growth on IQ during childhood.9,28 A study of the 1946 British birth cohort demonstrated a positive association between height and cognitive function at various ages up to adulthood.9 However, in contrast to our findings, an association in that cohort was shown between birth weight and cognitive function,24 independent of height, and further, the association between height at age 13 years was no longer significant after adjustment for height at 9 years.9 Although that study did not have gestational age available, the similar time periods covered by the two cohorts suggests that the conflicting results are likely to be due to factors other than those introduced by the immediate post-war environment.

The associations with childhood height in this study remained significant after adjustment for social class at birth, and in contrast to previous studies were of a similar magnitude to the effect of social class.9,29 Social class is a crude measure of social, educational, and familial circumstances. Therefore, it is possible that some residual effect of social background may confound the relationship between IQ and height. However, it is likely that other factors may play a role in this relationship. It has been suggested that insulin-like growth factors may target areas of the brain responsible for cognition, in addition to their role in determining body growth.30 Other suggested factors include diet, general health, and psychosocial stress.9 Further research is required to evaluate such potential mechanisms.

**Strengths and weaknesses**

The main strength of this study is that prospectively collected data on early life experience, including gestational age and parity and socioeconomic circumstances at the time of birth, could be analysed alongside later measures of height and intelligence in over 700 individuals. Birth weight was collected at the time of birth, ensuring that this study does not suffer the potential biases that may be introduced when using recalled information on birth weight. Childhood height was measured at 9 and 13 years, allowing an investigation of the differing relationships between IQ and height at different ages, although it should be noted that the IQ measurements used in this investigation were taken at 11 years (i.e. in between the height measurements). This allowed an assessment of how growth around the time of the IQ assessments may be associated with cognition. As height at age 11 was not available, it is possible that our findings of a significant association between height at age 13 and IQ at age 11 underestimate the effect that may have been seen had IQ at age 13 been available.

It has also been proposed that genetic factors and parental education levels may mediate the relationship between birth weight and cognitive ability.3,8 Maternal education and duration of breastfeeding have been linked with childhood intelligence,31 and more recently have been shown to be associated with height at age 7 years in a large study of the 1958 United Kingdom Birth Cohort.32 We were unable to take account of these possible confounding factors in this investigation.

As with any study of this nature, there was loss to follow-up, resulting in the inclusion of 733 study members in this investigation. Although loss to follow-up did not vary with gender or birth weight, the cohort members in this investigation were more likely to be of a lower social class and higher parity than the surviving members of the cohort not included. Otherwise, the study members are representative of the births in Newcastle upon Tyne at that time. Owing to the small number of children leaving the study between the age of 9 and 11 years, it was not possible to investigate any variation in childhood height between those studied and the members of the original cohort not included in this analysis. However, as the results for height were independent of the effect of social class, this is unlikely to have resulted in sufficient bias to affect these results.

**Conclusion**

In this cohort, there was no significant relationship between birth weight and childhood IQ. However, there were positive relationships between IQ and childhood socioeconomic advantage and height at both 9 and 13 years. In particular height at age 13 years was a predictor of childhood IQ, independently of the earlier height, suggesting a continued effect of growth on IQ beyond the age of 9 years. These results suggest that factors influencing post-natal growth, such as genetic factors and nutrition and socioeconomic circumstances in childhood may be more important than fetal growth in terms of childhood intelligence. Further research is required to identify the mechanisms behind such a relationship.

**Acknowledgements**

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KEY MESSAGES

- In the Newcastle Thousand Families cohort, there is no association between birth weight and IQ at age 11 years.
- There was an association between childhood height and IQ, after adjustment for socioeconomic status, parity, gender, and birth weight.
- The effect of childhood growth on cognition continued beyond the age of 9 years, independently of socioeconomic status and earlier height.
- Post-natal growth may have a greater influence on cognition than fetal growth.

References