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Sibling rivalry between twins in utero and childhood: Evidence from birthweight and survival of 95 919 twin pairs in 72 low- and middle-income countries

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Abstract

Background: This study explores the magnitude and timing of sex and gender disparities in child development by describing differences in health outcomes for male and female siblings, comparing twins to control for all aspects of life circumstances other than sex and gender.

Methods: We construct a repeat cross-sectional dataset of 191 838 twins among 1.7 million births recorded in 214 nationally representative household surveys for 72 countries between 1990 and 2016. To test for biological or social mechanisms that might favor the health of male or female infants, we describe differences in birthweights, attained heights, weights, and survival to distinguish gestational health from care practices after each child is born.

Results: We find that male fetuses grow at the expense of their co-twin, significantly reducing their sibling's birthweight and survival probabilities, but only if the other fetus is male. Female fetuses are born significantly heavier when they share the uterus with a male co-twin and have no significant difference in survival probability whether they happen to draw a male or a female co-twin. These findings demonstrate that sex-specific sibling rivalry and male frailty begin in utero, prior to gender bias after birth that typically favors male children.

Conclusions: Sex differences in child health may have competing effects with gender bias that occurs during childhood. Worse health outcomes for males with a male co-twin could be linked to hormone levels or male frailty, and could lead to underestimates of the effect sizes of later gender bias against girls. Gender bias favoring surviving male children may explain the lack of differences in height and weight observed for twins with either male or female co-twins.

1 | INTRODUCTION

Discrimination against girls and women is among the world's most profound, longstanding, and widespread constraints on human development, with extreme disparities in many indicators of wellbeing. This article addresses one demographic aspect of sex and gender differences, namely health outcomes among twins in low- and middle-income countries. A child's health could be influenced by their siblings in many ways, including rivalry in the allocation of scarce time, attention, and care within the household (Masters, Finaret and Block, 2022). Our objective was to control for gestational and early-life circumstances, such as adverse economic conditions by comparing twins to measure sex- and then gender- differences in health outcomes (Hanley, 2018; Margerison et al., 2019). Our innovation is to use a large sample of twins extracted from all Demographic and Health Surveys (DHS) conducted between 1990 and 2016, and use recorded birthweights, attained heights, weights, and survival to the date of the survey to test whether differences between male and female twins started in utero or emerged later in life.

To capture a wide range of insults to child health, we focus on birthweights, and survival as outcomes, as larger birthweight is associated with better health and economic outcomes (Behrman & Rosenzweig, 2004; Bharadwaj et al., 2019; Biks et al., 2021; Black et al., 2007; Kim et al., 2022). We use the term sex to refer to biologically determined factors, and we use the term gender to refer to the socially or culturally determined factors, or the interaction of sex- and gender-based factors. Gender is a socially constructed phenomenon, and so gender bias can play a role in resource allocation for children after they are born, but before a pair of opposite-sex twins is born, no gender bias in caregiving is possible. Our objective was to compare outcomes between twins who draw a male or female co-twin, to identify "sibling rivalry" effects whereby the sex and gender of one child affects development prospects for the other, in settings that control for all other aspects of both children's shared environment (Calais-Ferreira, Barreto, et al., 2021a; Lummaa et al., 2007; Morduch, 2000).

2 | LITERATURE REVIEW

2.1 | Twin studies

Twin studies have a long history in epidemiology, human biology, demography, and other fields (Conley et al., 2006). Behrman (2016) describes four main uses of data from twins: (1) comparing monozygotic to dizygotic pairs to isolate genetic similarity from other factors (Jahanfar, 2018); (2) comparing parental investments to distinguish compensation from reinforcement of initial endowments; (3) comparing fertility decisions after multiple births to identify parental preferences for the number and sex of children; and finally; (4) the *ACE* model and other quantitative genetics models that examine traits that vary continuously as opposed to discretely, and which link outcomes to additive genetic variance (A), common environmental factors (C), and measurement error (E) (Behrman, 2016). Our work employs the second approach, comparing parental investments between twins to distinguish sex- and then gender-specific inequities in resource allocation.

2.2 | Health outcomes between male and female children

Differences in health outcomes between male and female children have been estimated in many studies. Economics research on behavioral biases in care practices often centers on son preference and gender bias in South Asia (Behrman & Deolalikar, 1990; Chen et al., 1981; Clark, 2000; Kubo & Chaudhuri, 2017). Some studies address variance rather than averages, often finding greater variability in health among male children than female children under stressful circumstances (Ansar Ahmed et al., 1985; Drevenstedt et al., 2008; Kraemer, 2000; Sawyer, 2012). A variety of studies address sex-specific differences and gender bias against girls (Gupta et al., 2017; Khera et al., 2014; Klasen, 1996; Rockers & McConnell, 2017; Treleaven et al., 2016), sometimes finding worse outcomes for male children (Marcoux, 2002; Sahn & Stifel, 2002; Svedberg, 1990; Wamani et al., 2007), including higher rates of a miscarriage of male fetuses at times of environmental stress (Valente, 2015).

There is substantial heterogeneity in the existence, directions, and degrees of gender bias across regions, age groups, settings, and over time (Berti, 2012; Dercon & Singh, 2013; Marcoux, 2002). Variation in male–female differences has been linked to environmental factors that vary spatially and change slowly over time, as found in India (Kashyap & Behrman, 2020). Svedberg assembled health data from several African countries and found worse outcomes for boys from the 1960s through the early 1980s, while Klasen used DHS data from the 1980s to early 1990s and found that gender differences in Africa were increasingly similar to those seen earlier in Asia (Klasen, 1996; Svedberg, 1990). Updating Amartya Sen's pioneering work, Klasen and Wink (2002) found clear evidence for higher female than male mortality in Africa and Asia (Klasen & Wink, 2002; Sen, 1990).

Turning to nutritional status, an analysis of 16 household surveys across 10 African countries found that girls were less likely to be stunted than boys (Wamani et al., 2007), and there are worse height outcomes for boys in Jordan, Yemen, and Egypt (Sharaf et al., 2019). That pattern could be due to selection bias if similarly, malnourished girls did not survive, or selection of a cohort affected by adverse circumstances (Bruckner & Catalano, 2007), and it could also be due to interacting effects of sex-specific biology with gender bias in behavior. For example, adult women may experience inequalities in food intake that girl children do not (Gittelsohn, 1991; Marcoux, 2002), and there are important differences in how male and female infants respond to adverse climate and economic shocks (Mulmi et al., 2016).

Some twin and sibling studies track outcomes into later life, such as in Norway where females with male co-twins have worse educational and labor market outcomes, and are less likely to marry and have children of their own (Bütikofer et al., 2019). That result is consistent with Lummaa et al. (2007) who studied pre-industrial twins (between 1734 and 1888) in Finland, and found that daughters born with a male co-twin have reduced lifetime reproductive success compared to those born with a female co-twin and the United States where Huang et al. (2019) find that females with a male co-twin have lower earnings (Huang et al., 2019).

2.3 | Birthweight and child development

Researchers have often found larger birthweights to be associated with greater educational attainment, attained height, and many economic outcomes (Behrman & Rosenzweig, 2004; Black et al., 2007; de Souza et al., 2022.; Justin Cook & Fletcher, 2015; Lin & Liu, 2009; Rosenzweig & Zhang, 2013). Birthweight itself has a complex etiology relating to genetic predispositions, maternal size, and nutritional status as well as the infant's gestational age, and infants could grow to be healthy from a very wide range of birthweights (Almond et al., 2005; Maruyama & Heinesen, 2020). Like other studies, we use birthweight and other anthropometry as a metric of the whole population's exposure to adverse circumstances, in our case isolating sex-specific factors relating to the shared environment facing each child in every pair of twins and looking earlier in life than the mortality findings of Kashyap and Behrman (2020).

2.4 | Selection into twinning

Among twins, selection into male–male, female–female, or mixed-sex combinations depends not only on the odds of conception and survival for fetuses of each sex, but also, the probability of monozygotic versus dizygotic twinning (Bruckner & Catalano, 2007). Since only dizygotic twins can be mixed sex, if the sex of each twin is determined independently with equal numbers of males and females, then half of dizygotic pairs would be same-sex twins and half would be mixed sex; against that benchmark, which is known as Weinberg's rule, there is some evidence of differential selection towards same-sex twins in the United States but no evidence regarding differential conception of male–male as opposed to female–female pairs (Kanazawa et al., 2018). Overall, the most similar previous study is Stephenson et al. (2018), which used a less complete set of DHS data and considered only mortality and disease, without addressing differences in birthweight that can trace outcomes back to biological interactions in utero (Stephenson et al., 2018).

3 | METHODS

In this study, we use each twin as the other's control. We trace sex differences in health outcomes during three important early life stages, using four outcomes of interest. First, we test for sex-specific sibling rivalry during gestation by estimating the effects of having a boy co-twin on a male twin's recorded birthweight relative to a female twin. This analytical approach allows for time-invariant factors within a family and within a pregnancy to be held constant for a pair of twins. Second, we test whether these effects persist through infancy and early childhood by testing for differences in heights (HAZ), and weights (WHZ) at the time of the survey relative to the WHO child growth standards. Both HAZ and WHZ are continuous variables, with lower HAZ reflecting past constraints on children's linear growth of bone structure and lower WHZ reflecting current size in terms of body fat or muscle mass given their attained height. Finally, we examine differences in survival, using each mother's entire recorded birth history.

For continuous outcomes (birthweight, HAZ, and WHZ) we use Ordinary Least Squares (OLS) regression, and to test for differences in survival we use logistic regression. We employ country and year fixed effects, control for the child's own sex, and test for sibling rivalry using a binary indicator if their co-twin is male, with a further test for sex-specific sibling rivalry using the interaction between the child's own sex and having a male co-twin. The estimated coefficient on the interaction term is of greatest interest because it would indicate the presence of an effect based on the twin pair type, namely M(M), M(F), F(M), and F(F), in utero. For tests of differences in HAZ and WHZ, we add controls for maternal education, household occupation in agriculture, number of boys born prior to the index child, the birth interval between siblings, and maternal age at first birth. For tests of differences in survival, we also control for a cubic function of time elapsed since birth. In all regression models, standard errors of the coefficient estimates are clustered at the primary sampling unit level (enumeration areas).

We also employ nonparametric methods to visualize and test for differences in outcomes between twin sex-pairs. First, we estimate Kaplan–Meier cumulative survival probabilities which is the fraction of all recorded children who were reported to be alive at each number of elapsed years since birth (Kaplan & Meier, 1958). We also estimate a smoothed kernel density distribution of residuals obtained from OLS regressions of outcome variables on country, region, and survey year fixed effects. We further run a two-sample Kolmogorov–Smirnov test for equality of distribution functions to see whether there are differences between the K density curves of the different twin sex-pair types (Table S4). Finally, we show the unconditional averages and proportions of our outcome variables disaggregated by twin sex-pairs (Figures S1–S5).

3.1 | Data

The data come from 72 low- and middle-income countries (LMICs) surveyed by the Demographic and Health Surveys (DHS) program between 1990 and 2016 and comply with the Declaration of Helsinki with respect to research on human subjects. We draw from a total of 214 nationally representative surveys of mothers and their children which provide child survival data from mothers' recall of all children ever born and anthropometry for children under 5 years at the time of each survey. The DHS are nationally representative surveys of mothers and their children designed primarily to measure health, child survival, and other aspects of human development (ICF International, 2022). Detailed descriptions of the settings, sampling, and data collection are available from the DHS Program.

We included all possible countries over the 26-year period because it was a period of substantial improvement in public health and economic well-being across many LMICs, making it possible to leverage country- and year-fixed effects in the estimating models. We used mothers' recall of their birth history to construct a survival dataset of all twins ever born and used recorded birthweights and measurements during the survey to construct an anthropometry dataset of all twins ever measured. Singleton births and multiple births <2 sibling twins were excluded.

Selection bias could play a role, particularly for the anthropometry dataset, as birthweight is missing for 44% of the sample, and HAZ and WHZ are missing for 21% and 22% of the sample respectively. It is possible that male–male, female–female, and mixed twins were measured at different rates that are correlated with determinants of their health, for example if male–male twins are more likely to be measured even in disadvantaged households. As in previous work on missingness in the anthropometric modules of DHS data, we expect that missing data will attenuate coefficient estimates toward zero but not bias our test results for determinants of each outcome (Finaret & Hutchinson, 2018).

4 | RESULTS

The two extracts of DHS data used for this study are described in Table 1, first for an anthropometry dataset (Panel A, $n = 18\,856$) of twins who were under-five and present at the time of the survey, and second for a larger survival dataset (Panel B, $n = 191\,838$) from maternal recall of all children ever born asking whether they were alive at the time of the survey. Columns in Panel A report summary statistics that pool 199 surveys across 72 countries to make the anthropometry dataset, most of which come from 38 African countries (116 surveys) and a smaller subset of data coming from 6 South Asian countries (10 surveys). The survival data presented in Panel B of Table 1 combines 201 surveys across 72 countries, the majority of which come from Africa (39 countries, 121 surveys) with a smaller fraction from South Asia (6 countries, 14 surveys). Our principal results concern the entire sample, but we also show results for South Asia and Africa separately to demonstrate heterogeneity due to the many differences in ecological and socioeconomic conditions. The list of surveys used in this study is presented in Table S6.

One important difference between regions concerns the fraction of all children who are twins, as the overall number of twin births per 1000 births in Africa (27.24 $\pm$ 12.34) is almost double that of South Asia (14.29 $\pm$ 3.35; Panel A of Table 1). The difference is due to the frequency of dizygotic pregnancies, since the baseline rate of monozygotic twinning is known to be roughly constant across populations (Hall, 2003). Health outcomes vary widely in the sample, for example with stunting prevalence higher among African twins (46.3%) than South Asian twins (36.1%), while the prevalence of wasting was higher among South Asian twins (20.1%) compared to African twins (10.9%).

The child survival data described in Panel B of Table 1 indicate that a large fraction (32.2%) of all twin children ever born were no longer alive at the time of the survey, with particularly high mortality for twin births reported for South Asia (39.3%) compared to Africa (33.7%). These differences in sample selection imply that twins in the survival dataset have on average experienced more adverse circumstances than twins in the anthropometric dataset.

TABLE 1 Descriptive statistics for all twins in the anthropometric and survival datasets.

Panel A: Anthropometry dataset (used for birthweight and anthropometric analyzes)

	(1) All twins [N = 18 856]		(2) African twins [N = 10 894]		(3) S. Asian twins [N = 3798]		(4) Difference (African–S. Asian)	
	N	Mean (SD) or proportion	*N*	Mean (SD) or proportion	*N*	Mean (SD) or proportion	*N*	Mean (SE)
Male children	18 856	49.9%	10 894	49.2%	3798	52.6%	14 692	−0.034*** (0.009)
Time elapsed since birth (years)	18 856	2.25 (1.42)	10 894	2.22 (1.43)	3798	2.32(1.43)	14 692	−0.101*** (0.027)
Co-twin is male	18 856	50%	10 894	49.3%	3798	52.6%	14 692	−0.033*** (0.009)
Child's birthweight (kg)	18 856	2.47 (.68)	10 894	2.57 (0.68)	3798	2.17 (0.65)	14 692	0.401*** (0.013)
Height-for-age z-score	15 434	−1.63 (1.65)	8791	−1.80 (1.73)	2783	−1.48 (1.59)	11 574	−0.326*** (0.037)
Child is stunted	15 434	40.1%	8791	46.3%	2783	36.1%	11 574	0.102*** (0.011)
Weight-for-height z-score	15 311	−0.31 (1.42)	8709	−0.28 (1.47)	2783	−1.1 (1.13)	11 492	0.826*** (0.03)
Child is wasted	15 311	10.9%	8709	10.9%	2783	20.1%	11 492	−0.092*** (0.007)
Weight-for-age z-core	15 666	−1.22 (1.39)	8976	−1.30 (1.42)	2798	−1.78 (1.19)	11 774	0.483*** (0.03)
Child is under-weight	15 666	27.6%	8976	29.2%	2798	43.9%	11 774	−0.147*** (0.01)
Number of previous boys	18 856	0.29 (0.48)	10 894	0.29 (0.5)	3798	0.3 (0.48)	14 692	−0.006 (0.009)
Maternal education (years)	17 235	5.78 (4.39)	10 261	5.09 (4.28)	2841	4.35 (2.3)	13 102	0.744*** (0.083)
Household occupation incl. agriculture	18 856	24.7%	10 894	35%	3798	3.9%	14 692	0.311*** (0.008)
Proceeding birth interval (months)	14 515	45.73 (26.86)	9069	45.09 (24.78)	2292	43.6 (26.95)	11 361	1.497** (0.59)
Maternal age at first birth (years)	18 856	25.67 (6.54)	10 894	26 (6.77)	3798	22.14 (4.36)	14 692	3.865*** (0.117)
Share of twin births (twin births/1000 births)		22.55 (11.92)		27.24 (12.34)		14.29 (3.35)		
Number of countries	67		38		5			
Number of surveys	174		116		10			

Panel B: Survival dataset (used for survival analyzes)

	(1) All twins (N = 191 838)		(2) Africa (N = 130 330)		(3) South Asia (N = 16 352)		(4) Difference (African twins–South Asian twins)	
	N	Mean (SD) or proportion	*N*	Mean (SD) or proportion	*N*	Mean (SD) or proportion	*N*	Mean (SE)
Male children	191 838	50.4%	130 330	50.4%	16 352	51%	146 682	−0.006 (0.004)
Time elapsed since birth (years)	191 838	10.16 (7.16)	130 330	9.72 (7.04)	16 352	10.85 (7.31)	146 682	−1.130*** (0.06)
Co-twin is male	191 838	50.4%	130 330	50.4%	16 352	51%	146 682	−0.006 (0.004)
Child is Deceased	191 838	32.2%	130 330	33.7%	16 352	39.3%	146 682	−0.056*** (0.004)
Number of previous boys	191 838	1.59 (1.58)	130 330	1.67 (1.62)	16 352	1.46 (1.45)	146 682	0.207*** (0.012)

(Continues)

TABLE 1 (Continued)

Panel B: Survival dataset (used for survival analyzes)	(1) All twins (N = 191 838)		(2) Africa (N = 130 330)		(3) South Asia (N = 16 352)		(4) Difference (African twins–South Asian twins)	
	N	Mean (SD) or proportion	N	Mean (SD) or proportion	N	Mean (SD) or proportion	N	Mean (SE)
Maternal education (years)	190 776	3.83 (4.42)	130 232	3.25 (4.12)	16 334	2.46 (3.89)	146 566	0.793*** (0.032)
Household occupation incl. agric.	191 838	46.8%	130 330	52.5%	16 352	26.5%	146 682	0.260*** (0.004)
Proceeding birth interval (months)	156 691	37.23 (22.87)	108 981	36.93 (21.52)	13 066	34.9 (21.33)	122 047	2.033*** (0.198)
Maternal age at first birth (years)	189 314	19.19 (3.87)	127 806	18.87 (3.75)	16 352	18.71 (3.56)	144 158	0.154*** (0.03)
Number of countries	72		39		5			
Number of surveys	201		121		11			

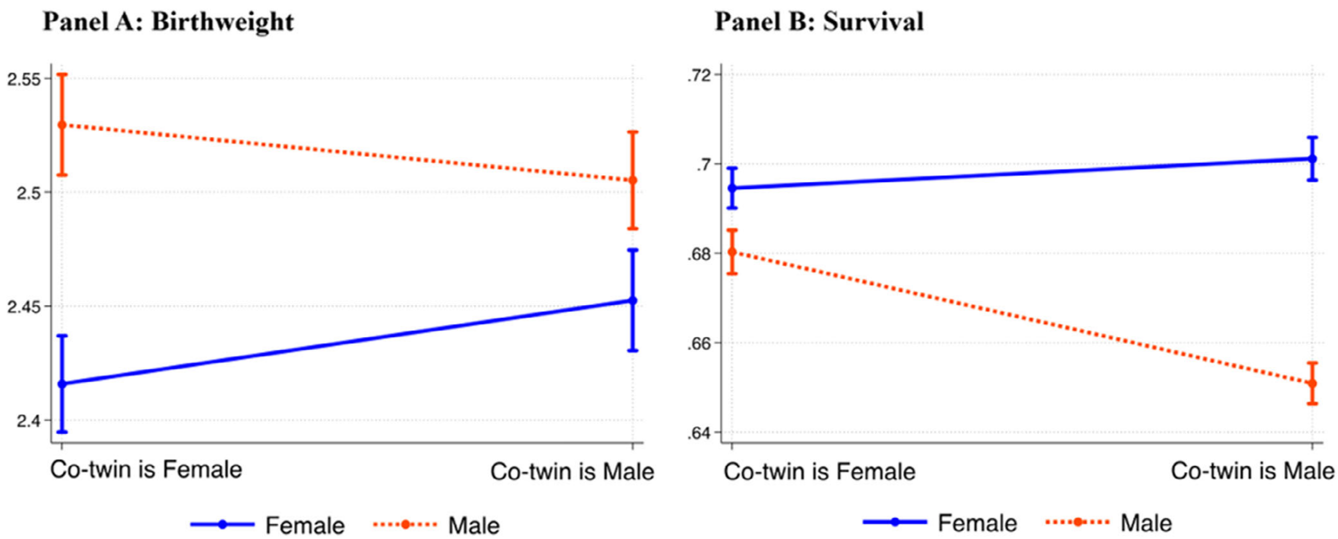

FIGURE 1 Predicted effect of having a female or male co-twin on birthweight and survival, by sex of child. Panel A: Birthweight Panel B: Survival. Data shown are the predicted differences in birthweight (Panel A) and survival (Panel B) associated with having a male co-twin (on the right side of each panel), compared to having a female co-twin (on the left), for females (in blue solid lines), and males (in red dotted lines). The marginal effects in panel A are from an OLS regression (Model 2 of Table 2) while that in panel B are from a logistic regression (Model 2 of Table 3). All models control for survey year and country fixed effects. The error bars represent the 95% confidence intervals of the point estimates. Standard errors are clustered at the enumeration area level.

4.1 | Effects of co-twin sex on birthweight

Our principal anthropometric finding is that having a male rather than female co-twin is associated with lower birthweight and survival for boys and with a higher birthweight with no significant survival advantage for girls (Figure 1). Boys with a male co-twin are 70 g lighter than boys with a female co-twin (Table 2). Estimation of the magnitude of these differences is shown in Table 2,

TABLE 2 OLS regressions for birthweight of twins across 66 countries, 1990–2016.

	(1)	(2)	(3)
	OLS	OLS	OLS
Male	0.08*** (0.06–0.10)	0.11*** (0.08–0.14)	0.12*** (0.09–0.15)
Co-twin is male		0.04* (0.01–0.07)	0.02 (−0.01–0.06)
Male X co-twin is male		−0.06* (−0.11 to −0.01)	−0.07* (−0.12 to −0.01)
Maternal education (years)			0.00 (−0.00 to 0.01)
Household occupation incl. agric.			0.03 (−0.01 to 0.06)
# of boys born prior to index child			0.03** (0.01–0.05)
Short birth interval (<24 months)			0.04* (0.00–0.08)
Mother's age at first birth			0.01*** (0.00–0.01)
Constant	2.66*** (2.45–2.86)	2.64*** (2.43–2.85)	2.50*** (2.17–2.83)
Country FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Observations	18 879	18 856	17 235
R-squared	0.11	0.11	0.11

Note: Dependent variable is child birthweight in kg. The coefficients in columns 1–3 are OLS regression estimates with 95% confidence intervals in parentheses, and significance levels are denoted ***$p < .001$, **$p < .01$, and *$p < .05$. Standard errors are clustered at the enumeration area level.

starting with the observation of larger birthweights for males than females in each of the unadjusted and adjusted models in Columns 1–3. A 70-g difference represents about a 2.8% difference in birthweight compared to the average birthweights for twins, which in this sample is 2.47 kg (Table 1). The difference of 70 g is about 15%–20% of the difference found for children of mothers who smoke tobacco cigarettes during pregnancy, a known significant risk factor for low birthweight (Kataoka et al., 2018). Therefore, the sibling rivalry effect estimated here is smaller in magnitude than the effect of smoking during pregnancy, which is to be expected, but is still a concern for future child health outcomes. Regression results for the split-sample tests by region are shown in Table S3.

A more intuitive depiction of the birthweight effect of having a male as opposed to a female co-twin is presented in the marginal plots of Figure 1. Panel A of Figure 1 shows that males who share the uterus with a male co-twin experience a significantly lower birthweight. On the other hand, females with a male co-twin are born heavier relative to those with a female co-twin. These interesting patterns can also be gleaned from Figure S1 (Panel A) which shows differences in the unconditional average birthweight between the different twin sex-pairs.

4.2 | Effects of co-twin's sex on heights and weights

We find no consistent association between the co-twin's sex and the child's attained height or weight. Results of the regression models for these outcomes are shown in the supplemental information, in Tables S1 and S2. Moreover, the unconditional averages of these outcomes disaggregated by twin sex-pair types also reveal similar patterns (Figures S4 and S5). Several factors could account for the null results, including behavioral responses and parental sensitivities to the child's sex and their observed health over the first 5 years after birth (Browne et al., 2018). The two-sample Kolmogorov–Smirnov test for equality of distributions in Table S4 shows a higher estimated HAZ and WHZ for females with female co-twin relative to those with male co-twin, but no difference for male children who draw a male versus female co-twins, and no difference between the different twin sex-pairs in terms of WHZ scores.

4.3 | Effect of co-twin's sex on survival

Logistic regression and Kaplan–Meier curves reveal a significantly lower likelihood of survival among males whose co-twin is also male, compared to females with a male or female co-twin. Regression results in Table 3 show lower survival for male twins, and considering the effect of their co-twin reveals an additional survival penalty among males whose co-twin is also male (OR = 0.87, CI: 0.83, 0.91, $p < .001$). Males with a male co-twin are therefore, 0.87 times as likely to survive to the time of the survey than males with a female co-twin. On the other hand, females have a survival advantage over males irrespective of the sex of their co-twin. These results are

TABLE 3 Logistic regression of twin child survival across 202 surveys, 1990–2016.

Variable name	Type	(1)	(2)	(3)	(4)
Male	Binary	0.84*** (0.83–0.86)	0.93*** (0.90–0.96)	0.92*** (0.89–0.95)	0.93*** (0.90–0.96)
Male co-twin	Binary		1.03* (1.00–1.07)	1.02 (0.99–1.06)	1.00 (0.97–1.03)
Male X co-twin is male	Binary		0.84*** (0.80–0.89)	0.86*** (0.82–0.91)	0.87*** (0.83–0.91)
Child's age (years)	Continuous			0.88*** (0.87–0.89)	0.89*** (0.88–0.90)
Child's age (years)^2	Continuous			1.01*** (1.01–1.01)	1.01*** (1.00–1.01)
Child's age (years)^3	Continuous			1.00*** (1.00–1.00)	1.00*** (1.00–1.00)
Maternal education (years)	Integer				1.06*** (1.05–1.06)
Household occupation incl. agric.	Binary				0.84*** (0.82–0.86)
# of boys born prior to index child	Years				1.03*** (1.02–1.04)
Short birth interval (<24 months)	Binary				0.60*** (0.58–0.61)
Maternal age at first birth (years)	Continuous				1.03*** (1.02–1.03)
Constant		0.20*** (0.14–0.28)	0.20*** (0.14–0.28)	0.09*** (0.07–0.13)	0.27*** (0.19–0.39)
Country FE		Yes	Yes	Yes	Yes
Year FE		Yes	Yes	Yes	Yes
Observations		191 838	191 838	191 838	188 266

Note: Dependent variable is child survival, an indicator variable equal to 1 if the child was alive at the time of the survey and 0 otherwise. The coefficients in Models 1–4 are odds ratios from logistic regressions using the DHS dataset of all children ever born.

***$p < .001$, **$p < .01$, and *$p < .05$.

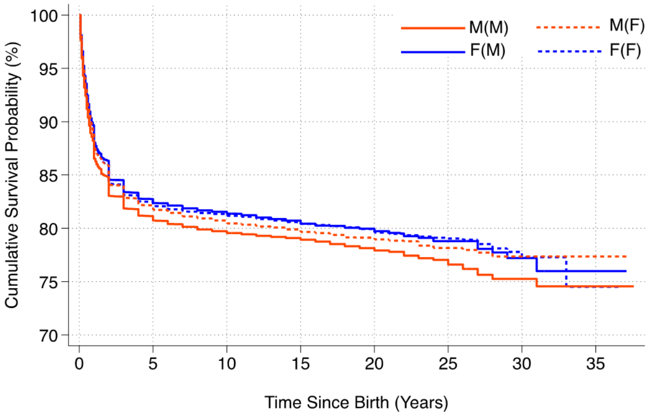

FIGURE 2 Cumulative survival probabilities for male and female twins, by sex of their co-twin. Data shown are Kaplan–Meier cumulative survival probability curves by twin sex-pair types. Survival probabilities are fractions of all recorded children who were reported to be alive at each number of elapsed years since birth. Survival probabilities are shown as solid lines when the co-twin is male and dashed when the co-twin is female, in a lighter shade for males (red in online versions) and a darker shade for females (blue in online versions). Subjects enter at time = 0 (baseline, at birth of a child) where all twin children are at risk and the survival probability is 1 (or 100%). In each subsequent year following birth, the survival probability is computed using $S_{t+1} = S_t{*}((N_{t+1} - D_{t+1})/N_{t+1})$. The graph is created using "sts graph" command of Stata MP software.

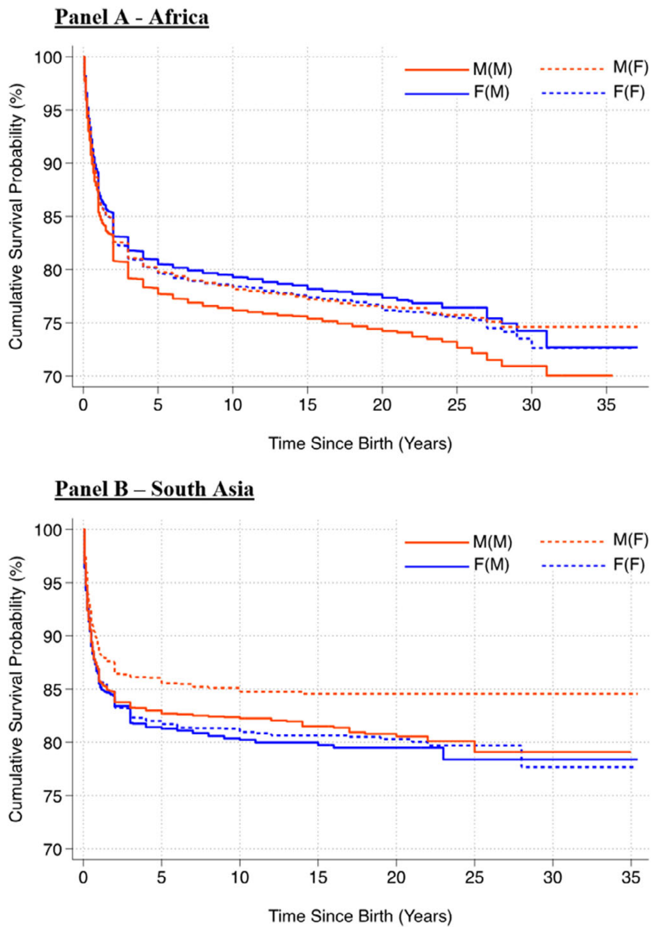

FIGURE 3 Cumulative survival probabilities for male and female twins, by region and sex of their co-twin. Panel A—Africa, Panel B—South Asia. Data shown are Kaplan–Meier cumulative survival probability curves by twin sex-pair types and geographic region. Survival probabilities are fractions of all recorded children who were reported to be alive at each number of elapsed years since birth. Survival probabilities are shown as solid lines when the co-twin is male and dashed when the co-twin is female, in a lighter shade for males (red in online versions) and a darker shade for females (blue in online versions). Subjects enter at time = 0 (baseline, at birth of a child) where all of the twin children are at risk and the survival probability is 1 (or 100%). In each subsequent year following birth, the survival probability is computed using $S_{t+1} = S_t{*}((N_{t+1} - D_{t+1})/N_{t+1})$. The graph is created using "sts graph" command of Stata MP software.

shown graphically using marginal plots (Panel B of Figure 1), and the unconditional average survival proportions (Figure S2).

The survival differential between the different twin sex-pairs across the life-course is shown in the KM survival probability curves (Figures 2 and 3). Over the entire sample in Figure 2, survival probabilities for males with a male co-twin rise above the curve for males with a female co-twin over the first 5 years, then the two curves run parallel until the gap grows again after 20 years. In contrast, females with male and female co-twins have similar KM curves at all ages. These curves are comparable to each other but are systematically lower than other survival estimates because the data were elicited retrospectively in cross-sectional surveys, rather than prospectively in cohort studies or vital statistics. In these results, more elapsed time since birth implies an earlier birth year, at a time when survival rates were lower than for children born in later years.

When comparing Africa to the smaller South Asia sample in Figure 3, we note a similar pattern for male children with a male co-twin as their cumulative survival probability falls more sharply and much earlier than those with a female co-twin. The drop in the survival of males with a male co-twin is more pronounced in the first 5 years of life and after about 15 years of age. However, unlike the pattern among African twins, females have the lowest survival probabilities in South Asia across the life-course whether they draw with a male or female co-twin (Figure 3). Similarly, a log-rank test for equality of survival functions indicates that there are differences in the survival of males depending on the sex of their co-twin, but not for female twins (Table S5).

5 | DISCUSSION

Sex and gender inequities are significant challenges across the life course. Male children have been shown to suffer from more growth faltering, higher mortality, and greater prevalence of certain diseases relative to female children in many contexts. Therefore, as living conditions improve and overall mortality falls, assuming there are no sex-specific changes in the treatment of children, the female advantage in child and adolescent health would be expected to *increase*. However, when there is differential treatment of children after birth, the female advantage disappears or even reverses, depending on the nature of the prevailing gender biases. Gender bias in caregiving of children can be difficult to disentangle from sex-specific hormones or other influences on child health and development. Leveraging twin study designs further may facilitate research in this area.

Sibling-rivalry externalities occur in utero and could reflect dose–response relationships in circulating testosterone. The *testosterone transfer hypothesis* is that circulating testosterone from a male co-twin may result in the prenatal development of more masculine features for his female co-twin, but the evidence for this is relatively weak so far among humans and requires additional research (Ahrenfeldt et al., 2017; Tapp et al., 2011). Animal studies of mice, rats, and gerbils have demonstrated that testosterone can diffuse across fetal membranes in utero and that females gestating next to males had more masculine traits compared to females gestating next to other females (Tapp et al., 2011). Measurements of circulating testosterone are not feasible during human pregnancies, so the research must rely on proxies, and the evidence is currently mixed.

This study contributes to understanding the role of sex-specific factors and gender bias in human development by assembling an exceptionally large and diverse dataset of twins in 72 low- and middle-income countries. Our dataset allows us to control for several determinants of gender differences in health, through gestation, infancy, and early childhood. Most measures of gender disparities in health come from comparing differences in outcomes subject to omitted variable bias, but we use each twin as the other's control to reduce the risk of omitted variable bias. We use recorded birthweights, attained heights, weights, and survival to determine whether differences in child health started in utero or emerged later in life, and test whether effects are due to a child's own sex, their co-twin's sex, or the interaction of the two. Twin pregnancies and births are a special case that can be used to estimate how resources are shared between siblings, starting in utero before caregivers could begin to treat the two infants differently.

In the context of sex-specific externalities, the sibling rivalry we observe is such that male–male twin pairs reduce each other's birthweights and survival prospects. We find clear evidence for lower birthweight and lower survival among males with a male co-twin, while females have higher birthweight when their co-twin is male instead of female. These results are consistent with earlier findings from smaller studies (Azcorra, 2020; Glinianaia et al., 1998). We find no detectable effect of co-twin sex with attained heights and weights, perhaps due to behavioral investments or parental sensitivities favoring boys after each twin pair is born, but other work has found that boy children are at a higher risk for stunting than girls in Sub-Saharan Africa (Wamani et al., 2007).

The evolution of both biological and social influences on parental investments in children could be subject to the hypothesis of Trivers and Willard (1973), in settings where selection pressures would favor traits and behaviors that protect the health and survival of females during times of scarcity, and lead to higher male–female sex ratios at times of abundance (Bruckner et al., 2022.; Trivers & Willard, 1973). Taking account of any such "male frailty" in populations under stress would be important for understanding behavioral biases and guiding intervention to promote child development, by establishing baseline expected outcomes for male and female infants given local conditions at the time of their birth (Vu et al., 2018).

5.1 | Twin studies in low- and middle-income countries

Data on twins typically come from volunteer registries and medical records in high-income settings, and are used for many purposes in the health sciences and social sciences (Behrman, 2016; Groene et al., 2022). Twin pregnancies have more adverse outcomes than other births (Cho & Lee, 2022; Groene et al., 2022; Vogel et al., 2013). Extracting data on twins from the DHS provides evidence from diverse and often more adverse environments than most prior twin studies, and twin pregnancies themselves have more adverse outcomes than other births (Vogel et al., 2013). Studying twins in the DHS provides a window into child development under a broader range of resource scarcity than most other data sources, and the surveys' design allows comparison over several key outcomes. Our analysis of sibling rivalry focuses on interaction effects in utero and infancy between males and females, as suggested by previous studies with smaller datasets, tracing the mortality results of Pongou (2012) and Kashyap and Behrman (2020) to earlier health outcomes (Calais-Ferreira, Mendonça, et al., 2021b; Barzilay et al., 2019;

Bayraktar et al., 2021; Glinianaia et al., 1998; Goldman et al., 2003; Kashyap & Behrman, 2020; Malinowska et al., 1998; Pongou, 2012).

5.2 | Limitations

Three main limitations of our analysis are (1) sample selection into twinning, (2) lack of data on gestational age, and (3) measurement error of birthweight. Our sample of twins comes from nationally representative surveys of all mothers with children under five, but the population of twins is not representative of all children in the dataset. Even in the absence of fertility treatment, twinning rates typically rise with maternal age, and twins have higher risks of preterm birth, lower birthweight, lower Apgar scores, and higher mortality than singletons (Jaffar et al., 1998; Justesen & Kunst, 2000; Monden et al., 2021). Selection into twinning is not random, and twins have systematically different health outcomes compared with singletons. Our study, therefore, concerns differential outcomes for children with a higher risk of exposure to adverse gestational factors and who were born alive. Our results may also be affected by gestational age, as demonstrated by a pooled analysis of 21 twin cohorts from 15 countries, and we cannot control for gestational age because the survey does not include that data for children who have been born, it is only estimated for current pregnancies at the time of the survey (Jelenkovic et al., 2018). Other work on twins in Canada has shown that birthweight is the only outcome measure that still differed by sex after controlling for gestational age, birth order, and other factors, which tells us that even if gestational age cannot be included in the model, birthweight depends on sex even after controlling for gestational age (Jahanfar & Lim, 2016).

While household surveys like the DHS are important sources of information on birthweight, there are data quality concerns due to difficulty of measurement, and about half of all recorded birthweights are heaped at intervals of 500 g (Biks et al., 2021). Our results should be interpreted given the limitations of the birthweight indicator and its measurement. Selection into birthweight recording is more likely for live births, and for births that occur at a facility instead of at home, and for women who have control over their babies' health records and health cards. Access to health cards and being birthed in a facility are also factors that indeed affect later health outcomes. The statistical impact of heaping of birthweights will be an attenuation of the measured association, which typically makes estimates more conservative (i.e., biased toward the null hypothesis) than the underlying true parameters (Bar & Lillard, 2012).

6 | CONCLUSION

The sibling rivalry we describe here is such that male–male twin pairs reduce each other's birthweights and survival prospects and that both sex-specific differences and gender bias that affect child health exist at different stages. Facts about twins can help reveal otherwise hidden aspects of child development such as male frailty, which in turn could help avoid underestimating the effect of son preference and behavioral factors favoring boys after they are born. We find significant rivalry between male twins, as drawing a male instead of female co-twin significantly lowers a boy's birthweight, whereas female twins with a male co-twin reach a higher birthweight relative to those with a female co-twin. Our large and diverse dataset also reveals that drawing a male co-twin negatively affects a boy twin's survival, while females have no difference in survival rates whether they draw with a male or female co-twin.

Estimated differences are large enough to result in underestimates of the effects of son preference and behavioral factors that typically favor boys after birth, because male frailty may end up largely balanced out with gender bias in favoring resource allocation toward boy children. Therefore, the absence of a gender disparity in child survival within a population of interest may indicate that girl children have already faced even more inequitable resource allocation than initially estimated. Further, use of periodic large-scale household surveys and other new sources of data about twins can help identify the various mechanisms that underlie health disparities and thereby could help inform health interventions and improve estimates of gender disparities around the world.

AUTHOR CONTRIBUTIONS

William A. Masters, Amelia B. Finaret: conceived the study. **William A. Masters, Amelia B. Finaret, Robel Alemu:** assembled the data and conducted the literature search. **Robel Alemu:** conducted the data analysis and wrote the manuscript. **William A. Masters, Amelia B. Finaret, Robel Alemu:** interpreted the data. **Amelia B. Finaret, William A. Masters:** edited the manuscript.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available in ICF International at https://dhsprogram.com/. These data were derived from the following resources available in the public domain: - Available Datasets, https://dhsprogram.com/data/available-datasets.cfm

ETHICS STATEMENT

Procedures and questionnaires for DHS survey data have been reviewed and approved by ICF International IRB and each country-specific IRBs.

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Additional supporting information can be found online in the Supporting Information section at the end of this article.

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