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Birth Spacing and Child Health Trajectories

RAY MILLER AND MAHESH KARRA

Using longitudinal data on a cohort of over 4,000 children from four low- and middle-income countries, we document the association between birth spacing and child growth trajectories. We find declines in child height at age 1 among children who are born within three years of an older sibling. However, we also observe catch-up growth for closely spaced children as they age. We find no evidence that catch-up growth is driven by remedial health investments after birth, suggesting substitutability in underlying biological processes. We also find that very widely spaced children (preceding birth interval of more than seven years) are similar in height at age 1 as children who are spaced three to seven years apart, but outgrow their more closely spaced counterparts as they age. However, further sibling comparisons suggest that the growth premium that is observed for very widely spaced children may be driven by unobserved confounding factors.

Introduction

The importance of birth spacing for maternal and child health has been of long-standing interest to researchers and policymakers alike. Empirical evidence has consistently found that a markedly short or wide preceding birth interval (length of time since last birth) is associated with increased risk of maternal and child mortality and morbidity (Conde-Agudelo et al. 2006; DaVanzo et al. 2004; Winikoff 1983). On the basis of these findings, the World Health Organization (WHO) has recommended birth-to-pregnancy intervals of at least 24 months, or about three years between births (World Health Organization 2006). The examined morbidity risks of short birth

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spacing have primarily concerned birth and early life outcomes, including pregnancy-related complications (high blood pressure, pre-eclampsia), preterm birth, low birthweight, and small for gestational age, while the evidence of birth spacing effects on downstream morbidity and the evolution of child health is scant and either weak or mixed (Dewey and Cohen 2007; Kozuki et al. 2013). This leaves an important gap in the existing literature, particularly as poor health in childhood has been shown to lead to lower educational attainment (Oreopoulos et al. 2008; Powell and Steelman 1993), poor labor market outcomes (Smith 2009; Case et al. 2005), lower human capital and social status (Case et al. 2001), and lower earnings in adulthood (Case et al. 2005; Schultz 2002).

In this study, we document the association between preceding birth interval and child growth trajectories using longitudinal data that were collected on a cohort of children and their siblings in four low- and middle-income countries. We assess whether and how the observed height gap associated with short and wide birth spacing changes for the cohort sample as children age, documenting patterns from raw data as well as estimates adjusted for a variety of child- and household-level characteristics. We also investigate potential mechanisms behind the observed patterns by (1) examining the relationship between birth spacing and parental investments in child health from conception to early adolescence, and (2) comparing siblings within the same family to analyze the potential influence of unobserved confounding factors on associations between birth spacing and health trajectories in our primary cohort panel.

Previous research

The relationship between short or wide preceding birth interval and high infant and child mortality is well-established in a wide range of populations (DaVanzo et al. 2004; Molitoris 2017; Kozuki et al. 2013; Conde-Agudelo et al. 2012). Conversely, there is relatively less empirical evidence that directly assesses the links between birth intervals and child morbidity. The closest approximation of child morbidity effects from birth spacing is provided by studies that examine the relationship between indicators of childhood malnutrition (stunting, wasting, underweight) and family formation patterns. A systematic review by Dewey and Cohen (2007) assessed the evidence from 52 studies and noted that approximately half found that a previous birth interval of at least 36 months was associated with a 10–50 percent reduction in childhood stunting (similar for wasting), whereas the remaining studies found no association or were inconclusive. A study by Rutstein (2008), which pooled birth history data from 52 Demographic and Health Surveys (DHS) that were conducted from 2000 to 2005, observed a positive association between birth interval length and child nutritional status outcomes. Similarly, a more recent study by Fink et al. (2014), which pooled 153 DHS surveys across 61 countries conducted between 1990 and 2011, found that birth intervals of less than 12 months and between 12 and 23 months were associated with higher risks for stunting (relative risks of 1.09 and 1.06) as compared to a 24- to 35-month interpregnancy interval. Due to the cross-sectional nature of the data, however, both the Rutstein (2008) and the Fink et al. (2014) studies were limited in their ability to make inferences on the persistence of these associations in children over time.

More recently, several studies have investigated the health impacts of birth spacing in high-income countries by comparing siblings within the same family who differ in preceding birth interval length. The aim of the "within family" fixed effects approach is to control for unobservable family factors that are correlated with birth spacing and are also risk factors for the adverse child health outcomes of interest (e.g., shared maternal frailty). Findings from these studies have been mixed, with some finding the association between short interpregnancy intervals and outcomes related to child morbidity (e.g., preterm birth, small for gestational age, etc.) to be negligible after applying family fixed effects (Ball et al. 2014; Class et al. 2017), while others find such associations remain (Mayo et al. 2017; Shachar et al. 2016). Several recent studies using family fixed effects in low- and middle-income countries have found that short birth intervals are still associated with mortality at lower levels of development; however, the association considerably attenuates with increasing development as well as with socioeconomic status of the family (Molitoris 2017; Molitoris, Barclay, and Kolk 2018).

Potential mechanisms

The relatively scarce evidence linking birth intervals and child morbidity is surprising considering that the mechanisms through which birth intervals may be associated with child health and well-being have been extensively discussed in the literature (DaVanzo et al. 1983; Miller 1991; DaVanzo et al. 2004). Broadly, we can group hypothesized mechanisms linking birth spacing to cross-sectional child health into three categories: (1) maternal physiology and biological mechanisms, (2) behavioral mechanisms, and (3) confounding factors.

Maternal physiology is perhaps the most common argument linking birth spacing to infant and child health outcomes. In particular, the consequences of a short birth interval have often been attributed to the physiological effects related to "maternal depletion syndrome," which postulates that the woman may not have fully recuperated from one pregnancy before supporting the next one (Conde-Agudelo et al. 2012; Dewey and Cohen 2007). By the same token, especially wide birth intervals have also been hypothesized to adversely influence perinatal outcomes through maternal physiology. Specifically, "physiological regression theory" suggests that a longer interval may allow for the physiological state of a mother to revert back to the physical state of a woman who has not yet experienced a pregnancy, which would imply that the mother is less physically primed for childbearing (Zhu et al. 1999). This may partially explain why both first-born children and children born after long intervals are more likely to be born preterm (Conde-Agudelo et al., 2012).[1]

The impacts of short birth spacing on child health may also be explained by increased infection transmission. Studies have proposed two kinds of infection transmission hypotheses that may mediate the relationship between birth spacing and child health outcomes (Conde-Agudelo et al. 2012). The first, vertical infection transmission, suggests that mothers who have shorter birth intervals may be more likely to have a premature birth because of increased risk of maternal infection. On the other hand, children who are shortly spaced may also be more exposed to horizontal infection transmission. In this case, children born after shorter birth intervals may face higher risks of contracting infections from siblings given that they may be vulnerable to similar kinds of diseases as their older sibling but have a less developed immune system; in this manner, the short interval affects child health by increasing exposure to disease.

In contrast to maternal physiology and infection transmission, the proposed behavioral mechanisms largely operate through differences in parental health investments associated with birth spacing. As a common example, short intervals have been hypothesized to increase competition between siblings for parental financial resources and/or time. Differences in parental investments could also directly stem from depleted household resources that were used for a relatively recent preceding birth. This may include a lack of physical resources or even a psychological or emotional inability to provide the later child with adequate attention if its birth came sooner than desired (DaVanzo et al. 2004; Conde-Agudelo et al. 2012).

When identifying potential channels that link spacing between two births to child health outcomes, it is important to highlight that (1) these channels are not mutually exclusive; and (2) channels may affect both the older and younger sibling. While the focus of this study is on preceding birth intervals (i.e., the younger sibling), spacing between two births may simultaneously and differentially impact the older sibling. For example, maternal nutritional depletion, particularly poor levels of folate, and physiological regression are more likely to affect the younger sibling (Buckles and Munnich 2012). On the other hand, behavioral responses to birth spacing through resource dilution, changes in parental investment, and sibling competition for parental time and resources are likely to affect both older and younger siblings (Desai 1995; Öberg 2015, 2017).

Short birth spacing and a woman's earlier return to pregnancy may also alter lactation and breastfeeding behavior (Conde-Agudelo et al. 2012).

Interestingly, the channels through which short birth spacing affects lactation and breastfeeding are both biologically and behaviorally based and are likely to affect both the older and younger sibling. Evidence from studies in Peru found that increased breastfeeding-pregnancy overlap—the continuation of breastfeeding for the older sibling into the first, second, or even third trimester of pregnancy—was associated with a change in breastmilk composition, lowering key immune-boosting enzymes and nutrient concentrations (Marquis et al. 2002, 2003). Combined with the evidence that a subsequent pregnancy may lead to earlier weaning from breastmilk (Bøhler and Bergström 1996), this suggests short birth spacing could lead to negative health consequences for the older sibling. Similarly, shorter birth intervals may impact the younger sibling through increased competition for maternal nutrition during the breastfeeding–pregnancy overlap (Boerma and Bicego 1992). The high nutritional demand on breastfeeding pregnant mothers, combined with maternal nutritional depletion from a recent pregnancy, may lead to suboptimal nutrition for the younger sibling. Moreover, while both siblings may be impacted by competition for nutrition from the mother, implications may be more severe for the developing fetus. Recent evidence from the United States, for example, has found that women who became pregnant after shorter interpregnancy intervals were more likely to breastfeed while they were pregnant with the next child and were more likely to suffer a miscarriage (Molitoris 2019).

Finally, observed associations between birth spacing and child health could be driven by a wide range of confounding factors such as socioeconomic status, mother's age at birth, race, and household size, among others. To the extent that relevant confounding variables are observable, they can be controlled for when estimating correlations. However, some confounding factors may be unobserved by the researcher, resulting in estimated associations that are not strictly causal in nature (Conde-Agudelo et al. 2012, 2006; DaVanzo et al. 2004; Dewey and Cohen 2007; Kozuki et al. 2013).

Birth spacing and health investments

One of our key aims is to understand not only cross-sectional associations between birth spacing and child health, but also how these relationships persist or change over stages of child development. Broadly, we can think that these relationships might change due to the interaction between underlying biological processes of child development and parental investment responses to the evolution of child health. To see this more clearly, we refer to the general theory of health and human capital formation proposed by Heckman (2007), which provides a useful framework for understanding the potential influence of parental investment response to birth spacing effects on child health trajectories. For a given level of initial health, the theory characterizes the evolution of child health over time in response to changes in parental health investments. Moreover, how much parents choose to invest in their child's health depends partially on how substitutable or complementary investments are with their child's existing health level. More precisely, investments are defined as good substitutes for health if health gains from investments are higher at lower levels of existing health. In this case, parents may be more motivated to compensate for low levels of initial health with additional investments over childhood as potential health returns are high (Currie and Almond 2011). On the other hand, complementarity between investments and child health would exist if health returns were larger for children already in better health. Under this condition, parents would have a greater incentive to reinforce the existing health levels of their children. For example, if a closely spaced child is of poor health at age 1, parents may decide to shift some resources to other siblings where the returns to their health investments are higher.

The theory's predicted evolution of health over time thus depends on the strength of substitutability or complementarity between investments and health. In the context of this study, consider a cohort of children with differing initial health levels due to differential birth spacing. If complementarity between investments and health is strong, the theory predicts reinforcing parental investments and a divergence in health within the cohort over time. In contrast, if investments and health are strong substitutes, the theory predicts compensatory investments with the potential for converging health over time.

Finally, it is also possible that parents' health investments do not respond to their child's initial health level and are instead equal for all children across the cohort. We may expect this to be the case if differences in child health are unobservable to the parent or if parents directly value equitable investments, for example, across peers or siblings. With equal investments across children, the theory predicts a divergence in health within the cohort if there exist strong complementarities between parental health investments and child health. In contrast, if there is adequate substitutability, the initial differences in health may persist but will not grow over time and may even converge, as has been predicted in the widely cited Grossman (1972) model of health capital. Thus, even in the absence of parental investment differences, the substitutability between health and investments will determine the extent to which there exists persistence in adverse early health outcomes that arise due to, for example, maternal physiology.

Our contributions

Our study contributes to the literature in several ways. First, we use a longitudinal dataset to document changes in the association between birth spacing and health over stages of child development. Existing studies have almost exclusively relied on cross-sectional data. Importantly, the cross-sectional structure of surveys like the DHS does not allow one to adequately control for both age and birth cohort effects when examining health trajectories over childhood. Moreover, the DHS does not include height measures for children after age 5. To our knowledge, no other studies have investigated whether adverse early life health outcomes associated with intrapartum spacing persist in a given cohort of children as they aged, especially as they transition into adolescence.

In addition, we analyze potential mechanisms driving observed results in two complementary ways. First, we attempt to isolate biological and behavioral mechanisms by examining parental investment patterns on the basis of birth spacing. This provides novel insight into the complementarity or substitutability of the underlying biological processes and how they interact with parental investments. Second, we employ an alternate statistical model that relies on within-family sibling comparisons of birth spacing for identification. This approach serves to minimize residual confounding by adjusting for all time-invariant factors that remain constant within the family and provides further evidence on the extent to which observed relationships in our cohort analyses may be interpreted as causal estimates of birth spacing effects on health trajectories.

More broadly, our study also speaks to the ongoing debate around the persistence of early childhood growth faltering and the potential for later-life catch-up growth. Catch-up linear growth, which refers to the accelerated growth that reduces, or possibly even erases, a child's early-life height deficit, has continued to be widely contested in the literature. While catch-up growth has been observed in clinical settings, the social science evidence for such growth at the population level, and in the absence of sustained intervention, is mixed (Leroy and Frongillo 2019; Leroy et al. 2014). Findings from Martorell et al. (1994), Monyeki et al. (2000), Handa and Peterman (2016), and Hoddinott and Kinsey (2001), among others, suggest that complete catch-up growth, even in the presence of later-life compensatory investments or behaviors, is unlikely, while studies by Adair (1999), Saleemi et al. (2001), and others find evidence of complete catch-up growth among children who experienced early-life stunting and nutritional deficits. Moreover, studies have shown that the potential for catch-up growth due to early-life faltering may be different for boys and girls, whereby girls are more likely to face persistent growth faltering and developmental delays into adolescence (Luo et al. 2003; Bosch et al. 2008; Proos and Gustafsson 2012). In using multiperiod panel data to observe changes in height for the same sample of children over an extended period of time (up to 15 years), our results contribute to this evidence base by improving on previous approaches to estimating catch-up growth, many of which are restricted by cross-sectional samples.

Data and methods

Data

For our analyses, we used longitudinal data from the Young Lives Study (YLS), which investigates the determinants of childhood poverty and well-being (Boyden et al. 2018). As part of the YLS, detailed health, nutrition, and other sociodemographic data were collected on a cohort of children born between 2001 and 2002 from four low- and middle-income countries—Ethiopia, India, Peru, and Vietnam. The sampling design included selecting 20 communities in each country and randomly selecting 100 children from each. Data were collected on approximately 8,000 children (2,000 from each country) over five survey waves that were conducted in 2002, 2006, 2009, 2013, and 2016, when children were approximately 1, 5, 8, 12, and 15 years old.[2] The study also collected information on household and child characteristics in each survey wave, including the anthropometric markers height and weight. Beginning in the third survey wave, anthropometric markers were also collected for a sibling of the primary cohort of children.[3]

In order to calculate preceding birth interval for our sample children, we used available survey data to estimate the date of birth of each sibling in the family. In each survey wave, child's age in months was collected for the primary cohort and for their siblings with anthropometric data. For remaining siblings, age in years was collected. We first subtracted reported age (in months or years) from the interview date for each of the five survey waves. We then chose the median of these values for each child as their estimated date of birth. A number of household and child characteristics were also used in analyses to help control for demographic and socioeconomic effects on child health outcomes. These included mother's age at birth, a wealth index, total number of siblings, caregiver's education, sex, number of older siblings, older sibling deaths, season of birth, and community of residence (refer to the Appendix in the Supporting Information for details on the construction of the outcomes and control variables).[4]

As our focus is on preceding birth intervals, we excluded first-born children from our primary panel analyses. For those with an older sibling, we grouped preceding birth interval into three categories: under three years, three to seven years, and seven years or more apart. We chose these categories primarily based on WHO birth spacing recommendations (24-month birth-to-pregnancy interval or roughly a 33-month birth interval) and to keep groups large enough to maintain statistical precision, particularly for subgroup analyses. However, we also examined robustness of results to defining finer birth spacing groups—in particular, see the Appendix in the Supporting Information for the full set of results in which the closest spaced children are divided into those spaced less than two years and two to three years from an older sibling.

Excluding first-born children, the YLS consisted of a total of 23,435 observations for the primary cohort of children summed across the five survey waves and four countries in the study. Of this sample, we dropped 0.3 percent of observations due to missing data on birth spacing and another 7.1 percent due to missing household or child characteristics (including height). This left a panel sample of 21,701 observations from 4,410 children born between 2001 and 2002. We used this birth cohort as our primary sample to examine the association between birth spacing and child health trajectories.

We also used data collected on siblings of the primary birth cohort to compare birth spacing effects across sibling pairs in the same family. The sample for this analysis included all families with at least two children. We retained first-born siblings in this sample by including “oldest child” as an additional birth spacing category. Of the 8,062 children included in the primary YLS cohort, 1,096 (14 percent) were excluded from the sibling sample because they did not have at least one sibling and 2,175 (27 percent) were excluded because of missing characteristics or sibling anthropometric data. This left us with an analytic sibling sample of 34,568 observations from 4,791 unique sibling pairs.

Outcomes

We used height (measured in centimeters) as our primary child health outcome. Height captures a child’s restricted growth potential associated with the chronic or long-term effects of health shocks and/or undernourishment and is an important predictor of later-life well-being and productivity (Schultz, 2002; Case et al., 2005; Heckman, 2007). In following Leroy et al. (2015), we used absolute height, as opposed to height that was standardized by age, as our main outcome in order to more appropriately evaluate changes in growth over time. However, we also conducted robustness analyses using standardized height-for-age z-scores and the probability of stunting (see the Appendix in the Supporting Information).

In addition to documenting associations between birth spacing and growth trajectories, we are also interested in understanding the underlying mechanisms. To this end, we examined the association between birth spacing and additional measures related to parental investments in children. Examined prenatal and birth investments included level of prenatal care (Prenatal care) and indicators for place of delivery (Home birth) and presence of a medical professional at birth (Pro at birth). These outcomes provide insight into how the relationship between birth interval and early infant health may be driven by maternal physiology relative to parental investment differences.

In order to understand the parental investment response to birth spacing after birth and over childhood, we also examined measures of nutritional investments—the variety of foods eaten by the child and the frequency of meals (in the past 24 hours). These analyses provide some suggestive evidence on the extent to which any observed effects of birth spacing on growth trajectories may have been operating through underlying biological channels relative to behavioral mechanisms (e.g., competition for resources).

Panel model

Our primary objective was to examine the association between birth spacing and longitudinal health trajectories. In our main empirical specification, we exploited the panel structure of the YLS by estimating the following model:

$$Y_{is} = \delta_s Space_i + \boldsymbol{X}_i \boldsymbol{\beta}_s + \gamma_s a_{is} + \kappa_s a_{is}^2 + \eta_s + \lambda_s \zeta_i + \varepsilon_{is} \tag{1}$$

where Y_{is} is an outcome for child i measured in survey round s; $Space_i$ is a categorical variable for preceding birth interval (three to seven years is the reference group); $\boldsymbol{X}_i$ is a vector of child-specific characteristics; a_i is age in months at time of measurement; η_s is a survey round intercept; ζ_i is an unobserved child-level random effect; and ε_i is a random error term. This approach allowed for comparison of effects at ages 1, 5, 8, 12, and 15, estimated longitudinally for a single birth cohort. Included in the vector of time invariant characteristics $\boldsymbol{X}_i$ are mother's age and age squared at birth, wealth index, total number of siblings, caregiver's education and dummies for sex, number of older siblings, older sibling deaths, season of birth,[5] and community of residence.

Coefficients in our model were allowed to vary by survey wave to capture heterogeneity in effects over childhood.[6] Identification of coefficients on child random effects λ_s required a normalization, so we set $\lambda_1 = 1$. We also assumed the error term is independent and identically distributed across individuals and independent across survey waves. As we wanted to examine association changes over time, we included only children without missing height in any of the five survey waves, leaving a total of 4,094 children. This inclusion ensured us that sample composition changes were not influencing results.

The coefficient of interest, which captures the effect of birth spacing on outcomes, is δ. Interpretation of the coefficient of interest requires careful consideration. Effects estimated from this model can only be interpreted as causal if birth spacing is uncorrelated with any unobserved determinants of examined outcomes. It is clearly the case that geographic residence is likely to be correlated with both health outcomes and birth spacing, as access to family planning and other health services vary considerably across countries and locales. However, effects associated with geographic area were controlled for with the inclusion of community fixed effects. An additional concern is the existence of seasonal patterns of fertility that correlate with our independent variables of interest. If, for example, pregnancies that are associated with shorter birth intervals are correlated with times of the year when food is relatively scarce, then results could be attributed to season of birth as opposed to birth spacing (e.g., Moore et al. 1999 2004; Rayco-Solon, Fulford, and Prentice 2005; McEniry 2011; Miller 2017). Moreover, studies have documented seasonal patterns of fertility across a variety of countries (e.g., Rajagopalan, Kymal, and Pei 1981; Panter-Brick 1996; Buckles and Munnich 2012). However, the inclusion of month-by-country of birth dummies controlled for seasonal effects that occurred at the country level and that were independent of birth spacing.

Family fixed effects model

While our main panel analysis controlled for many child- and household-level characteristics, it is still conceivable that fertility patterns could be correlated with additional unobserved characteristics of children or their families. To explore this possibility, we employed a secondary statistical model that relies on within-family sibling comparisons of birth spacing for identification. This approach served to minimize residual confounding by adjusting for all time-invariant factors that remain constant within the family. Specifically, we estimated the following family fixed effect model:

$$Y_{ifs} = \delta Space_{if} + \boldsymbol{X}_{if}\boldsymbol{\beta} + \gamma a_{ifs} + \kappa a_{ifs}^{2} + \eta_s + \zeta_i + \theta_f + \varepsilon_{ifs}, \tag{2}$$

where Y_{ifs} is an outcome for child i from family f measured in survey round s; θ_f is a family fixed effect; and other independent variables are as previously defined. Due to collinearity with the family fixed effect, we dropped the household wealth index, total number of siblings, and caregiver's education from the vector of child-level characteristics, $\boldsymbol{X}_{if}$.[7] However, we added the child's year of birth to control for cohort effects.

This approach controlled for any remaining permanent unobserved correlation between a child's family and the spacing measures by comparing children within the same family. We used this model to check sensitivity of the overall height gradients in birth spacing. However, there were two primary limitations to this specification. First, we could not directly observe trends in effects as a cohort aged. However, we also estimated this model with an interaction between birth spacing category and age. This allowed us to compare general age trends in the family fixed effects model with those from our panel model. Second, we do not have data on prenatal and childhood investments in siblings of the primary cohort of children, so we

TABLE 1 Descriptive statistics

	Panel sample				Sibling sample			
	Mean	**SD**	**Min**	**Max**	**Mean**	**SD**	**Min**	**Max**
Height (cm)	118.35	30.13	54.70	183.10	122.54	28.15	54.70	184.00
Preceding birth interval								
<3 years	0.40	–	0.00	1.00	0.35	–	0.00	1.00
3–7 years	0.46	–	0.00	1.00	0.34	–	0.00	1.00
7+ years	0.14	–	0.00	1.00	0.04	–	0.00	1.00
Oldest child	–	–	–	–	0.27	–	0.00	1.00
Older siblings								
1	0.51	–	0.00	1.00	0.36	–	0.00	1.00
2	0.23	–	0.00	1.00	0.17	–	0.00	1.00
3+	0.26	–	0.00	1.00	0.21	–	0.00	1.00
Male	0.53	–	0.00	1.00	0.51	–	0.00	1.00
Mother's age at birth	27.83	5.88	12.00	50.00	25.61	5.71	12.00	50.00
Age (months)	99.33	59.39	5.00	199.00	108.08	57.43	4.67	253.91
Wealth index	0.54	0.21	0.00	0.96	0.53	0.21	0.00	0.96
Total siblings	2.90	1.94	1.00	11.00	2.71	1.90	1.00	11.00
Caregiver's education	3.87	4.50	0.00	28.00	3.70	4.50	0.00	28.00
Ethiopia	0.28	–	0.00	1.00	0.31	–	0.00	1.00
India	0.25	–	0.00	1.00	0.34	–	0.00	1.00
Vietnam	0.23	–	0.00	1.00	0.19	–	0.00	1.00
Peru	0.23	–	0.00	1.00	0.16	–	0.00	1.00
Observations	21,701				34,568			
Individuals	4,410				9,582			
Sibling pairs					4,791			

NOTE: Sample of observations with nonmissing height or covariates (excluding first-born children for panel sample). See the Appendix in the Supporting Information for details on all variable definitions.
SOURCE: Young Lives Study, young cohort.

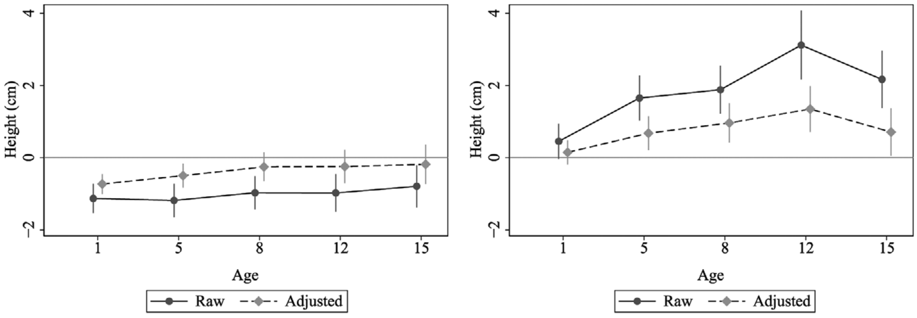
were unable to examine parental investment patterns with the family fixed effects model.

Results

Descriptive statistics

Table 1 presents descriptive statistics for the main panel sample as well as the sibling sample used in the family fixed effects model. Forty percent of the panel sample was spaced less than three years of an older sibling, while 14 percent was spaced seven or more years apart. About half of the panel sample had more than one older sibling with an average of 2.9 total siblings (by the final survey wave). The average maternal age at birth was nearly 28 years, and caregiver's average education was less than four years. The sample was somewhat skewed toward countries with higher overall fertility rates, namely, Ethiopia and India (as YLS children were less likely to be first-born in these countries).

FIGURE 1 Panel model: association between birth spacing and child height



(a) < 3 years to older sibling

(b) 7+ years to older sibling

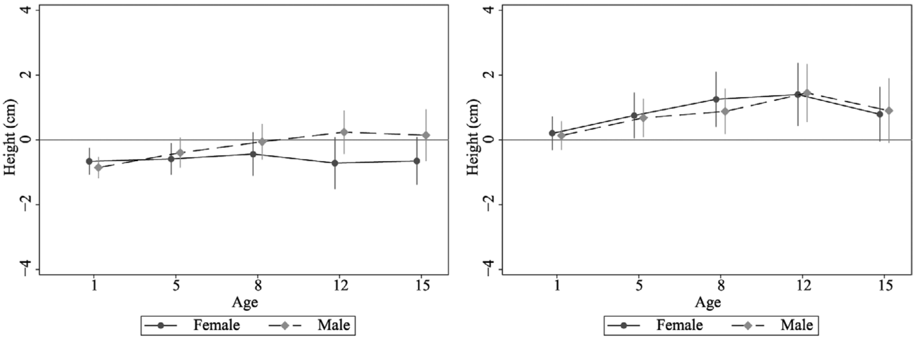
NOTES: This figure plots estimated coefficients (raw and adjusted for confounding variables) for those spaced less than three years (panel a) and greater than seven years (panel b) from an older sibling. Estimates are relative to being spaced three to seven years from an older sibling. Bars indicate 95 percent confidence intervals.

Compared to the panel sample, a somewhat lower 35 percent of the sibling sample was spaced within three years of an older sibling and only 4 percent was spaced more than seven years. This is largely due to the inclusion of first-born children (with a younger sibling) in the sibling sample. Total siblings and mother's average age at birth were slightly lower compared to the panel sample. Socioeconomic status was also lower as measured by wealth or caregiver's education and the sample was somewhat further skewed toward Ethiopia and India, where children are likely to have more siblings.

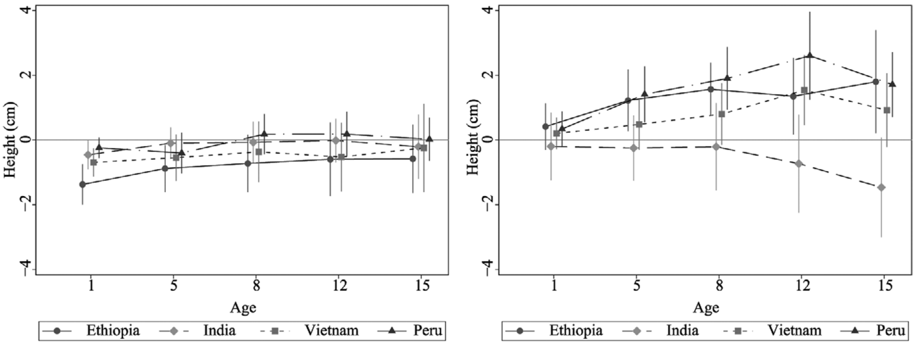
Main panel results

The associations between birth spacing and child height at each age for the primary YLS birth cohort are presented in Figure 1 (point estimates and standard errors are provided in Table A1 in the Supporting Information). Raw mean differences across spacing groups are provided as well as adjusted results estimated from model (1). Panel (a) plots estimated coefficients for children spaced less than three years from an older sibling relative to those spaced three to seven years. At age 1, short spacing was significantly associated with decreased height, even after controlling for confounding variables. Specifically, a preceding birth interval of less than three years was associated with an adjusted decrease in height of 0.72 cm—or about 15 percent of the standard deviation of age 1 height in the sample. However, the magnitude of the associations between short birth spacing and child height declined over time. Formally, we can reject the null hypothesis—that adjusted model coefficients are equal—at the 5 percent level between ages 1 and 12 ($\chi^2 = 5.08$) and between ages 1 and 15 ($\chi^2 = 3.91$).[8] This observed attenuation of birth spacing effects provides evidence of catch-up growth among more narrowly spaced children over childhood.

FIGURE 2 Panel model: heterogeneity in association between birth spacing and child height



(a) < 3 years to older sibling (b) 7+ years to older sibling



(c) < 3 years to older sibling (d) 7+ years to older sibling

NOTES: This figure plots estimated coefficients (by sex and country) for those spaced less than three years (panels a and c) and greater than seven years (panels b and d) from an older sibling. Estimates are relative to being spaced three to seven years from an older sibling. Bars indicate 95 percent confidence intervals.

Panel (b) in Figure 1 shows results for children spaced more than seven years from an older sibling. In contrast to adjusted results for short spacing, very widely spaced children did not significantly differ in height from children spaced three to seven years at age 1. However, very widely spaced children outgrew their more closely spaced counterparts over childhood. Again we can formally reject the null hypothesis of equal adjusted coefficients for widely spaced children at the 1 percent level between ages 1 and 12 $(\chi^2 = 18.32)$ and at the 10 percent level between ages 1 and 15 $(\chi^2 = 2.75)$.

Heterogeneity

Figure 2 shows results from our main panel model run separately for sex and by country-specific subsamples (point estimates are provided in Tables A2 and A3 in the Supporting Information). Panel (a) provides adjusted estimates by sex for children spaced less than three years from an older sibling. The point estimates are statistically significant and similar in magnitude for both sexes at age 1. However, for closely spaced males, the estimated negative effects of short birth spacing are quantitatively and statistically negated by age 8. In contrast, the magnitude and significance of the impact of short birth spacing persists through age 15 for closely spaced females. Thus, while estimated associations between short birth spacing and height did not worsen over childhood for females, the evidence for catch-up growth that was observed in the aggregate results appears to be driven primarily by catch-up growth in male children in the sample. The stronger persistence in height gaps for girls through age 15 is consistent with previous evidence of smaller peak height velocity gains (i.e., catch-up growth) during adolescence and changes in the timing of pubertal growth and development for girls following early-life growth faltering (Luo et al. 2003; Bosch et al. 2008; Proos and Gustafsson 2012). In contrast, panel (b) provides results by sex for children spaced more than seven years from an older sibling. While widely spaced males may have gained relatively more between ages 8 and 12 than widely spaced females, the overall pattern of results does not differ significantly between sexes.

Panels (c) and (d) in Figure 2 provide country-specific results. Overall, negative associations between short birth spacing and height were strongest in Ethiopia, followed by India and Vietnam; in contrast, the coefficients were smallest and statistically insignificant in Peru. However, a pattern of attenuating point estimates on short birth spacing was observed across all countries as children aged. For widely spaced children, similar patterns were present across all countries except India. In India, the estimated coefficient on wide spacing remained insignificant over most of childhood, with a marginally negative effect appearing at age 15.

Prenatal and childhood investments

Table 2 presents the association between birth spacing and prenatal and birth investments. Children who were closely spaced received less prenatal care (although not statistically significant), were more likely to be born at home, and were less likely to have a medical professional present at birth. These differences suggest that the health benefits of increased birth spacing observed by age 1 could be partially driven by differential parental investment behavior. To explore this possibility further, we ran our benchmark specification with and without the inclusion of the prenatal investment variables (results in Table A4 in the Supporting Information). The available investment variables had a mediating influence on the estimated coefficients of close birth spacing, thereby supporting our hypothesis for a parental investment mechanism. However, the mediation effect was generally small, which suggests that maternal physiological factors may still

TABLE 2 Panel model: association between birth spacing and prenatal and birth investments

	Prenatal care (1)	Pro at birth (2)	Home birth (3)
Space <3	0.892	0.706***	1.426***
	(0.066)	(0.076)	(0.145)
Space 7+	1.028	1.428**	0.837
	(0.093)	(0.254)	(0.138)
Observations	4,192	3,394	3,970

***$p < 0.01$, **$p < 0.05$.

NOTES: Odds ratios reported from (ordered) logit model. Robust standard errors (clustered at the community level) in parentheses. Dependent variable across columns: (1) level of prenatal care (0–3 scale), (2) medical professional present at birth, (3) birth was at home. Reported independent variables: spaced <3 or 7+ years from next oldest sibling (reference group spaced three to seven years). Additional independent variables in all regressions: mother's age at birth, mother's age at birth squared, age (months), age squared, wealth index, total number of siblings, caregiver's education, and dummies for number of older siblings, number of older sibling deaths, sex, survey round, season of birth, and community. See the Appendix in the Supporting Information for details on all variable definitions.

TABLE 3 Panel model: association between birth spacing and nutritional investments

	Meal frequency (last 24 hours)			Food variety (last 24 hours)		
	Age 5 (1)	Age 8 (2)	Age 12 (3)	Age 5 (4)	Age 8 (5)	Age 12 (6)
Space <3	–0.023	–0.006	–0.014	0.041	–0.084	–0.092
	(0.038)	(0.028)	(0.033)	(0.049)	(0.052)	(0.067)
Space 7+	0.033	0.070	–0.001	0.177**	0.112	0.046
	(0.053)	(0.046)	(0.051)	(0.075)	(0.091)	(0.101)
Observations	3,988	3,988	3,988	4,275	4,275	4,275

**$p < 0.05$.

NOTES: Robust standard errors (clustered at the community level) in parentheses. Dependent variable across columns: (1)–(3) meal frequency in last 24 hours collected at age 5, 8, and 12; columns (4)–(6) food variety in last 24 hours collected at age 5, 8, and 12. Reported independent variables: spaced <3 or 7+ years from next oldest sibling (reference group spaced three to seven years). Additional independent variables in all regressions: mother's age at birth, mother's age at birth squared, age (months), age squared, wealth index, total number of siblings, caregiver's education, and dummies for number of older siblings, number of older sibling deaths, sex, survey round, season of birth, and community. See the Appendix in the Supporting Information for details on all variable definitions.

be the primary mechanism that links birth spacing to perinatal and infant health.

In order to examine the association between birth spacing and nutritional investments after birth and over childhood, Table 3 presents results for our measures of nutritional investment—food variety and meal frequency. Point estimates were mostly negative but statistically insignificant for children spaced less than three years from an older sibling. This provides no evidence that closely spaced children received substantially more nutritional investments than wider spaced children over childhood. In contrast, point estimates were mostly positive for widely spaced children, and statistically significant for food variety at age 5. This suggests widely spaced children may have received somewhat higher nutritional investments over childhood.

TABLE 4 Family fixed effects model: association between birth spacing and height

	Height (1)	Height (2)	Height (3)	Height (4)
Space <3	–0.510***	–0.678***	–0.843***	–1.037***
	(0.179)	(0.244)	(0.187)	(0.282)
Space 7+	0.693**	–0.863	–0.599	–2.226***
	(0.320)	(0.680)	(0.366)	(0.737)
Space <3 × age			0.003**	0.003**
			(0.001)	(0.001)
Space 7+ × age			0.012***	0.012***
			(0.002)	(0.003)
Family FE	No	Yes	No	Yes
Observations	34,568	34,568	34,568	34,568

***$p < 0.01$, **$p < 0.05$.

NOTES: Robust standard errors (clustered at the community level) in parentheses. Dependent variable across all columns is height (cm). Reported independent variables: spaced <3 or 7+ years from next oldest sibling (reference group spaced three to seven years) and interaction with age in months. "Family FE" indicates inclusion of family fixed effects. Additional independent variables in all regressions: mother's age at birth, mother's age at birth squared, age (months), age squared, and dummies for number of older siblings, sex, survey round, year and season of birth. Simple OLS regressions (i.e., without family fixed effects) also include wealth index, number of siblings, caregiver's education, and community dummies. See the Appendix in the Supporting Information for details on all variable definitions.

Comparing siblings

Results from the family fixed effects model are presented in Table 4. The first column shows the association between birth spacing and height in the pooled sibling sample without the inclusion of a family fixed effect (i.e., model (2) with $\theta_f = 0$). Relative to being spaced three to seven years of an older sibling, being spaced less than three years was associated with a 0.510 cm decrease in a child's height, while being spaced at least seven years apart was associated with a 0.693 cm increase.[9] The second column shows results when the family fixed effect was added to the previous model specification. There was a moderate decrease in the coefficient estimate when moving from the simple OLS to the family fixed effect specification for closely spaced children. In contrast, the coefficient on widely spaced children becomes negative and statistically insignificant. This suggests there may be important unobserved confounding variables that are driving the observed patterns for very widely spaced children in our panel model results. However, we also note that the confidence intervals around the fixed effects estimates were wider than those from the standard OLS, particularly for the wide spacing group where there were generally fewer observations.

Columns 3 and 4 show results from the same regressions with the addition of an interaction term between birth spacing and child age in months. The interaction was positive and significant for both closely and widely spaced children. This is broadly consistent with our panel model results—closely and widely spaced children both outgrew the reference spacing group as they aged. However, we note that the base coefficient on the widely spaced group is negative and significant in the fixed effects specification. This suggests when comparing within a family, very widely spaced children may start out to be shorter than their more narrowly spaced siblings but then catch up over time. This finding is roughly consistent with maternal physiological regression theory, which hypothesizes worse early life outcomes for very widely spaced children. Thus, the health trajectories of very widely spaced children roughly mirror those of closely spaced children when comparing within sibling pairs. Specifically, results suggest closely and widely spaced children partially caught up to their siblings in height.

Discussion

We used longitudinal data collected between 2002 and 2016 on a cohort of approximately 4,000 children from four low-and middle-income countries to document the association between birth spacing and height trajectories over childhood. We found decreased height among children who were more narrowly spaced (less than three years) compared to children who were more widely spaced (three to seven years). However, we also found evidence of catch-up growth (estimated gaps in height that converge to the null) for closely spaced children. We also found that very widely spaced children (seven years or more) were of similar height to the reference spacing group (three to seven years) at age 1 but outgrew their more narrowly spaced counterparts over childhood.

Subgroup findings and mechanisms

Our prenatal and childhood investment results suggest that very widely spaced children (seven or more years) may have received more nutritional inputs over much of childhood. This is consistent with the positive and widening height gap observed for this group as they aged. However, our family fixed effects model suggests that much of this difference may be explained by unobserved confounding influences of the child's family. Thus, considerable caution should be taken if interpreting the observed associations between very wide birth spacing and improved height trajectories as a causal relationship.

In contrast to very widely spaced children, the family fixed effects model corroborated the panel finding of catch-up growth among closely spaced children (under three years) as they aged. Moreover, there was a strong negative association between short birth spacing and prenatal care-seeking. This suggests that the effects of birth spacing on prenatal growth and development may be partially driven by parental investment behavior. However, our mediation analysis of prenatal investments suggests that underlying maternal physiological factors play a primary role in explaining the emergence of height gaps by age 1.

After age 1, our childhood investment results provide no evidence that closely spaced children received significant additional nutritional inputs over their childhood that would allow them to catch up in height to those who were more widely spaced. This supports the observed catch-up growth after age 1 as an underlying biological phenomenon as opposed to being driven by parental investment behavior. These empirical finding—catch-up growth without remedial investments—provide evidence of substitutability between investments and child health (particularly for males, where observed catch-up growth was strongest).

In general, economic theory emphasizes that substitutability should be accompanied by compensatory investments (Ashenfelter and Card 2010; Currie and Almond 2011), which we did not observe in our data. We propose several possible explanations that may serve to reconcile these two seemingly contradictory observations. First, it is possible that some families were unable to optimally compensate closely spaced children due to financial constraints on available resources. This seems a viable potential explanation given data were collected from four low- and middle-income countries, where financial institutions are generally less developed (Svirydzenka 2016). Second, it may be that parents were not able to easily observe the adverse effects of short spacing and, as a result, did not see a need for improving their child's growth through compensatory investments. In order to explore this possibility, we examined the association between birth spacing and caregiver perceptions of child size from birth to age 5 (see Table A5 in the Supporting Information). We did not find a statistically significant relationship between close birth spacing and caregiver's perception of size, suggesting this as a viable explanation. However, point estimates suggest caregivers may have perceived closely spaced children to be smaller at birth and at age 1, but not at age 5. It therefore could be that the bulk of parental investments to compensate for poorer growth among closely spaced children are provided between ages 1 and 5 and that we simply do not have the necessary data within this time frame to observe these behaviors.

Finally, it may be that food variety and meal frequency are too noisy or blunt short-term measures of nutritional and other remedial investments. It is possible that a more precise measure of investment or specific types of investments (e.g., parental time spent with children, emotional investments, etc.) may exhibit negative associations with birth spacing. While we have proposed several possible explanations for the limited evidence of compensatory parental investments in our analyses, it is clear that additional research is needed to convincingly disentangle the biological and behavioral channels through which birth spacing may alter childhood growth and development.

Study limitations

There are several important limitations to our study that warrant discussion. First, we found considerable attenuation over time in initial height gaps associated with birth spacing, and the trajectory indicates a potential convergence of gaps to the null. However, given the relatively short (15-year) period over which our sample was observed, we are unable to say whether convergence is assured in the long run, particularly as children continue through periods of rapid growth and development during adolescence. Moreover, aggregate catch-up growth appears to be driven by males with little attenuation observed for females.

Second, our family fixed effects model provided no evidence that unobserved family characteristics are substantially influencing our panel model results for closely spaced children. However, there are several important caveats surrounding this conclusion. First, it is important to reiterate that the composition of our panel sample differs from our pooled sibling sample. Second, a common methodological criticism of the literature that relies on family fixed effects is the inability to adequately account for within-family heterogeneity in unobservable characteristics (Rosenzweig and Wolpin, 1988; Rosenzweig, 1986). Likewise, our use of a family fixed effect would not be sufficient in adjusting for any time-varying residual confounding that is associated with differential birth timing decisions across siblings (e.g., family wealth shocks or mother's employment status). However, in spite of these caveats, it is important to recall that our main results were estimated longitudinally on a single birth cohort of children. Therefore, even if some residual confounding remains, it does not invalidate the fact that there was catch-up growth among children who were more narrowly spaced in our panel sample, nor does it invalidate evidence that supports catch-up growth as an underlying biological as opposed to purely behavioral phenomenon. These findings provide novel evidence on the substitutability or complementarity between investments and health over childhood and the influence of parental investment response to early health differentials.

Finally, while we observed possible convergence in height in our sample across birth spacing groups, disparities in other outcomes may persist or emerge. For example, several studies have found longer intrapartum spacing to be associated with improved school test scores in older siblings, though the effects were found to be minimal for younger siblings (Broman et al. 1975; Buckles and Munnich 2012). Further investigation along this line is warranted in order to determine the extent to which gaps in other key outcomes of health and development may persist over time for children who are more closely or widely spaced.

Conclusions

While our findings were somewhat mixed for very widely spaced children, we find that short preceding birth intervals are associated with growth faltering by early childhood. This suggests that interventions aiming to increase birth intervals and support the healthy timing and spacing of pregnancies may be particularly important in promoting early childhood health and development. After infancy, we find evidence of substitutability in the evolution of child health, implying sustained investments over childhood may be able to combat the early negative effects of birth spacing. For example, our findings suggest that policies to promote increased nutritional investment for closely spaced girls could successfully narrow the persistent health gaps observed in our sample. Moreover, substitutability implies that such remedial investments would promote both equity and efficiency in the allocation of investments for child health; in contrast, dynamic complementarities imply a trade-off between equity and efficiency. Finally, it is essential that we continue to investigate the biological and behavioral mechanisms through which birth spacing may contribute to child health. A more thorough understanding of these causal pathways is essential for the development of effective policies, programs, and evidence-based interventions that seek to promote healthy growth and development in children from conception through adolescence and into adulthood.

Data Availability

The data used in this paper are from the Young Lives Study, a 15-year study of the changing nature of childhood poverty in Ethiopia, India, Peru, and Vietnam (www.younglives.org.uk). The Young Lives Study is core-funded by UK aid from the Department for International Development (DFID). The views expressed here are those of the authors and are not necessarily those of the Young Lives Study, the University of Oxford, DFID, or other funders.

Ethical Considerations

Ethical approval for the evaluation was granted by the Harvard T.H. Chan School of Public Health Institutional Review Board (IRB), Protocol No. IRB17-0028.

Notes

1 For wide spacing intervals, it is especially important to control for confounding arising from maternal age, since women who have long intervals between births are likely to be older than women who have short birth intervals.

2 The YLS excluded all multiple births from the study.

3 Markers were collected for closest aged younger sibling provided they were over two years old for Peru and India or over three years old for Ethiopia and Vietnam. If no such younger sibling was present, data were collected on closest aged older sibling (except for Peru).

4 Appendixes are available at the supporting information tab at wileyonlinelibrary.com/journal/pdr.

5 Season of birth was controlled for with a month of birth by country dummy.

6 We used Stata's *gsem* command to estimate the system via maximum likelihood.

7 The YLS does not collect data on miscarriages or infant deaths, so we are unable to control for any sibling deaths/miscarriages that may have occurred between the birth of siblings in our sibling sample. We are also unable to construct number of older sibling deaths for siblings of the primary YLS cohort, so this control is excluded from the family fixed effects model.

8 All χ^2 results from Wald test with 1 degree of freedom.

9 The higher point estimates compared to the panel model is due to sample selection. For example, the pooled sibling sample had more children from Ethiopia and India where birth spacing effects were stronger.

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