This study investigated the relation between birth characteristics and numeracy attainment at age 8 years. Using a multilevel approach, the authors analyzed all non-Aboriginal singletons born in Western Australia who attended government schools and participated in a Western Australia–wide numeracy test in grade 3 between 1999 and 2005. Appropriateness of intrauterine growth was expressed as the proportion of optimal growth parameters for gestational duration, infant sex, and maternal height and parity, which was derived from a total population of births without risk factors for growth restriction. After the authors controlled for sociodemographic factors, term birth and proportion of optimal head circumference at birth were associated with higher numeracy scores. Increasing proportion of optimal birth length and being firstborn were associated with relatively higher numeracy scores among children born to mothers residing in the most educationally deprived area. The relative advantage of being born first was also higher for children born to single mothers. In contrast, higher Apgar scores and greater proportion of optimal birth weight were associated with a lower relative advantage for children born to single mothers. In summary, term birth and increased growth in head circumference and length are key birth characteristics associated with higher numeracy scores, especially among disadvantaged children.

Children born preterm or at low birth weight tend to have poorer educational outcomes, including numeracy scores, than children of normal birth weight born at full term (1–4). This disadvantage remains after accounting for family and child characteristics, such as social class at birth, maternal age, parental education, gender, birth order, and breastfeeding duration (5).

Lower educational attainment has also been associated with higher birth order (6–8). However, in large families, the effect of birth order on educational outcomes is U-shaped, with both last- and firstborns having better outcomes (8, 9).

Nevertheless, birth outcomes are not the only determinants. Although children of both teenage mothers and mothers older than 35 years of age are at increased risk of preterm birth and low birth weight (10, 11), educational outcomes tend to increase with increasing maternal age (12), often accounted for by maternal education, family income, and marital status (13–15). Similarly, the educational disadvantage of children from single-parent families (16) has been partially attributed to single mothers having less education, income, and parenting time (17–19). Neighborhood characteristics are also important (20) because their associations with achievement scores are comparable with those of...
family income, maternal education, and living in a household with at least one employed parent (21).

Few studies have examined the effect of individual birth and contextual characteristics on educational outcomes simultaneously. Most were based on small samples and were analyzed without the multilevel approach required to account for similarities between students from the same school (22, 23). They have also investigated associations with birth weight alone rather than appropriateness of intrauterine growth and length of gestation at delivery, which are different in terms of both etiologies and outcomes. Blair et al. (24) have pointed out that birth weight is not an adequate indicator of intrauterine growth, and they have derived formulas for calculating optimal birth weight, birth length, and head circumference that account for gestational age, birth order, maternal height, and infant sex. Appropriateness of intrauterine growth can be expressed as the proportions of optimal birth dimensions achieved, and they have been used previously (25).

Cognitive functioning, intellectual ability, and educational achievement are separate dimensions of neurocognitive development. Numeracy, one key indicator of children’s school performance (2, 26), is related to specific aspects of neurocognitive functioning. Those with inadequate numeracy skills are more likely to leave school early, experience prolonged unemployment, and endure poverty in later life (27).

It is likely that specific perinatal risk factors are associated with specific neurocognitive deficits. The present study therefore focused on numeracy with the aim of investigating the association of birth characteristics, maternal sociodemographic characteristics at birth, and school and neighborhood socioeconomic status (SES) with numeracy attainment at grade 3 in non-Aboriginal singletons. We hypothesized that birth characteristics are more strongly associated with numeracy attainment for children from socially disadvantaged backgrounds. This study was part of a major population record linkage study on developmental pathways in Western Australian children.

MATERIALS AND METHODS

Subjects

Subjects included all non-Aboriginal singletons born in Western Australia between 1990 and 1997 who attended government schools and participated in the annually administered, curriculum-based numeracy test of the Western Australian Literacy and Numeracy Assessment (WALNA) program at grade 3 between 1999 and 2005 (28, 29). Of 203,402 Western Australia births in 1990–1997, 80,118 eligible children were included in the study (table 1).

Sources of data

Three existing databases were used. The WALNA data set was provided by the Western Australia Department of Education and Training. WALNA is a statewide test used by the Australian government for a national comparison of children’s skills across Australia, and it is directly comparable to other Australian statewide assessment programs that monitor children’s progress in literacy and numeracy skills. WALNA was developed in keeping with standards of best psychometric practice, and every year it is evaluated by expert judges for content and construct validity and scrutinized by psychometricians for misfitting items, precision, and bias. The separation index (internal reliability) of the test has been reported to be at least 0.8, thus suggesting a good separation of students. The power of the fit has also continuously been good. The Western Australia Midwives Notification System provided by the Western Australia Department of Health contained information on maternal and infant characteristics for all Western Australia midwife-attended births (99.5% of all Western Australia births) of at least 20 weeks’ gestation or 400 g of weight (30). Neighborhood SES was available from the Australian Bureau of Statistics census (31, 32).

These data sets were linked by the Health Information Linkage Branch at the Western Australia Department of

<table>
<thead>
<tr>
<th>TABLE 1. Data selection for the analysis of numeracy among non-Aboriginal singletons born in Western Australia in 1990–1997 (n = 203,402) who participated in the Western Australian numeracy test between 1999 and 2005</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exclusion criterion</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Stillbirth</td>
</tr>
<tr>
<td>Multiple pregnancy</td>
</tr>
<tr>
<td>No year 3 WALNA* record†</td>
</tr>
<tr>
<td>Nongovernment school</td>
</tr>
<tr>
<td>Aborigional and Torres Strait Islander child</td>
</tr>
<tr>
<td>Aborigional and Torres Strait Islander mother</td>
</tr>
<tr>
<td>Western Australian numeracy assessment score missing</td>
</tr>
<tr>
<td>Socioeconomic indices for areas missing</td>
</tr>
<tr>
<td>School socioeconomic status missing‡</td>
</tr>
<tr>
<td>Gestational age missing</td>
</tr>
<tr>
<td>Apgar score missing</td>
</tr>
<tr>
<td>Mother’s height missing</td>
</tr>
<tr>
<td>Proportion of optimal birth weight &lt;50 or &gt;200</td>
</tr>
<tr>
<td>Proportion of optimal birth length missing or &lt;50</td>
</tr>
<tr>
<td>Proportion of optimal head circumference missing</td>
</tr>
</tbody>
</table>

* WALNA, Western Australian Literacy and Numeracy Assessment.
† Children had no year 3 WALNA record if they were absent during the testing period, they were temporarily/permanently disabled, they moved out of Western Australia, or their Midwives Notification System and WALNA records did not link. The majority of children born in 1990 and 1997 (because of changes in school starting age in 2003) were too old or young to have a year 3 WALNA record between 1999 and 2005.
‡ This information was missing for 22 government schools.
<table>
<thead>
<tr>
<th>Type of predictor</th>
<th>Predictor</th>
<th>Category</th>
</tr>
</thead>
</table>
| Infant characteristics at birth | Birth order | No older siblings alive (firstborn)*
| | | 1 older sibling alive†
| | | 2 or 3 older siblings alive
| | | ≥4 older siblings alive
| | Percentage of optimal birth weight | Centered at 98.3%
| | Percentage of optimal birth length | Centered at 100.5%
| | Percentage of optimal head circumference | Centered at 100.6%
| | Gestational age | 0 for preterm birth (<37 weeks)†
| | | 1 for term birth (≥37 weeks)
| | Apgar score at 5 minutes | 0 for lower (score of <8)†
| | | 1 for higher (score of 8–10)
| Maternal characteristics at birth | Mother's age | <20 years
| | | 20–24 years
| | | 25–29 years†
| | | 30–34 years
| | | ≥35 years
| | Mother's marital status | 0 for married/de facto†
| | | 1 for single/other
| Neighborhood characteristics at birth | SEIFA‡ index of relative socioeconomic disadvantage (quantile) | Lowest (SEIFA <10%)
| | | Low (10% ≥ SEIFA <25%)
| | | Low middle (25% ≥ SEIFA <50%)
| | | High middle (50% ≥ SEIFA <75%)
| | | High (75% ≥ SEIFA <90%)
| | SEIFA index of education and occupation (quantile) | Highest (SEIFA ≥90%)†
| | | Lowest (SEIFA <10%)
| | | Low (10% ≥ SEIFA <25%)
| | | Low middle (25% ≥ SEIFA <50%)
| | | High middle (50% ≥ SEIFA <75%)
| | | High (75% ≥ SEIFA <90%)
| | SEIFA index of economic resources (quantile) | Highest (SEIFA ≥90%)†
| | | Lowest (SEIFA <10%)
| | | Low (10% ≥ SEIFA <25%)
| | | Low middle (25% ≥ SEIFA <50%)
| | | High middle (50% ≥ SEIFA <75%)
| | | High (75% ≥ SEIFA <90%)
| School characteristics at grade 3 | School socioeconomic status | Centered at a score of 101.4
| Control variables | Child’s gender | 0 for boys†
| | | 1 for girls
| | Child’s age | Centered at 98.5 months
| | Language background | 0 for English†
| | | 1 for non-English
| | Mother’s ethnicity | 0 for Caucasian
| | | 1 for others
| | Calendar year of WALNA‡ test | 1999†
| | | 2000
| | | 2001
| | | 2002
| | | 2003
| | | 2004
| | | 2005
| Geographic location of school | Metropolitan†
| | Rural
| | Remote
| | Very remote

* Refers to all births with no older sibling alive (therefore, socially firstborn).
† Reference category.
‡ SEIFA, socioeconomic indices for areas; WALNA, Western Australian Literacy and Numeracy Assessment.
TABLE 3. Summary statistics for continuous variables in the analysis of numeracy among non-Aboriginal singletons born in Western Australia who participated in the Western Australian numeracy test between 1999 and 2005 (n = 80,118)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean (SD*)</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Numeracy score</td>
<td>340.3 (75.2)</td>
<td>–87.0</td>
<td>735.0</td>
</tr>
<tr>
<td>Child’s age in months</td>
<td>98.5 (3.8)</td>
<td>80.0</td>
<td>121.0</td>
</tr>
<tr>
<td>Percentage of optimal birth weight</td>
<td>98.3 (12.2)</td>
<td>50.0</td>
<td>198.0</td>
</tr>
<tr>
<td>Percentage of optimal birth length</td>
<td>100.5 (4.3)</td>
<td>65.0</td>
<td>125.0</td>
</tr>
<tr>
<td>Percentage of optimal head circumference</td>
<td>100.6 (3.9)</td>
<td>73.0</td>
<td>148.0</td>
</tr>
<tr>
<td>School socioeconomic status score</td>
<td>101.4 (7.9)</td>
<td>60.4</td>
<td>125.0</td>
</tr>
</tbody>
</table>

* SD, standard deviation.

FIGURE 1. Distribution of the proportion of optimal birth weight (centered) among non-Aboriginal singletons born in Western Australia who participated in the Western Australian numeracy test between 1999 and 2005.

RESULTS

The study included 80,118 students in 610 schools, whose mean age was 8.2 years and mean numeracy score was 340 (table 3). Centered percentage of optimal birth weight ranged from –48.3 to 99.7, with most between –24.4 and 24.4 (±2 standard deviations from the mean) (figure 1).
There was little difference in mean numeracy scores between non-English-speaking and English-speaking children (table 4). However, girls; children who were born preterm; children who were at least third-born in a birth order of three or more; children who were born to young, single, or Caucasian mothers; or children who had a lower Apgar score (<8) tended to have lower numeracy scores. Mean numeracy attainment was positively associated with all three measures of SES and was higher in metropolitan than non-metropolitan schools.

Of the total variance in numeracy score in the null, multi-level model that did not include any predictors (not presented), 19.2 percent (95 percent confidence interval: 16.8, 21.6) could be attributed to the school level and 80.8 percent (95 percent confidence interval: 80.0, 81.6) to the student level.

Compared with preterm birth, term birth was associated with a 7.83-point increase in numeracy attainment (table 5). Two percent of optimal birth weight interaction terms were significant in the final model, indicating that the effect of percentage of optimal birth weight varied between subgroups of children. For children born to married mothers or to mothers in more educationally privileged areas, a one percentage point increase in percentage of optimal birth weight was associated with a 0.26-point increase in numeracy. The negative squared term indicated that lower and higher percentages of optimal birth weight were associated with an increasingly lower numeracy score than...
Higher percentage of optimal birth weight was associated with increasing numeracy scores. In contrast to the finding associated with higher percentage of optimal birth weight was,

however, reduced among children born to single mothers or to mothers in the most educationally deprived areas. Higher percentage of optimal birth length was associated with increasing numeracy scores. In contrast to the finding associated with higher percentage of optimal birth weight was,

would be expected from a linear association; further increases of more than 2 standard deviations above the optimal proportion of birth weight were associated with a sharp decrease in numeracy scores, but this finding applied to only very few children (figure 2). Any advantage associated with higher percentage of optimal birth weight was,
advantage was higher for children born to mothers in the most educationally disadvantaged areas but was lower for children attending higher-SES schools. For every percentage point increase in percentage of optimal head circumference, children achieved 0.4 points more, irrespective of maternal and neighborhood characteristics. There was also a positive association between Apgar scores and numeracy attainment, except for children born to single mothers.

Birth order was negatively associated with numeracy attainment, with children born fifth or later having the lowest attainment. Statistically significant positive interactions between birth order and marital status or SEIFA suggested that the advantage associated with being firstborn was enhanced for children born to single mothers or to mothers in the most educationally disadvantaged areas.

Numeracy scores increased with higher maternal age, reaching an additional 9 points for children born to mothers older than 35 years of age. School SES was positively associated with numeracy attainment and accounted for the association with geographic location in univariate analysis. However, children whose school SES was lower and higher performed slightly better than would have been expected given a linear trend. Children’s numeracy was positively associated with SEIFA quintiles for education and occupation, which accounted for much of the variation observed with other SEIFA measures. However, being in an area with a SEIFA score below the 10th percentile remained a significant independent, negative predictor of numeracy. The overall fit of the model (table 5) was assessed by calculating explained variance at the school and student levels (37). The final model explained 52 percent of the variability between schools but, despite the large number of predictors in the model, only 16 percent of variability between students.

DISCUSSION

Our results show that birth characteristics are associated with numeracy attainment of children at grade 3 independently of their socioeconomic context. Our finding that term birth was associated with improved numeracy outcome is in line with a meta-analysis by Bhutta et al. (1) and research investigating the relation between extreme prematurity and numeracy attainment at age 8 years (2). The positive association of head growth with numeracy is also consistent with previous studies, which reported a direct link between head circumference at birth and subsequent intelligence quotient and logical reasoning (38, 39). We found that term birth and head growth were associated with numeracy attainment independently of all other characteristics. If these associations are causal, then these results suggest that longer gestation and greater head growth have the potential to benefit all children, irrespective of their background, and that faster skeletal growth (but not faster growth in mass) tends to reduce the disadvantage associated with being born in the most disadvantaged neighborhoods.

Our analysis of birth weight and numeracy differed in three important ways from the study by Jefferis et al. (5). The latter did not differentiate preterm birth from growth restriction, test for interactions between variables, or account for clustering of students within schools. In overcoming these limitations, our results showed a curvilinear association between percentage of optimal birth weight and numeracy attainment, with both lower and higher (up to 2 standard deviations) percentages of optimal birth weight being associated with lower numeracy scores than would be anticipated from a purely linear association, and with additional increases in percentage of optimal birth weight having a negative association with achievement (as shown in figure 2). This difference may be the result of the marked increase in prevalence of maternal obesity since the time of the Jefferis et al. cohort, which has been particularly acute in areas of socioeconomic deprivation (40). High percentage of optimal birth weight may reflect either greater skeletal growth or greater accumulation of adipose tissue, or both.

Apgar scores of > 7 (97 percent of children) were positively associated with numeracy attainment. However, for children born to single mothers, unexpectedly, higher Apgar scores were associated with a lower relative advantage. If this association reflects a causal association with a better condition at birth, then the attainment disparities between children born to single mothers and those born to married mothers were exacerbated by higher Apgar scores. We found a strong, negative association between numeracy attainment and birth order. This finding is consistent with earlier evidence that firstborn children are advantaged in terms of educational achievement (6, 7), but we found no evidence of a U-shaped association between birth order and numeracy attainment, as reported in other studies (8, 9). However, these studies relied on comparisons within families, whereas our comparisons were essentially between families. In addition, we found that the relative advantage associated with being firstborn was greater for those born to single mothers or to mothers residing in the most educationally disadvantaged areas.
In line with previous evidence (20, 21), we have shown that the socioeconomic statuses of school and areas were important predictors of numeracy attainment. We have further shown that SES interacts with birth characteristics in their effect on numeracy. In multivariate analysis, language background and mother’s ethnicity were also important predictors of numeracy. In Australia, a large proportion of non-Caucasian and immigrant mothers are now of Asian origin. Children of these parents have been reported to be more successful in educational testing compared with their peers (41). This difference may stem from the high regard that Asian parents have for educational attainment, although it could also reflect the policies of actively targeting immigration of well-educated and -qualified Asian migrants. Child age was positively associated with numeracy attainment, but higher-powered terms indicate that very young age was associated with higher numeracy scores than would have been expected, whereas some of the oldest children scored worse than expected on the basis of a purely linear association. It is likely that the group of the very young children (less than age 7.5 years) who participated in WALNA systematically differed from their older classmates in their readiness to learn at the start of their schooling.

Our study has several strengths. We considered several birth characteristics simultaneously, analyzed a total population, accounted for the multilevel nature of the data, and considered interactions between maternal, school, and neighborhood characteristics. Because our study was based on administrative data from two Western Australia government departments, we minimized possible selection bias. Our findings highlight the importance of social contexts for a better understanding of the impact of child biologic characteristics on numeracy achievement. In contrast, previous studies were often based on small samples and failed to consider interaction effects or the correlation between students in the same school (2, 4, 6, 7). Because uniform numeracy testing was used across Western Australia beginning in 1999, we have confidence that our comparisons over time are valid.

A limitation of our study was exclusion of the one quarter of children attending nongovernment schools, because permission to access the SES of these schools was denied. Nongovernment schools consist of private schools to which parents pay fees and schools affiliated with religious or educational institutions. Children attending the former are likely to be the most economically advantaged, but those attending the latter are from more socioeconomically mixed environments. Similarly, disadvantaged children may have been overrepresented because of the small number of children absent during the testing week, since they tend to miss school more often. Children were exempt from taking the test if they were intellectually impaired, lacked competency in English when it was not their first language, and in special circumstances. Further exclusions consisted of the small number of Western Australia–born children who moved out of Western Australia and children whose Midwives Notification System records did not link to WALNA data (many of whom would not have been born in Western Australia), all of which apply to only a small number of children and are unlikely to have had an appreciable effect on our findings.

In conclusion, this multilevel study is the first known to investigate the associations between numeracy achievement in primary school children and characteristics of the newborn, mother, school, and neighborhood at birth simultaneously and their interactions. Term birth, faster intrauterine head growth, male gender, and lower birth order were all independently associated with increased numeracy scores. The associations with other birth characteristics varied with maternal and neighborhood characteristics and may either buffer or exacerbate the negative influence of socioeconomic disadvantage on numeracy attainment, but mechanisms underlying these effects require further investigation. Our analysis also suggests that much of the school variation in numeracy outcomes is explained by these early factors; hence, an excessive focus on schools, which ignores the pathways into school, may be limited in its ability to improve numeracy. Future research should also consider other factors likely to affect numeracy at the individual level, such as early stimulation in the home environment, family resources, parenting quality, parental and child mental health and nutrition, and prior numeracy attainment. Our findings have important implications for the future development of evidence-based strategies aimed at improving educational outcomes for all children by integrating both public health approaches and social interventions.

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Conflict of interest: none declared.

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