Early life predictors of childhood intelligence: findings from the Mater-University study of pregnancy and its outcomes

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Summary

Lawlor DA, Najman JM, Batty GD, O'Callaghan MJ, Williams GM, Bor W. Early life predictors of childhood intelligence: findings from the Mater-University study of pregnancy and its outcomes. *Paediatric and Perinatal Epidemiology* 2006; **20:** 148–162.

Growing evidence linking childhood intelligence with adult health outcomes suggests a need to identify predictors of this psychological characteristic. In this study, we have examined the early life determinants of childhood intelligence in a population-based birth cohort of individuals born in Brisbane, Australia between 1981 and 1984. In univariable analyses, family income in the year of birth, maternal and paternal education, maternal age at birth, maternal ethnicity, maternal smoking during pregnancy, duration of labour, birthweight, breast feeding and childhood height, and body mass index were all associated with intelligence at age 14. In multivariable analyses, the strongest and most robust predictors of intelligence were family income, parental education and breast feeding, with these three variables explaining 7.5% of the variation in intelligence at age 14. Addition of other variables added little further explanatory power. Our results demonstrate the importance of indicators of socio-economic position as predictors of intelligence, and illustrate the need to consider the role of such factors in generating the association of childhood intelligence with adult disease risk.

Keywords: *childhood intelligence, IQ determinants, Mater-University study.*

Introduction

Childhood psychometric intelligence is related to a number of health outcomes and health-related behaviours in later life, including smoking habits,[1] schizophrenia,[2–4] depression,[2,5] blood pressure,[6] cardiovascular disease,[7,8] some cancers[7] and premature mortality.[7–10] For the most examined outcome, all-cause mortality, the inverse relationship with childhood intelligence is consistent, strong and incremental, such that an intelligence–mortality gradient is apparent across the full distribution of intelligence quotient (IQ) scores, rather than being related only to those with severe intellectual impairment.[11,12] Further, some studies have shown that the raised risk of adult mortality with lower childhood intelligence still holds after adjustment for early life socio-economic position, birthweight and childhood illness.[1,4,7,8,10] It is currently unclear whether this association is mediated via adult indicators of socio-economic position such as educational attainment and occupational social class.[10,11] Having a clear picture of the early life determinants of childhood intelligence is potentially important in developing our understanding of what mechanisms might explain the associations between childhood intelligence and adult mortality.

There is considerable debate about the important determinants of childhood intelligence, in particular, the relative roles of environmental factors that might be modifiable, and genetic factors.[13,14] With regard to environmental indices, a number of studies have identified antenatal, postnatal and family-related factors that are associated with childhood intelligence. However, most of these have assessed associations with severe mental impairment and/or examined the extremes of exposure, for example, the effects of premature birth or being small-for-gestational-age. As such, there is a paucity of population-based studies.[15] Birthweight or birthweight-for-gestational-age demonstrates a weak positive gradient with childhood intelligence,[15–20] while associations with a range of indicators of socio-economic position – parental educational attainment, parental intellectual ability and family income[21–23] – are somewhat stronger. Children who were breast fed as infants have been shown in many,[23–27] although not all,[28] studies to have higher intellectual abilities. While reduced performance on intelligence tests is apparent in children with childhood malnutrition, some investigators have also shown that indicators of less severe sub-optimal nutrition, such as shorter childhood stature and lower weight, are also linked with reduced intelligence.[29–32] Finally, birth complications, fetal distress and childhood illnesses may be associated with lower childhood intellectual ability.[10]

Most of these risk factors are strongly interrelated and, to some extent, may reflect the broad effects of early life social disadvantage on intellectual ability. Few previous studies have examined the independent effects of exposures or attempted to identify how they relate to each other in causal pathways leading to variations in childhood intelligence. For example, the largest of six studies identified in a systematic review of the association between birthweight and intelligence did not adjust for socio-economic position.[15] Moreover, only one study to date has examined the independent effects of birthweight and childhood size,[32] despite the clear importance from other areas of research, most notably with cardiovascular disease outcomes, of considering jointly the effects of intrauterine and postnatal growth.[33] In addition, the tendency for investigators to report the relationship between only a single predictor variable to intelligence limits insights into specificity of association.

The aim of this study was to identify independent early life determinants of childhood intelligence in a cohort of Australian individuals who have been followed up since their intrauterine period. Using some of these data, we have previously shown an association between early life exposures and mild or borderline impairment of intellectual ability at age 5.[21] In the present paper, we focus on predictors of intelligence across the full distribution of scores at age 14 and report on differences, where they occur, when intelligence at 5 years of age is the outcome of interest.

Methods

Participants

The Mater-University study of pregnancy and its outcomes (MUSP) is a prospective study of women, and their offspring, who received antenatal care at a major public hospital (Mater Misericordiae Hospital) in South Brisbane between 1981 and 1984.[34] Consecutive women attending their first obstetric visit were invited to participate in the study. Pre- and post-birth phases of data collection were undertaken prior to hospital discharge. Of the 8556 mothers invited to participate, 98 mothers refused, 710 did not deliver a live birth at the hospital (including 169 miscarriages and those who chose to use other facilities), 59 mothers had multiple births, 312 did not complete the post-birth data collection phase, 99 infants died during or immediately post-delivery and 55 were adopted prior to discharge. In total, 7223 women (84% of those invited) agreed to participate, delivered a live singleton baby who was not adopted and did not die prior to leaving hospital, and completed both initial phases of data collection. These mothers and their offspring form the MUSP prospective cohort.

Full perinatal data concerning mother and child were obtained at the start of the study. The mothers and children have been followed up prospectively with maternal questionnaires, covering a wide range of psychosocial and health characteristics of themselves, their partners and their children. These were administered when the children were 6 months, 5 years and 14 years of age. In addition, at 5 and 14 years, detailed physical, cognitive and developmental examinations of the children were undertaken. At 14 years, the children themselves responded to questionnaire enquiries regarding their health, welfare and life style.

Assessment of intelligence

Intelligence was measured on two occasions, at 5 and 14 years of age. At age 5 years, intelligence was assessed using the revised Peabody Picture Vocabulary Test.[35] In most instances (except where circumstances necessitated a home visit), these were administered under controlled conditions by a trained researcher. The Peabody test is a measure of verbal comprehension in which the child is shown a series of cards each containing four images. They are required to identify which of the pictures depicts a word spoken by the administrator.[35] The Peabody test has been shown to be reliable and correlates well with other measures of intelligence, in both childhood and later life.[35–37] The Peabody test scores were age-standardised using 6-monthly age groups.

At 14 years of age, assessment of intelligence was based on youth scores on Raven's standard progressive matrices (Raven's SPM).[38] In addition, the participants undertook the Wide Range Achievements Test version 3 (WRAT3).[39] The Raven's SPM are a test of non-verbal reasoning ability or general intelligence. It has been widely used in clinical, occupational, educational and research contexts.[38] The Raven's SPM scores were also age-standardised in 6-monthly intervals. The WRAT3 is an age-normed reading reference test that is correlated with tests of intelligence.[39] In this study population, the Raven's SPM and WRAT3 scores were moderately correlated (Pearson's correlation coefficient 0.42, $P < 0.001$). However, for all of the associations assessed herein, the results were similar when either Raven's SPM or WRAT3 were used as the outcome. We therefore present results for the Raven's SPM scores at age 14 years only.

Assessment of predictor variables

Maternal ethnicity (White, Asian, Abor-islander [aborigine or those from Torres Strait Islands]), maternal smoking during pregnancy (yes versus no), family income in the year of pregnancy (low: <\$A10 400; middle: \$A10 400–15 599; high: ≥\$A15 600) and parental educational attainment (did not complete high school; completed high school; completed higher or further education) were obtained at the start of the study from interviews with the mothers during the antenatal and immediate postnatal period (paternal educational attainment was from maternal self-report). The following information was obtained prospectively from obstetric records: maternal age at delivery (years), pregnancy complications (any of antepartum haemorrhage, gestational hypertension, gestational diabetes), gravidity, fetal distress during labour, duration of labour and mode of delivery, birthweight (nearest gram), gestational age (weeks), and Apgar scores at 1 and 5 min. A sex and gestational age (in weeks) standardised birthweight *z*-score was computed to give a measure of intrauterine growth. Information on the duration of breast feeding (never, <4 months, ≥4 months) was obtained from the mothers at the 6-month follow-up assessment.

Height and weight were measured directly at 5 and 14 years of age. Weight was recorded with the participant lightly clothed using a scale accurate to within 0.2 kg. A portable stadiometer was used to measure height to the nearest 0.1 cm. Both weight and height were recorded twice during each assessment, with the average of these used in the present analyses. Body mass index (weight [kg] divided by height squared [m^2]), an indicator of adiposity, was derived from these data. Sex and age (in months) standardised *z*-scores were computed for both height and body mass index.

Statistical methods

Means and standard deviations of each of the childhood intelligence measures are presented by categories of each potential predictor variable. Linear regression was used to estimate mean differences and 95% confidence intervals [CI] of each measure of intelligence across these exposure categories. A series of multivariable linear regression models were computed to assess the independent effects of each predictor and to examine possible causal pathways. In the results, we distinguish between covariates that we consider to be confounders in any of the associations and those that we regard as mediating variables. For example, in examining the association between family income around the time of birth and later childhood intelligence, parental education, maternal age at birth, maternal smoking during pregnancy and gravidity were all considered to be potential confounding factors, whereas complications during the labour, signs of fetal distress, Apgar scores, birthweight for sex and gestational age (an indicator of intrauterine growth), breast feeding and childhood height for sex and age and body mass index for sex and age (an indicator of postnatal growth) were regarded as potential mediating factors. We assessed the possibility that these characteristics did mediate the association by examining whether there was marked attenuation of the confounder-adjusted association with addition of each potential mediator to the model. All covariates were decided a priori, thus avoiding data-driven inclusion.[40]

In the regression models, birthweight, birthweight-for-gestational-age and sex *z*-scores, and childhood height and body mass index *z*-scores were all entered as continuous variables. Maternal age at birth, family income, parental education, gravidity and breast feeding were all entered as categorical (indicator) variables; all other variables were binary. Of the original 7223 cohort members, 3999 (55%) had complete Peabody scores at age 5 years and 3794 (53%) had complete Raven's scores at age 14 years. Of the total, 2944 (41%) had complete intelligence test results at both measurement points. As reported previously,[41] loss to follow-up was selective, such that study participants without these intelligence test data were more likely to have mothers who were from poorer social backgrounds, who had lower educational attainment, and who were younger at the birth of their child than those children who had these data. In order to determine whether selection bias influenced our results, we repeated all of the regression analyses using Heckman's sample selection bias adjustment (heckman command in Stata), with maternal age, parental education and family income as the selection variables.[42] The results of these regression models did not differ substantively from those presented here on the subsample with intelligence test scores for age 5 and 14 years. All analyses were conducted using STATA version 8.0 (Stata Corporation, College Station, TX, USA, 2002).

Results

Table 1 shows the univariable associations between each early life characteristic and intelligence test scores at age 14 among the 3794 study participants with complete data. All parental characteristics were related to offspring IQ score. Thus, lower intelligence test scores were associated with younger maternal age at birth, having a mother who was aborigine or from Torres Strait islands, maternal smoking during pregnancy, low family income during the year of birth and low parental educational attainment. Participants whose mothers were Asian had higher intelligence scores than those whose mothers were white or Abor-islanders. Characteristics of labour (fetal distress, duration of labour, mode of delivery and Apgar scores) were unrelated to childhood intelligence. With regard to birth and infancy characteristics, study participants born <37 weeks' gestation tended to have lower IQ scores at age 14 than those born at term. Birthweight, birthweight-for-gestational-age and height at age 14 were positively associated with intelligence, while body mass index at age 14 showed a negative gradient with intelligence scores. Girls had on average higher intelligence scores than boys.

For all of the remaining multivariable results, the analyses were conducted on a subgroup ($N = 3099$; 84% of the 3794 persons with Raven's scores) with complete data on all variables included in any of the models. The sex-adjusted associations in this subgroup did not differ from those among the total 3794 individuals.

Parental characteristics in relation to intelligence at age 14

Table 2 shows the multivariable associations of parental characteristics with intelligence at age 14. Maternal age at birth, ethnicity (borderline statistical significance), gravidity, maternal smoking during pregnancy, family income and parental education all remained associated with intelligence at age 14 in confounder-adjusted analyses (model 2). The effect of maternal age at birth and smoking during pregnancy on intelligence appeared to be mediated, at least in part, by the associations of these exposures with breast feeding, given the marked attenuation when this factor was added to the model (model 5). Other mediators had little effect on these associations. The increased intelligence at age 14 among children of Asian mothers remained following adjustment for all confounders and mediating factors, while the decreased intelligence among children of Abor-islander mothers attenuated after controlling for family income, parental education and other parental characteristics. The associations of family income and parental education with intelligence at age 14 were robust to the adjustment of potential confounder and mediating factors.

Complications of labour, infant distress in relation to intelligence at age 14

In the crude analyses, neither complications of labour nor Apgar scores were associated with intelligence. These null associations remained in all multivariable models (all P-values > 0.20).

Intrauterine growth, postnatal anthropometry, breast feeding in relation to intelligence at age 14

The crude association between sex and gestational age-standardised birthweight z-scores and intelligence at age 14 was 0.92 [95% CI 0.44, 1.40], $P < 0.001$. This attenuated to 0.68 [0.21, 1.14], $P = 0.005$ with adjustment for parental characteristics (maternal age

Table 1. Unadjusted associations of early life characteristics with intelligence[a] at age 14 years

	N	Mean (SD)	Mean difference [95% CI]	*P*[b]
Parental characteristics				
Maternal age at birth (years)				
13–19	425	98.0 (15.1)	0.00 Reference	
20–34	3160	100.3 (15.0)	2.24 [0.73, 3.75]	
≥35	209	101.0 (13.4)	3.03 [0.56, 5.50]	0.004
Maternal ethnicity				
White	3447	100.0 (14.9)	0.00 Reference	
Asian	113	104.8 (12.0)	4.76 [1.96, 7.57]	
Abor-islander	107	95.7 (18.4)	–4.38 [–7.26, –1.50]	<0.001
Gravidity				
1	1265	100.5 (15.1)	0.00 Reference	
2	1133	100.7 (14.7)	0.19 [–1.00, 1.39]	
3	718	99.8 (14.3)	–0.67 [–2.04, 0.69]	
≥4	678	98.4 (15.5)	–2.13 [–3.52, –0.74]	0.003
Maternal smoking during pregnancy				
No	2445	100.9 (14.9)	0.00 Reference	
Yes	1338	98.7 (14.7)	–2.20 [–3.19, –1.21]	<0.001
Family income (Australian $)				
<10 400	1044	97.9 (15.2)	0.00 Reference	
10 400–15 599	1419	100.5 (14.3)	2.53 [1.34, 3.71]	
>15 599	1133	101.8 (15.0)	3.84 [2.59, 5.08]	<0.001
Maternal education				
No high school	612	96.2 (15.6)	0.00 Reference	
Completed high school	2430	99.7 (14.7)	3.53 [2.22, 4.84]	
College/university	739	104.3 (13.3)	8.16 [6.58, 9.75]	<0.001
Paternal education				
No high school	604	96.4 (16.2)	0.00 Reference	
Completed high school	2246	99.6 (14.8)	3.17 [1.86, 4.49]	
College/university	772	104.9 (13.0)	8.49 [6.93, 10.05]	<0.001
Characteristics of labour				
Fetal distress[c]				
No	2779	100.3 (14.8)	0.00 Reference	
Yes	995	99.4 (15.3)	–0.88 [–1.96, 0.20]	0.11
Duration of the 1st stage (to full cervical dilation) (hours)				
<3	762	99.8 (14.8)	0.00 Reference	
3–5	1249	99.2 (15.1)	–0.57 [–1.92, 0.78]	
6–8	868	101.0 (14.5)	1.24 [–0.21, 2.69]	
>8	915	100.5 (15.2)	0.72 [–0.72, 2.15]	0.14
Duration of the 2nd stage (to delivery) (min)				
<10	1125	99.7 (15.4)	0.00 Reference	
10–14	630	99.1 (14.0)	–0.61 [–2.07, 0.84]	
15–30	917	100.1 (15.0)	0.46 [–0.85, 1.76]	
>30	1122	100.9 (14.9)	1.18 [–0.05, 2.42]	0.07
Mode of delivery				
Spontaneous vaginal	2932	100.1 (14.8)	0.00 Reference	
Other	863	99.9 (15.6)	–0.15 [–1.28, 0.99]	0.80
Birth and infancy characteristics				
Sex				
Male	1976	98.7 (16.0)	0.00 Reference	
Female	1818	101.5 (13.6)	2.77 [1.83, 3.72]	<0.001
Birthweight (kg)				
Per SD (0.52) increase	3794		0.77 [0.29, 1.24]	0.002

Table 1. *Continued*

	N	Mean (SD)	Mean difference [95% CI]	P^b
Gestational age (weeks)				
<37	91	97.9 (17.7)	–2.09 [–4.51, 0.33]	
37–41	3464	100.0 (14.9)	0.00 Reference	
>41	239	101.7 (13.0)	1.65 [–0.31, 3.61]	0.06
Birthweight for sex and gestational age *z*-score				
Per *z*-score increase	3794		0.81 [0.39, 1.24]	<0.001
Apgar score at 1 min				
>8	1930	100.3 (14.9)	0.00 Reference	
≤8	1690	99.7 (15.0)	–0.65 [–1.63, 0.33]	0.19
Apgar score at 5 min				
>8	3367	100.1 (14.8)	0.00 Reference	
≤8	211	98.5 (17.8)	–1.64 [–3.72, 0.44]	0.12
Breast feeding (months)				
Never	694	94.9 (15.9)	0.00 Reference	
<4	1372	99.3 (15.0)	4.43 [3.09, 5.77]	
≥4	1606	103.1 (13.8)	8.20 [6.89, 9.49]	<0.001
Childhood characteristics				
Height at 14 years (cm)				
Per SD (8.0) increase	3791	100.1 (14.9)	1.77 [0.89, 2.66]	<0.001
Height for age and sex *z*-score at 14 years				
Per *z*-score increase	3791	100.1 (14.9)	2.27 [1.37, 3.16]	<0.001
BMI at 14 years (kg/m^2)				
Per SD (3.8) increase	3790	100.1 (14.9)	–0.94 [–1.41, –0.46]	<0.001
BMI for age and sex *z*-score at 14 years				
Per *z*-score increase	3790	100.1 (14.9)	–1.09 [–1.57, –0.62]	<0.001

Total *N* with intelligence scores = 3794.
[a]Intelligence scores are age-standardised.
[b]*P*-values refer to tests for linear trends for ordered categorical exposures, *F*-tests for non-ordered categorical variables or variables where linear trends would not be anticipated (ethnicity, duration of labour and gestational age); and *t*-tests for binary exposures.
[c]Fetal distress = any of: heart rate < 110 BPM, heart rate > 160 BPM, irregular heart beat, meconium-stained liquor.
CI, confidence interval; SD, standard deviation; BMI, body mass index.

at birth, ethnicity, smoking during pregnancy, family income and parental education). This association equated to an increase of 0.12 [0.01, 0.24] intelligence points per 100 g increase in birthweight, with adjustment for parental characteristics, sex and gestational age. Additional adjustment for height at age 14 attenuated the association of sex and gestational age-standardised birthweight *z*-scores towards the null: 0.26 [–0.21, 0.73], $P = 0.28$, with other potential confounders and mediators having little effect on the association.

Table 3 shows the multivariable associations of childhood height and body mass index with intelligence at age 14. As all of the other covariates included in these models were assessed prior to the assessment of height and body mass index, they are all considered to be potential confounding factors. The positive associations between childhood height and intelligence remained with adjustment for all potential confounders. The inverse relationship of body mass index with intelligence test performance (both at age 14 years) held after controlling for all potential confounders. There was no evidence of any interaction between birthweight and either height or body mass index at age 14 in their associations with intelligence (all *P*-values > 0.5).

Table 4 shows the multivariable associations of breast feeding with intelligence at 14 years of age. The elevated intelligence score in children who were breast fed was robust to all statistical adjustments.

Comparison of predictors of intelligence at ages 5 and 14

We compared predictors of intelligence at age 14 with those of intelligence at age 5 among those participants

Table 2. Multivariable associations (mean difference) of parental characteristics with intelligence[a] at age 14 years

	Mean difference [95% CI] in intelligence score					
	Confounder adjusted		Mediator adjusted			
	Model 1: Child's sex[b]	Model 2: Child's sex, and other parental characteristics[c]	Model 3: As model 2 plus characteristics of labour and Apgar scores[d]	Model 4: As model 3 plus birthweight-for-gestational-age[e]	Model 5: As model 4 plus breast feeding[f]	Model 6: As model 5 plus height and BMI *z*-scores at age 5[g]
Maternal age at birth (years)						
13–19	0.00 Reference	0.00 Reference	0.00 Reference	0.00 Reference	0.00 Reference	0.00 Reference
20–34	3.62 [1.86, 5.39]	1.88 [0.11, 3.65]	1.90 [0.13, 3.68]	1.82 [0.05, 3.59]	1.17 [−0.57, 2.93]	0.92 [−0.87, 2.71]
≥35	4.53 [1.83, 7.27]	3.22 [0.50, 5.93]	3.17 [0.45, 5.87]	3.06 [0.35, 5.78]	2.32 [−0.37, 5.01]	2.61 [−0.12, 5.35]
P^h	<0.001	0.01	0.01	0.02	0.07	0.06
Maternal ethnicity						
White	0.00 Reference	0.00 Reference	0.00 Reference	0.00 Reference	0.00 Reference	0.00 Reference
Asian	4.61 [1.70, 7.51]	3.10 [0.24, 5.96]	3.10 [0.24, 5.96]	3.25 [0.38, 6.11]	4.09 [1.26, 6.92]	4.40 [1.54,7.26]
Abor-islander	−2.99 [−6.14, 0.15]	−1.87 [−4.95, 1.21]	−1.89 [−4.97, 1.20]	−1.89 [−4.97, 1.19]	−1.86 [−4.89, 1.18]	−1.97 [−5.07, 1.12]
P^h	0.001	0.05	0.05	0.04	0.008	0.004
Gravidity						
1	0.00 Reference	0.00 Reference	0.00 Reference	0.00 Reference	0.00 Reference	0.00 Reference
2	0.07 [−1.22, 1.35]	0.17 [−1.09, 1.43]	0.17 [−1.09, 1.43]	0.05 [−1.22, 1.31]	0.15 [−1.10, 1.40]	0.15 [−1.11, 1.42]
3	−1.12 [−2.58, 0.34]	−0.80 [−2.24, 0.64]	−0.80 [−2.24, 0.64]	−0.97 [−2.42, 0.47]	−0.83 [−2.26, 0.60]	−1.11 [−2.56, 0.34]
≥4	−2.13 [−3.63, −0.64]	−1.41 [−2.90, 0.08]	−1.40 [−2.90, 0.07]	−1.65 [−3.15, −0.15]	−1.57 [−3.05, −0.08]	−1.43 [−2.94, 0.07]
P^h	0.003	0.04	0.04	0.02	0.02	0.03

Maternal smoking during pregnancy						
No	0.00 Reference	0.00 Reference	0.00 Reference	0.00 Reference	0.00 Reference	0.00 Reference
Yes	−2.34 [−3.42, −1.26]	−1.44 [−2.51, −0.37]	−1.40 [−2.47, −0.33]	−1.24 [−2.32, −0.16]	−0.46 [−2.32, −0.16]	−0.50 [−1.60, 0.60]
P^h	<0.001	0.01	0.01	0.03	0.41	0.37
Family income in the year of birth (Australian $)						
<10 400	0.00 Reference	0.00 Reference	0.00 Reference	0.00 Reference	0.00 Reference	0.00 Reference
10 400–15 599	2.68 [1.42, 3.94]	1.89 [0.65, 3.13]	1.89 [0.65, 3.13]	1.83 [0.59, 3.08]	1.37 [0.15, 2.60]	1.22 [−0.03, 2.47]
>15 599	3.84 [2.52, 5.15]	2.34 [1.03, 3.65]	2.34 [1.03, 3.65]	2.30 [0.98, 3.61]	1.72 [0.43, 3.03]	1.64 [0.32, 2.96]
P^h	<0.001	0.001	0.001	0.001	0.01	0.02
Maternal education						
No high school	0.00 Reference	0.00 Reference	0.00 Reference	0.00 Reference	0.00 Reference	0.00 Reference
Completed high school	3.67 [2.25, 5.09]	2.45 [1.00, 3.91]	2.45 [1.00, 3.91]	2.45 [1.00, 3.91]	1.79 [0.35, 3.23]	1.57 [0.11, 3.04]
College/university	8.23 [6.54, 9.92]	5.45 [3.67, 7.22]	5.46 [3.67, 7.22]	5.46 [3.68, 7.24]	4.24 [2.47, 6.01]	4.08 [2.29, 5.88]
P^h	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Paternal education						
No high school	0.00 Reference	0.00 Reference	0.00 Reference	0.00 Reference	0.00 Reference	0.00 Reference
Completed high school	3.25 [1.86, 4.64]	2.39 [0.97, 3.81]	2.39 [0.97, 3.81]	2.39 [0.97, 3.81]	2.26 [0.86, 3.66]	2.17 [0.75, 3.59]
College/university	8.39 [6.76, 10.0]	6.11 [4.39, 7.81]	6.11 [4.39, 7.81]	6.08 [4.37, 7.79]	5.58 [3.89, 7.27]	5.59 [3.89, 7.30]
P^h	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

N = 3099 with complete data on all variables included in multiply adjusted models.

[a]Intelligence scores are age-standardised; [b]Child's sex (binary variable); [c]As in [b]plus mutually adjusted for each of the other parental characteristics listed in the first column all entered as indicator variables except maternal smoking in pregnancy (binary); [d]As in [c]plus fetal distress (binary), duration of the first and second stage of labour (indicator variables), mode of delivery (binary), Apgar scores at 1 and 5 min (binary); [e]As in [d]plus birthweight for sex and gestational age z-scores; [f]As in [e]plus breast feeding (indicator variables); [g]As in [f]plus height for age and sex z-scores and BMI for age and sex z-scores at 5-year follow-up; [h]P-values are for linear trends except for where main exposure is binary variable.

CI, confidence interval.

Table 3. Multivariable associations of childhood height and body mass index (BMI) with intelligence[a] at age 14 years

	Mean differences [95% CI] in intelligence score					
	Model 1: Crude[b]	Model 2: Child's sex, and parental characteristics[c]	Model 3: As model 2 plus characteristics of labour and Apgar scores[d]	Model 4: As model 3 plus birthweight for sex and gestational age *z*-scores[e]	Model 5: As model 4 plus breast feeding[f]	Model 6: As model 5 plus height or BMI *z*-scores[g]
Height for sex and age *z*-score at age 14 (per score increase)	1.11 [0.51, 1.70]	0.91 [0.33, 1.50]	0.92 [0.34, 1.50]	0.83 [0.24, 1.42]	0.73 [0.15, 1.32]	0.84 [0.25, 1.43]
P	<0.001	0.002	0.002	0.006	0.01	0.005
BMI for sex and age *z*-score at age 14 (per score increase)	−0.74 [−1.33, −0.14]	−0.58 [−1.16, 0.00]	−0.57 [−1.15, 0.01]	−0.62 [−1.20, −0.04]	−0.60 [−1.16, −0.02]	−0.71 [−1.29, −0.13]
P	0.02	0.05	0.05	0.04	0.04	0.02

[a]Intelligence scores are age-standardised; [b]No covariates (main exposure variable is sex and gestational age standardised); [c]As in [b]plus maternal age at birth, maternal ethnicity, maternal educational attainment, paternal educational attainment, family income in the year of birth, gravidity (all indicator variables) and maternal smoking during pregnancy (binary); [d]As in [c]plus fetal distress (binary), duration of the first and second stage of labour (indicator variables), mode of delivery (binary), Apgar scores at 1 and 5 min (binary); [e]As in [d]plus birthweight for sex and gestational age *z*-score (indicator variables); [f]As in [e]plus breast feeding; [g]As in [f]plus mutual adjustment for height or BMI for age and sex *z*-scores (continuous variables).
CI, confidence interval.

Table 4. Multivariable associations of breast feeding with intelligence[a] at age 14 years

	Mean difference [95% CI]					
	Confounder adjusted				Mediator adjusted	
	Model 1: Child's sex[b]	Model 2: Child's sex, and parental characteristics[c]	Model 3: As model 2 plus characteristics of labour and Apgar scores[d]	Model 4: As model 3 plus birthweight-for-gestational-age[e]	Model 5: As model 4 plus height z-scores[f]	Model 6: As model 5 plus BMI z-scores[g]
Breast feeding duration (months)						
Never	0.00 Reference	0.00 Reference	0.00 Reference	0.00 Reference	0.00 Reference	0.00 Reference
<4	4.85 [3.37, 6.32]	4.05 [2.59, 5.51]	3.99 [2.53, 5.45]	3.99 [2.53, 5.46]	3.99 [2.53, 5.45]	4.07 [2.61, 5.53]
≥4	8.63 [7.20, 10.07]	6.89 [5.43, 8.36]	6.87 [5.40, 8.34]	6.85 [5.38, 8.31]	6.78 [5.32, 8.25]	6.79 [5.33, 8.26]
P	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

$N = 3099$ with complete data on all variables included in multiply adjusted models.
[a]Intelligence scores are age-standardised; [b]Sex adjusted; [c]As in [b]plus maternal age at birth, maternal ethnicity, maternal educational attainment, paternal educational attainment, family income in the year of birth, gravidity (all indicator variables) and maternal smoking during pregnancy (binary); [d]As in [c]plus fetal distress (binary), duration of the first and second stage of labour (indicator variables), mode of delivery (binary), Apgar scores at 1 and 5 min (binary); [e]As in [d]plus birthweight for sex and gestational age z-score (continuous variable); [f]As in [e]plus height for age and sex z-score at age 5 when outcome is intelligence at age 5 and at age 14 when outcome is intelligence at 14 (continuous variables); [g]As in [f]plus BMI for age and sex z-scores at age 5 when outcome is intelligence at age 5 and at age 14 when outcome is intelligence at age 14 (continuous variables).
CI, confidence interval.

with complete data on intelligence scores at both ages and data on all covariates ($N = 2442$). Although less precise, as evidenced by the wider CI, the point estimates for the associations between predictors and intelligence at age 14 did not differ markedly from those presented above (data not shown). For most associations there was no difference in effect when the outcome was intelligence at age 5 or when it was intelligence at age 14 (data not shown). The only exceptions were maternal ethnicity and the child's body mass index.

At age 5 years, both children whose mothers were Asian and those whose mothers were Abor-islanders had on average lower intelligence scores than children born to white women: sex-adjusted differences for Asian compared with white mothers were –3.45 [–6.44, –0.45] and for Abor-islander compared with white mothers –3.15 [–6.63, 0.23]. These associations were attenuated towards the null with adjustment for potential confounders and mediators, with a shallower gradient seen after adjusting for family income, parental education and breast feeding (fully adjusted differences were –1.87 [–4.82, 1.09] for those with Asian mothers, and –1.56 [–4.89, 1.69] for those with Abor-islander mothers). Similar results were found for the association between having an Abor-islander mother and intelligence at age 14 years in the subsample with complete intelligence scores at 5 and 14 years. However, children of Asian mothers had, on average, higher intelligence scores at age 14 than those of white mothers in sex (5.25 [1.89, 8.62]) and multiply adjusted analyses (5.20 [1.83, 8.57]). Using a z-test based on the standard errors of the regression coefficients, there was evidence of a difference in the gradient of the association between having an Asian mother and intelligence at age 5 years, and that between having an Asian mother and intelligence at age 14 years ($P = 0.003$).

At age 5 years, body mass index was weakly positively related to intelligence in crude (0.79 [0.14, 1.44] per increase of 1 sex and age-standardised body mass index) and multiply adjusted models (0.63 [–0.01, 1.29]), whereas at age 14 body mass index was weakly inversely associated with intelligence (–0.71 [–1.29, –0.13] in fully adjusted models) with a marked difference (P-value < 0.001) in the regression coefficients at ages 5 and 14. In prospective analyses, there was no association between body mass index at age 5 and intelligence at age 14 (crude association –0.29 [–0.84, 0.86]).

Life course predictors of childhood intelligence

By far, the strongest and most robust associations were parental education, family income and breast feeding with intelligence at both ages. Parental education alone explained 5.8% of the variation in intelligence at age 5 and 4.4% at age 14. With addition of family income to parental education, 7.3% of the variation in intelligence at age 5 and 4.6% at age 14 was explained. Addition of breast feeding increased the proportion of variation explained to 10.4% for intelligence at age 5 and 7.5% at age 14. In the final models containing all potential explanatory factors, these early life characteristics explained 12.7% and 8.3% of the variance in intelligence test results at ages 5 and 14 respectively.

Discussion

In the present study, a wide range of parental, birth, infancy and childhood characteristics were found to be associated with childhood intelligence. Of these, parental education, family income and breast feeding emerged as the most powerful determinants with other factors either mediating these associations or adding little additional explanatory power to the variation in childhood intelligence.

Only two characteristics showed differences in their associations with intelligence at the two ages. Children of Asian mothers tended to have lower intelligence scores at age 5 than children of white mothers, although this attenuated towards the null with adjustment for potential confounding and mediating factors. By contrast, children of Asian mothers had higher intelligence scores at age 14 than those of white mothers, and this association remained with adjustment for potential mediating and confounding factors. Additionally, at age 5, body mass index was positively associated with childhood intelligence, whereas at age 14, body mass index was inversely associated with intelligence.

Study strengths and limitations

The main strengths of the present study are its capacity to test the independent associations of a range of early life characteristics with childhood intelligence; the records-based nature of the birthweight and obstetric data which were collected prospectively rather than being retrospectively reported; the controlled conditions in which childhood anthropometry and intelligence were assessed using standard research protocols; the use of a population-based sample; and the availability of repeated measures of intelligence.

The main limitation is loss to follow-up, with data on childhood intelligence at each age being available on just 50% of the original cohort. Loss to follow-up was selective, with those without intelligence test data being more likely to have mothers from poorer backgrounds, parents with lower educational attainment, and mothers who were younger at the birth of their child than those children who had these data.[41] Our results would only be biased if the associations we have found between a given factor and intelligence were non-existent or in the opposite direction among those who did not participate or who had incomplete data. That is, if parental educational attainment, for example, was inversely associated with childhood intelligence. The results from our regression models in which we considered the effect of selection suggested that it did not materially affect the results presented here for the associations of early life factors with childhood intelligence. A second limitation concerns the problem of multiple comparisons. In the present analyses, we related intelligence measured at two points in time to a large number of potential predictor variables. While examination of these associations was hypothesis driven, it is plausible that, owing to the large number of statistical tests necessarily conducted, some of the associations may have arisen by chance alone.

Comparisons with other studies and possible explanations for associations

Our results are consistent with previous studies showing that childhood intelligence is related to socioeconomic position and parental education.[21–23] Family income may influence childhood intelligence through a number of pathways, including childhood nutrition, access to educational materials and quality of schooling. In our study, adjustment for birthweight had very little effect on the association between family income and childhood intelligence, but some attenuation occurred with adjustment for breast feeding and anthropometric measurements at age 14. This suggests that infant nutrition and childhood growth may partially explain the family income–childhood intelligence relationship. In the US National Longitudinal Survey of Youth, the association between family poverty (income below the official poverty line) and childhood intelligence was completely mediated by four latent variables representing 'cognitive stimulation in the home', 'parenting style', 'physical environment in the home' and 'poor child health at birth'.[43] We do not have the necessary family and parental data to be able to test these pathways in our study.

Parental education is likely to be linked to offspring intelligence via both genetic factors and environmental factors, such as parents being actively involved with their child's intellectual development and encouraging educational attainment. There is considerable debate about the important determinants of childhood intelligence, with differing estimates of the relative contributions of environmental and genetic factors.[13,14] Twin and adoption studies suggest heritability estimates of approximately 0.50 for intelligence with modest common environmental influences[44,45] while, elsewhere, the relative contributions of genetic and environmental contributions to childhood intelligence appeared to vary by family income.[13] Thus, among children brought up in impoverished families, 60% of the variance in intelligence scores at age 7 years were accounted for by shared environmental factors with very little contribution from genetic factors. By contrast, among children from affluent families, most of the variation in intelligence was accounted for by genetic factors.[13]

Further support for the importance of environmental factors in determining intelligence in children can be found in trials of early learning and school readiness programmes. In two recent systematic reviews of such interventions,[46,47] one of which focused on randomised trials,[46] the conclusion of both was that these programmes had important effects on reading, arithmetic ability and general intelligence that extended to secondary school ages.[46,47] Finally, the observation of secular increases in IQ across a range of populations is strong, albeit indirect, evidence for an important environmental effect. In these studies, the increases – widely referred to as the Flynn Effect – have occurred far too quickly for them to be explained purely by changes in the gene pool.[47] A similar argument is widely cited – and accepted – for the role of environmental factors in the so-called obesity epidemic.

Examining the association between ethnicity and intelligence has a contentious past,[11] as exemplified by the vigorous debates that followed the release of Herrnstein and Murray's *The Bell Curve: Intelligence and Class Structure in American Life*.[48] In this text, analyses of data from the US National Longitudinal Survey of Youth were used by the authors to illustrate ethnic differences in general intelligence, which resulted in their assertion that eugenic-like reforms should be made to the modern US welfare system. However, the authors failed to fully recognise that intelligence tests are clearly not ethnically or socially neutral. For example, verbal reading tests often depend upon correct pronunciation and do not always test word comprehension.[39] Notably, the work of Herrnstein and Murray, while impressive in the breadth and quantity of the analyses conducted, was never subjected to the scrutiny of peer review.

In the present study, the lower scores that we found among Abor-islanders at both ages and among Asians at age 5 compared with whites were largely explained by other parental characteristics, in particular family income and education, suggesting that any difference would be improved by improved social circumstances of these groups. The higher scores among children of Asian mothers at age 14 may be due to their experiences in the education system, in particular acquisition of the English language, and/or may reflect the differences between the tests used at each age. Field workers on the MUSP noted that at age 5, many of the Asian children (particularly those of Vietnamese parents) spoke their parents' language but not English, but that by age 14, they tended to be fluent in both their Asian language and English. The effects of this on the IQ tests would be marked as the Peabody test used at age 5 is given in English and requires verbal skills, whereas the Raven's test at age 14 requires neither of these.

While many investigators have reported on the birthweight–intelligence associations, there are few studies of population-based groups.[15] A recent systematic review identified six population-based studies and concluded, consistent with our findings, that there was a weak association between birthweight and childhood intelligence that was independent of socio-economic position.[15] In the only previously published study that we are aware of examining the combined effects of intrauterine and postnatal growth, birthweight and height were both independently associated with intelligence.[32] In the present study, we also found a positive association between childhood height and intelligence that was independent of birthweight and other potential confounding factors. However, unlike the previous study, we found that the association between birthweight and intelligence was attenuated towards the null with adjustment for childhood height. This suggests that postnatal linear growth, or factors affecting postnatal growth such as childhood nutrition, may be more important than intrauterine growth in terms of childhood intelligence. As only two studies, including the present report, have assessed these joint effects, further research is required to determine whether intrauterine growth has an effect on intelligence that is independent of postnatal height.

In cross-sectional analyses in the present study, we found differing intelligence–body mass index associations: at age 5 the relationship was positive, while at age 14 it was negative. In three cross-sectional studies relating intelligence to body mass index, an inverse relationship was seen in both young adult military draftees,[49,50] and a group of primary school children aged between 9 and 10 years.[51] These results are broadly consistent with the inverse association we have found at age 14. However, in these studies, as in our cross-sectional analyses, establishing the direction of association is problematic. Notably, when we prospectively related body mass index at age 5 to intelligence at age 14, there was little evidence of any association. In the only other study of which we are aware examining this association prospectively, weight at age 7 years was also unrelated to intelligence at age 15 in the 1946 birth cohort study, although an inverse association of weight at age 7 was seen with intelligence assessed in early and mid-adulthood.[32] It is possible that low body mass index in childhood, representing poor childhood nutrition, results in low intelligence with a lasting effect into adulthood, but that any association is masked in adolescence because of changes in body composition at this time and because of the inter-relationships between being overweight/obese, psychological distress and performance on intelligence tests. Studies with more detailed serially collected measures of anthropometry and intelligence (for example, yearly measures) would be required to further explore these issues.

We found that breast feeding was strongly associated with intelligence, such that those who had been breast fed for at least 4 months had, on average, intelligence scores that were 7 points higher than those who had never been breast fed when all potential confounders and mediators were taken into account. These findings are consistent with a number of other studies,[23–27] and provide further evidence of the benefits of breast feeding. Breast feeding may influence childhood intelligence through postnatal nutritional factors or may reflect the social interaction between a mother and her child, which continues throughout early childhood to influence childhood learning and cognitive development. Although the association between breast feeding and childhood intelligence remained even with adjustment for socio-economic indicators, maternal characteristics and perinatal factors, evidence from randomised controlled trials that effectively increased breast feeding would be required to be confident that this association was causal.

Implications

Family income, parental education and breast feeding were the strongest predictors of childhood intelligence in our study. Taken together, all of the early life predictors we examined explained just 13% of the variation in intelligence at age 5 and just 8% at age 14. If we had been able to allow for within-subject variation, these estimates may have been larger. Further, the point estimates of effect for family income, parental education and breast feeding are substantial. For example, in one study the risk of all-cause mortality was 12% higher for each standard deviation lower intelligence score in childhood, even when the association was adjusted for adult socio-economic position and potential confounding variables.[7] The difference in intelligence scores in our study computes to a 0.1 standard deviation for family income (highest vs. lowest), 0.3 standard deviations for mothers and a 0.4 for father's educational attainment (university or college education vs. not completing secondary education) and 0.5 standard deviation for breast feeding (breast fed for =4 months vs. never).

Our study is unable to determine the extent of genetic vs. environmental influences on childhood development, but our results, taken together with recent findings from twin studies and trials of education-type interventions, suggest that environmental factors are important determinants of intelligence among children. Further, the strong associations that we have found between indicators of socio-economic position and childhood intelligence illustrate the importance of ensuring that in studies suggesting an association between childhood intelligence and adult disease outcomes, there is adequate control for such potential confounders. Indeed, in order to maximise statistical control, it may be optimal to present associations stratified by childhood socio-economic position in such studies.

Acknowledgements

We are grateful to all participants in the study. Greg Shuttlewood, University of Queensland helped with data management for the study.

Funding: The core study is funded by the National Health and Medical Research Council of Australia. DA Lawlor is funded by a UK Department of Health Career Scientist Award. When work on this began, GD Batty was supported by a University of Copenhagen Senior Research Fellowship; he is now funded by a Wellcome Trust Advanced Training Fellowship. The views expressed in this publication are those of the authors and not necessarily those of any funding body.

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