Research Square

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A large national cohort study exploring the association between small for gestational age birthweight and educational achievement in secondary school

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Abstract

Purpose

Small for gestational age (SGA) birthweight is an important predictor of childhood intelligence, yet longitudinal evidence on its association with school achievement is scarce. We aimed to explore the association between small for gestational age birthweight and educational achievement in secondary school in a national linked data study of New Zealand adolescents.

Methods

This population study included all children born in New Zealand with gestational age, birthweight and sex information available between 1998–2005. This cohort was followed until Jul 31, 2024. Exclusion criteria were children born overseas, multiple births, and children absent from school for more than 6 months in the calendar year they would be expected to sit examinations. SGA was defined using the New Zealand Sex-Specific Population Birthweight Standard. Educational achievement was defined as the highest qualification attained in secondary school.

Results

The analysis included 372,519 children (n = 25,341 [6.8%] small-for-gestational-age [SGA] and n = 347,178 appropriate-for-gestational-age [AGA]). Compared with infants born appropriate for gestational age, in multivariable analysis, SGA children are at an elevated risk of achieving no formal school qualification (aRR 1.15, 95% CI: 1·08 – 1·24) compared to finishing secondary school with the maximum qualification available. This risk was greater for those with severe-SGA birthweight (aRR 1.20, 95% CI: 1·08 – 1·34). There was a statistically significant interaction with preterm birth.

Conclusion

SGA children are significantly less likely to achieve high school qualifications compared to their AGA peers. This risk is largest for those not achieving any formal qualification and increases with the severity of SGA. The interaction with preterm birth suggests SGA is only a risk factor for term-born children. Adjustment for confounders decreases but does not eliminate the effect of SGA birthweight.

What is Known

Few studies have looked at the effect of SGA birthweight on achievement in school.

There exist only two robust studies that conclude SGA birthweight is a risk factor for low educational achievement in secondary school.

What is New

- This is the first study in New Zealand to use administrative data to explore the association between SGA birthweight and educational achievement in secondary school.
- There appears to be a small but statistically significant association between SGA birthweight and education in secondary school. The effect size is small, but the number of children affected is not inconsequential at the population level.

Introduction

Small for gestational age (SGA) is considered a proxy for intrauterine growth restriction (IUGR) and is attributed to infants born in the lowest 10th percentile of birthweight on a national standard adjusted for gestational age, and infant sex [1]. SGA is a heterogeneous group of infants, with only a subset having experienced IUGR. The remaining infants are considered constitutionally small (genetically predisposed to small stature but otherwise healthy). SGA birthweight, along with preterm birth and low birthweight, accounts for most of perinatal and postnatal mortality and morbidity; however, despite recent estimates suggesting that almost 20 million children are born IUGR annually, SGA/IUGR remains a largely under-researched area [2].

Historically, research on SGA birthweight has primarily explored perinatal and neonatal mortality; however, with increased survival of SGA neonates, due to advancements in medical intervention and growth monitoring, there has been a shift towards understanding childhood morbidities associated with SGA birthweight; including studies exploring the onset of renal disease, cardiovascular disease, and diabetes, which find SGA birthweight is an important risk factor [3, 4]. More recently, studies have suggested a potential link between small for gestational age birthweight and cognitive functioning, demonstrated through lower intelligence quotients on a range of developmental tests in childhood, and more sparingly with impaired school performance [5–8].

Despite increasing research into intelligence and educational outcomes for small for gestational age children, results remain contradictory. It is suspected that this is due to a combination of insufficient sample power [9], inconsistent control of confounders [9, 10], differences in the definition of lower intelligence and educational achievement [8, 11], differing birthweight thresholds for identifying small for gestational age [12–14], and the presence of comorbidities such as preterm birth [12, 15].

This research aimed to address some of these weaknesses and gain a deeper understanding of the relationship between SGA birthweight and educational achievement. The primary objective of this analysis is to determine if there is a significant relationship between SGA birthweight and achievement on standardised examinations in New Zealand secondary school. Secondary objectives include analysis of the SGA severity and achievement, as well as assessing a potential interaction between SGA birthweight and preterm birth.

Methods

Study Design

Information was available through the Statistics New Zealand Integrated Data Infrastructure (IDI), a collection of datasets sourced from various governmental and non-governmental organisations that can be linked at the individual level based on unique identifiers. This is a de-identified database, and all information published has undergone rigorous checking to ensure anonymity [16].

Study population

The birth population of interest was from Jan 1, 1998, to Dec 31, 2005. This ensures all children in the cohort have had the opportunity to complete secondary school, with conservative estimates suggesting most children graduate at the age of 18 (e.g. in 2023 for the youngest in the cohort). All singleton live births were considered eligible; multiple births were excluded (n = 14,443). Children missing gestational age, birthweight or infant sex were excluded as it prevented the calculation of birthweight percentiles (n = 6,784); a small proportion of these individuals had erroneous gestational age or birthweight records which were removed. If a participant was out of the country for more than 6 months during the calendar year they would normally be attending secondary school in years of national assessments (ages 16 to 18) or away during the exam period (August through November), they were excluded from the study population (n = 56,688). Children who could not be linked to education records (n = 10,521) were also excluded. The final population was 372,519 (SGA [25,341, (6.8%)]; AGA [347,178]). Children with congenital abnormalities were not identified and thus remained in the study population. These only constitute approximately 4% of the sample population (based on prevalence data from the Plunket National Child Health Study from 1990–1991)[17].

Exposures

Small for gestational age was defined as a birthweight in the lowest 10th percentile on the New Zealand sex-specific birthweight standard [1]. Secondary analysis categorised severe small for gestational age as a birthweight below the 3rd percentile, and moderate SGA was a birthweight between the 3rd and 10th percentile. Gestational age was categorised as very preterm (< 32 weeks' gestation), preterm (32 to < 37 weeks' gestation), and term birth (37 + weeks' gestation) to explore interactions with small for gestational age. For sensitivity analyses, birthweight percentiles were recalculated on the New Zealand Customised Standard [18].

Outcome

The outcome of interest was the highest qualification attained in secondary school (as per the New Zealand Qualification Framework) [19]. Secondary school achievement is measured using certificate

attainment. These certificates are achieved by passing a series of assessments and exams in chosen subjects across the school year. There are three certificates: level one, level two, and level three, attempted sequentially across the last three years of secondary school (ages 16–18). Children in New Zealand are required by law to remain at school until the age of 16; thus, most students will attempt at least their level one certificate. Level two and three certificates are optional; however, a level two certificate is the minimum requirement for entry to tertiary education. University entrance is generally gained concurrently with the level three certificate, and early entry into university (following a level two qualification) requires exemption by individual tertiary providers. Obtaining a qualification is not a requirement for leaving secondary school.

Statistical Analysis

The chi-square test of independence was used to assess differences in the distribution of variables between the small for gestational age and appropriate for gestational age populations. We used a series of log-binomial models to derive the relative risk of achieving the highest level of no qualification, a level one qualification, or a level two qualification compared to a level three qualification in secondary school.

Each model was adjusted for a variety of a priori confounding factors: ethnicity (categorical), deprivation (New Zealand Deprivation Index of 2001 [20], ordinal), parity (categorical), maternal and paternal age at delivery (5-year increments, categorical), maternal and paternal qualification (ordinal, categorical), maternal and paternal death (categorical), length of child's youth their mother or father was on the benefit (ordinal, categorical), length of child's youth their mother or father was in prison (ordinal, categorical), and number of household residents (ordinal, categorical).

Statistical analyses were performed using SAS version 9.4 software (SAS Institute Inc.). A p-value < 0.05 was assessed as defining statistical significance.

Sensitivity Analysis

Small for gestational age was redefined using an updated birthweight standard, the New Zealand Customised Birthweight Standard [18]. This aims to improve the discrimination between constitutionally small infants and those with intrauterine growth restriction. A subgroup analysis of all study participants born in 2003 to 2005 was reanalysed using the same analyses described above. Analysis was restricted to a subset of the original population as the necessary information for customised birthweight centile calculation was not available for the entire study period (i.e., maternal height and weight were not routinely recorded until 2003). The adjusted subgroup analysis did not control for the effects of ethnicity or parity, as these factors were already accounted for in the centile calculation.

Ethical Approval

This project involved data sourced from the Statistics New Zealand Integrated Data Infrastructure (IDI). Access to IDI data for public good research is available researchers by application. The application to access data for this research was approved on 12/04/2024 by the University of Auckland Human

Participants Ethics Committee (UAHPEC27332). The UAHPEC standards are designed to meet high international ethical benchmarks, which align with the principles of the Declaration of Helsinki. Consent to Participate declaration is not applicable in accordance with the legislation governing the Integrated Data Infrastructure.

Results

From Jan 1, 1998, to Dec 31, 2005, 464,049 children were born in New Zealand. A total of 446,512 singleton, live-births were eligible for inclusion. Of these, 6,784 were missing any combination of gestational age, birthweight or sex information. A further 67,200 were either not enrolled in secondary school or were unable to be linked to education records (n = 56,688 moved overseas). Thus, the total number of children included in the final study population was 372,519 (**Figure 1**). Of those identified, 6·8% (n = 25,341) were found to be SGA at birth.

The comparison of baseline characteristics of SGA and AGA infants is included in **Table 1**. The baseline characteristics differed significantly between the SGA and AGA populations. Of particular note is the greater number of SGA children with teenage mothers at the time of birth (7·3% vs 5·1%, $p < 0.001$), teenage fathers at the time of birth (3·1% vs 2·1%, $p < 0.001$), nulliparity (65·7% vs 50·2%, $p < 0.001$), and Māori ethnicity (38·8% vs 30·4%, $p < 0.001$). The average age of participants at the time of data extraction was 22 years 6 months.

Over the study period, 20,943 (5·6%) children did not attain a formal secondary school qualification, 54,204 (14·4%) attained at most a level one qualification, 116,001 (30·9%) attained at most a level two qualification, and 181,374 (49·1%) finished secondary school with the maximum level three qualification. When comparing qualification attainment by SGA status using a log-binomial model, the level of educational achievement differed significantly between small for gestational age and appropriate for gestational age children ($p < 0.001$). After adjusting for confounding, the relative risk of achieving no formal qualification compared to a level three qualification was 1·15 times greater for the SGA group compared to their AGA peers (95% CI, 1·08-1·24). This risk was smaller but remained statistically significant with increasing achievement level. SGA children are at a 1·05 (95% CI 1·01-1·10) times greater risk of only achieving at most a level one qualification and a 1·07 (95% CI 1·02-1·12) times greater risk of only achieving a level two qualification (**Table 2**). The estimated adjusted relative risk of confounding variables is presented in **Supplementary Table 1**.

Severity of SGA birthweight shows larger effect sizes for severe SGA (<3%) than moderate SGA (3-10%). After adjustment for confounding, severe SGA children are at a 1·20 times greater risk of attaining no formal qualification (95% CI 1·08-1·34), a 1·09 times greater risk of attaining at most a level one qualification (95% CI 1·02-1·16) and a 1·07 times greater risk of attaining a level two qualification compared to their AGA peers (95% CI 0·98-1·16). The respective risks for moderate SGA are 1·13 (95% CI, 1·04-1·23), 1·04 (95% CI, 0·99-1·09), and 1·07 times (95% CI, 1·02-1·13) greater than those for AGA children (**Table 3**).

There is a significant interaction between SGA and preterm birth when associated with achievement ($p < 0.0001$). When stratifying by gestational age categories, SGA children born at term are at an elevated risk of attaining a no qualification, a level one qualification or a level two qualification, compared to AGA term children (aRR: 1·14, 95% CI: 1·07, 1·23 [no qualification]; aRR: 1·07, 95% CI: 1·03, 1·11 [level one]; aRR: 1·07, 95% CI: 1·02, 1·12 [level two]). SGA children born preterm are also at an elevated risk of achieving at most a level two qualification compared to their preterm-born AGA peers (aRR 1.12, 95% 1.01, 1.23). There was no statistically significant effect of SGA birthweight in the very preterm group (**Table 4**). The independent effect of being born very preterm has a greater effect on attaining no formal qualification, or a level two qualification (aRR: 1.33, 95% CI: 1.17, 1.52 [no qualification]; aRR: 1.11, 95% CI: 1.01-1.22 [level two]); and a comparable effect of attaining a level one qualification compared to the effect of SGA birthweight (aRR: 1.05, 95% CI: 0.94, 1.17 [level one]). Preterm birth has a marginally smaller independent effect on SGA birthweight across all achievement levels. Only the effect of preterm birth on no formal qualification reaches statistical significance (aRR: 1.08, 95% CI: 1.00, 1.16 [no qualification])(**Figure 2**).

Importantly, the results attained in the primary analysis were closely replicated in the sensitivity analysis of customised SGA and educational attainment (**Supplementary Table 2**) (aRR: 1·16, 95% CI: 1·06, 1·28 [no qualification]; aRR: 1.10 95% CI: 0.98, 1.24 [level one], aRR: 1·03, 95% CI: 1·01, 1·06 [level two]).

Discussion

Principal Findings

We aimed to assess the risk of low educational attainment in secondary school for small for gestational age children, using nationally representative administrative health and education data in New Zealand. We found that SGA birthweight was significantly associated with secondary school achievement. After adjustment for confounding, SGA were at the greatest risk of achieving no formal qualification compared to a level three qualification. The risk of attaining a level one or two qualification compared to a level three qualification was statistically significant, but smaller in effect size. The estimated effects in this paper, while statistically significant, are relatively small in magnitude. Despite this, with approximately 10% of the population born SGA, the finding is important at the population level.

The present study also demonstrates that the severity of SGA birthweight modifies the relationship with education. Children with severe SGA birthweight (< 3%) were at the greatest risk of low attainment. This is consistent with previous studies that find decreasing birthweight percentile is associated with significantly increased risk of low school achievement [13,15]. It is suspected this is the result of an increase in sensitivity for detecting IUGR using a 3rd percentile threshold for SGA, and decreasing the threshold for SGA increases Type II error related to IUGR detection. Research has suggested that growth restriction, rather than constitutional smallness, drives low brain development and subsequent educational underachievement [15].

Stratified analyses of this study cohort revealed that the effects of SGA birthweight are limited to those born at term. There was no difference in the risk of low achievement for SGA children born very preterm or preterm compared to their AGA peers born at a similar gestational age. Furthermore, the independent effect of very preterm birth and preterm birth on educational outcomes is comparable in effect size to that of SGA birthweight. Therefore, while studies have emphasised the relative importance of gestational age, this paper has demonstrated SGA birthweight at term is equally important, particularly as SGA has a higher prevalence in the population. The biological mechanisms for this have not been well established. Studies have suggested that antenatal steroid administration in very preterm infants can improve brain development [21–23]; however, the effect of antenatal steroid administration on long-term neurodevelopmental outcomes has not been demonstrated [22,23].

The association between SGA birthweight and education was still apparent after adjustment for confounding, despite several confounders having a strong association with educational outcomes. For example, the risk of low attainment increases with deprivation at the time of birth, a high number of household residents, young parental age at delivery and parents with no formal qualifications. The estimated effect sizes for these variables are greater than the independent effect of being small for gestational age, indicating that environmental factors drive underachievement to a comparable or greater extent than SGA birthweight.

Interpretation

Many studies have explored the association between small for gestational age birthweight and education; few have used school outcomes as a measure of academic performance. Those that do differ greatly in the specific outcome of interest (e.g. school entry, school grades, baccalaureate attainment) [8,9,13]. Few studies find that SGA children have a greater risk of lower school achievement [8,13]. Those that fail to detect differences are often underpowered due to small sample sizes [9]. Of particular interest is a study by Gustafsson (2023). This study used a national birth register and compulsory schooling data for over two million children. Gustafsson et al found that term-born SGA children were 1·41 times as likely to have a final average grade below the 10^{th} percentile and 1·15 times as likely to have grades between the 10^{th} and 25^{th} percentile compared to AGA children (after adjustment for confounders)[7]. These estimates are similar to those obtained in this study. However, the present study was also able to demonstrate a dose-response relationship between SGA severity and risk of low achievement, as well as an interaction with preterm birth.

The current paper also explored the effect of SGA severity on educational achievement. Decreasing the threshold for defining SGA to the 3^{rd} percentile aims to capture those with the greatest degree of growth restriction and increases the likelihood that low birthweight has a physiological cause. As mentioned previously, this paper found severe-SGA children are at an elevated risk of low attainment compared to those with moderate-SGA birthweight. This has only been demonstrated in one previous study which found an inverse relationship between birthweight percentile and risk of low achievement [13]. Other studies have aimed to capture the effect of IUGR using direct diagnoses such as the ponderal index or

serial ultrasound measurements [8,15,24]. However, only one looked at the effect of IUGR on school achievement (as opposed to intelligence); this study found the risk of IUGR children not achieving their baccalaureate was comparable to the severe-SGA effect of certificate attainment shown in the present study [8].

There are many suspected mechanisms for the association between SGA birthweight and educational achievement. The Barker Hypothesis suggests that an adverse intrauterine environment during critical periods of embryonic and fetal development can permanently program the structure and physiology of the developing fetus [25]. While brain-sparing (a prioritisation of blood flow to the brain) has been shown to protect the brain in times of reduced nutrients, early nutritional insults can limit brain development [26]. Alternatively, the Developmental Origins of Health and Disease paradigm extends this also to consider environmental factors such as maternal stress as a possible cause for poor outcomes. Both could result in epigenetic changes that could manifest as lower cognitive function [27].

Study Strengths and Limitations

The estimates obtained in this paper are representative of the New Zealand population, particularly for births occurring in the late 1990s and early 2000s. Since then, there has been a rapid advancement in prenatal and neonatal care that could alter the observed effect. This change is difficult to estimate, as multiple factors will occur simultaneously. First, improvements in preterm care have decreased the gestational age of viable neonates, inadvertently increasing the size of the intrauterine growth restriction population and those at a greater risk of impaired intelligence. Conversely, mothers are offered more robust fetal growth tracking, allowing for timely intervention for suspected intrauterine growth restriction. Assuming this affects a small proportion of the population, the estimated effects for this paper are robust.

Where most countries quantify secondary school achievement as an individual's performance on a final bursary test, New Zealand has a cumulative approach to secondary school achievement (qualifications are accumulated across several years)[28]. As a result, this paper was able to compare SGA and AGA achievement on certificates attained across three consecutive years. Interestingly, there is evidence that SGA is not only a risk factor for not achieving a formal qualification, but the risk persists with increasing certificate level. This effect is present even though New Zealand school qualifications (National Certificate of Educational Attainment) are personalised to focus on the student's strengths and future aspirations, encouraging achievement.

Many current studies suffer from methodological issues such as a limited sample size and the inability to control for a wide range of confounding factors. This study is sufficiently powered to adjust for numerous confounding effects, explore the attenuation of estimates when comparing small for gestational age severity and the potential interaction between small for gestational age birthweight and preterm birth. This paper also benefited from the wide range of individualised information that can be used for the adjusted analysis, such as maternal and paternal death, incarceration and benefit history, which is not often collected in cohort or case-control studies.

Recall bias is mitigated when using the IDI. Most variables used in this study are recorded by the participant at a certain time (census) or by a governmental organisation at the time of the event (incarceration, death or benefit support). This information is not immune to recording error. Erroneous observations were removed where identifiable, as the sample size was sufficient to risk losing a small number of observations suspected to be incorrect. Long-term outcomes can be assessed in the IDI without fear that those lost to follow-up represent a critical population or that the sample size decrease will impair study power. This makes it possible to explore outcomes that occur well into adulthood. Linkage errors within the IDI need to be considered. Errors can be caused by incorrect linkage between two individuals or missing linkage for the same individual. This can lead to information bias and selection bias, particularly since linkage errors are not evenly distributed across groups of individuals. The Ministry of Education (MOE) dataset has a 1.8% false positive rate. Previous research has indicated that linkage error in MOE data does not appear to have much impact on results [29].

Conclusion

Our results, alongside previous publications, show that those born SGA are significantly less likely to achieve high school qualifications compared to their AGA peers born preterm or term. This risk increases with the severity of SGA. Adjustment for confounders decreases the effect size of SGA birthweight; however, it remains significant in the analysis. This suggests that SGA birthweight is an independent risk factor for educational attainment; however, social and environmental factors also influence academic achievement. While the effect size is small, the number of children affected is not inconsequential. Therefore, improvements in educational standards for these children could have societal effects.

Declarations

Conflicts of Interest

The authors declare no conflicts of interest.

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Author Contributions

All authors contributed to the study conception and design. Data collection and analysis were performed by Alexia Searchfield. The first draft of the manuscript was written by Alexia Searchfield. All authors read and approved the final manuscript

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Tables

Table 1 to 4 are available in the Supplementary Files section.

Figures

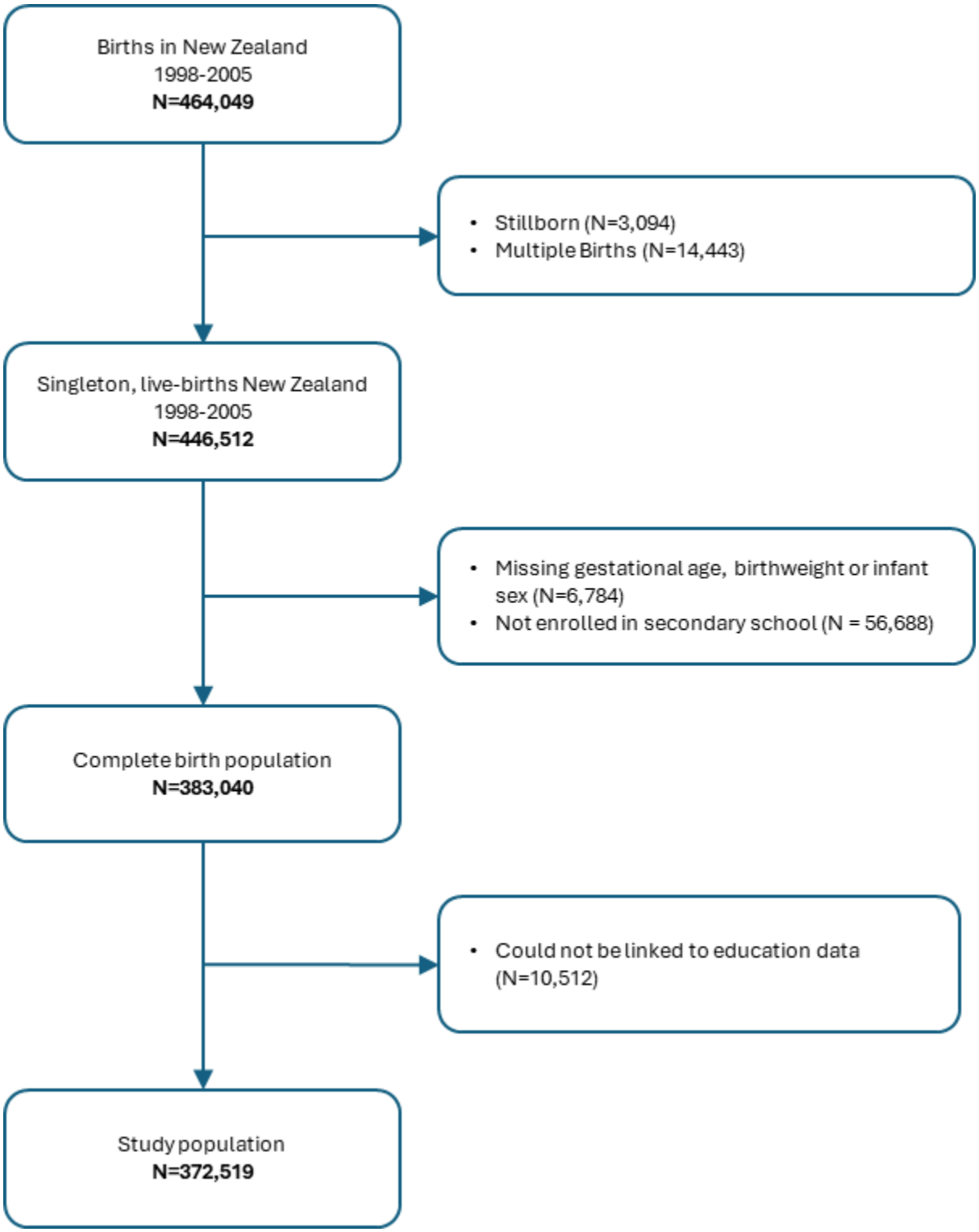


Figure 1

Flow diagram of study population.

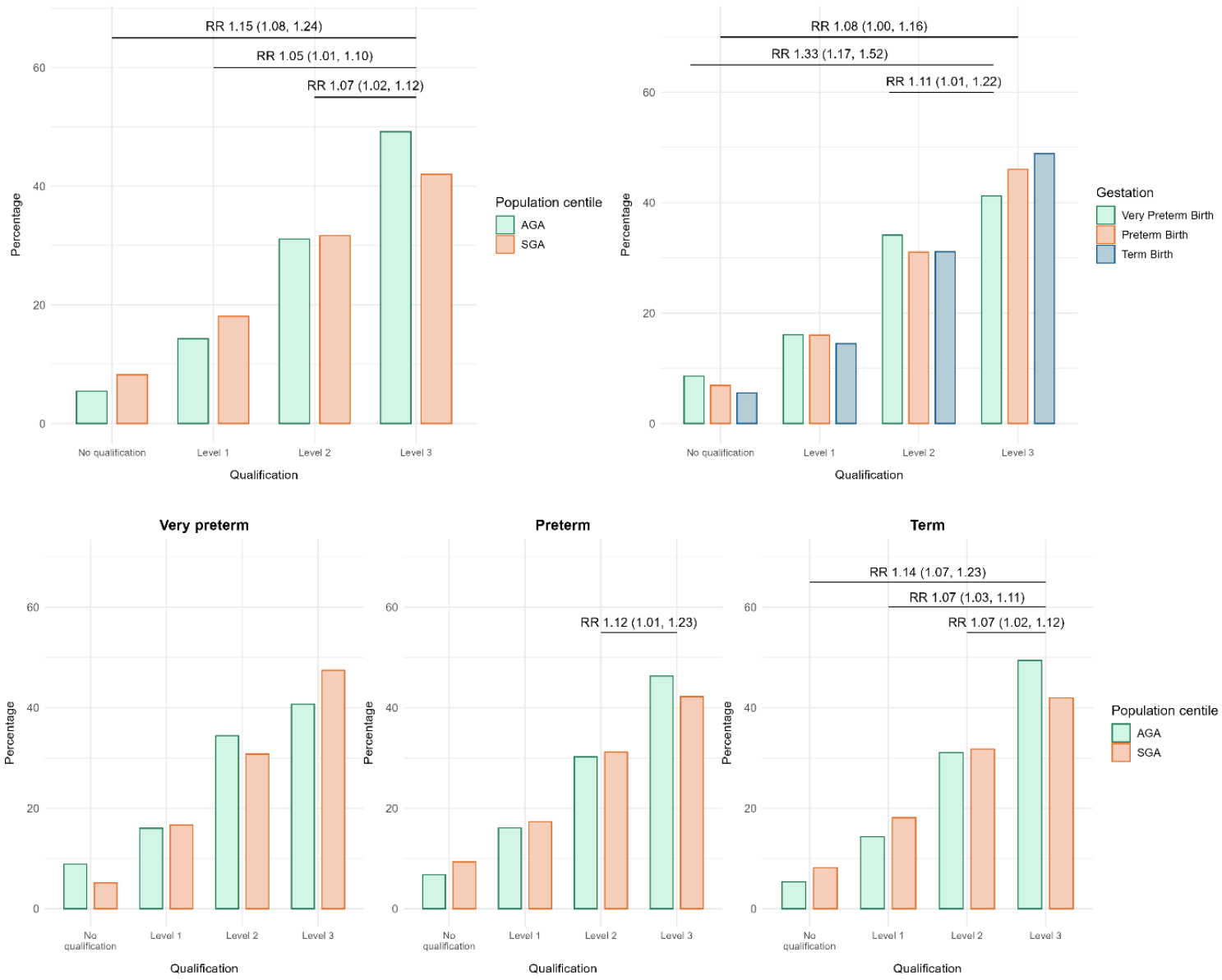


Figure 2

Distribution of qualification attainment by population birthweight percentiles and gestational age.

Supplementary Files

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