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Season of birth and childhood intelligence: Findings from the *Aberdeen Children of the 1950s* cohort study

Debbie A. Lawlor[1]*, Heather Clark[2], Georgina Ronalds[3] and David A. Leon[3]

[1]Department of Social Medicine, University of Bristol, UK
[2]The Dugald Baird Centre for Research on Women's Health, University of Aberdeen, Scotland, UK
[3]Department of Epidemiology and Population Health, London School of Hygiene and Tropical Medicine, UK

Background. In this study, 2 main hypotheses have been put forward to explain the variation in childhood intelligence or school performance by season of birth. In the first hypothesis, it is suggested that it is due to school policy concerning school entry, whereas the second suggests that a seasonally patterned exposure such as temperature, maternal nutrition, or infection during critical periods of brain development have a lasting effect on intelligence.

Aims. To determine whether childhood performance on tests of different domains of intelligence is patterned by season of birth and to examine possible mechanisms for any associations.

Sample. 12,150 individuals born in Aberdeen, Scotland between 1950 and 1956.

Methods. Birth cohort study in which the variation in different domains of childhood intelligence measured at ages 7, 9, and 11 by season of birth were examined.

Results. Reading ability at age 9 and arithmetic ability at age 11 varied by season of birth, with lowest scores among those born in autumn or early winter (September–December) and highest scores among those born in later winter or spring (February–April); $p = .002$ for joint sine-cosine functions for reading ability at age 9 and $p = .05$ for sine-cosine function for arithmetic ability at age 11. The child's perception and understanding of pictorial differences at age 7, verbal reasoning at 11, and English language ability at 11 did not vary by season of birth. Age at starting primary school and age relative to class peers were both associated with the different measurements of childhood intelligence and both attenuated the association between month of birth and reading ability at age 9 and arithmetic ability at age 11 towards the null. Both adjusted

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Correspondence should be addressed to D. A. Lawlor, Department of Social Medicine, University of Bristol, Canynge Hall, Whiteladies Rd, Bristol BS8 2PR, UK (e-mail: d.a.lawlor@bristol.ac.uk).

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and unadjusted differences in reading ability at age 9 and arithmetic ability at age 11 between those born from September to December compared with other times of the year were less than 0.1 of a standard deviation of the test scores. Ambient temperature around the time of conception, during gestation, and around the time of birth did not affect intelligence.

Conclusion. Any variation in mean childhood intelligence by season of birth is weak and largely explained by age at school entry and age relative to class peers.

Season of birth patterns in educational attainment and intellectual ability have been reported in a large number of studies in different populations, including general populations, for over six decades (Bergund, 1967; Geldhill, Ford, & Goodman, 2002; Huntington, 1938; Jinks, 1964; Orme, 1954, 1963; Russell & Startup, 1986; Wallingford & Prout, 2000; Williams, Davies, Evans, & Ferguson, 1970). Although the majority of studies have found an association between season of birth and intellectual ability in the general population, a small study of 384 adults found no difference in mean scores on the Wechsler adult intelligence scale between those born in the summer months (May–October) and those born in the winter months (November–April; Mascie-Taylor, 1980). Others have suggested that the association between season of birth and intelligence is restricted only to subgroups of individuals who are mentally subnormal (Martindale & Black, 1970; Orme, 1963).

Two main theories have been proposed to explain the association between month of birth and school performance or intellectual ability. In the first, it is suggested that the association is really an artifact of school entry policy and not truly an effect of risk factors that vary between the seasons (Geldhill *et al.*, 2002; Goodman, Gledhill, & Ford, 2003; Williams, Davies, Evans, & Ferguson *et al.*, 1970). For example, in educational systems with a single annual cut-off date for school entry the age at which children start school will cover a 12-month range. Those who are youngest in the class may be less able than the older children when they first enter school and/or may be perceived by the teachers as being less able and as a consequence become incorrectly labelled and treated as slow learners.(Geldhill *et al.*, 2002) In systems where children can enter school at different times (terms) of the year, but all leave primary school at the same time, ability may be influenced by the varying length of primary school attendance. Prior to the Plowden committee's recommendation of a single date of entry for English schools, which became policy in 1967 (Department of Education and Science, 1967), children entered primary school in the term that they turned 5 years of age. As a result, summer-born children spent a shorter period of time in their primary schools than did children born at other times of the year.

Some evidence for the suggestion that seasonal patterning of childhood outcomes are due to school policy rather than being caused by a seasonally patterned risk factor comes from comparisons between areas that experience similar seasons but have different educational policies regarding school entry. For example, Goodman, Gledhill, and Ford (2003) recently compared season of birth patterns of psychopathological symptoms among children in England and Scotland. They found that symptoms were greatest among children born in the summer months in England and among those born in January or February in Scotland. For both countries, these represent the youngest in the school year since age on the first of September defines school entry in England and age at the beginning of March defines school entry in Scotland. Any seasonally patterned exposure, such as temperature, nutrition, or infection would be expected to produce similar season of birth patterns for England and Scotland. However, others have found consistent patterns in childhood intelligence by season of birth in neighbouring areas with different educational policies, suggesting that a seasonally patterned exposure may affect childhood intelligence (Fitt, 1941; Huntington, 1938).

An alternative suggestion is that intelligence is affected by a seasonally patterned exposure such as ambient temperature during intrauterine development, maternal nutrition, or perinatal infection (Huntington, 1938; Orme, 1963; Martindale & Black, 1970). The idea here is that seasonally patterned exposures during sensitive periods of brain development – the intrauterine or early infancy period – have a lasting effect on intellectual ability. In support of this theory, several studies linking birth weight to intelligence in later childhood and early adulthood suggest that intelligence is importantly influenced by intrauterine factors (Breslau, Chilcoat, DelDotto, Andreski, & Brown, 1996; Jefferis, Power, & Hertzman, 2002; Richards, Hardy, Kuh, & Wadsworth, 2001; Shenkin *et al.*, 2001; Sorensen *et al.*, 1997) Further, the season of birth patterning of mental health problems, which are consistent across a large number of populations, provides support for the theory that seasonally patterned exposures during the intrauterine period and/or in infancy influence brain development and functioning. Most research has focused on schizophrenia and bipolar disorders, with a review of 250 studies concluding that there was a 5%–8% excess of schizophrenia and bipolar depression in the winter and early spring months (Torrey, Miller, Rawlings, & Yolken, 1997). A recent meta-analysis based on 126,196 individuals with schizophrenia reported a pooled odds ratio for schizophrenia among those born in the winter/spring in the Northern Hemisphere compared with the summer/autumn of 1.07 (95% confidence interval 1.05, 1.08; Davies, Welham, Chant, Torrey, & McGarth, 2003). Similar season of birth patterns have also been found for depression and major personality disorders (Hare, 1975; Huntington, 1938; Kendell & Kemp, 1987; Videbech, Weeke, & Dupont, 2004). Among children, there is evidence that autism is more common in those born in late winter/early spring (Barak, Ring, Sulkes, Gabbay, & Elizur, 1995; Mouridsen, Nielsen, Rich, & Isager, 1994), and that eating disorders are more common among girls born in April in northern hemispheres (Nielsen, 1992; Rezaul, Persaud, Takei, & Treasure, 1996).

To our knowledge, no previous study has been able to assess whether school policy or seasonally patterned exposures explain season of birth variations in childhood intelligence within the same study. Further, most previous studies have had small selected samples or have been based on routinely available data and have therefore had large samples but have been unable to take account of possible confounding by sociodemographic factors.

The aim of this study was to determine whether intelligence measured on three separate occasions (age 7, 9, 11) in the same children – a large cohort of children born in Aberdeen, Scotland – is patterned by season of birth. Since different tests of intelligence (assessing different domains) were used at each age, we have assessed seasonal patterning of the test results at each age separately. Thus, we sought to examine whether there is seasonal patterning of the child's perception and understanding of pictorial differences at age 7, reading ability at age 9, and verbal reasoning, English, and arithmetic ability at age 11. However, we were unable to assess the effect of season of birth on intelligence trajectories over time. We had information on a number of potential confounding factors and have information on the participant's age, in months, at which they first started primary school and their age relative to their primary school class peers. This information allowed us to determine whether any seasonal patterning is explained by differences in age at school entry or age relative to class peers. Further, we have examined the role of ambient outdoor temperature around the time of conception and during gestation on the different domains of intelligence measured at different ages, since it has been proposed that temperature around conception or during gestation could explain the seasonal patterning of intelligence and mental health problems (Bark & Krivelevich, 1996; Huntington, 1938; Kinney, Waternaux, Spivak, LeBlanc, & Vernooy, 1993; Martindale & Black, 1970; Orme, 1963; Templer, Ruff, Halcomb, Barthlow, & Ayers, 1978).

Methods

Study Participants

Data were used from the *Aberdeen Children of the 1950s* cohort study. This study has been described in detail previously (Batty *et al.* 2003). The study cohort consists of 12,150 children who were born in Aberdeen between 1950 and 1956 and who participated in the Aberdeen Child Development Survey (ACDS; Illsley & Wilson, 1981; Batty, *et al.* 2003) For cohort members, we have detailed perinatal data that was collected during their perinatal period and recorded in the Aberdeen Maternal and Neonatal Database. Participants underwent routine primary school physical examinations and undertook intelligence quotient (IQ) tests as they progressed through primary school and we have collected the data from these tests and linked them to the perinatal data. The children went through five grades of primary school (Year III–Year VII) and attended 1 of 52 different schools in Aberdeen.

Assessment of childhood intelligence and behaviour

The intelligence tests used in this study are the tests that were routinely administered to all children in Aberdeen throughout the 1950s when the children were aged 7, 9, and 11 years of age. The tests used at age 7 were the Moray House Picture Intelligence tests, Number 1 or 2. All participants sat the test within 6 months of their 7th birthday. The test was based entirely on line drawings and examines the child's perception and understanding of pictorial differences. The tests at age 9, sat within 6 months of the child's 9th birthday, were the Schonell and Adams Essential Intelligence tests, Form A or B, which were primarily used to assess the child's reading ability. The tests at age 11 included a battery of Moray House tests; two tests of verbal reasoning and one each of arithmetic and English. These were all written tests and were taken within 6 months of the child's 11th birthday. The mean score for verbal reasoning was calculated from the two verbal reasoning tests. All measurements of childhood intelligence were age standardized. In 1964, teachers completed the Rutter scale B of minor behavioural disorder (Rutter, 1967) for each student. Students were classified as having no problems or either antisocial or neurotic problems.

Age at school entry, age relative to class peers, school admissions policy in Aberdeen in the 1960s, and temperature data

Age (in months) at school entry for each child was provided on the school medical records. Age relative to their primary school class (Year III through to Year VII) was calculated from records of each child's age and the class that they were in at the time of the ACDS in 1964.

Information concerning entry policy to Aberdeen schools in the 1960s was obtained by searching town council records and minutes kept at the Aberdeen Central Library. Minutes of a statement by the Director of Education to a Town Council of Aberdeen meeting that took place on 3rd October 1960 state:

> The Education Act requires an Authority to have two or more admission dates approved by the Secretary of State. This means that all children who attain the age of five years before the next admission date have to attend school as from the first school day following that admission date. In practice this Authority operates three admission dates coinciding with the commencement of the three school terms and the details of the arrangements are as follows:
>
> (i) in August, children born between April and the end of August are admitted, with the addition in some instances of September or even October children in order to make the class(es) form a reasonable size; (ii) in January, children born between September and December are admitted, and children born between January and March may be admitted if the parents agree; (iii) in April, the comparatively small number born between January and March, not admitted in January are admitted to existing classes.

From searches of subsequent minutes and documentation, it appears that this system of admission to primary schools in Aberdeen continued until the Plowden' committee report of 1967 and therefore was the system under which all participants in this study entered primary school. All participants left primary school to start secondary school at the same time – in the year of their 11th birthday. Consequently, there will have been a tendency for children born between January and March to have had the least years of primary school education, and those born between April and August to have had the most years of primary school education in this cohort.

Temperature data were obtained from the archives of the Meteorological Office via the British Atmospheric Data Centre (http://badc.nerc.ac.uk/). Data from the local Craibstone weather station, which is situated close to Aberdeen Airport and approximately 2 miles from the city centre, were used. Data from this station were available for the period 1949–1956, which included the years in which the participants were born and their full gestational periods.

For the period of gestation of each subject, we calculated the mean outdoor temperature in the middle 10 days of each trimester of pregnancy. For the first trimester, the middle ten days were defined as Days 42–51 of gestation; for the second trimester, these were defined as Days 135–144; and for the third trimester, they were defined as Days 228–237. The participants' gestational age (based on date of last menstrual period and converted from weeks to days) and date of birth were used to define Day zero (the day of the last menstrual period). In addition, we estimated mean temperature around the time of conception as 10 days around 'day zero' (-4 to $+5$) and mean temperature around the time of birth as 10 days around this date (4 days before, the day of birth, and 5 days after). Data on the minimum and maximum air temperatures (taken from 24 hour readings) for most of these days were available. For the maximum temperature data set, there was a recording for all days included in the analysis for 9,815 (81%) of the cohort participants. For the minimum temperature data set, there were recordings for all but 4 of the participants. There was a high level of correlation between the two temperature measures (Pearson's correlation coefficient .85) and the results using either the minimum or the maximum temperature were similar. Therefore, results based on the daily minimum temperatures are presented here.

Assessment of other covariates

Birth weight and gestational age were recorded at the time of birth in the Aberdeen Maternal and Neonatal Database (Batty *et al.* 2003). The participants' intrauterine growth rate was estimated by calculating sex and gestational age standardized z (standard deviation) scores. Means and standard deviations of birth weight were calculated for participants by sex and single weeks of gestational age. The z scores were then calculated as a participant's birth weight minus the mean for their gestational age and sex category and divided by the standard deviation for their gestational age and sex category. Social class at birth was based on the child's father's occupation as originally stated in the obstetric records (seven categories: I-professional; II-managerial; III-non-manual/skilled non-manual; III-manual: skilled manual; IV-semi-skilled; V-unskilled manual and unemployed, which are collapsed in some analyses into two categories non-manual (I-IIInm) and manual (IIIm to V)). Maternal age at the birth of the child was also as originally stated in the obstetric records and was recorded in 7 five-year age categories from 15 to 19 to 45 years or older. Birth order of the participant was obtained at the time of the 1962 survey.

Statistical methods

Means of each measure of intelligence for each month of birth were estimated and examined graphically. Linear regression models were used to explore seasonal trends and temperature effects on these measures. In these models, each measure of intelligence was the dependent variable. Month of birth, entered as a 12-level categorical variable, was the main exposure variable of interest. Very few of the participant's mothers were aged 45 or older when the participant was born (Table 1), and therefore participants in this category were combined with the 40- to 44-year-old category in the regression models. Similarly, the 11 participants who were born in 1956 were combined with those born in 1955 in the regression models. In the simplest model, adjustment was made for sex only. In subsequent models, adjustment was made for the following covariates: birth weight for sex and gestational age z score (continuous variable), year of birth (6-level categorical), maternal age at birth (6-level categorical), birth order (7-level categorical), social class at birth (5-level categorical variable), age at school entry (5-level categorical variable, mostly in 3-month categories), age relative to class peers (10-level categorical).

In order to formally assess seasonal patterns of intelligence, graphs of mean scores by month of birth were examined and a sinusoidal curve was fitted to the data by fitting sine and cosine functions into a regression model assuming a 6-month periodicity; that is, one peak and one trough over the 12-month period. An F test was used to test the joint effect of the sine and cosine functions.

Linear regression models were used to assess the association of the mean temperature measures with intelligence scores. In these models, the mean temperature variables (i.e. mean temperature for each of the 10-day periods around conception, in the middle of the first-, second-, and third-trimester and around birth) were entered as categorical variables (fifths of the distribution) or as continuous variables. Other covariates were entered as described above in the models for the association of month of birth with intelligence. In final models, month of birth, and temperature during gestation and around the time of birth were entered simultaneously into regression models in order to try to determine whether the temperature variables explained any seasonal patterning in intelligence.

Table 1. Study participant characteristics ($N = 12{,}150$)

Characteristic	Mean (*SD*) or number (%)
Female (no. [%])	5868 (48.3)
Perception and understanding of pictorial differences at age 7	107.1 (16.4)
Reading ability at age 9	111.3 (17.0)
Arithmetic ability scores age 11	99.5 (14.3)
English language ability scores age 11	99.6 (14.4)
Verbal reasoning scores age 11	99.4 (13.9)
Teachers report of any behaviour problems (no. [%]) (*data were missing on 370 participants*)	4675 (39.5)
Age (months) starting school (no. [%])	
≤ 54 months	295 (2.4)
55–57 months	498 (4.1)
58–60 months	4,422 (36.4)
61–63 months	5,113 (42.1)
64–66 months	1,029 (8.5)
≥ 67 months	794 (6.5)
Birth weight (g)	3299.13 (513.18)
Gestational age (week)	39.2 (1.8)
Year of birth (no. [%])	
1950	616 (5.1)
1951	2344 (19.3)
1952	2325 (19.1)
1953	2403 (19.8)
1954	2579 (21.2)
1955	1872 (15.4)
1956	11 (0.09)
Mother's age at birth of participant (no. [%]) (*6 participant's mothers could not be classified*)	
15–19	567 (4.7)
20–24	3798 (31.3)
25–29	3777 (31.1)
30–34	2546 (21.0)
35–39	1108 (9.1)
40–44	335 (2.8)
≥ 45	13 (0.1)
Birth order (no. [%]) (*data were missing on 90 participants*)	
1st	4555 (37.8)
2nd	3784 (31.4)
3rd	1971 (16.3)
4th	990 (8.2)
5th	439 (3.6)
6th	187 (1.6)
7th or greater	134 (1.1)
Social class at birth (based on fathers occupation) (no. [%])	
I and II	1163 (9.6)
III non-manual	1335 (11.0)
III manual	5319 (43.8)
IV	1689 (13.9)
V	1963 (16.2)
Unemployed	680 (5.6)

Some percentages do not add up to exactly 100 because of rounding.

F tests were used to assess statistical evidence of interactions with sex. There was no evidence of any statistical interactions between sex and month of birth or any of the temperature measures (all p values $>.75$) and stratified (by sex) analyses did not differ from each other therefore results of the regression analyses are presented for both sexes combined. In all analyses, robust standard errors, taking account of non-independence between children from the same school at the time of each test, were used to estimate p values and 95% confidence intervals.

Results

Table 1 shows the distributions of characteristics of study participants. Figure 1 shows the distribution of age relative to mean class age. As expected, the majority of pupils were within 6 months of their class mean; 95% of the students were in the range 7.3 months younger than the class mean to 10.1 months older than the class mean.

Variation of intelligence by season of birth

Figures 2a–e show the mean scores for each of the different measurements of domains of intelligence by month of birth. There was no statistical evidence of a sinusoidal pattern for the child's perception and understanding of pictorial differences at age 7 ($p = .40$), English language skills at age 11 ($p = .27$), verbal reasoning at age 11 ($p = .76$), or either antisocial or neurotic behaviours (the figure shows prevalence of either antisocial or neurotic behaviour by month of birth, patterns were essentially the same if either of just antisocial or neurotic behaviours were plotted, all p values $>.9$). However, there was evidence of a sinusoidal seasonal pattern for both reading ability at age 9 ($p = .002$) and arithmetic ability at age 11 ($p = .05$). For both of these, scores were lowest among those born in late autumn/early winter (September–December) and were highest among those born at the end of winter/early spring (from February to April for intelligence age 9 and from January to March for arithmetic ability at age 11).

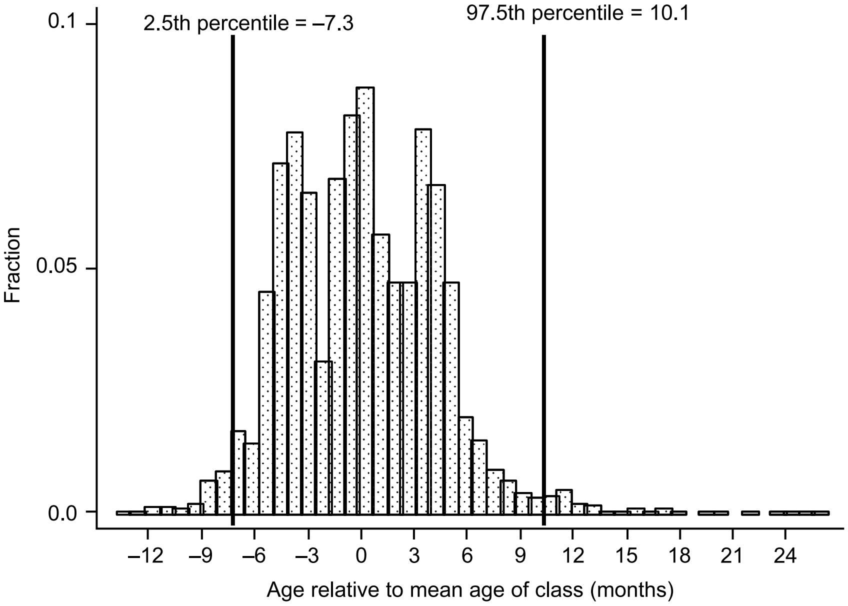

Figure 1. Distribution of age relative to average of class.

Examination of the graphs shows that English language skills and verbal reasoning at age 11 were also highest among those born in February and March, but for these outcomes, there was no clear trough of ability among the other birth months. The association between month of birth and child's perception and understanding of pictorial differences at age 7 appears completely random.

Age at starting school and age relative to peers

Table 2 shows the sex adjusted associations between the child's age at starting primary school and each measure of intelligence. Child's perception and understanding of pictorial differences at age 7 and reading ability at age 9 were both affected by the age at which a child started school with those who were younger than 61–63 months (the most common age category for school entry age) and the oldest age category having lower scores in both of these tests. Age at school entry was less strongly associated with any of the measurements taken at age 11, although there was a tendency for those who were

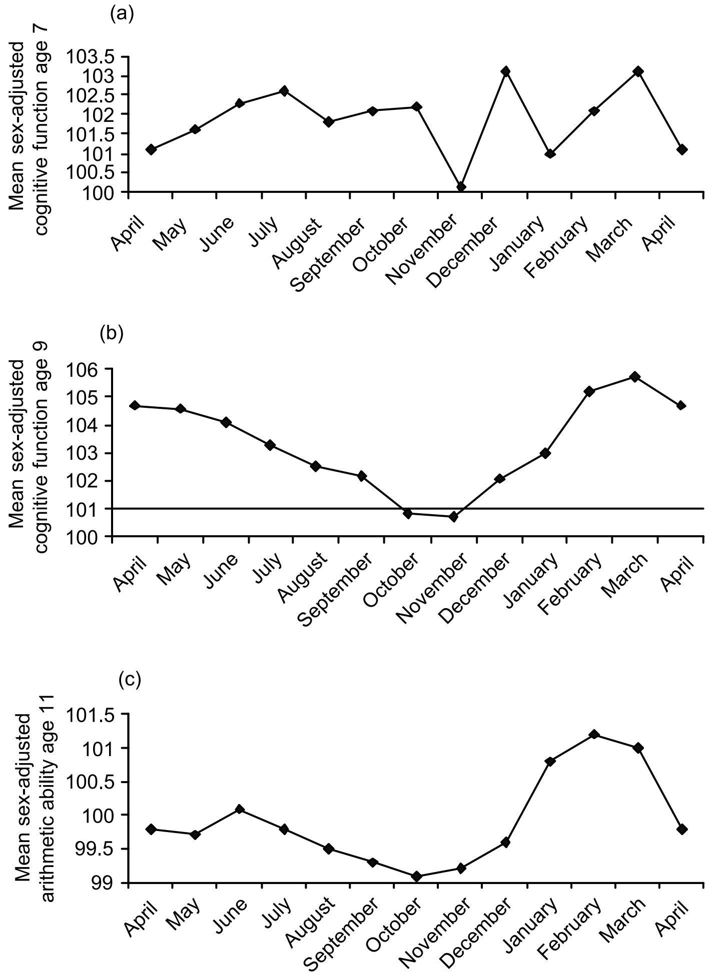

Figure 2. (a) Sex adjusted perception and understanding of pictorial differences at age 7 by month of birth. (b) Sex adjusted reading ability at age 9 by month of birth. (c) Sex adjusted arithmetic ability age 11 by month of birth. (*Continued overleaf*)

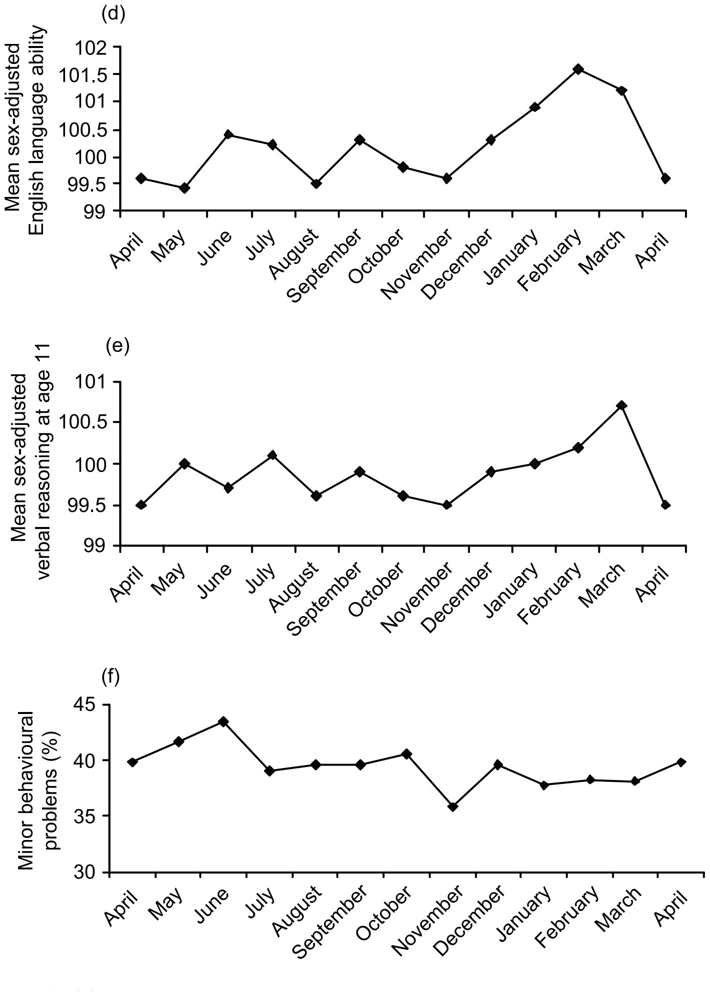

Figure 2. (*Continued*) (d) Sex adjusted English language ability at age 11 by month of birth. (e) Sex adjusted verbal reasoning at age 11 by month of birth. (f) Prevalence (%) of teacher reported minor behavioural problems.

younger than 61–63 months when they started school and the oldest age category to have lower arithmetic ability at age 11. Those who were relatively young compared with their class peers and those who were more than 12 months older than the average age of the class tended to have higher scores on perception and understanding of pictorial differences at age 7 and reading ability at age 9 than those around the mean age of their class. In general, the associations between age relative to peers and the results of all of the tests at age 11 were weaker, although those who were 6–9 months older than the average for their class had lower scores on arithmetic ability than those around the average age of their class. Teacher reports of childhood behavioural problems were not related to either age at school entry or age relative to class peers (both p values $> .6$). Age at starting school and age relative to class peers were not strongly correlated with each other (Pearson's correlation .03, $p = .01$) and when their effects on intelligence at age 9 and arithmetic ability at age 11 were mutually adjusted for each other, the results were essentially the same as those presented in Table 2.

Table 2. Difference in intelligence test scores at ages 7, 9 and 11 by age at starting primary school

	Sex-adjusted difference (95% confidence interval) in intelligence measurement scores				
	Perception and understanding of pictorial differences age 7	Reading ability age 9	Arithmetic ability age 11	English language ability age 11	Verbal comprehension age 11
Age at starting school					
≤ 54 months	− 2.24 (− 5.30, 0.81)	− 3.56 (− 7.27, 0.14)	− 0.83 (− 2.74, 1.07)	0.15 (− 1.76, 2.07)	0.20 (− 1.51, 1.91)
55–57 months	− 0.70 (− 3.10, 1.70)	− 2.92 (− 5.84, − 0.02)	− 0.94 (− 2.44, 0.56)	0.54 (− 0.97, 2.05)	0.57 (− 0.76, 1.91)
58–60 months	0.38 (− 0.66, 1.45)	− 1.46 (− 2.73, − 0.19)	− 0.02 (− 0.62, 0.58)	0.99 (0.34, 1.64)	0.56 (− 0.02, 1.13)
61–63 months	reference	reference	reference	reference	reference
64–66 months	− 1.24 (− 2.99, 0.51)	0.01 (− 2.11, 2.12)	0.13 (− 0.93, 1.20)	− 0.29 (− 1.37, 0.78)	− 0.26 (− 1.23, 0.70)
≥ 67 months	− 7.89 (− 9.85, − 5.94)	− 6.82 (− 9.18, − 4.46)	− 0.28 (− 1.47, 0.91)	− 0.05 (− 1.16, 1.24)	0.07 (− 1.04. 1.17)
p^a	< 0.001	< 0.001	0.06	0.05	0.40
Age relative to class peers					
> 9 and ≤ 12 months younger	8.90 (2.60, 15.21)	2.90 (− 4.70, 10.49)	− 0.56 (− 4.69, 3.57)	− 1.21 (− 5.39, 2.96)	1.59 (− 2.04, 5.22)
> 6 and ≤ 9 months younger	8.15 (2.25, 14.04)	8.04 (0.95, 15.15)	− 0.26 (− 4.13, 3.59)	− 0.94 (− 4.83, 2.96)	0.05 (− 3.36, 3.47)
> 3 and ≤ 6 months younger	8.09 (2.19, 14.00)	9.33 (2.20, 16.45)	− 0.34 (− 4.22, 3.53)	− 1.50 (− 5.41, 2.40)	− 0.18 (− 3.61, 3.24)
> 1 and ≤ 3 months younger	7.77 (1.85, 13.69)	8.05 (0.91, 15.19)	0.60 (− 3.29, 4.48)	− 0.24 (− 4.16, 3.68)	− 0.16 (− 3.59, 3.27)
Within 1 month of class mean	reference	reference	reference	reference	reference
> 1 and ≤ 3 months older	7.65 (1.76.13.54)	8.01 (0.91, 15.11)	− 1.32 (− 5.18, 2.53)	− 1.66 (− 5.54, 2.23)	− 0.96 (− 4.36, 2.46)
> 3 and ≤ 6 months older	6.25 (0.00, 12.50)	7.88 (0.34, 15.42)	− 2.66 (− 6.69, 1.36)	− 3.58 (− 7.65, 0.48)	− 3.05 (− 6.65, 0.58)
> 6 and ≤ 9 months older	0.53 (− 6.38, 7.43)	7.03 (− 1.29, 15.35)	− 5.30 (− 9.65, − 0.95)	− 5.13 (− 9.52, − 0.74)	− 4.86 (− 8.80, − 0.92)
> 9 and ≤ 12 months older	− 0.20 (− 6.44, 6.05)	− 1.82 (− 9.35, 5.71)	− 2.93 (− 6.99, 1.14)	− 2.78 (− 6.90, 1.30)	− 1.69 (− 5.30, 1.93)
> 12 months older	8.91 (3.00, 14.82)	10.16 (3.04, 17.29)	0.29 (− 3.59, 4.16)	0.76 (− 4.67, 3.17)	0.19 (− 3.22, 3.62)
p^a	< 0.001	< 0.001	0.03	0.06	0.05

[a] *F* test for hypothesis that age at school entry or age relative to class peers is not associated with IQ.

Figures 3 and 4 show the variations in reading ability at age 9 (Fig. 3) and arithmetic ability at age 11 (Fig. 4) by month of birth with adjustment for potential covariates. Adjustment for birth weight for sex and gestational age z score, year of birth, maternal age at birth, birth order, and social class at birth produced very little change in the season of birth patterns and statistical evidence for a sinusoidal pattern remained ($p = .004$ for reading ability age 9 and $p = .05$ for arithmetic ability at age 11). With

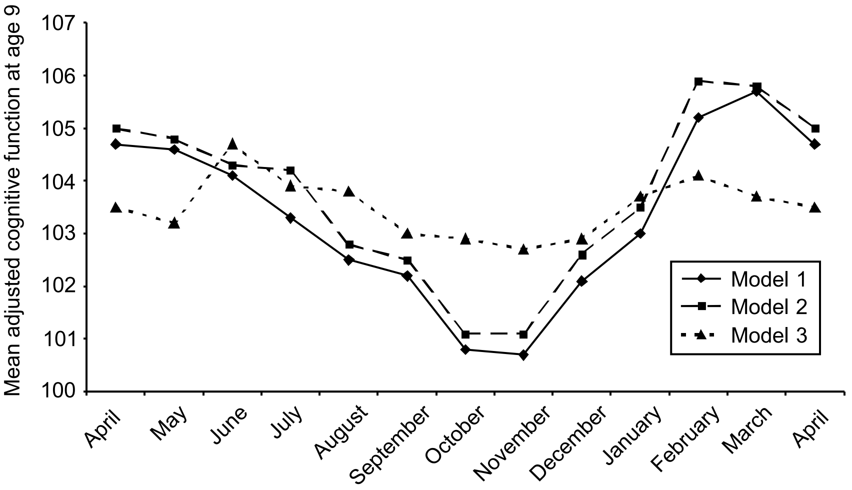

Figure 3. Mean reading ability at age 9 by month of birth with adjustment for difference covariates. Model 1: Sex adjusted. Model 2: Sex, maternal age, birth year, birth order, birth weight, gestational age, and social class at birth adjusted. Model 3: Adjusted for all characteristics included in Model 2 plus age at school entry and age relative to class peers.

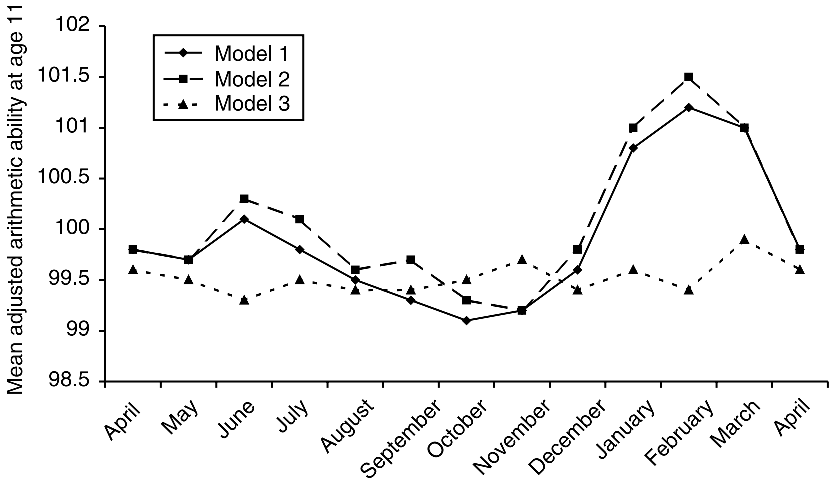

Figure 4. Mean arithmetic ability at age 11 by month of birth with adjustment for different covariates. Model 1: Sex adjusted. Model 2: Sex, maternal age, birth year, birth order, birth weight, gestational age, and social class at birth adjusted. Model 3: Adjusted for all characteristics included in Model 2 plus age at school entry.

further adjustment for age (in months) at starting school and age relative to class peers, the season of birth variation in reading ability at age 9 (p for sinusoidal function = .23) and arithmetic ability at age 11 (p for sinusoidal function = .83) were both attenuated towards the null.

Table 3 shows the difference in reading ability at age 9 and arithmetic ability at age 11 comparing those born between September and December with those born at any other time in the year. The lower abilities among those born in the autumn and early winter months compared with all other months were largely unaffected by adjustment for maternal age, birth order, birth weight for gestational age, year of birth, and social class (Model 3). However, both age at school entry and age relative to class peers attenuated the difference (Models 4 and 5). When both were included in the models, there was no difference in arithmetic ability at age 11 between those born September–December compared with the rest of the year, and there was only a very small difference in reading ability at age 9. When these differences are expressed as standard deviations of the test scores, the unadjusted difference for reading ability at age 9 comparing those born from September to December to those born in any other month was -0.06 (-0.10, -0.02) standard deviations, and that for arithmetic ability at age 11 was -0.05 (-0.10, -0.01) standard deviations. The fully adjusted (equivalent to Model 5) difference for reading ability at age 9 was -0.04 (-0.08, -0.005) standard deviations.

Ambient outdoor temperature around conception, during gestation and around birth and intelligence

Mean ambient temperature for each year showed the expected pattern of variation with highest temperatures in the summer months and lowest temperatures in the winter months (Fig. 5). The patterns of temperature at different stages of conception, gestation, and around birth were as one would expect from their temporal relationship to each other (e.g. a moderate positive correlation between temperature around the time of conception and in the middle of the first trimester; Pearson's correlation coefficient = .52, $p < .001$ but a weak inverse correlation between temperature around the time of conception and the time of birth: Pearson's correlation coefficient = .03, $p = .001$). In simple sex-adjusted models, temperatures around the time of conception and in the first trimester were positively associated with reading ability at age 9 (p linear trend $< .001$) and temperature in the second and third trimesters were inversely associated with this outcome (p linear trend for both $< .001$). Temperature in the first trimester was also positively associated with arithmetic ability at age 11 (p linear trend = .01) and temperature in the third trimester (p linear trend = .002) and around the time of birth was inversely associated with arithmetic ability at age 11 (p linear trend = .03). These patterns of association are consistent with the season of birth patterns seen for these two outcomes. For example, intelligence was greater among those born between February and April. These individuals will usually have been conceived between June and August, and since these are the warmest (summer) months in Scotland, one would expect warmer temperatures around the time of conception and in the first trimester to be associated with greater score for this outcome. When month of birth was included in the regression models, these associations between temperature and reading ability at age 9 and arithmetic ability at age 11 all attenuated to the null (all p values $> .2$). Adjustment of month of birth associations with reading ability at age 9 and arithmetic ability at age 11 was not significantly affected by adjustment for temperature around the time of conception,

Table 3. Difference in reading ability at age 9 and arithmetic ability at age 11 comparing those born between September and December to those born in all other months

	Difference in reading ability at age 9 (95% confidence interval): children born September to December minus those born in other months	Difference in arithmetic ability (95% confidence interval): children born September to December minus those born in other months
Model 1: Unadjusted	− 1.05 (− 1.68, − 0.40)	− 0.81 (− 1.41, − 0.20)
Model 2: Sex	− 1.04 (− 1.70, − 0.38)	− 0.80 (− 1.40, − 0.21)
Model 3: Sex, birth characteristics[a]	− 1.05 (− 1.68, − 0.41)	− 0.80 (− 1.39, − 0.20)
Model 4: Sex, birth characteristics, age at starting primary school adjusted	− 0.80 (− 1.45, − 0.16)	− 0.49 (− 1.08, 0.09)
Model 5: Sex, birth characteristics, age relative to class peers	− 0.72 (− 1.38, − 0.08)	− 0.11 (0.70, 0.48)
Model 6: Sex, birth characteristics, age at starting primary school adjusted, age relative to class peers	− 0.68 (− 1.34, − 0.04)	0.07 (− 0.51, 0.65)

[a] Birth characteristics: maternal age, year of birth, birth weight for gestational age, birth order, social class at birth.

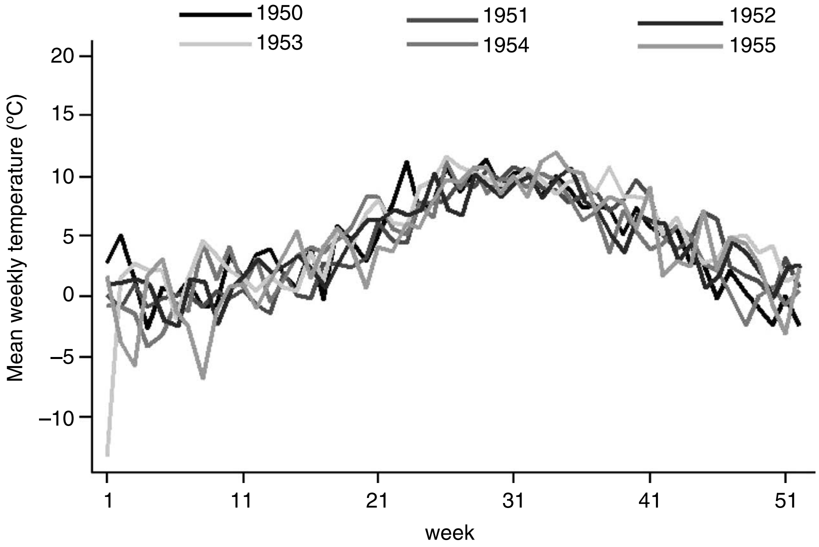

Figure 5. Mean ambient outdoor temperature in Aberdeen for years 1950–1955.

during gestation, or around the time of birth. Temperature around the time of conception, gestation, and birth was not associated with the teacher's assessment of the child's behavioural problems (all p values $>.4$).

Discussion

In this study of 12,150 children born in Aberdeen in the North of Scotland, we have found reading ability at age 9 and arithmetic ability at age 11 to vary by season of birth, with lowest scores among those born in the months from September to December and highest scores among those born in the months from February to April for reading ability at age 9 and from January to March for arithmetic ability at age 11. However, these differences were small and with adjustment for age at school entry and age relative to class peers, they attenuated towards the null. The child's perception and understanding of pictorial differences at age 7, verbal reasoning at age 11, and English language skills at age 11 and behavioural problems were not seasonally patterned.

Study strengths and limitations

Strengths of this study are its large size, the availability of data on the child's age at school entry in months, and the ability to link the child's ability and other data to daily temperature data from one weather station located in the city where all births occurred. One weakness is that the different tests performed at each age have not been validated with respect to whether or not they are measuring the same underlying attribute. Indeed, some of the differences in effects may be because the measurements at different ages measure different aspects of cognitive functioning. Nonetheless, this weakness does not alter the main finding here that any seasonal patterning is weak and most probably explained by school entry policy. The results refer to measures of a child's perception and understanding of pictorial differences at age 7, reading ability at age 9, and arithmetic, English, and verbal reasoning at age 11, all measured during the 1960s and therefore may not be applicable to current school children. However, our main conclusion, that any effect is weak, is unlikely to be different for contemporary populations since contemporary populations in industrialized countries would be more able to protect themselves from seasonally patterned exposures such as weather extremes, food availability, and infection. As an extension of this work and other studies in this area, it would be interesting to consider the effect of season of birth on changes in intellectual ability over time. A limitation of this study is the use of measures of different domains of intelligence at each age, which would make such an analysis difficult to interpret.

Season of birth and childhood intelligence

The variation in two out of five of our measures of intelligence by season of birth may be a chance finding or may indicate a mechanism that specifically affects certain domains of intelligence and/or has little detectable effect at younger ages. The attenuation of the effects with adjustment for age at school entry and age relative to peers supports the hypothesis that any variation in childhood ability by season of birth is largely explained by educational policy related to school entry in this population. This conclusion is supported by results from other studies (Goodman, Gledhill, & Ford, 2003).

However, the seasonal patterns that we observed (with lower scores from September to December and highest scores from February to April) are not what we would have predicted based on the admissions policies in place at the time these participants entered school. The participants in this study would have entered school at three (term) times during the year in such a way that, in general, those born between January and March had least primary school education and therefore might have been expected to be the ones with lowest scores, and those born April–August should have had most primary school education and might therefore have been expected to have had the highest scores. It is possible that those who had least time in primary school but most time at home were in fact given extra tuition by their parents. We have no information concerning this but parental occupational social class did not importantly influence the seasonal patterns we observed. Another reason why the seasonal patterns are not as one might expect from the policy operating is that the above quote from the council meeting concerning the admissions policy suggests that it was not strictly administered and that, depending upon class size and parental agreement, some children were allowed to enter school at an earlier age than the policy specified. Our ability to adjust for both age at school entry and age relative to school peers may together capture most of the effect of school entry policy on the apparent season of birth patterning of intelligence. If the season of birth patterning is largely due to age at school entry, then the effect at age 9 (but not at age 7) suggests that how children of different ages interact with the educational system – rather than their innate ability – is important, since the test at age 7 provides an indication of intellectual ability before a large amount of formal education has been provided.

In this study, we have focused on mean scores across the distribution of each measurement and the effect on these of season of birth. Our justification for this is that the results obtained then pertain to all children. However, it is possible that a seasonally patterned exposure during critical periods of childhood development does affect extremes of ability or other brain pathology. For example, the effect of season of birth on 'eminency' demonstrated by Huntington (1938) and the established season of birth patterning of mental health problems, in particular schizophrenia, (Davies *et al.*, 2003) are unlikely to be explained by school entry policy. Thus, our data suggest that, in general, parents need not worry that their child's school performance on intelligence tests will be markedly affected by season of birth patterned exposures. However, we cannot role out the role of seasonally patterned exposures in the aetiology of more extreme brain pathology. Our results do not support a role for ambient outdoor temperature around the time of conception or during intrauterine growth as a mechanism for variations in general population childhood intellectual ability by season of birth.

Whatever the mechanism for the variation in some intelligence measures by month of birth, it is important to note that the magnitudes of the effects are small in our study. Although the adjusted values give some indication of factors that might explain the seasonal patterns, the unadjusted results are the best estimate of the real life effect of any seasonal patterning. Both adjusted and unadjusted differences in reading ability at age 9 and arithmetic ability at age 11 between those born between September and December compared with other times of the year were less than 0.1 of a standard deviation.

In conclusion, we have found weak season of birth effects on some aspects of childhood intelligence, which appear to be explained by differences in age at school entry and/or age relative to peers. Our results do not support the hypothesis that a seasonally patterned exposure such as infections or cold ambient temperature around the time of conception, gestation or birth have important influences on childhood cognition, but we cannot rule out the effect of such an exposure on more severe brain pathology.

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Conflict of interest. None.

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