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Sibling composition during childhood and adult blood pressure among native Amazonians in Bolivia☆

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ABSTRACT

Sibling configuration, including birth order, or the number, age, and sex of siblings is associated with parental resource allocation between children and is thus associated with a person's well-being. Little is known about the association between specific types of siblings and adult health outcomes. Here we test several hypotheses about sibling composition (number of older brothers, older sisters, younger sisters, younger brothers) and adult blood pressure in a foraging-farming society of native Amazonians in Bolivia (Tsimane'). We collected data in 2007 from 374 adults (16–60 years of age) from 196 households in 13 villages. Household random-effects multiple regressions were run using systolic (SBP) or diastolic blood pressure (DBP) as outcomes; covariates included the four sibling categories and control variables (e.g., sex, age, education, body mass index [BMI]). Mean SBP and DBP were 114 (SD = 14) and 66 (SD = 11) mmHg. The prevalence of hypertension was 5.08%. Having an additional younger brother bore a small (3.3–5.9%) positive association with both SBP and DBP, with the effect weakening as people aged. Having an additional younger sister was associated with a small (3.8%) increase in SBP among women, with the magnitude shrinking as people aged. In a large family, the number of younger brothers may exert an impact on an individual's blood pressure.

1. Introduction

Sibling configuration, including birth order or the number, age, and sex of siblings is associated with the allocation of parental resource between offspring (Butcher and Case, 1994; Conley, 2000; Dayioðlu et al., 2009; Garg and Morduch, 1998; Khoury et al., 1984; Zeng et al., 2012), and is thus associated with a person's well-being. Steelman et al. (2002) reviewed the literature on sibling configuration and concluded that people with many siblings had less

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education and less wealth in adulthood, and that birth order affected a person's educational attainment.

Recently, studies on sibling configuration have been extended to health outcomes. Some studies have documented the links between (a) adult health and either (b) sibling size or with birth order. Lawson and Mace (2008) followed 13,176 British children from birth to 10 years of age and found that an additional older sibling of either sex depressed the growth rate and height of younger siblings. Garg and Morduch (1998) studied 5203 children in Ghana and found that an additional sister was associated with a greater *Z*-score of height-for-age among older siblings. Wang et al. (2007) studied 7959 junior high-school students in Japan and found that the risk of being overweight among boys was negatively associated with the number of older sisters, whereas the risk of being overweight among girls was negatively associated with the number of any siblings. Several studies (Bernsen et al., 2003; Karmaus et al., 2001; Karmaus and Botezan, 2002; Miyake et al., 2004; Ohfuji et al., 2009; Westergaard et al., 2005) suggest that having older siblings protects against the risk for allergies and respiratory infections.

We draw two conclusions from this literature. First, there seems to be a link between sibling configuration and health among children, and some of these links may persist into adulthood. Second, researchers have generally examined how broad categories of siblings (e.g., sisters versus brothers; older siblings versus younger siblings) affect health, but they have paid less attention to the comparative effects of specific sibling categories (e.g., having an additional older brother) on health. We equate the term *sibling size* with the total number of siblings, and use it instead of the synonym *sibship size*. We shall have more to say about the term *sibling composition*, but for the most part we use it to refer to the specific number of older brothers, older sisters, younger brothers, and younger sisters of a person.

Despite increasing interest in the relation between siblings and health, there is still disagreement on whether siblings contribute to a person's good health (Williams, 1997). The disagreement arises from four possible reasons. First, most studies use sibling size, birth order, or sex composition without distinguishing the role of specific sibling categories, which may matter when specific sibling categories play a prominent role (e.g. older brother versus older sister). Second, some health indicators may be more sensitive to early life events while others not. Careful selection of indicators would strengthen the internal validity of the research. Third, the social setting probably matters. In a society with a pro-male bias, brothers would likely affect the education and health of sisters, but the effects of brothers would be less salient in a society without a marked pro-male bias. Last, sibling composition is endogenous, and likely reflects parents' biological characteristics and parental preferences for the sex and number of offspring (Khoury et al., 1984; Ruder, 1985). The inability to address the endogeneity of sibling configuration may bias results.

Here, we use data from a native Amazonian society of forager-farmers in Bolivia, Tsimane', to examine the association between particular types of siblings and blood pressure in adulthood. The use of the Tsimane' as a case study has merit because Tsimane' families are large with many siblings, and because the impact of siblings on health is likely to be prominent because the Tsimane' face many resource constraints (Rucas et al., 2010; Godoy et al., 2005).

We selected blood pressure as an outcome for two reasons. First, blood pressure predicts risks of cardiovascular diseases (Beevers, 2004; Pastor-Barriuso et al., 2003), the leading cause of death in industrializing nations (Gaziano, 2007). Second, studies have shown contemporaneous associations between (a) blood pressure and variables associated with socioeconomic status (SES; e.g., schooling) and between (b) sibling composition and these same variables for socioeconomic status (Blane et al., 1996; Lawlor et al., 2006; Steelman et al., 2002; Sweet et al., 2007). Therefore, we expect a relation between blood pressure and sibling composition.

Drawing on the theory of human capital (Becker, 1991) and on the ethnographic characteristics of the Tsimane', in this exploratory study we test four hypotheses about the links between sibling composition and adult blood pressure:

1. Having older brothers will increase the blood pressure of younger siblings, particularly of sisters. The theory of human capital predicts that in a pro-male society parents will skew investments to boys because the labor market favors males (Gibson and Sear, 2010; Garg and Morduch, 1998). Tsimane' women have lower economic and educational attainment than Tsimane' men of the same sex and age (Godoy et al., 2006b). Under such conditions, having older brothers will harm girls because brothers will compete for and dilute the fixed amount of parental resources available to invest in all offspring. Given the negative association between socioeconomic status and blood pressure (Blane et al., 1996; Lawlor et al., 2006), having older brothers should be associated with higher blood pressure among younger siblings.
2. Having older sisters will be associated with an increase in the blood pressure of younger siblings, mostly of younger sisters. Older sisters divert resources away from younger siblings. In a society with a pro-male bias, such as Bolivia, the impact of older sisters may not be strong among younger brothers, but may be more prominent among younger sisters.
3. Younger siblings, particularly younger brothers, will increase the blood pressure of older siblings, particularly of older sisters. Given the responsibilities of older sisters (e.g. taking care of younger siblings) and older brothers (e.g. finding job for younger brothers) in Tsimane' society, younger siblings are likely to likely to increase the work load and stress of older siblings, which should result in higher blood pressure among older siblings.
4. The associations between sibling configuration and adult blood pressure will be more marked in poorer households. The theory of human capital makes clear predictions about the strength of the associations between sibling composition and parental investments. It predicts that the effects will be most marked in

societies with a sharp gender bias in the labor market, and among households facing more binding resource constraints and fewer possibilities of lifting those constraints. For this reason we would expect that the effects of siblings on blood pressure will be more marked among households with fewer resources.

For the empirical analysis we use a sample of 206 men and 220 non-pregnant women ≥16 years of age surveyed during 2007. We estimate the association between (a) systolic blood pressure (SBP) and diastolic blood pressure (DBP) (outcome variables) and (b) the number of younger sisters, younger brothers, older sisters, and older brothers that people currently had (main explanatory variables). In the main analysis we excluded people > 60 years old to avoid the influence of older age on blood pressure (Feldman et al., 2012; Sander, 2004), but we include them in the sensitivity analysis. The final sample used in the main analysis consists of 181 men and 193 non-pregnant women with complete data on all the outcomes and explanatory variables.

2. The Tsimane'

The Tsimane' are a native Amazonian society of farmers and foragers who live mainly in the department of Beni, Bolivia. They number ~15,000 people and live in ~120 villages, each of which has an average of 19.3 households (standard deviation [SD] = 11.8 households). In modern times, the Tsimane' have been in sporadic contact with Westerners since the early 1950s (Huanca, 2008; Ringhofer, 2010). Tsimane' subsistence centers on hunting, fishing, plant foraging, and slash-and-burn farming. 75% of Tsimane' practice preferential, bilateral, cross-cousin marriage, meaning that a man marries the daughter of his mother's brother or his father's sister (Godoy et al., 2008). Though infant or childhood mortality are similar between the sexes (Godoy et al., 2010b; Zeng et al., 2012), adult women lag behind men in formal schooling, academic skills, fluency speaking Spanish, monetary income, and the value of physical assets they own (Godoy et al., 2006b). For example, adult men earn 520% more income, own 173% more wealth, are 7% more likely to speak Spanish, and have 0.28 more years of education than adult women (Godoy et al., 2006b; Zeng et al., 2012).

Two recent publications contain ethnographies, histories, and descriptions of the geographic setting of the Tsimane' (Huanca, 2008; Ringhofer, 2010). Recent publications also contain descriptions of the general health and economic status of the Tsimane' (Godoy et al., 2006a, 2010a; Nyberg, 2009; Tanner et al., 2009; Patel et al., 2007). Since background material has been covered elsewhere, we limit the rest of this section to a discussion of sibling composition.

Adult Tsimane' in the sample had an average of 6.9 siblings and a median of seven siblings (SD = 2.7 siblings; range: 0–11). Table 1 suggests that between younger sisters and younger brothers, or between older sisters and older brothers, the number of brothers exceeded the number of sisters. Specifically, Tsimane' had an average of 1.4 younger sisters (SD = 1.4), but they had an average of 1.8 younger brothers (SD = 1.7). The difference was statistically significant ($t = 4.20$, $p = 0.001$). On average, Tsimane' had 1.5 older brothers (SD = 1.5), but they had only 1.3 older sisters (SD = 1.3). The difference between the mean number of brothers and sisters was statistically significant ($t = 2.48$; $p = 0.013$).

The skewed ratio in the number of brothers compared with the number of sisters could reflect (a) greater omission when recalling the number of sisters than when recalling the number of brothers, (b) selective mortality of females in the past, and (c) pro-male preference.

3. Materials and variables

3.1. Materials

Information comes from the 2007 survey of an annual panel study among all Tsimane' in 13 Tsimane' villages along the Maniqui River, department of Beni (Leonard and Godoy, 2008). The panel study started in 2002 and continued uninterruptedly until 2010. At the start of the panel, we selected the 13 villages to capture geographic variation in proximity to the market town of San Borja (mean village-to-town distance = 25.96 km; SD = 16.70 km),

Table 1
Sibling composition of Tsimane' adults (16–60 years of age; $n = 374$), 2007.

Number of siblings	Sibling category							
	Sisters				Brothers			
	a. Younger		b. Older		c. Younger		d. Older	
	Obs	%	Obs	%	Obs	%	Obs	%
0	123	32.89	119	31.82	114	30.48	110	29.41
1	91	24.33	113	30.21	74	19.79	109	29.14
2	87	23.26	76	20.32	71	18.98	71	18.98
3	40	10.70	43	11.50	54	14.44	43	11.50
4	24	6.42	18	4.81	36	9.63	21	5.61
5	6	1.60	3	0.80	15	4.01	15	4.01
6	3	0.80	2	0.53	7	1.87	3	0.80
7					3	0.80	2	0.53
Total		100.00		100.00		100.00		100.00
Mean	1.4		1.3		1.8		1.5	
Standard deviation (SD)	1.4		1.2		1.7		1.5	

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the only town along the Maniqui River. For this article we use the 2007 survey because it is the only time we asked about sibling composition and measured blood pressure at the same time.

The 374 adults between 16 and 60 years of age (non-pregnant women = 193; men = 181) came from 196 households. The average age in the sample was 33.87 years (SD = 11.54). We chose 16 years of age as a cut-off to define adulthood because at that age Tsimane' set up their households and stop attending school. The median age of first union for women was 16 years (SD = 3.14) and the median age of first union for men was 19 years (SD = 3.14).

Surveyors visited villages twice during June-September, 2007. During the first visit, surveyors collected socio-economic and demographic data. During the second visit, surveyors took anthropometric measures, asked about perceived health, and measured blood pressure. Surveys took place in the home of study participants, but blood pressure and anthropometric measures were taken in the village school. Four Bolivian university graduates did the surveys and four Tsimane' who worked in the panel study from its beginning translated survey questions.

3.2. Variables: blood pressure and sibling composition

Using an automatic blood pressure monitor, surveyors took three measures of blood pressure for each adult on the upper left arm according to standard protocol, with the participant's feet on the floor and arm rested at heart level. Each participant was seated and rested for at least five minutes before the initial measure and for a minimum of two minutes between successive measures (Alpert et al., 2006). Participants remained still until we completed the three measures. For the analysis we used the average of the three measures. A recent university graduate with a bachelor's degree in biology and a Tsimane' translator who had worked in the project from the beginning took blood pressure; Nyberg and Tanner trained the staff to measure blood pressure.

Surveyors asked each adult in the household for the current number of living younger sisters, older sisters, younger brothers, and older brothers. We took two steps to reduce errors in the measure of sibling composition. First, we only asked about siblings from the same mother; we did not ask about half siblings on the father's side to reduce the response burden on participants. Second, we only asked about currently living siblings. Asking people to recall their sibling composition during childhood would have provided a better metric of the possible sibling rivalry faced by the target subject when the subject was a child, but the measure would have been vulnerable to recall bias from omission. Based on the four categories of siblings, we calculated sibling size and an index of birth order, expressed as (birth order − 1)/(sibling size − 1) (Dayioðlu et al., 2009). The index of birth-order allows us to address the concern that children with low birth order tend to have a higher probability of being in a small household. In the analysis we transformed sibling size to its natural logarithm because the distribution for sibling size was skewed.

3.3. Control variables

Control variables in the regressions include a person's: (a) current age, (b) sex (men = 1; women = 0), (c) maximum schooling level attained (hereafter, education), and (d) body-mass index (BMI; weight [kg]/height [m]^2). We use education as a proxy for resource constrain since education tends to be positively associated with income in industrial nations (Alba-Ramirez and San Segundo, 1995; Ashenfelter and Rouse, 1998) and among the Tsimane' (Godoy et al., 2007).

4. Analysis

We first describe blood pressure among Tsimane' and compare it to other native Amazonian populations. We then analyze the data in two stages to examine the association between siblings composition and blood pressure. We do all the analyses separately for women and men.

[a]. *First stage: Association of blood pressure with different sibling categories*. We first estimate the association between blood pressure and different sibling categories. For greater clarity, we do the analysis separately for women and men. We constructed a basic model, leaving out path variables (e.g. education, BMI) that may mediate the association between sibling composition and blood pressure. We also leave out interaction terms between sibling composition and education, sibling composition and age, and their three-way interaction (sibling composition × age × education). We then incorporate these excluded variables in the full model. One problem with using different sibling categories as explanatory variables is that it ignores the possibility of more general effects from total sibling size. For this reason we move to the second stage.

[b]. *Second stage: Association of blood pressure with total sibling size or birth order*. In the second stage we merge different sibling categories to create a variable measuring the total number of siblings (sibling size) and then estimate the association between blood pressure and either total sibling size or birth order.

The regressions used in stage 1 or stage 2 include the natural logarithm of either systolic or diastolic blood pressure as outcomes because we assume the impact of covariates on blood pressure to be multiplicative. We use a household random-effects model to address individual household impacts. We do not use ordinary least squares (OLS) regressions since OLS regressions are unable to deal with household heterogeneity and would produce inefficient estimates. For the statistical analysis we use Stata for Windows, version 10 (Stata Corporation, College Station, TX).

5. Results

5.1. Description of blood pressure among the Tsimane'

Adults in the sample had a mean SBP of 115 mmHg (mmHg = millimeters of mercury) and a median SBP of 114 mmHg (SD = 14.4). Mean and median DBP were 66 mmHg (SD = 10.80) and 65 mmHg. DBP had more variation than SBP; the coefficients of variation (SD/mean) for SBP and DBP were 0.13 and 0.16. After controlling for age, men had 9.44 mmHg (t = 6.80, $p < 0.001$) or 8.29% (t = 7.09, $p < 0.001$) higher SBP than women (103 mmHg) and 3.21 mmHg (t = 2.94, p = 0.004) or 4.74% (t = 2.89, p = 0.004) higher DBP than women (61 mmHg).

Only 5.08% of the sample (19 out of 374) had hypertension, defined as DBP >90 mmHg or SBP >140 mmHg (U.S. Department of Health and Human Services et al., 2004). A χ^2 test showed no statistically significant difference between the share of women (9 out of 193 [4.66%]) and the share of men (10 out of 181 [5.52%]) with hypertension (χ^2 = 0.14; p = 0.70). A larger share of the sample, 29.14% (109 out of 374), showed evidence of pre-hypertension, defined as follow: DBP falls between 80 and 89 mmHg or SBP falls between 120 and 139 mmHg (U.S. Department of Health and Human Services et al., 2004). 40.88% of men but only 18.13% of women had pre-hypertension (χ^2 = 23.0; $p < 0.001$), and of the 109 people with pre-hypertension, 67.89% were men and 32.11% were women.

5.2. Comparison with other native Amazonian societies

In Table 2 we summarize published studies on mean blood pressure among other native Amazonian societies. To enhance the validity of the comparison, we specify the age and the sex composition of the comparison group, and then compute the statistic for the same demographic group among the Tsimane'. For example, if a study estimated systolic blood pressure among women 21–40 years of age, we compute the same statistic for Tsimane' women 21–40 years of age.

We found five published studies of blood pressure among other native Amazonian societies besides the Tsimane'. The samples used in these studies contained an average of 144 people, roughly evenly split between women (mean = 70) and men (mean = 75). The sample size of our study (men = 181; women = 193) was larger than the sample size of the other studies.

The results of Table 2 suggest that Tsimane' consistently had higher SBP than other native Amazonian groups. If there is a 50% probability that adult Tsimane' SBP is higher than the adult blood pressure of adults in other native Amazonian societies, the probability of observing higher SPB among adult Tsimane' for 10 consecutive times would be 0.0009. The higher SBP in our sample is unlikely to be due to chance. Probably, the sample used in this article captures the higher end of the distribution of blood pressure among native Amazonians. Since this study took place in 2007 and most of the studies summarized in Table 2 took place on or about the same time (1994–2009), we doubt that the differences could reflect secular changes in blood pressure in the region.

5.3. Regression results

[A]. *Different sibling categories* (Table 3). After controlling for BMI and education, only the number of younger brothers (Table 3, row b) bore a consistent association with adult blood pressure among both women and men. At age 16, the addition of a younger brother was associated with an increase in SBP of 4.4% (Table 3, row b, column III) among women and with an increase in SBP of 3.3% among men (Table 3, row b, column VII) and was associated with an increase in DBP of 5.9% among both women and men (Table 3, row b, columns IV and VIII). The effect diminished with age by ~0.1% per year (Table 3, row l).

Additional younger sisters were associated with increased blood pressure among women, but only when using SBP as an outcome. When people were 16 years old, the addition of a younger sister was associated with a 3.8% increase in SBP among women (Table 3, row a, column III). Again, as people aged, the impact of having an additional young sister waned by 0.1% per year (Table 3, row j, column III). We did not find a similar association between younger sisters and blood pressure among men. Neither did we find any associations between blood pressure and either older sisters or older brothers.

After including BMI and education as control variables (columns III–IV, VII–VIII), the coefficients for younger brothers became statistically significant. The coefficients for BMI were statistically significant in all four full regression models (Table 3, row n), which suggests that the association between siblings composition and blood pressure could not be fully explained by the role of BMI and education. Instead, there are probably other mechanisms

Table 2
Comparison of mean diastolic (DBP) and systolic blood pressure (SBP) among other native Amazonian societies and Tsimane'.

Other native Amazonian societies							Tsimane'		
Study	Group	Sex	Age	*n*	DPB	SBP	DBP	SBP	*n*
1.	Cofán	M	21–76	43	70	NA	68	NR	157
		F		27	68	NA	64	NR	160
2	Yanomano	M	20–59	99	64	101	68	120	160
		F		96	56	90	64	110	169
	Xingu	M	20–59	99	65	103	68	120	160
		F		99	59	96	64	110	169
3	Karaja	M	>17	26	66	106	68	120	178
		F		37	64	103	64	111	187
4	Parakateje	M	20–79	56	73	111	68	120	160
		F		34	70	107	64	110	169
5	Karib Xingu	M	20–79	125	70	107	68	120	160
		F		126	65	100	64	110	169

Notes: NA = not available; NR = not relevant for the comparison. Study: 1 = Fitton (2005); 2 = Mancilha-Carvalho and de Souza e Silva (2003); 3 = Silva and Eckhardt (1994); 4 = Tavares et al. (2003); 5 = Gurven et al. (2009).

Table 3
Relation between blood pressure and sibling composition among Tsimane' adults (16–60 years of age; $n = 374$), 2007.

Covariates	Women ($n = 193$)				Men ($n = 181$)			
	Basic model		Full model		Basic model		Full model	
	Systolic (I)	Diastolic (II)	Systolic (III)	Diastolic (IV)	Systolic (V)	Diastolic (VI)	Systolic (VII)	Diastolic (VIII)
a. # young sis	−0.001	−0.006	0.038*	0.005	0.000	−0.018*	−0.010	−0.028
b. # young bro	−0.006	0.011	0.044†	0.059*	0.012†	0.017†	0.033*	0.059†
c. # old sis	0.001	0.001	−0.005	0.010	−0.002	0.012	0.003	0.009
d. # old bro	−0.004	−0.001	−0.005	−0.012	0.002	−0.007	0.016	0.028
e. Age	0.003‡	0.002†	0.007‡	0.005†	0.001*	0.003‡	0.002	0.005†
f. # young sis × edu			−0.002	0.000			0.001	−0.004
g. # old sis × edu			−0.002	−0.005			0.001	−0.003
h. # young bro × edu			−0.004	−0.007			0.000	0.000
i. # old bro × edu			0.001	0.003			0.002	0.001
j. # young sis × age			−0.001†	0.000			0.000	0.001
k. # old sis × age			0.000	0.000			0.000	0.000
l. # young bro × age			−0.001‡	−0.001			−0.001	−0.001†
m. # old bro × age			0.000	0.000			−0.001	−0.001
n. BMI			0.008‡	0.009†			0.012‡	0.011‡
o. Edu			0.016	0.021			−0.004	0.012
Constant	4.657‡	4.109‡	4.393‡	3.826‡	4.731‡	4.132‡	4.444‡	3.828‡
Difference in the effect between brothers and sisters								
p. Young bro–young sis			0.007	0.054			0.043	0.087*
q. Old bro–old sis			0.0004	−0.022			0.013	0.019

Notes: SBP and DBP are in natural logarithm. Regressions include robust standard errors and clustering by household. Age is relative to 16 for ease of interpretation.
* Significant at the ≤10% level.
† Significant at the ≤5% level.
‡ Significant at the ≤1% level.

beyond education and BMI through which sibling composition is associated with blood pressure.

We tested whether the difference in the coefficients between younger brothers and younger sisters and those between older brothers and older sisters (Table 3, rows p and q) were statistically significant, and found no statistically significant differences between brother and sisters, with one exception. Although seven out of the eight coefficients that represented differential impacts between brothers and sisters were positive (but insignificant), one coefficient did show statistically significant results at 0.10 level (Table 3, row p, column VIII). An additional younger brother would increase the DBP of an adult men by 5.9% (Table 3, row b, column VIII), while having a younger sister would decrease the DBP of an adult men by 2.8% (Table 3, row a, column VIII).

We found no significant results for interaction terms between sibling composition and education (Table 3, rows f-i), which suggests that the association between sibling composition and adult blood pressure is not necessarily more prominent among people with fewer resources (as proxied by school attainment).

[B]. *Total sibling size and birth order* (Table 4). The broad conclusion of the analysis presented so far is that having younger siblings, particularly having younger brothers, is associated with higher adult blood pressure and that having brothers produces weaker associations. In this section we present results of additional analysis without specific sibling categories, but with the total number of siblings (sibling size) or with birth order as the main explanatory variables, and additional estimates for a wide range of interaction effects. Table 4 contains the regression results of the additional analysis.

First, of the eight coefficients for the main direct effects of the total number of siblings (sibling size) and of the eight coefficients for birth order (Table 4, rows a–b), only two coefficients were statistically significant. Among women, an increase in the birth order index was associated with lower blood pressure, but only when using SBP as an outcome. An increase in the birth order index of 0.1 when a woman was 16 years old was associated with a decrease of 1.2% in SBP (Table 4, row b, column III).

Second, we found no evidence of interaction effects between sibling size and age (Table 4, row f) and little evidence of interaction effects between the birth order index and age (Table 4, row g). Two of the four coefficients measuring interaction effects between age and birth order index were statistically significant, indicating that in spite of lower SBP and DBP among younger sisters in comparison with older siblings, the difference became smaller as people aged, at an annual rate of 0.68–0.82% (Table 4, row g, columns III and IV).

Third, we found no evidence of interaction effects between sibling size and education (Table 4, row d) or of interaction effects between the birth order index and education (Table 4, row e). Of the eight coefficients indicating interact effects between education and either sibling size or birth order index, none was statistically significant.

Fourth, we found little evidence of three-way interaction effects between sibling size, education, and age (Table 4, row h), and no evidence of three-way interaction

Table 4
Relation between blood pressure and sibling size and birth-order index (BOI) among Tsimane' adults (16–60 years of age; $n = 374$), 2007.

Covariates	Women ($n = 193$)				Men ($n = 181$)			
	Basic model		Full model		Basic model		Full model	
	Systolic (I)	Diastolic (II)	Systolic (III)	Diastolic (IV)	Systolic (V)	Diastolic (VI)	Systolic (VII)	Diastolic (VIII)
[a] Sib size	−0.016	0.015	0.026	0.042	0.034	0.018	0.051	0.090
[b] BOI	0.032	0.008	−0.120†	−0.108	−0.045*	−0.024	0.035	−0.073
[c] Age	0.003‡	0.002*	0.003	0.001	0.001	0.003‡	0.006*	0.009*
[d] Sib size × edu			−0.004	−0.008			0.009	−0.006
[e] BOI × edu			0.018	0.028			−0.011	0.017
[f] Sib size × age			−0.002	−0.001			−0.002	−0.003
[g] BOI × age			0.008‡	0.007*			−0.004	0.001
[h] Sib size × edu × age			−0.000	−0.000			−0.0004*	−0.000
[i] BOI × edu × age			−0.000	−0.002			0.001	−0.000
[j] Edu			0.010	0.018			−0.003	0.018
[k] BMI			0.007‡	0.009‡			0.013‡	0.013‡
Constant	4.660‡	4.092‡	4.472‡	3.853‡	4.714‡	4.128‡	4.320‡	3.677‡

Note: Same as Table 3, except variable BOI = (birth order − 1)/(sibling size − 1).
* Significant at the ≤10% level.
† Significant at the ≤5% level.
‡ Significant at the ≤1% level.

effects between the birth order index, education, and age (Table 4, row i). Only one of the eight coefficients of three-way interaction effects was statistically significant. The three-way interactions suggest that the association between sibling size and blood pressure depends on the level of education and age. As the main effect of sibling size was not statistically significant and the coefficients for the three-way interaction term were small, the effect of the interactions seems negligible.

5.4. Sensitivity analysis

After including people over 60 years of age and repeating the analysis using the same model specification as in Tables 3 and 4, we found that the signs and magnitudes of coefficients were similar to those reported in Tables 3 and 4 (additional results not shown). Having younger brothers was consistently and positively associated with higher blood pressure among older siblings. For SBP, the coefficients of younger brothers in the full model of Table 3 were 0.017 and 0.032 for men and women respectively. For DBP, the coefficients of younger brothers were 0.037 and 0.063 for men and women respectively.

5.5. Limitations

Parameter estimates for the four sibling categories of Table 3 or for the variable sibling size or birth order index of Table 4 might be biased or inefficient for several reasons. First, people might have reported the number of siblings with random measurement error from poor recall, producing an attenuation bias. Second, both because the elder have fewer living siblings than the young and because of positive associations between blood pressure and age and between siblings and blood pressure, we might have overestimated the impact of siblings on blood pressure. Third, we had no data on variables such as parental preferences and biological characteristics that probably mediate the relation between sibling composition and blood pressure (Dayioðlu et al., 2009; Khoury et al., 1984; Ruder, 1985). Unfortunately, we did not have instrumental variables to correct for the endogeneity of sibling composition. Fourth, observations in our sample might not be independent from each other. The Tsimane' are a highly endogamous, small-scale society so an individual could be a sibling to others in the sample, which would result in inefficient, albeit unbiased and consistent estimates. Last, we lacked data to control for co-variates of blood pressure, such as smoking and alcohol use of siblings.

6. Discussion and conclusions

6.1. Prevalence of hypertension

Among Tsimane' adults the prevalence of hypertension is low (∼5.0%) compared with the prevalence of adult hypertension in developing countries (20–30%) (Damasceno et al., 2009; Hendriks et al., 2012; Ma et al., 2012). The prevalence of hypertension is slightly higher than the prevalence measured by Gurven et al. (2012) for a different sample of Tsimane'; they found prevalence rates of 3.9% for women and 5.2% for men. Although the share of adults with hypertension is low, the share of adult Tsimane' with pre-hypertension is high (∼30%). A study in the same Tsimane' population found that adults' BMI increased at an annual rate of 0.64% and 0.37% among women and men during 2002–2006 (Zeng et al., in press). As incomes in a society increase, the prevalence of hypertension often increases, which would increase the risk of cardiovascular illnesses, in conjunction with increased obesity, and the expenses to treat and prevent them.

6.2. Hypotheses

This study used sibling composition, sibling size, and birth order index to estimate the association between sibling configuration and blood pressure in a low-income rural society. We found that having more siblings might be detrimental to a person's cardiovascular health. The most important finding is that younger siblings, particularly younger brothers, are associated with higher blood pressure of older siblings (H3). Using the average values of SBP and DBP and the average age of people in the sample, we found that having a younger brother was associated with 1.65 mmHg higher SBP and with 4.32 mmHg higher DBP among older sisters, and with 1.02 mmHg higher SBP and 4.70 mmHg higher DBP among older brothers. In a typical family with seven siblings, and assuming that the eldest brother or sister had three younger brothers, he or she would have 3.06–4.95 mmHg higher SBP and 12.96–14.10 mmHg higher DBP, which could result in significant clinical implication in certain circumstances (Adler et al., 2000). Thus, the effect on older siblings of having younger siblings is not negligible.

We found little evidence for the hypothesis that older brothers increase younger siblings' blood pressure (H1). Among men, we did not find statistically significant associations between having an additional older brother and higher blood pressure. Contrary to our expectations, having older brothers was associated with lower blood pressure among women.

We did not find evidence that having more older sisters was associated with higher blood pressure among younger siblings (H2). The results were not statistically significant, and the effect size was small.

We found no evidence that the association between sibling composition and blood pressure was more marked among individuals with fewer resources (H4). Human capital theory predicts stronger effects of sibling composition on blood pressure among people with less education. If so, then the interaction of education with sibling categories or the interaction of education with number of sibling (sibling size) or with birth order should have been significant. Most of these interaction effects were insignificant, suggesting that resource constraints within Tsimane' society do not affect blood pressure.

Generally, the associations between sibling types and adult blood pressure were weak with the exception of younger siblings, which raises the question of the type of early life event likely to have a lasting impact on adult health. Perhaps only large adverse shocks experienced in early life (e.g., maternal smoking) leave an imprint on adult health; next to those large adverse shocks, sibling composition might be too modest to produce lasting effects.

6.3. Potential mechanisms

The role of older sister and brothers may explain why having younger brothers is associated with higher blood pressure among older siblings. Studies suggest that the presence of younger siblings is associated with poorer mental health and behavior problems (Lawson and Mace, 2010). Children see the arrival of a younger sibling as a stressor because the newborn competes for parental investments. In addition, more younger siblings might increase the workload of older sisters. Among Tsimane' the oldest unmarried sister living at home is responsible for her youngest sibling. This means that by the time the youngest child is old enough to walk, the older sister, even if she is young, is given the responsibility of watching the newly mobile younger sibling. Responsibilities include watching the child, cleaning up after the child stools or urinates, making sure the child is fed, making sure the child receives gifts or food equally to the other children in the family, comforting the crying child, changing the child's clothing, and bathing the child. The oldest sister retains this responsibility for the youngest sibling as more children enter the family. Middle sisters then take care of second and third youngest siblings. This responsibility of the oldest sister is only relinquished once she has her own children. If she moves into her own house before having her own children and remains near to her mother's house, the oldest sister maintains her responsibility for the youngest walking sibling.

Older brothers often show more financial responsibilities as they get older, particularly toward their brothers. If there are more younger brothers in a family, older brothers are probably under more financial pressure to help younger brothers construct homes and find paid work and a wife. Younger brothers will seek the appropriate siblings to ask for money or to help answer experiential questions. In a pro-male economy, having additional younger brothers would exert a larger impact on older sisters and older brothers. The persistence of such stressors would results in higher blood pressure (Matthews et al., 2004). As time goes by, people are more independent from their parents and older siblings, and thus the effect wanes.

6.4. Values of using sibling categories

One striking result in Table 4 is the weakness of the standard coefficients of sibling size or birth order; few coefficients for sibling size or birth order were statistically significant. The coefficients for sibling size in Table 4 suggest a positive association between blood pressure and sibling size, but the coefficients do not allow one to compare the role of different types of siblings in these total effects. In contrast, what the disaggregated analysis of Table 3 buys is the ability to see with clarity that some types of sibling increase blood pressure, but other types of sibling decrease it. Thus, the conventional approach of examining total sibling size or birth order on health outcomes might, by construction, blur the significant role played by specific types of siblings. The conventional approach neglects how the age and sex of siblings might affect intra-household resource allocation and, thus, various health outcomes over the life cycle of the person.

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