Birth Spacing and Health and Socioeconomic Outcomes Across the Life Course: Evidence From the Utah Population Database

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ABSTRACT The relationship between birth interval length and child outcomes has received increased attention in recent years, but few studies have examined off-spring outcomes across the life course in North America. We use data from the Utah Population Database to examine the relationship between birth intervals and short- and long-term outcomes: preterm birth, low birth weight (LBW), infant mortality, college degree attainment, occupational status, and adult mortality. Using linear regression, linear probability models, and survival analysis, we compare results from models with and without sibling comparisons. Children born after a birth interval of 9–12 months have a higher probability of LBW, preterm birth, and infant mortality both with and without sibling comparisons; longer intervals are associated with a lower probability of these outcomes. Short intervals before the birth of the next youngest sibling are also associated with LBW, preterm birth, and infant mortality both with and without sibling comparisons. This pattern raises concerns that the sibling comparison models do not fully adjust for within-family factors predicting both spacing and perinatal outcomes. In sibling comparison analyses considering long-term outcomes, not even the very shortest birth intervals are negatively associated with educational or occupational outcomes or with long-term mortality. These findings suggest that extremely short birth intervals may increase the probability of poor perinatal outcomes but that any such disadvantages disappear over the extended life course.

KEYWORDS Birth spacing • Sibling fixed effects • Perinatal health • Mortality • Socioeconomic attainment

Introduction

Birth timing and spacing are of core interest to demographers, and many researchers have examined whether the spacing between siblings has consequences for a child's health and development. Defining birth spacing as the time in months between two live births, we examine the length of the birth intervals preceding and following the index person. Research has long examined how spacing is related to infant and child mortality in historical contexts and contemporary low- and middle-income countries

(Bean et al. 1992; Conde-Agudelo et al. 2006; Lynch and Greenhouse 1994; Molitoris 2017; Molitoris et al. 2019). Many studies have also examined whether birth spacing is associated with perinatal outcomes, such as low birth weight (LBW), and long-term educational and socioeconomic outcomes in high-income countries (Ball et al. 2014; Barclay and Kolk 2017; Buckles and Munnich 2012; Powell and Steelman 1990). Recent years have seen a resurgence of interest in this topic as researchers began to use instrumental variables and fixed effects to isolate the net effect of birth spacing on child outcomes. The prevailing consensus that short preceding birth intervals have a negative effect on offspring outcomes in high-income countries has been called into question by a series of studies reporting null associations after adjusting for unobserved confounding (e.g., see Ahrens, Hutcheon et al. 2019; Ball et al. 2014; Barclay and Kolk 2017, 2018; Hanley et al. 2017). Some studies have also suggested that short subsequent birth intervals are not associated with poor outcomes either (Barclay and Kolk 2017, 2018).

One challenge in drawing conclusions from the literature on the association between birth intervals and offspring outcomes is uncertainty about the relative importance of the social and public health context, the application of different statistical methods, and the occasional lack of careful distinction between preceding and subsequent birth interval length. For example, there is no association between either the preceding or the subsequent birth interval length and educational outcomes in Sweden (Barclay and Kolk 2017), but short subsequent birth intervals are associated with worse educational outcomes in the United States (Buckles and Munnich 2012). However, the extent to which these different patterns can be explained by considerable differences between the Swedish and American welfare and health care systems or by different research designs remains unclear.

The goal of this study is to examine whether birth intervals are associated with offspring outcomes in the short and long term in the United States when using a population-based data set and applying statistical methods that compare siblings to reduce residual confounding. We use data from the Utah Population Database to examine the association between the birth interval lengths preceding and following the index person and offspring outcomes over the life course. We find that very short preceding birth intervals are strongly associated with the probability of LBW, very LBW, extremely LBW, preterm birth, very preterm birth, extremely preterm birth, and infant mortality. However, very short *subsequent* birth intervals are also associated with all degrees of LBW and preterm birth. This pattern raises concerns that sibling comparison models do not fully adjust for within-family factors predicting both spacing and perinatal outcomes. In further analyses, we find that any potential negative effects of birth spacing disappear over the long term: after accounting for unobserved differences between families, we find no disadvantages in college degree attainment, occupational status, or adult mortality for those born before or after even very short birth intervals.

Previous Research on Birth Spacing and Perinatal Outcomes in High-Income Countries

Until recently, research had consistently shown that especially short and especially long birth intervals were associated with poor perinatal outcomes. A meta-analysis of

67 studies published up to 2006 showed a J-shaped curve in the relationship between preceding birth interval length and perinatal and child health outcomes: interpregnancy intervals (IPIs) shorter than 18 months and those longer than 59 months were significantly associated with poor perinatal outcomes (Conde-Agudelo et al. 2006). On the basis of this evidence, the World Health Organization (WHO) recommended that women avoid pregnancy until at least 24 months after the birth of the previous child (WHO 2007). The American College of Obstetricians and Gynecologists (ACOG) recommended an IPI of at least six months (ACOG 2019). Still, research suggests that many prospective mothers do not recall ever having been advised about IPI length and are unaware of the potential importance of IPIs for pregnancy outcomes (Yang et al. 2019).

In 2014, a study using Australian data and sibling fixed effects to study the relationship between interpregnancy intervals and the probability of poor perinatal outcomes shook the long-held consensus about the negative effects of short preceding birth intervals (Ball et al. 2014). The Ball et al. (2014) study compared siblings born to the same mother to hold constant unobserved factors shared by siblings that are correlated with preceding birth interval length and with perinatal outcomes. They found that the association between short preceding IPIs (0–5 months) and preterm birth, LBW, and being small for gestational age (SGA) declined to almost zero after they adjusted for unobserved heterogeneity at the maternal level. These results suggest that preceding birth interval length may not have a causal effect on the risk of poor perinatal outcomes and that the long-documented association might result from omitted variable bias. Birth intervals are not randomly distributed across families, and children born after short birth intervals might be more likely to be born to mothers with worse health, for example.

This surprising finding triggered several follow-up studies using the same research design. Using data from Canada, Hanley et al. (2017) reached the same conclusions as Ball et al. (2014). Studies using data from Sweden also found that short preceding IPIs were not associated with the risk of LBW or SGA when they used a fixed-effects analysis (Barclay et al. 2020; Class et al. 2017). However, some follow-up studies reached different conclusions, particularly when examining preterm birth. Studies using data from the United States (Lonhart et al. 2019; Mayo et al. 2017; Shachar et al. 2016) found that short preceding IPIs (variously defined as 0–5 months or 0–18 months) are associated with the risk of preterm birth even when comparing siblings born to the same mother, as has research using data from Sweden (Class et al. 2017) and the Netherlands (Koullali et al. 2017); the latter study, though, conditioned on the mother having had a preterm birth at parity 1. A recent review of the evidence for high-income countries concluded that the findings are mixed, requiring further research that carefully considers potential confounding (Ahrens, Nelson et al. 2019).

Previous Research on Birth Spacing and Long-Term Outcomes in High-Income Countries

In comparison to the voluminous literature on birth spacing and perinatal outcomes, there is far less research on the long-term consequences of birth intervals (Steelman et al. 2002). Research using standard regression approaches has consistently found that short birth spacing and higher overall sibling density are associated with worse

long-term outcomes, such as lower test scores or a lower likelihood of making educational transitions (Dandes and Dow 1969; Pfouts 1980; Powell and Steelman 1990, 1993). Recent studies that have attempted to identify the net effect of birth spacing on educational and cognitive outcomes using instrumental variables and sibling fixed effects have, however, come to differing conclusions.

Using data from the National Longitudinal Survey of Youth, Buckles and Munnich (2012) employed miscarriage as an instrument for birth spacing (a miscarriage induces a longer birth interval than would otherwise be expected) and found that a 12-month increase in spacing increased test scores for the older sibling in a sibling pair by approximately 0.17 standard deviations; birth spacing of less than two years negatively affected both math and reading scores. However, they did not find that spacing affected the younger sibling of the pair. Using Swedish population data, Pettersson-Lidbom and Skogman Thoursie (2009) leveraged a 1980 policy reform that encouraged women to have shorter birth intervals to increase the value of their parental leave benefits as an instrument for birth interval length. They found that longer birth intervals were associated with a higher probability of completing the academic track of upper secondary education. A one-month decrease in spacing decreased the probability of this specific educational outcome by 2 percentage points—an enormous effect if extrapolated to longer intervals.

Nguyen (2014: chapter 4), using data on 800 sibling pairs from the National Longitudinal Study of Adolescent to Adult Health (Add Health), found that the length of preceding birth intervals was no longer associated with test scores, educational attainment, or earnings after applying the sibling comparison design. Other studies applying sibling comparisons to Swedish population register data found that neither preceding nor subsequent birth interval length was substantively or significantly associated with high school grade point average, cognitive scores, educational attainment, earnings, unemployment, receiving welfare support, or multiple dimensions of health and mortality (Barclay and Kolk 2017, 2018). A study by Grätz (2018) reported that birth spacing has no effect on cognitive scores or upper secondary attendance (Gymnasium) in Germany after applying sibling fixed effects, but these analyses averaged the preceding and subsequent birth interval lengths, potentially obscuring a negative effect specific to either interval length.

It is certainly possible that birth spacing could affect long-term outcomes in the United States. Research on the link between the length of preceding IPIs and perinatal outcomes suggests an association in the United States (Lonhart et al. 2019; Mayo et al. 2017; Shachar et al. 2016), and a large body of literature shows that preterm birth and LBW are associated with lower test scores and lower educational and socioeconomic attainment (Baranowska-Rataj et al. 2019; Behrman and Rosenzweig 2004; Black et al. 2007; Conley and Bennett 2000; D'Onofrio et al. 2013).

Birth Intervals and Offspring Outcomes: Potential Explanatory Mechanisms

Physiological Explanations

In a detailed review of potential mechanisms linking birth intervals to perinatal and child health outcomes, Conde-Agudelo et al. (2012) reported at least six plausible

physiological mechanisms: maternal nutrient depletion, folate depletion, cervical insufficiency, vertical transmission of infections, suboptimal lactation related to breastfeeding–pregnancy overlap, and physiological regression. Most of these theories point to the risks of short birth intervals, which do not allow the mother enough time to recover from the previous pregnancy. For example, the maternal nutrient depletion and folate depletion hypotheses are based on findings that particularly short intervals do not enable the mother to replenish nutrients to a level optimal for the development of a new fetus (King 2003; Smits and Essed 2001).

As noted earlier, intervals longer than five years have also been linked with worse perinatal outcomes. One potential explanation that has been offered to explain this phenomenon is the role of physiological regression, whereby the physiological adaptations the mother experienced during pregnancy reverse over time to a physiological state more akin to that seen among women who have not experienced pregnancy (Zhu et al. 1999). Research suggests that long IPIs can also increase the relative risk of pregnancy complications, which may also contribute to the increased risk of poor outcomes for infants (Gebremedhin et al. 2020).

If these mechanisms link preceding birth interval length to the probability of being born premature or with LBW, they could also plausibly link the preceding birth intervals and long-term outcomes. Several studies have shown that LBW and preterm birth are associated with long-term status attainment (Baranowska-Rataj et al. 2019; Behrman and Rosenzweig 2004; Black et al. 2007; Conley and Bennett 2000; D'Onofrio et al. 2013). A plausible mechanism for this link is that children born extremely preterm (i.e., at a gestational age of <28 weeks) miss a crucial *in utero* development stage that contributes to the development of brain matter. More specifically, between week 29 of gestation and full term, gray matter increases threefold, and white matter also increases substantially. These differences in neurodevelopment by gestational age at birth have been empirically linked to neuromotor and cognitive performance, providing a compelling explanation for why children born extremely preterm have lower test scores and worse educational performance (Keunen et al. 2016; Kinney et al. 1988; Kuban et al. 1999; Nosarti et al. 2002).

Social and Environmental Explanations

Social and environmental factors may be important for both the association between birth intervals and poor perinatal outcomes and any potential long-term effects of birth spacing. Closely spaced siblings, and the average spacing in the sibling group as a whole, may affect access to parental resources, time, and investment (Blake 1989). On average, infants and young children could reasonably expect to receive more parental attention in the absence of another newly born sibling. Given empirical evidence regarding the importance of early-life investments for long-term development trajectories, any birth spacing pattern that reduces sibling competition may be beneficial for long-term outcomes (Cunha et al. 2006; Heckman 2006).

The spacing of siblings in the household has also been linked to the degree of children's intellectual stimulation (Zajonc 1976). This finding is consistent with the *confluence hypothesis*, which argues that a child's intellectual development is linked to the degree of stimulation experienced in the household and that the average degree

of stimulation experienced is strongly linked to the intellectual maturity of the other members of the household (Zajonc and Markus 1975). Shorter birth intervals would therefore mean more interactions at an early age with relatively younger siblings, who would be less intellectually stimulating than parents and older siblings.

Spacing between siblings may also affect infection transmission. Research suggests that the younger sibling in a sibling dyad with a birth interval of approximately two years is particularly likely to be infected by diseases brought into the home environment by the older sibling of the pair (Conde-Agudelo et al. 2012). Although most of the infections transmitted between children in high-income countries today are rhinovirus variants with negligible long-term health or development consequences (Peltola et al. 2008), it is possible that some infectious diseases in early twentieth-century Utah may have been more serious. For example, the United States experienced regular epidemics of poliomyelitis from the beginning of the twentieth century until a vaccine was developed in the 1950s (Paul 1971). However, to the extent that infectious diseases today are mild, disease transmission may improve immune system development and performance—a theory dubbed the *hygiene hypothesis* (Strachan 1989).

Selection Processes

Despite numerous plausible mechanisms linking birth spacing to short- and long-term offspring outcomes, the empirical evidence suggests that birth spacing is not randomly distributed across families (Gemmill and Lindberg 2013). Data from the United States from 2006 to 2010 show that births following interpregnancy intervals of 18 or fewer months were most common among relatively disadvantaged and relatively advantaged mothers: for example, IPIs shorter than 18 months were most common among teenage mothers, mothers aged 30 or older, individuals with less than a high school diploma, and individuals with a college degree (Gemmill and Lindberg 2013). However, births following short intervals were reported as intended by more-advantaged mothers and were reported as being mistimed or unwanted among less-advantaged mothers (Gemmill and Lindberg 2013). More generally, socioeconomic variation in household resources that affects nutrition or access to health care could affect birth spacing as well as perinatal health outcomes.

To reduce omitted variable bias, we estimate sibling fixed-effects models to examine the relationship between birth spacing and the outcomes we study. These models hold constant all factors that siblings share and are therefore a powerful tool for addressing selection and confounding. However, these models are not without limitations. For example, these sibling comparison models do not implicitly adjust for within-family factors that vary between siblings. Nor do they address sibling spillover effects (Black et al. 2021; Nicoletti and Rabe 2019) or parental behavior that may compensate for differences between siblings (Behrman et al. 1982) or exacerbate such differences (Grätz and Torche 2016). Furthermore, estimates from sibling models may be biased if the outcome for one sibling influences the exposure for another sibling (Kravdal 2020; Sjölander et al. 2016)—for example, if one child's LBW influences the following birth interval length or even the probability of having another child. Nevertheless, these models remain a powerful tool for research and may help identify the net effect of birth spacing on offspring outcomes. As a kind

of placebo analysis to check for the presence of within-family endogeneity in spacing that is not absorbed by the fixed effects, we also estimate models to check for an association between the subsequent birth interval length and the probability of LBW and preterm birth.

Data and Methods

Data

In this study, we use the Utah Population Database (UPDB) to examine the relationship between birth intervals and preterm birth, LBW, infant mortality, college degree attainment, occupational status, and adult mortality. The UPDB at the Huntsman Cancer Institute at the University of Utah is a remarkable source of in-depth information that supports research on genetics, epidemiology, demography, and public health (Smith and Mineau 2021). The central component of the UPDB is an extensive set of Utah family histories in which family members are linked to demographic and medical information. Records are linked into family pedigrees spanning many generations based on genealogies from the Genealogical Society of Utah as well as from Utah state vital records. The UPDB includes diagnostic records about cancer, cause of death, and medical details associated with births.

We use data on cohorts born in 1947–2019 to study how the birth interval length both preceding and following the index person is associated with the probability of LBW, preterm birth, and infant mortality. Our analyses of college degree attainment and occupational status are based on cohorts born in 1950–1990. Our analyses of adult mortality are based on cohorts born in 1900–1949; we therefore observe individuals up to at least age 70 in our youngest birth cohort. The measure for the birth interval used in this study is the birth-to-birth interval length: the period (in months) from one live birth to another. We group birth interval length into 10 categories (9–12, 13–18, 19–24, . . . , 55–60, >60 months). The reference category for the preceding and subsequent birth interval is 25–30 months. The 1900–2019 distribution of birth intervals for Utah is shown in Figure 1.

Our analysis is based on the population of sibling groups with at least three children. The reason that we focus on such groups is that the sibling fixed-effects models that we employ, described in greater detail below, exploit variance within the sibling group to generate the estimates. Thus, we need to observe at least two birth intervals within a sibling group to be able to estimate the relationship between birth interval length and the outcomes that we examine (Hutcheon and Harper 2019). To obtain the preceding birth interval length, we also need to observe at least two sets of sibling pairs with adjacent birth orders in each sibling group. That is, to calculate the preceding or subsequent birth interval length, we need at least two children for whom we can observe the birth timing for the index child and the adjacent sibling. We omit families with plural births, such as twins.

The proportion of children in two-child families varies between each of the birth cohorts we examine for each outcome variable. After we exclude only-children, the percentage of children in two-child families over the full birth cohort span (1900–2019) is 26.6%, compared with 14.0%, 29.6%, and 23.6% in the 1900–1949,
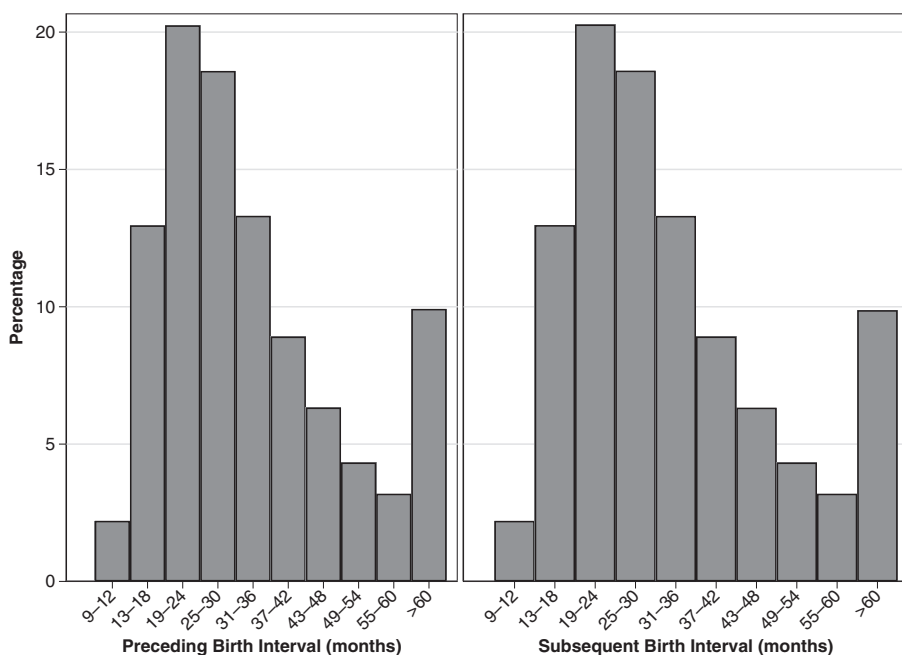
Fig. 1 Distribution of the length of preceding and subsequent birth intervals (in months) in Utah, 1900–2019

1947–2019, and 1950–1990 cohorts, respectively. However, the percentage of the total number of observable birth intervals that are excluded when we omit two-child families is smaller than the number of observations that are excluded because two-child sibling groups contribute only one birth interval to the total universe of potentially observable birth intervals, whereas three-child sibling groups contribute two intervals each, four-child sibling groups contribute three intervals each, and so on. When dropping two-child families, we retain 80.7% of observable birth intervals over the full birth cohort span (1900–2019) and 90.8%, 78.0%, and 83.1% of observable birth intervals from the 1900–1949, 1947–2019, and 1950–1990 cohorts, respectively.

Outcome Variables

We follow the standard definitions for categorizing *LBW*: infants with a birth weight of less than 2,500 grams, 1,500 grams, and 1,000 grams are classified as being born with LBW, very LBW, and extremely LBW, respectively. Following standard practice, we categorize *preterm births* as those occurring before 37 weeks of gestation; births before 32 weeks of gestation are classified as *very preterm*, and births before 27 weeks of gestation are classified as *extremely preterm*. *Infant mortality* is defined as death in the first 12 months of life.

Our measures of *college degree attainment* and *occupational status* are drawn from census data, birth certificates, marriage certificates, and divorce certificates. The age at measurement of educational and socioeconomic variables varies across individuals depending on the data source. We use the most recent measure of college

degree attainment and occupational status available; in our regression analyses, we adjust for the age at which the measure was recorded. The measure of occupational status is based on a transformation of the occupational data to the Nam-Powers-Boyd Occupational Status Score (Nam and Boyd 2004; Nam and Powers 1968). This score is a measure of occupational prestige that ranges from 1 to 100. Occupations that rank at the top of the scale include physicians, surgeons, lawyers, and judges (all with scores of 100); occupations at the bottom of the scale include dishwashers (1) and housekeeping cleaners (6). Some additional examples may assist the interpretation of the results: hairdressers have a score of 27; bus drivers, 32; preschool teachers, 50; mail carriers, 63; firefighters, 76; sociologists, 82; and civil engineers, 93.

To study *adult mortality*, we examine cohorts born in 1900–1949, with follow-up to 2019. Data on mortality are drawn from genealogical records as well as Social Security–derived death certificates. Thus, we can observe deaths occurring in the United States even if they occur outside of Utah.

Covariates

We include controls for birth order as both the confluence hypothesis and the resource dilution hypothesis predict independent effects of birth order and birth spacing, and previous research has indicated that birth order is related to the probability of LBW and preterm birth (Kramer 1987; Shah 2010). Birth interval length is also likely to be associated with maternal age, and maternal age is associated with perinatal outcomes and infant mortality (Andersen et al. 2000; Finlay et al. 2011). We adjust for maternal age using five-year categories. Given the well-known secular trends in infant mortality rates and the incidence of LBW and preterm birth, we adjust our analyses for birth year using individual-year dummy variables. In addition, we adjust for offspring sex. In our analyses of college degree attainment and occupational status, we also adjust for the ages at which those measures were assessed.

Statistical Analyses

Perinatal, Educational, and Occupational Outcomes

To study the relationship between birth intervals and the outcomes LBW, preterm birth, infant mortality, college degree attainment, and occupational status, we use linear regression and linear regression with sibling fixed effects in the form of linear probability models. Sibling fixed effects implicitly adjust for all factors that remain constant within the sibling group—in this case, the size of the sibling group and, to the extent that they remain constant, parental resources and family characteristics.

For each outcome—LBW, very LBW, extremely LBW, preterm birth, very preterm birth, extremely preterm birth, infant mortality, college degree attainment, and occupational status—we estimate four models. Note that for LBW and preterm birth, the analyses by the subsequent birth interval length are a type of placebo analysis. For each outcome, we estimate one model with sibling fixed effects and one without for both the preceding and the subsequent birth interval:

$$y_i = \beta_1 BI_i + \beta_2 Sex_i + \beta_3 BirthOrder_i + \beta_4 Size_i + \beta_5 MatAge_i + \beta_6 BirthYear_i + \alpha + \varepsilon_i \quad (1)$$

$$y_{ij} = \beta_1 BI_{ij} + \beta_2 Sex_{ij} + \beta_3 BirthOrder_{ij} + \beta_4 MatAge_{ij} + \beta_5 BirthYear_{ij} + \alpha_j + \varepsilon_{ij}, \quad (2)$$

where y_{ij} is the outcome for individual i in sibling group j on preterm birth and LBW. In Model 1, we use a regular linear regression (i.e., no sibling fixed effects) to examine the relationship between the preceding birth interval length (BI_i) and the outcome, and control for biological sex, birth order (2, 3, . . . , 10+), sibling group size (3, 4, . . . , 10+), maternal age (15–19, 20–24, . . . , 40–44, 45+), and birth year. In our analyses of college degree attainment and occupational status attainment, we also adjust for the age at which those measures were assessed using discrete age dummy variables (15, 16, 17, . . . , 69, 70). BI_i enters the model as a series of 10 dummy variables based on six-month categories for the preceding birth interval length. In Model 1, our analysis population is second- and later-born children in sibling groups with at least three children. We exclude firstborns because they have no value for the preceding interval length. In Model 2, we introduce the sibling fixed effect (α_j) and remove the control for sibling group size because it is adjusted for in the fixed-effects approach. We use the same analysis sample for Model 2 as in Model 1.

We estimate two further models that parallel Models 1 and 2, but replace the preceding birth interval length with a variable for the subsequent interval length. In these models we include firstborns, but we exclude last-born children because they have no value for the subsequent interval length.

For the outcomes LBW and preterm birth, we also examine whether the association between birth intervals and the perinatal outcomes we study varies by birth cohort:

$$y_i = \beta_1 Cohort \times BI_i + \beta_2 Sex_i + \beta_3 BirthOrder_i + \beta_4 Size_i + \beta_5 MatAge_i$$
$$+ \beta_6 BirthYear_i + \alpha + \varepsilon_i \quad (3)$$

$$y_{ij} = \beta_1 Cohort \times BI_{ij} + \beta_2 Sex_{ij} + \beta_3 BirthOrder_{ij} + \beta_4 MatAge_{ij} + \beta_5 BirthYear_{ij}$$
$$+ \alpha_j + \varepsilon_{ij}, \quad (4)$$

where *Cohort* refers to birth cohort, grouped as 1947–1959, 1960–1969, 1970–1979, 1980–1989, 1990–1999, 2000–2009, and 2010–2019. In these models, we also include a continuous term for birth year to adjust for any linear effect of birth year within the broader cohort groups. We estimate parallel models for the subsequent birth interval length.

Adult Mortality

To study mortality, we conduct a survival analysis using Cox proportional hazard regressions (Cox 1972). The proportional hazards model is expressed as follows:

$$h(t \mid X_1, \ldots, X_k) = h_0(t) exp\left(\sum_{j=1}^{k} \beta_j X_j(t)\right), \quad (5)$$

where $h(t \mid X_1, \ldots, X_k)$ is the hazard rate for individuals with characteristics $X_1, \ldots, X_k$ at time t; $h_0(t)$ is the baseline hazard at time t; and $\beta_j, j = 1, \ldots, k$, are the estimated coefficients. Because the failure event in our analysis is the individual's

death, the baseline hazard of our model, $h_0(t)$, is age. Individuals are censored at loss to follow-up or in 2019, whichever comes first. To estimate a sibling comparison model, we use stratified Cox models (Allison 2009), stratified by the shared sibling group ID. The stratified Cox model of the hazard for an individual from stratum s takes the following form:

$$h_s(t \mid X_1, \ldots, X_k) = h_{0s}(t) exp\left(\sum_{j=1}^{k} \beta_j X_j(t)\right), \tag{6}$$

where $h_{0s}(t)$ is the baseline hazard for stratum s, $s = 1, \ldots, S$. Each stratum, s, is a sibling group. In the standard Cox proportional hazard regression, the baseline hazard h_0 is common to all individuals in the analysis. In the stratified Cox model (Eq. (6)), we allow the baseline hazard to differ between strata drawing on the assumption that unobserved factors particular to each sibling group may confound the relationship between birth intervals and adult mortality (Allison 2009: chapter 5). As with the fixed-effects approach applied to linear regression, these stratified Cox models adjust for all time-invariant factors that siblings share. We estimate the following models:

$$\log h(t) = \beta_1 BI_i + \beta_2 Sex_i + \beta_3 BirthOrder_i + \beta_4 Size_i + \beta_5 MatAge_i \\ + \beta_6 BirthYear_i + \alpha + \varepsilon_i \tag{7}$$

$$\log h(t) = \beta_1 BI_{ij} + \beta_2 Sex_{ij} + \beta_3 BirthOrder_{ij} + \beta_4 MatAge_{ij} \\ + \beta_5 BirthYear_{ij} + \alpha_j, \tag{8}$$

where $\log h(t)$ is the log hazard of mortality, α_j is the fixed effect for sibling group j, and the index ij refers to the individual i in sibling group j. As with the linear regression analyses, BI_i is included in the model as a series of 10 dummy variables based on six-month categories for the preceding birth interval length. In analyses based on Eq. (7), our analysis population is second- and later-born children in sibling groups with at least three children; we exclude firstborns because they have no value for the preceding interval length. In Eq. (8), we introduce the sibling fixed effect α_j and remove the control for sibling group size, which is implicitly adjusted for. We use the same analysis sample for models with and without the sibling fixed effect. We estimate parallel models in which we replace the preceding birth interval length with a variable for the subsequent birth interval length, exclude last-born children from the analysis sample, and include firstborn children.

Results

Descriptive Statistics

Table 1 shows summary statistics by categories of the preceding and subsequent birth interval length for each outcome we study. Further detailed descriptive statistics for each outcome and all covariates can be found in Tables S1–S4 (see online appendix). Note that the birth cohorts and sample sizes vary across outcomes.

Table 1 Summary statistics: Length of the preceding and subsequent birth intervals in relation to LBW (birth cohorts 1947–2019), preterm birth (birth cohorts 1947–2019), infant mortality (birth cohorts 1947–2019), college degree (birth cohorts 1950–1990), occupational status (birth cohorts 1950–1990), and mortality (birth cohorts 1900–1949) among men and women born in Utah

	Birth Interval Length (months)										
	9–12	13–18	19–24	25–30	31–36	37–42	43–48	49–54	55–60	>60	All
Preceding Birth Interval											
LBW (mean)	.113	.048	.034	.031	.030	.033	.033	.036	.037	.049	.038
Very LBW (mean)	.018	.005	.003	.003	.003	.003	.003	.004	.004	.005	.004
Extremely LBW (mean)	.007	.002	.002	.001	.001	.001	.001	.002	.002	.002	.002
Preterm (mean)	.139	.065	.052	.048	.048	.049	.050	.051	.053	.062	.055
Very preterm (mean)	.028	.008	.005	.004	.004	.004	.004	.005	.006	.007	.006
Extremely preterm (mean)	.009	.003	.002	.002	.001	.001	.001	.002	.002	.002	.002
Infant mortality (mean)	.0288	.0126	.0078	.0067	.0068	.0067	.0073	.0074	.0074	.0092	.0085
College degree (mean)	.25	.31	.35	.35	.35	.34	.34	.33	.33	.31	.33
Occupational status (mean)	53.10	55.09	55.97	55.96	56.21	56.20	56.17	56.43	56.42	56.02	55.82
Number of deaths	2,401	20,614	39,363	35,959	21,507	13,570	9,467	6,625	4,974	15,535	170,015
Mortality rate (10^{-4})	7.70	8.27	9.26	9.58	9.04	8.52	8.15	7.90	7.63	7.24	8.68
Subsequent Birth Interval											
LBW (mean)	.096	.049	.037	.035	.034	.035	.034	.035	.038	.041	.039
Very LBW (mean)	.021	.007	.004	.003	.003	.003	.003	.003	.004	.004	.004
Extremely LBW (mean)	.011	.003	.002	.001	.001	.001	.001	.001	.001	.001	.002
Preterm (mean)	.105	.062	.050	.048	.048	.050	.049	.051	.052	.052	.052
Very preterm (mean)	.026	.009	.005	.005	.004	.005	.005	.005	.005	.006	.006
Extremely preterm (mean)	.011	.003	.002	.001	.001	.001	.001	.001	.001	.001	.002
Infant mortality (mean)	.0504	.0220	.0098	.0058	.0041	.0043	.0036	.0040	.0045	.0048	.0091
College degree (mean)	.26	.32	.36	.37	.38	.37	.36	.35	.33	.31	.35
Occupational status (mean)	53.69	55.74	56.76	57.01	57.05	56.87	56.47	56.61	56.58	55.66	56.44
Number of deaths	1,691	19,176	39,924	36,316	21,926	14,226	10,184	7,468	5,702	20,282	176,895
Mortality rate (10^{-4})	6.42	7.96	9.22	9.48	8.75	8.27	7.82	7.80	7.54	7.33	8.49

In both of our analytic samples (one for studying the preceding interval length and one for the subsequent birth interval), approximately 4% of all births were LBW, 0.4% were very LBW, and 0.2% were extremely LBW. In the preceding birth interval sample, 5.5% were preterm; in the subsequent birth interval sample, 5.2% were preterm. Approximately 0.6% and 0.2% were born very preterm or extremely preterm, respectively, in both samples. Approximately 0.9% of children died in the first year of life in both samples. Across these seven outcomes, the recurring pattern is that children born before or after birth intervals less than 19 months or more than 60 months have the poorest outcomes, but the pattern is clearest for children born before or after intervals of 9–12 months. For example, among children born after intervals of 9–12 months, the percentages born with LBW, very LBW, and extremely LBW were 11.3%, 1.8%, and 0.7%, respectively; these percentages are much higher than the baseline level. The percentages born preterm, very preterm, or extremely preterm after intervals of 9–12 months were 13.9%, 2.8%, and 0.9%, respectively. Poor outcomes are also more common for children whose next youngest sibling was born 9–18 months after them.

A similar pattern prevails for two of the later-life outcomes we examine. First, the percentage who obtained a college degree is lowest among those born after intervals of 9–12 months—at approximately 25%, in contrast to the baseline mean of approximately 34%. Those born before or after intervals of 13–18 months or >60 months are also underrepresented among college graduates. Second, mean occupational status is lower among those born before or after the shortest birth intervals.

Finally, the descriptive statistics from the mortality analysis show that unconditional mortality rates in our sample are actually highest among those born before or after birth intervals of 25–30 months, and they are lowest among those born after intervals of less than 13 months or more than 55 months. The bimodal pattern in the mortality data is therefore distinctive from the patterns observed in the other sample groups.

Low Birth Weight

Figure 2 shows the results from analyses examining the relationship between the preceding and subsequent birth interval length and the probability of LBW, with and without sibling fixed effects and pooling across all birth cohorts. Detailed results are shown in Tables S5 and S6 (online appendix).

The left panel in Figure 2 shows the results of analyses of the preceding interval length. The shortest preceding birth intervals are associated with a higher probability of LBW in models both with and without sibling fixed effects. In the within-family model, children born after a birth interval of 9–12 months are estimated to have a .051 higher probability of LBW relative to children born after a birth interval of 25–30 months. Given that the baseline probability of LBW in the analytic sample across these cohorts is .038, the relative probability of LBW is more than twice as high for children born after an interval of only 9–12 months ((.051 + .038) / .038 = 2.34). Intervals of 13–18 months are associated with a much smaller elevated probability, at just under .01 higher than the reference category—approximately 26% higher than the baseline. Intervals of 19–36 months lead to very similar outcomes. Where the results from the models with and without sibling fixed effects clearly diverge is for children
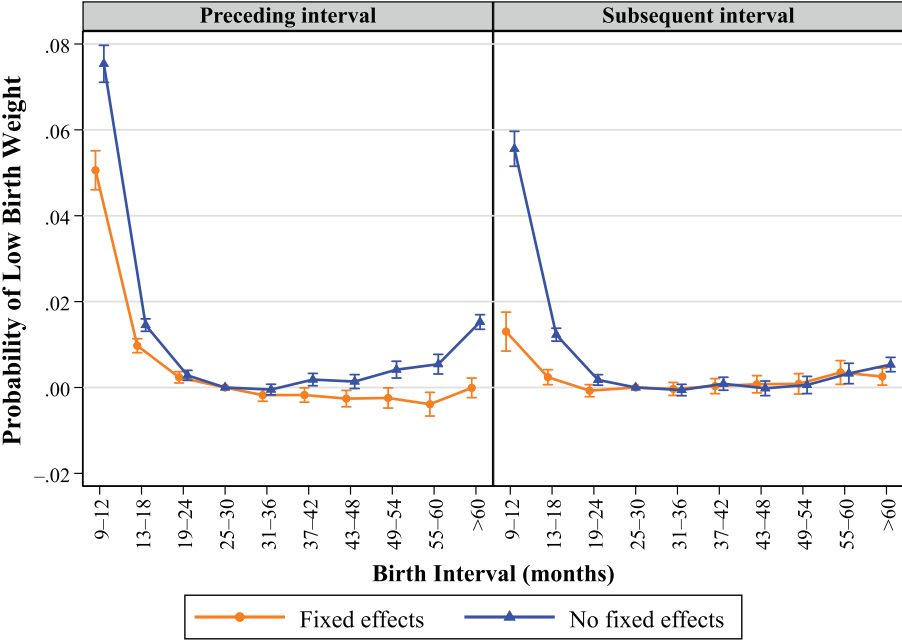
Fig. 2 The relationship between the length of the preceding and subsequent birth intervals and the probability of LBW in sibling groups with at least three children born in Utah in 1947–2019. Results are from linear probability models with and without sibling fixed effects.

born after intervals longer than 37 months: in the model without sibling fixed effects, longer intervals are associated with an increased probability of LBW, whereas the within-family comparisons indicate that longer intervals up to 60 months are associated with a lower probability of LBW.

The right panel of Figure 2 shows the results from analyses examining the relationship between the subsequent interval length and the probability of LBW. These placebo analyses show that even in the sibling comparison analysis, the subsequent birth interval length is associated with an increased probability of LBW when the interval is 9–12 or 13–18 months. Because of the implied reverse causality, this pattern should not exist. Although the magnitude of the association is much smaller in the right panel, this pattern raises concerns that the sibling comparison models do not fully adjust for within-family factors predicting both spacing and perinatal outcomes.

Figures S1 to S6 of the online appendix display results for the association between the preceding and subsequent interval length and both very LBW and extremely LBW. These results differ by birth cohort. The pooled results for very LBW and extremely LBW are qualitatively similar to those presented in the main text for all LBW births. The results from the models interacting birth intervals by birth cohort show that birth intervals of only 9–12 months are associated with a substantially higher probability of LBW regardless of birth cohort, and few patterns clearly diverge from those shown in the pooled analyses. Note that the higher probability of LBW observed in the results from models without sibling fixed effects is perhaps most evident from 2000 onward.
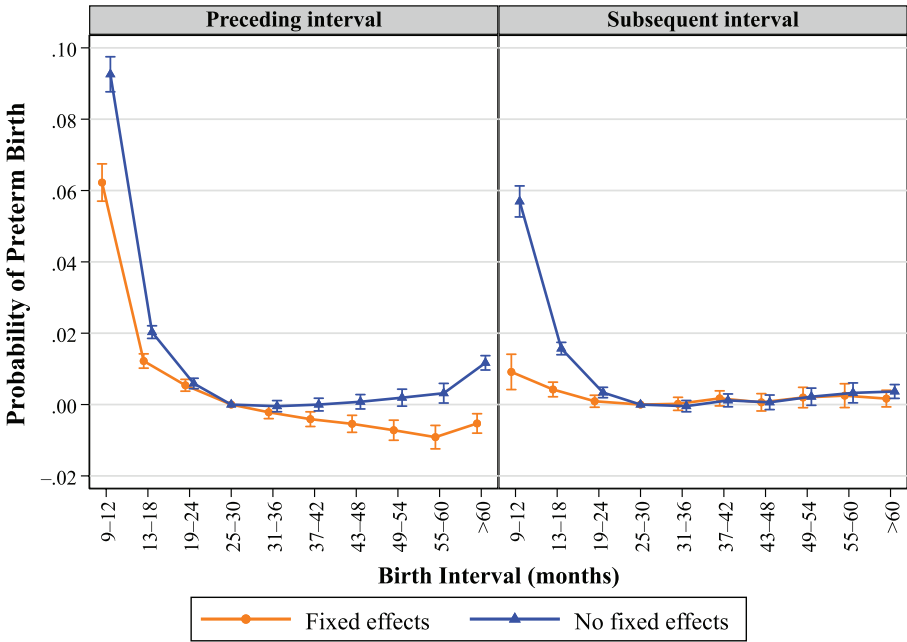
Fig. 3 The relationship between the length of the preceding and subsequent birth intervals and the probability of preterm birth in sibling groups with at least three children born in Utah in 1947–2019. Results are from linear probability models with and without sibling fixed effects.

Preterm Birth

Figure 3 shows the results from four models examining the relationship between birth intervals and the probability of preterm birth. Detailed regression output can be seen in Tables S7 and S8 (online appendix). The results in the left panel show that preceding birth intervals of 9–12 months are associated with a substantially higher probability of preterm birth, estimated as .062 in the sibling fixed-effects analysis and .093 in the model without sibling fixed effects. The baseline probability of preterm birth across these cohorts is .055. Children born after an interval of 13–18 months have an elevated probability of preterm birth, at .012 in the within-family comparison and .020 in the model without sibling fixed effects. As in the results for LBW, longer birth intervals are associated with a lower probability of preterm birth in the sibling comparison analysis. The right panel again shows that very short subsequent birth intervals are associated with an increased probability of preterm birth, although the magnitude of the association is much smaller than that in the left panel.

Additional analyses of very preterm birth, extremely preterm birth, and by birth cohort for all degrees of prematurity are shown in Figures S7 to S12 (online appendix). The qualitative patterns in the results for very and extremely preterm birth are similar to those seen for all preterm births, including the pattern by subsequent birth interval length. The results from the analyses by cohort show that the protective effect of longer preceding birth intervals is evident across all birth cohorts in the within-family comparisons.
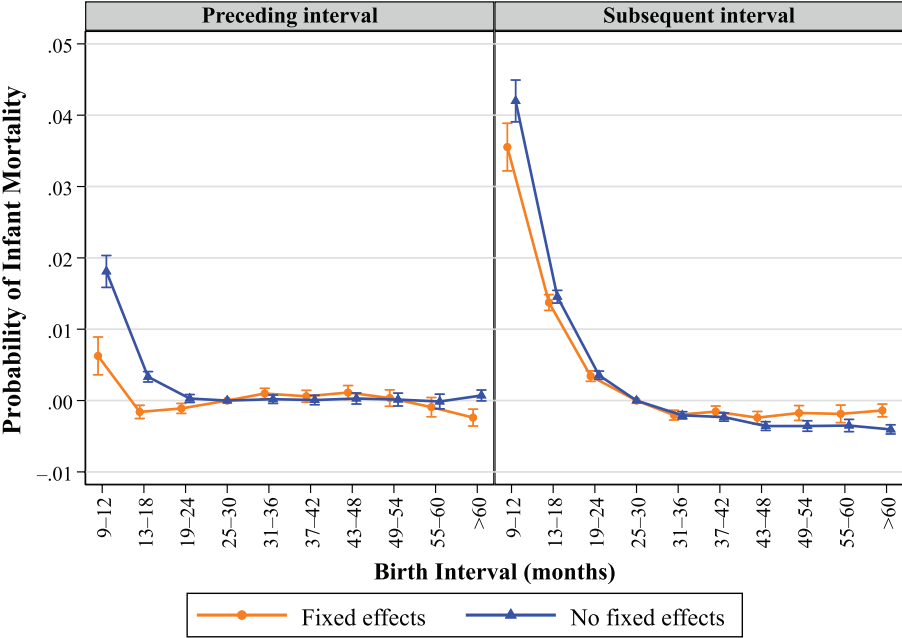
Fig. 4 The relationship between the length of the preceding and subsequent birth intervals and the probability of infant mortality in sibling groups with at least three children born in Utah in 1947–2019. Results are from linear probability models with and without sibling fixed effects.

Infant Mortality

The results for infant mortality are shown in Figure 4. The results from the analysis without a sibling comparison show that birth intervals shorter than 19 months are associated with a higher probability of mortality in the first 12 months of life, and this is particularly clear for intervals of 9–12 months, which, consistent with the pattern shown in the descriptive statistics, have a probability approximately 2 percentage points higher than the reference category to experience infant mortality. In the model without sibling fixed effects, there is no discernible meaningful variation in outcomes for children born after intervals longer than 18 months. The results from the sibling comparison models point toward a higher probability of mortality for infants born after an interval of 9–12 months, but they also indicate that there is a lower probability of mortality for infants born after intervals of 13–24 months, or longer than 60 months. The analyses by the subsequent birth interval length show that a short subsequent interval is associated with a much higher relative probability of infant mortality. Subsequent birth intervals of 9–12 months may be plausibly associated with an increased probability of infant mortality for the older sibling, and the probability gradient seen in Figure 4 is also consistent with a waning effect of infant death on subsequent birth intervals over time. Full tables of results can be seen in Tables S9 and S10 (online appendix).
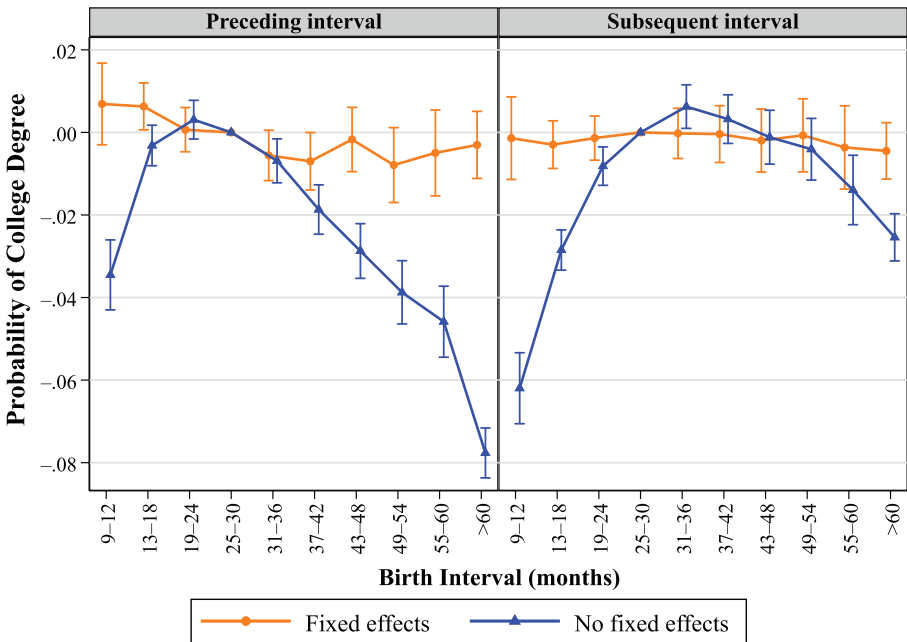
Fig. 5 The relationship between the length of the preceding and subsequent birth intervals and the probability of college graduation in sibling groups with at least three children born in Utah in 1950–1990. Results are from linear probability models with and without sibling fixed effects.

College Degree Attainment

We now turn to several longer term outcomes. Figure 5 shows the results from models that examine the relationship between the preceding and subsequent birth interval length and the probability of college degree attainment. Detailed results can be seen in Tables S11 and S12 (online appendix). The results in both the left and right panels of Figure 5 show that shorter and longer birth intervals, whether preceding or following the index person, are associated with a lower probability of college degree attainment in models that do not compare siblings. Relative to the baseline probability, the relative difference for those born after 9–12 months is approximately 10% lower; for those born after an interval of five or more years, it is approximately a quarter lower than the baseline probability. However, the results from the sibling comparison models suggest that birth spacing is not associated with long-term educational achievement: there are almost no differences in the probability of college degree attainment by the subsequent interval length, and the patterns by the preceding birth interval length suggest, if anything, that short birth intervals may be associated with a higher probability of college degree attainment.

Occupational Status

The results for occupational status are shown in Figure 6; detailed results are available in Tables S13 and S14 (online appendix). As in the analysis of college
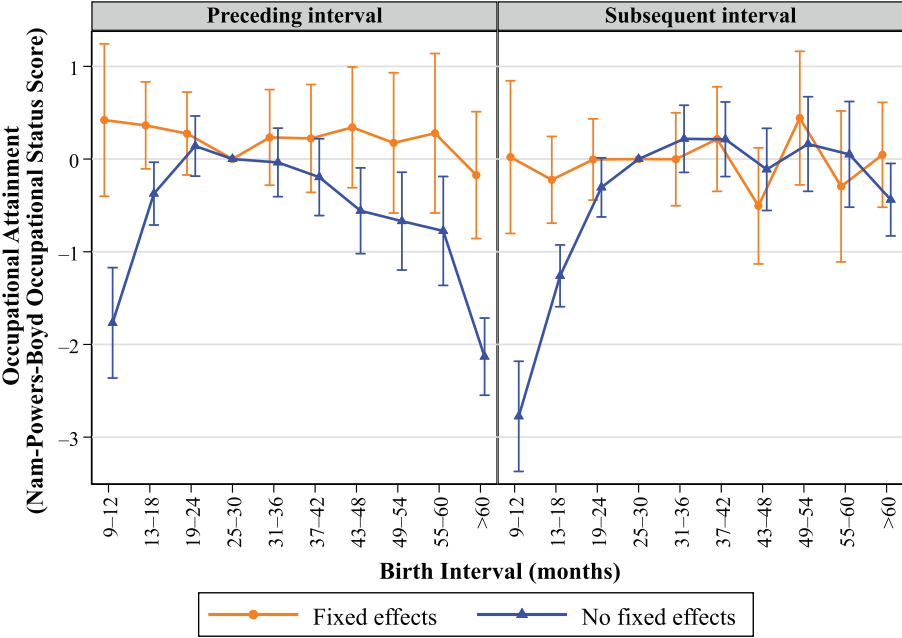
Fig. 6 The relationship between the length of the preceding and subsequent birth intervals and occupational status in sibling groups with at least three children born in Utah in 1950–1990. Results are from linear regression models with and without sibling fixed effects.

degree attainment, the results from the model without sibling fixed effects show a clear pattern in which those born after very short preceding birth intervals or longer intervals (43 months or longer) are disadvantaged in terms of occupational status. The mean score on the Nam-Powers-Boyd scale in our analytic sample is 56, and the standard deviation is 23. Even in the results from the model without sibling fixed effects, the relative disadvantage of children born after very short or very long birth intervals appears to be small—at less than 10% of a standard deviation both for children born after an interval of 9–12 months and for children born after an interval of more than 60 months. However, in the within-family comparison, we find no substantially or statistically significant differences in occupational status by the preceding birth interval length. Similar patterns are evident in the right panel of Figure 6, showing results from models examining whether birth interval length following the index person is associated with long-term occupational status.

Adult Mortality

Finally, Figure 7 shows the results for the relationship between birth intervals and adult mortality; full results are shown in Tables S15 and S16 (online appendix). Individuals in our sample were followed until at least age 70, and the oldest birth cohort, born in 1900, was surely extinct by the end of our follow-up period in
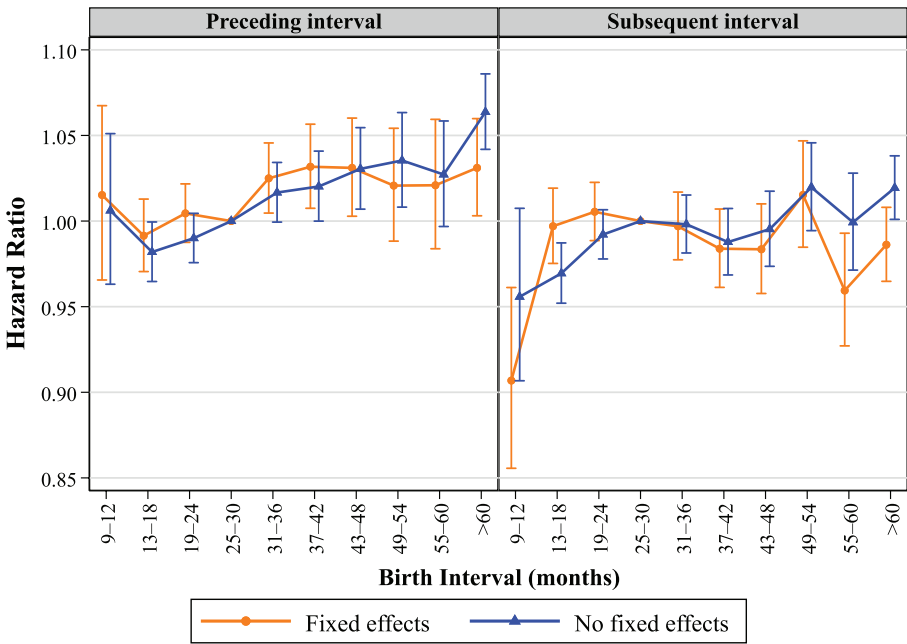
Fig. 7 The relationship between the length of the preceding and subsequent birth intervals and hazard of mortality in sibling groups with at least three children born in Utah in 1900–1949. Results are from Cox regression models and Cox models stratified by sibling group.

2019. The results in the left panel of Figure 7 do not point to a clear relationship between birth intervals and adult mortality in the models with or without sibling fixed effects. We see some indication that longer birth intervals are associated with higher mortality—particularly among those born after intervals of more than 60 months, for whom the mortality rate is 6% and 3% higher than among those born after intervals of 25–30 months in the nonstratified and stratified models, respectively. The results for the subsequent birth interval length (right panel) reveal only one clear pattern: the shortest birth intervals are associated with lower adult mortality.

Additional Analyses

In an additional analysis, we examined whether any of the associations between birth intervals and our 10 outcomes vary by gender. We did not observe any significant gender differences. We also tested for differences by maternal education in our sibling comparison models and found none. To check whether patterns of mortality might be observable at earlier adult ages, we examined mortality between ages 18 and 40. We found that mortality between 18 and 40 does not seem to vary meaningfully by the preceding or subsequent birth interval length, although intervals longer than 60 months may be protective in the sibling comparison analyses (see Figure S13, online appendix). We also estimated models of variation in mortality between ages 18 and

65 by birth cohort; these results are shown in Figures S14 and S15. Data on the standard deviation of birth intervals and outcome variables within and between families are provided in Table S17.

Discussion

This study adds to a growing literature on the relationship between birth spacing and offspring outcomes. We contribute to a relatively large literature examining how birth spacing is associated with perinatal outcomes in contemporary high-income settings, as well as to a much smaller literature examining how birth spacing may be associated with long-term outcomes. We find evidence that children born after very short birth intervals of 9–12 months have a higher probability of being born preterm or with LBW in Utah, even in the 2010s. Children born after intervals of 13–18 months are also at risk, but to a much lesser extent. Unlike several recent studies, we find that short intervals are associated with the probability of LBW and preterm birth even after we compare siblings born to the same parents (cf. Ball et al. 2014; Hanley et al. 2017). We also find evidence that longer birth intervals are associated with a lower probability of being born preterm or with LBW, even beyond the interpregnancy intervals recommended by the ACOG and WHO.

However, the credibility of our estimates for the relationship between the preceding birth interval length and perinatal outcomes is somewhat undermined by our additional finding that the birth interval length following the index person is associated with an elevated probability of LBW and preterm birth. It seems likely that the sibling comparison models do not adjust for all factors that are associated with both birth spacing and the probability of experiencing adverse perinatal outcomes. One plausible interpretation of these results is that we overestimate the negative effect of short preceding birth intervals on LBW and preterm birth. However, we cannot be sure about this interpretation, and we do not have access to other variables to control for additional potential within-family heterogeneity.

Our analyses of infant mortality also show that short preceding and subsequent birth intervals increase the probability of negative outcomes. In the analyses concerning the preceding interval length, we observe some discrepancies between the estimates from the models with and without sibling fixed effects: the results from the model without sibling fixed effects show no meaningful variation among birth intervals longer than 18 months, whereas the fixed-effects analyses indicate a protective effect of birth intervals of 13–24 months. Recent research has highlighted the possibility that offspring deaths change parents' fertility behavior, indicating that the birth interval length itself is influenced by the preceding sibling's death; when the outcome for one sibling influences the exposure for another, sibling fixed-effects models may be biased (Kravdal 2020; Sjölander et al. 2016). This situation is particularly likely for infant mortality but may also be true for our analyses of LBW and preterm birth, and it is an important limitation of the sibling comparison analyses. We suggest caution in the interpretation of the within-family comparison results for LBW, preterm birth, and infant mortality. Further, our study highlights the potential need for caution in interpreting the results from other studies of birth spacing and perinatal outcomes using sibling fixed effects.

This study is one of only a handful to examine the relationship between birth intervals and long-term outcomes or health outcomes. Our results are consistent with the most recent literature comparing siblings born to the same parents to examine how birth intervals are associated with socioeconomic attainment. Several studies using a sibling fixed-effects analysis and data from Sweden and the United States have reported that neither short nor long preceding birth intervals influence long-term outcomes once unobserved factors that are likely to be correlated with birth timing and spacing, as well as the long-term outcomes of interest, are held constant (e.g., see Barclay and Kolk 2017, 2018; Nguyen 2014). Our results for preceding birth intervals are also consistent with those reported in a previous study using miscarriage as an instrument for birth spacing in the United States; that study did not report a negative effect of short preceding birth spacing on the test scores of the younger sibling of a sibling pair (Buckles and Munnich 2012). However, we find that the subsequent birth interval length does not matter for college degree attainment or occupational status, whereas Buckles and Munnich (2012) reported that a longer interval following the index person was associated with higher test scores. Finally, the results from our analyses of long-term mortality, showing that birth spacing is inconsequential, are also consistent with previous work conducted using Swedish population data (Barclay and Kolk 2018).

An interesting inconsistency in our findings is that short birth intervals are associated with an increased probability of preterm birth and LBW (including very and extremely LBW and preterm birth) but not with any long-term disadvantage in educational attainment or occupational status. This latter finding is surprising for two reasons: (1) studies have found that preterm birth and LBW are associated with long-term socioeconomic and health disadvantages (Baranowska-Rataj et al. 2019; Behrman and Rosenzweig 2004; Black et al. 2007; D'Onofrio et al. 2013; Petrou et al. 2001), and (2) we can observe the same birth cohorts for our analyses of perinatal outcomes and the long-term educational and socioeconomic outcomes. One potential explanation for this inconsistency in our findings is that the association between birth intervals and perinatal outcomes may be overestimated, as discussed earlier. If the association between birth spacing and perinatal outcomes is actually negligible, this would help to explain why birth spacing also would not be associated with long-term status attainment.

Several potential explanations exist for why birth spacing might be associated with poor perinatal outcomes but not poor long-term outcomes, even if we assume that short intervals causally increase the probability of poor perinatal outcomes. For example, any negative effects of short birth spacing may be concentrated among children born extremely preterm or with extremely LBW; because the proportion of such infants is only a small fraction of the total number of births, the overall effect on long-term outcomes may be weaker. Alternatively, parents may seek to compensate for inequalities between their children by investing more in children disadvantaged by worse perinatal outcomes, thereby reducing variation in longer term outcomes (Conley and Glauber 2007). It is also possible that positive selection explains the discrepancy between the results for LBW and preterm birth and the long-term outcomes. Our analyses of infant mortality show that children born after the very shortest intervals have a significantly higher probability of dying in the first 12 months of life; this indicates that the children who are most negatively affected by short birth

intervals do not survive to be included in our analytic sample of long-term outcomes, which would reduce the potential for an association between short intervals and relatively worse long-term outcomes. Another potential explanation for the discrepancy between the results for perinatal and long-term outcomes may be drawn from recent research showing that differences in outcomes by the preceding birth interval length seem to diminish with increasing age (Miller and Karra 2020).

Another limitation of our research design is that we study the impact of birth spacing on a variety of outcomes using data from families with at least three children. This approach, common in the literature using sibling fixed effects to study birth intervals, is necessary to implement our sibling comparison design: because a sibling group with two children has no variance in the birth interval length, it cannot be exploited for an analysis of the impact of birth intervals (Hutcheon and Harper 2019). We therefore exclude children without any siblings and children raised in two-child sibling groups. The latter are among the most common family sizes, despite Utah's unusually high fertility rates. This exclusion potentially limits the generalizability of our findings. However, one-child sibling groups do not have a birth interval to study. Further, a high proportion of all measurable birth intervals occur in sibling groups with three or more children because, compared with a two-child group, a three-child sibling group has twice as many birth intervals, a four-child sibling group has three times as many birth intervals, and so on. Given the hypothesized mechanisms by which short intervals are expected to lead to worse outcomes, we would also expect the consequences of multiple short intervals to be worse in larger sibling groups than in a two-child sibling group: multiple short intervals in larger sibling groups would further exacerbate factors such as maternal nutrient depletion or resource dilution among siblings at pivotal young ages.

Despite some limitations, this study makes important contributions to the literature. It is the first study to use population data (albeit at the state level) from the United States to examine long-term offspring outcomes in relation to birth spacing. The results from our analyses allow us to conclude that in a country with a much weaker welfare state system than Sweden or even Germany, extremely short birth intervals are not associated with long-term offspring educational, socioeconomic, or mortality outcomes. Further, this study builds on the literature examining whether birth intervals are associated with perinatal health outcomes: our finding that the subsequent birth interval length is also associated with the risk of LBW or preterm birth suggests that the sibling comparison does not hold constant all factors driving both birth spacing and perinatal outcomes and that the results from previous studies applying this approach may need to be revisited and reevaluated. Although this finding is somewhat concerning, we hope that it will eventually lead to a better understanding of the true association between birth spacing and perinatal outcomes in high-income countries. ∎

Data Availability Data from the UPDB are available only for approved health-related research studies, and access is project specific and granted after review and approval by a Resource for Genetic and Epidemiologic Research (RGE) oversight committee and the University of Utah's IRB. Requests for UPDB data used in this study will be reviewed by the RGE.

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