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Abbreviated Title: Child stunting related to lower human capital

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Abstract

Objectives. We assess the association between childhood stunting and growth recovery (e.g., from stunted to non-stunted) with years of schooling and cognitive and academic skills in a remote native Amazonian society of horticulturalists-foragers (Tsimane').

Methods. We used cross-sectional data (2008) from1,262 children 6≤age≤16yin 53 villages to assess contemporaneous associations between three height categories: stunted (height-for-age Z score, HAZ<-2), moderately stunted (-2≤HAZ≤-1), and non-stunted (HAZ>-1), and three human capital outcomes: completed grades of schooling, test-based academic skills (math, reading, and writing), and local plant knowledge. We used longitudinal data (2002-2010) from all children (n=853)in 13 villages to estimate the association between changes in height categories between the first and last years of measurement and schooling and academic skills. We used OLS regressions with household fixed effects.

Results. Stunting was associated with 0.34 fewer completed grades of schooling (~20% less)and with a 11-12 percentage-point lower probability of showing math or writing skills. Moderate stunting was not associated with less schooling or lower academic skills but was associated with 23% lower scores in local plant knowledge. Compared with non-stunted children: children who became stunted completed 0.3-0.6 fewer grades of schooling and had a 19-23 and a 16-22 percentage-points lower probability of showing math writing skills, stunted had 0.5-0.6 fewer completed grades of schooling, and stunted children who became non-stunted did not show better human capital outcomes.

Conclusions. Results confirm the adverse association between stunting and schooling and human capital skills, even in a largely autarkic society.

1 Introduction

Childhood stunting is widespread in low-income nations (Black et al., 2008; de Onis et al., 2011; Walker et al., 2015) owing to deprivations in the form of poverty, inadequate nutrients, and disease burden (Black et al., 2008; Victora et al., 2008).Recent estimates suggest that globally as many as 175 million children(25%) <age 5 years (y) suffer from stunting(de Onis et al., 2011).Persistent stunting affects brain development and function, risk of illness, energy levels, motor development, and exploratory behaviors and -through some of these paths - erodes cognitive and academic skills and educational attainment during early life (Berkman et al., 2002; Casale and Desmond, 2016; Crookston et al., 2013; Fink and Rockers, 2014; Georgiadis et al., 2016; Ghosh, et al., 2015; Sudfeld et al., 2015), with some effects lasting into adulthood (Alderman, et al., 2006; Hoddinott et al., 2013; Hoddinott, et al., 2008; Prendergast and Humphrey, 2014; Victora et al., 2008) and even across generations (Behrman et al., 2009; Victora et al., 2008; Walker et al., 2015).Some researchers have defined a window for interventions<age 2yto redress stunting, suggesting that the effects of stunting at age 2y might be irreversible after this window (Victora et al., 2008; Victora et al., 2010).However, recent panel (longitudinal)evidence suggests that stunting is reversible after age 2y (Georgiadis et al., 2016; Lundeen et al., 2014; Mani, 2012; Prentice et al., 2013; Schott et al., 2013).In some instances this reversal has been observed even without public health interventions, probably from general improvements in socio-economic conditions(Crookston et al., 2014).Some recent evidence also suggests that children who recover from stunting have better cognitive skills and complete more years of schooling than children who do not recover(Crookston, et al., 2013; Fink and Rockers, 2014), but the evidence remains inconclusive (Casale and Desmond, 2016).

Here we contribute to research on childhood stunting and human capital by estimating the associations in a unique setting: a remote, relatively economically self-sufficient rural society of native Amazonian horticulturalists-foragers in Bolivia: the Tsimane' (Figure 1). Such a setting contributes to childhood stunting studies in at least three ways. *First*, estimates of the links between child stunting and child human capital are biased by the effects of many omitted socioeconomic confounders, such as ethnic and racial heterogeneity and access to healthcare(Prendergast and Humphrey, 2014). Tsimane' villages are racially and ethnically homogeneous, with non-Tsimane' accounting for ~5% of the population in their villages, and with most Tsimane' having limited access to Western health care (Byron, 2003; Gurven et al., 2007).*Second*, the setting allows us to test the hypothesis that childhood stunting is associated with weaker academic skills and educational attainment among children when traditional rural societies begin to modernize, have functioning school systems, and provide children with opportunities to use academic skills learned in school. In remote, economically self-sufficient rural societies, such as the Tsimane', these conditions associated with modernization were largely absent at the time of data collection, so we hypothesize that stunting should not be associated with weaker educational attainment or formal academic skills. *Third*, the setting allows testing a new, culturally appropriate way of measuring human capital. We extend the work linking childhood stunting with skills by examining the association between stunting and local plant knowledge, defined here as:

> *....a cumulative body of knowledge, practice, and belief, evolving by adaptive processes and handed down through generations by cultural transmission, about the relationship of living beings (including humans) with one another and with their environment* (Berke et al., 2000).

Prior research has found that parental local plant knowledge in rural societies co-varies positively with both parental and child health and may overshadow formal educational attainment and academic skills in practical importance (McDade et al., 2006; Quave and Pieroni, 2015; Reyes-García et al, 2016b; Reyes-García et al., 2007).

[Insert Figure 1]

For the analysis we use data from the Tsimane', a native Amazonian society in the department of Beni, Bolivia. At the time of research, the Tsimane' had low levels of monetary income, weak links to the market economy, and mostly primary schools that operate sporadically, with Tsimane' as the primary language of instruction(Godoy et al., 2007b; Undurraga et al, 2013).During the last year of the panel (2010), the mean monetary daily earnings per person reached only $0.9, about half the global poverty line (US$1.9 Purchasing Power Parity) used by the World Bank (2015).In a worldwide comparative study of 15 small-scale rural societies, the Tsimane' ranked next to last in market interactions, with only 7% of total household calories bought in the market (Henrich et al., 2010).Nevertheless, Tsimane' villages vary in the depth and frequency of contact with outsiders, and we control for some of these effects by using road access in the robustness analysis. Last, most Tsimane' self-reported as being monolingual in Tsimane'. For instance, the 2008 survey from the longitudinal study showed that of the 396 children and adults for whom we had data on language skills, 57% self-reported as being monolingual in Tsimane', 35% reported having some fluency in Spanish, and 8% reported being fluent in Spanish.

Our prior work among the Tsimane' suggests that the share of stunted children is high but declining (Godoy et al., 2010; Zhang et al., 2016).In 2000, 52% of all boys and 43% of all girls < age 9y were stunted (Foster et al., 2005); by 2010 stunting rates for children <age 9y had fallen to 34% for all boys and to 30% for all girls (Zhang et al., 2016).In 2008, the year we used for much of the analyses (Figure 2), 34% of children 6y ≤ age ≤ 16y were stunted (girls=31%; boys 36%), 41% were moderately stunted (girls=44%; boys=38%), and 26% were not stunted (girls=25%; boys=26%).Our prior work shows some evidence of catch-up growth (Godoy et al., 2010), but persistent height deficits and modest year-to-year changes between height categories (Zhang et al., 2016).

[Insert Figure 2]

We focus on children of school age (6y to 16y) to estimate two sets of associations. *First*, using cross-sectional data from2008, we estimate the contemporaneous association between *(i)*children's height categories - stunted(HAZ<-2), moderately stunted(-2≤HAZ≤-1), non-stunted (HAZ>-1) - and *(ii)*human capital, measured as completed grades of schooling, test-based academic skill(math, reading, writing), and local plant knowledge. *Second*, using a nine-year annual (2002-2010) panel or longitudinal data set from all children in 13 villages along the Maniqui River, we estimate the association between *(a)*changes in height category (e.g., from stunted to non-stunted, or vice versa) from the first to the last year in which the child was measured and *(b)*the schooling and academic skills during the last year of measurement. Appendix 1 shows visually the overlap between the two data sets, and how each data set relates to the associations we want to estimate. The two datasets are described next.

2 Study participants and methods

2.1 Data

The information used comes from two studies: an annual panel of all Tsimane' living in 13 villages during 2002-2010 (Leonard et al., 2015)and a cross-sectional dataset collected in 2008 in an additional 40 villages, which was done as part of a baseline survey for a randomized controlled trial (RCT) (Undurraga et al., 2016).We used the same field staff and methods of data collection in the two studies. During the annual survey of 2008 in the 13 villages of the panel study we also used a convenience sample to collect data on local plant knowledge from 138children 6y≤age≤16y.

2.2 Stunting

We define stunting as being 2 standard deviations below the median age-sex standardized height Z-score (HAZ) for well-nourished, globally representative international populations (UNICEF-WHO-WB, 2012; World Health Organization, 2006).We measured standing height following the protocol of Lohman et al. (1988) and calculated HAZ scores using the World Health Organization's (WHO) growth standards for children >age 60 months (de Onis et al., 2007). We used a portable stadiometer to measure height.

2.3 Human capital outcomes: Completed grades of schooling, academic skills, and local plant knowledge

We use the term *human capital* as an umbrella term encompassing completed grades of schooling (hereafter schooling), academic skills, and knowledge of local plants, all measured at the time of the interview.

Schooling and academic skills. We limit the analysis to children 6y ≤ age ≤ 16y because Tsimane' children typically start school by age 6y and by age 16ytheytypically stop attending school to form new households. Parents reported the grades of completed schooling of their dependents. To assess math skills we had children solve four arithmetic operations that required them to add, subtract, multiple, or divide (in that order) 1-2 digit numbers (Undurraga et al., 2013).The computation for the math questions were written in numerals on a white card, but they were then read to children in case they could not read. Scores in the math test ranged from zero to four, with one point for each correct answer. The test stopped if the child provided an incorrect answer, or could not answer a question. Thus, some children received only one math problem. For the reading test we showed children simple sentences written in a white card in Spanish, the second language of instruction in schools, and we asked them to read the sentence. For the writing test we asked children to sign their name(Godoy et al., 2007a; Saidi et al., 2013).The reading test might have been harder for children in villages with Tsimane' school teachers who were not completely bilingual in Tsimane' and Spanish. The reading, writing, and math tests were done under broad daylight. Surveyors coded answers to the reading and writing tests into one of three categories: cannot, with difficulty, and well. Since 50.2%, 55.7%, 72.3% of the children scored zero in the writing, math, and reading tests, we converted the variables into discrete binary variables, with a value of one for any proficiency and zero otherwise (Table 1).Later we assess whether the main results hold up using the original scores.

[Insert Table 1]

Local plant knowledge. We used a structured questionnaire to assess children’s knowledge of six common local wild plants(Martinez-Rodriguez, 2009).To select the plants, we first asked 20 adult Tsimane' in neighboring villages to list all the useful plants they knew (Puri and Vogl, 2005).We then used the free-listing procedure in Anthropac software to generate a list of the useful plants. We retained plants reported by at least two adults and for which we could obtain a botanical identification. We used Smith's Saliency Index derived from free-listing (Puri and Vogl, 2005) to classify plants into three groups according to the number of people who listed the plant and the order in which the plant was listed: high, medium, and low saliency. We then randomly selected two plants from each of the three groups to construct the test of plant knowledge.

The knowledge test assessed(1) whether a child recognized the name of each of the six plants when researchers named it,(2) the child’s ability to name the most popular uses of the plants listed, and (3) the child’s ability to name at least one animal typically associated with each of the plants in the list. We refer to (3) as ecological knowledge. The exact question for task (3) was: "Are there animals, birds, or insects that live on or eat this plant?"For practical reasons we did not show children a fresh botanical specimen or a picture of the plant. It is possible that some children knew the plant, but did not know it by its common name. If so we would have scored those children as not knowing the plant. Surveyors asked the child the test questions. If a child could not identify the plant (1), surveyors did not ask the child about (2-3).We used responses to construct three scores of individual local plant knowledge regarding (1) plant identification, (2) skills using the plant, and (3) ecological knowledge of the plant. To compute a score for the plant identification task we assigned one point for each plant the child knew, producing a score that ranged from zero to six. To score skills we first calculated the modal response given by the full sample (i.e., the most popular use of the plant listed) and then assigned on point if the child’s answer matched the modal response (Reyes-García et al., 2016a)(range: 0-6).Finally, to obtain a score for ecological knowledge we added a point if the child mentioned at least one association of the listed plant with another plant or animal, again producing a score ranging from zero to six. We added scores from the three tasks to construct a total score for the three dimensions of local plant knowledge (range: 0-18).

2.4 Analysis

2.4.1 Height category and human capital (2008 cross-sectional data)

We use the following Ordinary-Least Squares (OLS) regression with household fixed effects and robust standard errors adjusted for clustering at the village level to analyze the 2008 cross-sectional data:

$$HK_{ihvj} = \alpha + \beta \cdot S_{ihv} + \gamma \cdot MS_{ihv} + \chi C_{ihv} + \varepsilon_{ihv} \text{ (Eq. 1; OLS)}$$

In equation 1 the subscripts i, h, v, and j stand for individual child (i), household (h), and village (v), with (j) indexing for the type of human capital(HK) used as an outcome. HK_{ihv} stands for human capital, and captures one of the following: grades of completed schooling, score in the math, reading, or writing test, or local plant knowledge. S_{ihv} and MS_{ihv} are binary variables for stunted (S) and for moderately stunted (MS), with non-stunted children serving as a reference category.

Control variables (C) include the child's age in 2008 and the child's sex, and a binary variable for the study (TAPS longitudinal study [2002-2010] = 1; 2008 cross-sectional study from the baseline of the randomized controlled trial=0).We control for the study type because repeated exposure by study participants to the same surveyors in the panel study might have introduced panel conditioning (Zwane et al., 2011).Because most households (59%) had only one child who was tested for local plant knowledge, we do not use household fixed effects when using local plant knowledge as an outcome, but we continue to cluster by village. For ease of interpretation, we use OLS even for binary outcomes, but later use logit regressions as a robustness check (Appendix 3).ε_{ihv} is an error term.

2.4.2 Change in height category and human capital (2002-2010 panel data)

To estimate what happens to schooling and academic skills when a stunted child becomes non-stunted or when anon-stunted child becomes stunted we use annual 2002-2010 data collected from ~850 children 6y ≤ age ≤ 16y during this period from the 13 villages of the longitudinal study. Following Crookston et al. (2010), we created a variable that captured changes in height categories (ΔHAZ), defined as HAZ during the last year a child was measured minus HAZ during the first year the child was measured. The child had to be in the range of 6y ≤ age ≤ 16y in both time periods to be included in the analysis. The first and the last measure do not necessarily refer to the first (2002) and last (2010) year of the longitudinal study. We decided to take into account the first and last measure because limiting the analysis to children who were measured in 2002 and 2010 would have reduced the sample size of observations. Our definition of change in HAZ has the advantage of capturing any change in height category during the maximum length of time we measured a child who was between 6y and 16y;transitory changes between height categories are thus swept away in the sample we consider(Cole, 1997; Hermanussen et al., 2002). The mean and median duration between the first and last measure was four years (SD=2.2; min=1; max=8).

Using ΔHAZ, we created three variables for the regression analysis:ΔHAZ^{+}, ΔHAZ^{-}, and ΔHAZ^{0}.These variables stand for children whose height improved (recovered) from stunted to non-stunted (ΔHAZ^{+}), children whose height worsened (faltered) from non-stunted to stunted (ΔHAZ^{-}), children who remained stunted in both measurement years (ΔHAZ^{0}), with children who remained non-stunted in both measures serving as the reference category in the regressions. We also estimate ΔHAZ between the first and last measurements for all children without taking into account the stunted and non-stunted distinction, and then estimated the association between ΔHAZ and human capital outcomes.

Because the policy concern is with what happens to a child's human capital when a non-stunted child becomes stunted or vice versa, we focus on changes from stunted to non-stunted or vice versa, without taking into account the category of moderately stunted. The category of moderately stunted is useful in the cross-sectional analysis because it permits a finer-grained description of how children’s human capital varies in relation to height categories. However, our approach of focusing on the two-way change from stunted to non-stunted has a limitation since it defines the boundary between stunted and non-stunted by a single number (HAZ=-2).A child whose height changed from -2.01HAZ to -1.99HAZ would be regarded as someone who had transitioned from stunted to non-stunted even though the size of the height improvement was trivial. To address this concern, we used the standard definition of stunting, but then consider a child to have changed height category only if the child passed the threshold by an additional 0.2HAZ units. For example, a child with a HAZ of -2.1 would have to improve to at least -1.9HAZ to be considered having transitioned from stunted to non-stunted. Adding 0.2HAZ units to the threshold reduces the likelihood of counting as meaningful very small height changes near the boundary.

To estimate the association between changes in height categories and human capital outcomes we used the following OLS regressions, with one observation per child, and with household fixed effects and robust standard errors adjusted for clustering at the village level:

$$HK_{ihvjt} = \alpha + \beta \cdot \Delta HAZ^{+}_{ihv} + \gamma \cdot \Delta HAZ^{-}_{ihv} + \delta \cdot \Delta HAZ^{0}_{ihv} + \chi \cdot C_{ihvt=first} + \varepsilon_{ihv} \text{ (Eq. 2; OLS)}$$

In equation 2, the outcomes remain the same as in equation (1)but refer to the last year in which the child was surveyed. Control variables include the child's age and HAZ during the first year of measure, the child's sex, the baseline measure of the outcome, and a variable for the number of years between the first and the last height measurement.

With both the cross-sectional and the longitudinal data we use household fixed effects to control for well-known confounds linking deprivation, child stunting, and child human capital at the household level. This matters to ensure we observe the association between child stunting and child human capital, and not the association between stunting and socioeconomic status. By adding household fixed effects we control for all observed and unobserved, unmeasured household variables. Examples of these confounds include the height and education of the parents, abilities and preferences of the parents, household socioeconomic status (e.g., asset wealth), and household demographics. Elsewhere we show little change in households socioeconomic status over time among the Tsimane' (Undurraga et al., 2010).

3 Results

3.1 Height category and human capital (2008 cross-sectional data)

Table 1 highlights that stunted children differed significantly at $p<0.10$ in completed grades of schooling and in math skills compared with their non-stunted peers. Table 1 and Figure 3 show that stunted children had significantly lower mean (1.5) and median (1)years of completed schooling than non-stunted children (mean=1.8; median=2)($p=0.01$).Almost two-thirds (59.2%) of stunted children scored zero on the math test, compared with 56.1% and 50.8% among moderately stunted and non-stunted children. The mean math score of stunted children (0.8) was significantly lower than the mean math score of non-stunted children (1.1) (p=0.03).No difference was observed by stunting status for reading, writing, or local plant knowledge. In sum, despite low levels of schooling and few opportunities to practice academic skills, descriptive statistics suggest that non-stunted children had more years of completed schooling and more math skills than their age-sex stunted peers, but they did not have better reading or writing skills, and they did not know more about local plants than other children.

Table 2 contains the results of the regression analyses (Eq. 1) and shows three findings.(i) Stunting bore a negative association with schooling and with the probability of having any math or writing skills, but these results must be read with caution as they are only significant at p<0.10.Compared with their non-stunted age-sex peers, stunted children had 0.34 fewer completed grades of schooling (p=0.06) and were 11 percentage points less likely to have any writing skills (p=0.10),and 12 percentage points less likely to have any math skills (p=0.06).(ii) Moderate stunting bore no statistically significant association with schooling or with academic skills at p<0.10.(iii) Children with moderate stunting scored 1.59 fewer points (or ~24% less) in local plant knowledge than non-stunted children (p=0.02) while stunted children scored 0.45 fewer points than non-stunted children, but results were not statistically significant (p=0.61).

[Insert Table 2]

Appendixes 2-3 contain robustness analyses. Appendix 2 shows that the variables stunting and moderately stunted generally bore no significant interaction effects at p<10% with the following variables: (i) a child's sex, (ii) a child's age,(iii) village road access, and (iv) household socioeconomic status. Stunting and moderate stunting also bore no significant interaction effects with schooling in the regressions with academic skills as outcomes. In

Appendix 3 we used different types of regressions than those used in Table 2 to recover the raw scores of academic skills, to assess if OLS results of regressions with binary outcomes changed when using logit regressions, and to estimate associations using models with household random-effect. The results from Appendix 3 buttress the results from Table 2.

3.2 Change in height category and human capital (2002-2010 panel data)

Sections A-B of Table 3showfour findings that hold up irrespective of the HAZ threshold used to define stunting or moderate stunting: -2HAZ or -2HAZ±0.2HAZ.*(i)*Compared with a child who was not stunted during the first and the last year of measurement, a child who was not stunted but who became stunted (faltered) had 0.3-0.6 fewer completed grades of schooling in the last measure ($p<0.10$ or $p<.05$ depending on the definition of stunting), a 19-23 percentage-point lower probability of knowing any math ($p<0.05$), and a 16-22 percentage-point lower probability of knowing how to write ($p<0.05$). (ii) Children who remained stunted in both the first and the last year of measurement had 0.49-0.59 fewer completed grades of schooling than their age-sex peers who were not stunted in both periods ($p<0.10$ or $p<0.05$ depending on the definition of stunting).(iii)Transitioning from stunted to non-stunted was not associated with improvements in completed grades of schooling or in math, reading, or writing skills.(iv)Section C suggests that if children caught up or lost more ground, they showed smaller changes in completed grades of schooling and in math and writing skills than children who just lost or caught up a small amount of ground ($p<0.05$ for schooling and writing; $p<0.10$ for math).In sum, faltering was associated with an erosion in more human capital outcomes than persistent stunting, but growth recovery was not associated with improvements in children's human capital.

[Insert Table 3]

4 Limitations

Beyond measurement errors with reported age (Gurven et al., 2007)and height (Godoy et al., 2008)and a small sample size to assess associations between stunting and local plant knowledge, our results might suffer from at least four types of omitted variable bias.

First, we could not control for unobserved abilities, such as intelligence, drive, attention, memory, or patience. If these traits covary positively with child human capital and negatively with stunting, then the negative coefficients of stunting that we estimated would be less pronounced than the true values. Alternatively, if stunting covaries with factors such as task comfort that may decrease performance (Gibson et al., submitted), the estimated stunting effects should be adjusted down accordingly. Unfortunately, it is difficult to quantity these kinds of effects because they will influence performance on all behavioral tasks.

Second, we did not have information to capture the perceptual pathways that would allow stunting to influence human capital outcomes. For example, stunting may impair attention, motivation, memory, or a combination of these factors (Aburto et al., 2009; Baker-Henningham et al., 2009; Chang et al., 2002; Fernald and Grantham-McGregor, 1998; Gardner et al., 1999).Understanding the pathways will be important for directly addressing the underlying human capital deficits.

Third, a limitation of our study was the absence of information on vision and hearing loss in our cohorts, two relatively under-explored topics in the stunting literature. Poor hearing and vision associated with stunting would hamper children's ability to accumulate human capital. Dietary factors and height have been associated with visual development (Chua et al., 2015; Jonas et al., 2014; Lim et al., 2010; Sharma et al., 2010; Xu et al., 2011). Poor visual development has been associated with lower educational attainment (Chua and Mitchell, 2004;

Steward-Brown et al., 1985), higher psychosocial difficulties (Packwood et al., 1999), and decreased opportunities for employment in the armed forces or the public sector (Kanonidou, 2011).

The relation between hearing and speech and language development is well established (Tomblin et al., 2015; Wake et al., 2004).In high-income settings such as the USA and Europe, multiple studies have suggested that children with even mild hearing loss fall behind their peers in school performance, including grade failure (Bess et al., 1998), placement in low achieving classes (Khairi et al., 2010), requiring an individualized education plan (Lieu et al., 2012), and increased likelihood of dropping out prior to intermediate or higher education (Jarvelin et al., 1997).There are also compelling data linking hearing loss with poor cognitive outcomes, including lower scores on intelligence testing (Davis and Hind, 1999; Teasdale and Sorensen, 2007).The association between hearing loss and cognitive outcomes appear to extend beyond verbal abilities and span high and low-income settings alike, as there is data associating hearing loss with decreased nonverbal intelligence from both the USA (Emmett and Francis, 2014) and Nepal (Emmett et al., 2014).In addition to the relation between hearing loss and cognition, there is early data from Nepal associating early childhood stunting with chronic suppurative otitis media (Emmett et al., 2015) and hearing loss in young adulthood (Emmett et al., 2013). Although preliminary, these studies highlight the possibility that hearing loss could serve as a mediator in the relation between stunting and human capital outcomes. It will therefore be interesting to include hearing assessment in future studies on this topic.

Fourth, we did not measure the social and household context in which stunting occurs. Some of the adverse effects of stunting on schooling and academic skills might take place because of discrimination faced by stunted children. In an earlier study we found that adult

Tsimane' attributed more positive traits to taller children, but not to taller adults (Undurraga et al., 2012).Even though stunting could elicit discrimination, it could also elicit compensatory behaviors from caretakers in the form of extra stimulation to redress the adverse effects of faltering (Engle and Fernández, 2010; Pollitt et al., 1993; Prado and Dewey, 2014; Wachs, 2009; Wachs et al., 1992).We do not have data on attitudes toward stunted children or on caretakers' behavior, though we control for some of these behaviors by using household fixed effects.

One final limitation deserves mention. Recall that our measures of human capital had shortcomings. For example, data on schooling came from caretakers rather than from more reliable sources (e.g., school records).Since we found significant associations even when variables were measured with error, having improved measures should yield sharper results.

5 Discussion and conclusions

The study yields two main findings and three puzzles. First, the ubiquitous adverse cross-sectional association between child stunting and child human capital found in previous studies extends to remote societies without well-established educational systems. The magnitude of these associations is meaningful. For example, Table 2suggests that stunted children had 0.3 fewer completed grades of schooling than their non-stunted age-sex peers. Since the average number of completed grades of schooling was 1.7, a 0.3 deficit amounts to ~20% fewer completed grades of schooling.

The second main finding has to do with the ambiguous associations between changes in stunting and human capital. We found that persistent stunting was associated with 0.5-0.6 fewer completed grades of schooling, but that it was not consistently and significantly associated with weaker academic skills. Faltering was associated with 0.3-0.6 fewer completed grades of schooling and with a 16-23 percentage-point lower probability of having any math or writing skills. These results agree with -- but also differ from -- the results of the Young Lives Study, a recent comparative longitudinal study of child growth in Peru, Ethiopia, India, and Vietnam (Crookston et al., 2013).Crookston et al. measured changes in HAZ categories of children between about 1y and 8y and found that children in the four nations who remained stunted were more likely to be overage for their grade, a result along the same lines than our findings that persistent stunting was associated with fewer completed grades of schooling. Like us, they found no consistent association between schooling and recovery; in Peru and in Vietnam recovery was associated with an increase in the age of the child for their school grade, but in Ethiopia and India recovery bore no significant association with appropriate school age. In academic skills we found only one consistent association; an inverse association between faltering and math and writing skills. In contrast, Crookston et al. only found a consistent negative association between persistent stunting and math scores, reading comprehension, and receptive vocabulary. They found that children who recovered lagged behind non-stunted children in math, reading, and receptive vocabulary, but the gap was generally half as large as the gap separating children who were persistently stunted. These and other studies (Berkman et al., 2002; Casale and Desmond, 2016; Fink and Rockers, 2014)suggest that, compared with children who remain non-stunted, children who falter, recover, or who remain stunted do not tend to fully catch up in academic or cognitive skills.

We found three puzzles. (i) Moderate stunting (but not stunting) was associated with lower scores in knowledge of local plants. Other than possibly reflecting noise from a small sample, it is hard to come up with a meaningful interpretation for the results. That said, the negative sign is at least consistent with the other findings, which show that being stunted was associated with weaker human capital. (ii) Stunting or moderate stunting almost never bore a significant association with reading skills. One possible explanation is that the tests of math and writing did not hinge as much in understanding Spanish.(iii) Why wasn't growth recovery associated with improvements in child human capital? At present, we lack enough data with hearing or with vision loss and stunting to know the answer to this puzzle, but it is possible that once stunting has harmed hearing or vision (either in utero or in early childhood via infections), the hearing and vision loss is permanent, and thus, even if a child's growth recovers or if the socioeconomic status of the household improves, the negative effects on children's human capital remain because they are actually secondary to the perceptual deficit (i.e., the hearing or vision loss) and not the stunting. This hypothesis is worth pursuing in future research.

Prior studies have documented the ubiquity of child stunting in remote native Amazonian societies (Benefice et al., 2006; Blackwell et al., 2009; Cobayashi et al., 2006; Godoy et al., 2005; Pedraza et al., 2014; Roche et al., 2011).Taken together, our results suggest that some of these remote societies might not be able to offer their children enough protection to foster normal growth, leaving open the question of how best to redress faltering and avoid losses in the human capital of these children.

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Author contributions: RAG and VRG designed the study, and directed implementation and data collection.RAG and RZ analyzed the data and drafted the paper. JRB, SDE, CK, STP, VRG, AS, EAU, RZ, and RAG edited the manuscript for intellectual content, helped analyze the data, and provided critical comments on the manuscript.

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Table 1. Summary statistics of outcomes by height categories of Tsimane' children 6y≤age≤16y, 2008.

Human-capital outcome	Statistic	Height category			Total
		Not stunted (HAZ>-1)	Moderately stunted(-2≤HAZ≤-1)	Stunted (HAZ<-2)	
Schooling[a]	N	328	516	418	1,262
	Mean	1.86	1.78	1.57**	1.73
	SD	1.65	1.77	1.54	1.67
	% zero	19.21	24.22	26.56	23.69
Academic skills					
Math: Test score (0-4)[b]	N	289	420	351	1,060
	Mean	1.12	1.04	0.89*	1.01
	SD	1.36	1.37	1.28	1.34
	% zero	50.87	56.19	59.26	55.75
Reading:[c]	N	256	382	315	953
Cannot	%	71.48	71.20	74.29	72.30
With difficulty	%	19.53	19.11	19.05	19.20
Well	%	8.98	9.69	6.67	8.50
Writing:	N	288	410	347	1,045
Cannot	%	46.53	49.76	53.89	50.24
With difficulty	%	30.56	27.07	25.65	27.56
Well	%	22.92	23.17	20.46	22.20
Local plant knowledge	N	49	52	37	138
	Mean	9.93	8.76	9.94	9.50
	SD	3.78	3.92	3.71	3.83
	% zero	4.08	7.69	5.41	4.35

Notes: *, **, and *** significant at ≤10%, ≤5%, and ≤1% in OLS regression with schooling, math, or local plant knowledge as outcomes, against stunted and moderate stunted binary variables as covariates, with non-stunted children as the excluded category. For reading and writing we used a chi-squared test between reading or writing and the three height categories, and found no significant differences at p<0.10 between the three height categories.

[a] Schooling = completed grades of schooling at the time of the survey, as reported by caretaker.

[b] Math = score in a test with four questions, each of which asked the child to either add, subtract, multiply, or divide 1-2 digit numbers, with one point assigned for each correct answer. The test stopped if the child provided an incorrect answer, or could not answer.

[c] Reading = a child was asked to read a simple sentence in Spanish and surveyor judged whether the child could read well or with difficulty, or could not read. The text was written in a large white piece of paper and children were shown the paper in broad daylight.

[d] Writing = a child was asked to sign her/his name and surveyors coded whether the child could sign the name easily, with difficulty, or could not sign her/his name. In the regressions, the variables for math, reading, and writing have been converted into binary variables, with the value of one for a child who displayed any skill, and zero otherwise.

[e] Definition of local plant knowledge and details on the measurement of academic skills in text.

Table 2. Association between height categories and schooling and academic skills among Tsimane' children 6y≤age≤16y, 2008

Explanatory variables:	Schooling	Academic skills			Local plant knowledge
		Math	Reading	Writing	
N	1,262	1,060	953	1,045	138
Stunted	-0.34*	-0.12*	-0.01	-0.11*	-0.45
	(0.18)	(0.06)	(0.05)	(0.06)	(0.86)
Moderately stunted	-0.14	-0.07	-0.02	-0.08	-1.59**
	(0.15)	(0.05)	(0.04)	(0.04)	(0.59)
Male	0.31***	0.14***	0.06**	0.10***	0.56
	(0.10)	(0.04)	(0.03)	(0.03)	(0.65)
Age	0.35***	0.08***	0.06***	0.08***	0.69***
	(0.03)	(0.008)	(0.009)	(0.009)	(0.18)
TAPS[a]	-0.16*	0.17***	0.75***	0.35***	Not applicable
	(0.09)	(0.03)	(0.03)	(0.03)	
Constant	0.04	-0.23**	0.25*	0.04	1.44
	(0.10)	(0.11)	(0.11)	0.10	(2.25)
R^2	0.76	0.71	0.76	0.75	0.13
Household fixed effects	Yes				No

Notes: *, **, and *** significant at ≤10%, ≤5%, and ≤1%. OLS regressions; robust standard errors were adjusted by clustering at the village level (shown in parentheses). See Table 1 and Figure 2 for definition of variables.

[a] TAPS = Tsimane' Amazonian Panel Study; longitudinal study with 13 village. The variable TAPS=1 if the village is in the TAPS sample, and 0 if the village was part of the baseline survey for the randomized controlled trial (RCT).

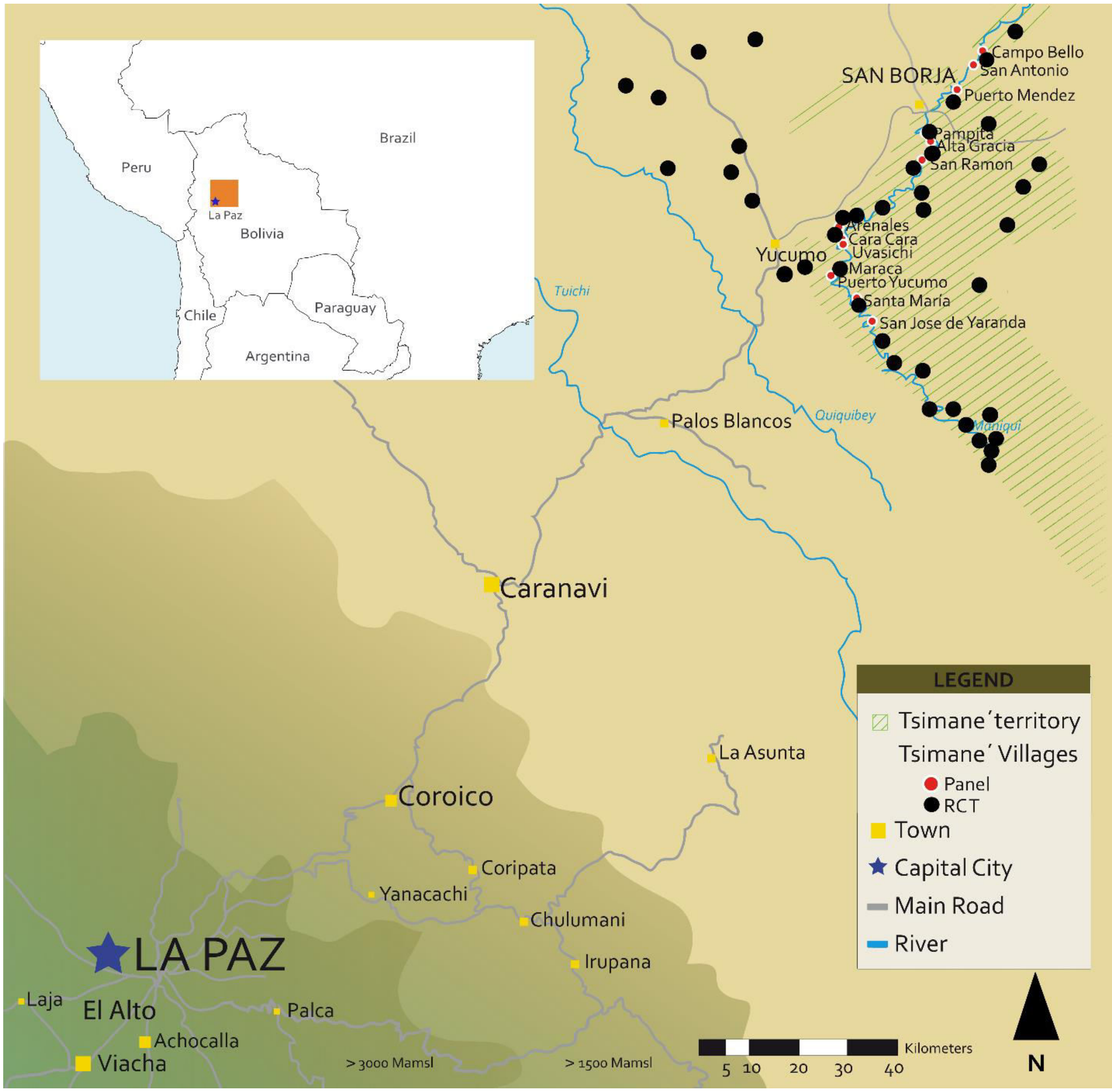
Table 3. OLS regressions for Eq 2 showing association between (i) changes in height category (from stunted to non-stunted or vice versa) from year of first measure to year of last measure and (ii) schooling and academic skills in last year of measure for Tsimane' children 6y≤age≤16y during 2002-2010

Change in HAZ (HAZ in last year of measure minus HAZ in first year of measure)	Outcome during last measurement year			
	Schooling	Math	Writing	Reading
A. Change from stunted to non-stunted or vice versa: Child crosses threshold of -2 HAZ				
ΔHAZ^{-} [worsened (faltered); from non-stunted to stunted]	-0.33*	-0.19**	-0.16**	-0.19
	(0.17)	(0.07)	(0.06)	(0.05)
ΔHAZ^{+} [improved (recovered); from stunted to non-stunted]	-0.23	-0.05	0.01	0.02
	(0.19)	(0.06)	(0.06)	(0.07)
ΔHAZ^{0} [stunted in both periods (persistent stunting)]	-0.59**	-0.13*	-0.03	-0.08
	(0.26)	(0.07)	(0.04)	(0.05)
Number of observations (children)	853	845	845	845
R^2	0.72	0.61	0.62	0.57
B. Change from stunted to non-stunted or vice versa: Child crosses threshold of -2 HAZ ± 0.20HAZ				
ΔHAZ^{-} [worsened (faltered); from non-stunted to stunted]	-0.62**	-0.23**	-0.22*	-0.06
	(0.18)	(0.07)	(0.09)	(0.06)
ΔHAZ^{+} [improved (recovered); from stunted to non-stunted]	-0.20	-0.05	0.04	0.04
	(0.22)	(0.07)	(0.06)	(0.07)
ΔHAZ^{0} [stunted in both periods (persistently stunted)]	-0.49*	-0.09	-0.01	-0.06
	(0.23)	(0.06)	(0.05)	(0.06)
Number of observations (children)	853	845	845	845
R^2	0.72	0.61	0.61	0.57
C. Change in the level of HAZ from the first to the last measure				
ΔHAZ	-0.10**	-0.02*	-0.02**	0.006
	(0.04)	(0.01)	(0.01)	(0.01)
Number of observations (children)	853	845	845	845
	0.71	0.61	0.62	0.57

Notes: *, **, and *** significant at ≤10%, ≤5%, and ≤1%. The excluded group in all regressions was children who were non-stunted in both periods. Regressions include household fixed effects, a child's sex, a child's age and HAZ during the first year of measure, a variable for the number of years elapsed between the year of the child's first and the year of the child's last HAZ measure, baseline measure of the outcome, and a constant. Regressions include robust standard errors, adjusted for clustering at the village level (shown in parentheses).

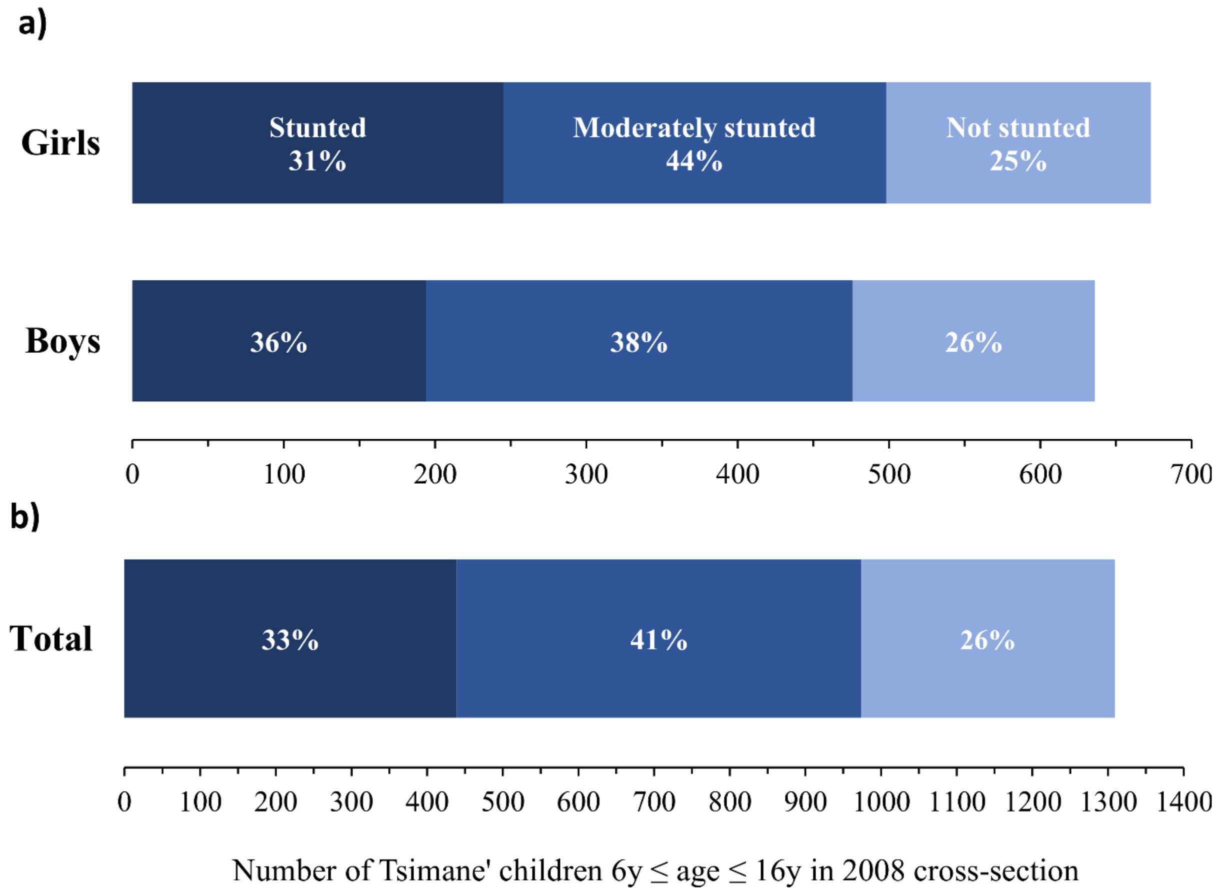
Legends for Figures.

Figure 1. Map showing location of [1] 13 Tsimane' villages of the nine-year (2002-2010) annual panel study along the Maniqui River and [2] 40 additional Tsimane' villages of the randomized controlled trial (RCT), both in the department of Beni, Bolivia



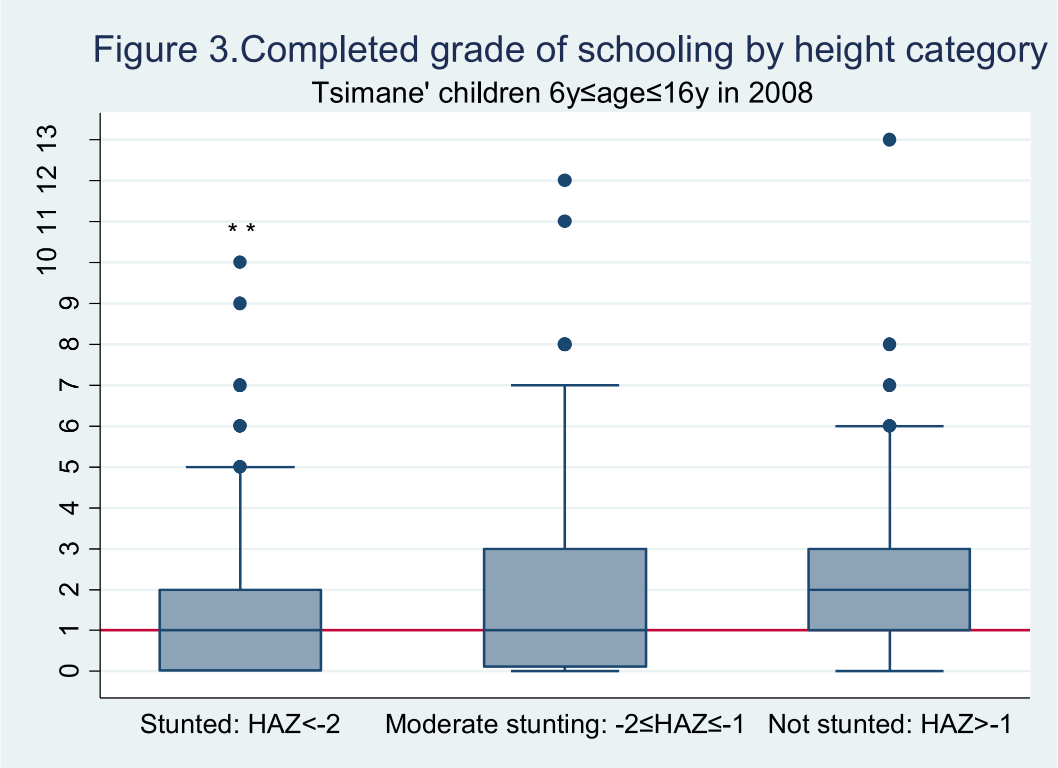
Notes: The shading of the territory denotes elevation (Mamsl=meters above sea level). The square symbols and letters in each town are approximately proportional in size to the population of the town. The Tsimane' territory is an administrative division and does not capture all the lands inhabited by the Tsimane'.

Figure 2. Share of Tsimane' children 6y ≤ age ≤ 16y by height category, 2008, for a) boys and girls, and b) total children.



Height category:	Definition	Girls		Boys		Total	
		n (%)	%	n (%)	%	n (%)	%
Not stunted	HAZ>-1	160 (25)	48	175 (26)	52	335 (26)	100
Moderately stunted	-2≤HAZ≤-1	282 (44)	53	253 (38)	47	535 (41)	100
Stunted	HAZ<-2	194 (31)	44	245 (36)	56	439 (34)	100
Total		636 (100)		673 (100)		1,309 (100)	

Figure 3. Completed grade of schooling by height category

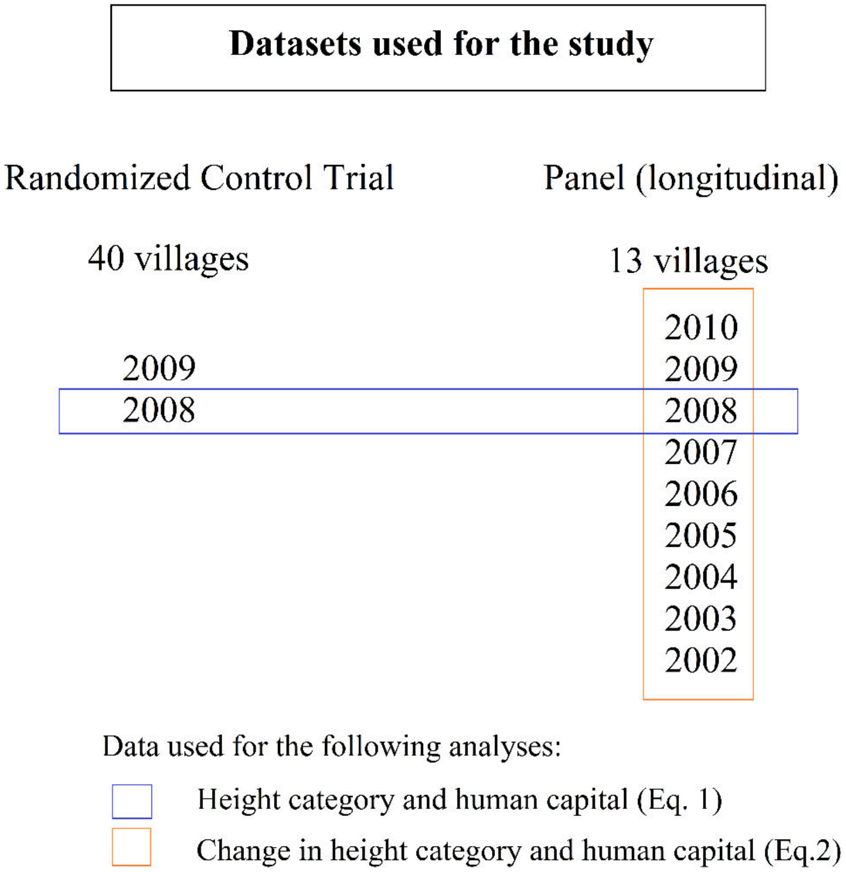


Notes: For the test of statistical significance we ran an OLS regression of completed grade of schooling (outcome) against two binary variables, stunted and moderate stunting, with non-stunted children as the excluded category.** $p<0.05$; years of completed schooling was significantly less for stunted children than for non-stunted children, but there was no significant difference between moderately stunted and non-stunted children in the regression ($p=0.52$).See Table 1 for definition of variables.

Supplementary material

Childhood stunting is associated with weaker child human capital outcomes among native Amazonians in Bolivia

Appendix 1.A visual representation of the datasets and the two sets of estimations



Appendix 2. Test of interaction effects between *(i)* explanatory variable and *(ii)* child's sex and age, village road access, and household wealth in physical assets among Tsimane' children 6y≤age≤16y, 2008: OLS regressions results

Table A1 contains estimates of interaction effects with: (i) child's sex (section B), (ii) child's age (section C), (iii) village road access (section D), (iv) household wealth (section E). In addition, we also test for interaction effects between schooling and explanatory variables when using math, reading, and writing as outcomes (section F).To facilitate the interpretation of the tables we have colored in purple all the interaction terms between (1) stunted or non-stunted and (2) third variables that were not statistically significant at p<0.10 and in red those interaction terms that were significant.

Among the interaction effects estimated, household wealth (section E) deserves closer scrutiny because it overlaps with deprivations that correlate with stunting. Wealth bore both positive and negative associations with child human capital. Household wealth bore no statistically significant association at p<0.10 with schooling or with local plant knowledge, but it was negatively associated with tests in math (p=0.01),reading (p=0.04), and writing (p=0.001).The coefficient in section E imply that increase of 1,000 *bolivianos* would be associated with only a 0.02 and 0.07 percentage-point increase in the probability of knowing any math, or how to read or write. In sum, household wealth seems to bear no significant interaction effects with stunting variables, and the direct effect of household wealth on child human capital was inconsistent, with small size effects.

Table A1. Test of interaction effects between *(i)* explanatory variable and *(ii)* child's sex and age, village road access, and household wealth in physical assets among Tsimane' children 6y≤age≤16y, 2008: OLS regressions results

	Outcome				
		Academic skills			Local plant knowledge
Explanatory variables:	Schooling (n=1,262)	Math (n=1,060)	Reading (n=953)	Writing (n=1,045)	(n=138)
[A] Basic regression [Eq 1] from Table 2					
Stunted	-0.34*	-0.12*	-0.01	-0.11*	-0.45
	(0.18)	(0.06)	(0.05)	(0.06)	(0.86)
Moderately stunted	-0.14	-0.07	-0.02	-0.08	-1.59**
	(0.15)	(0.05)	(0.04)	(0.04)	(0.59)
Male	0.31***	0.14***	0.06**	0.10***	0.56
	(0.10)	(0.04)	(0.03)	(0.03)	(0.65)
Age	0.35***	0.08***	0.06***	0.08***	0.69***
	(0.03)	(0.008)	(0.009)	(0.009)	(0.18)
TAPS	-0.16*	0.17***	0.75***	0.35***	Not applicable
	(0.09)	(0.03)	(0.03)	(0.03)	
Constant	0.04	-0.23**	0.25*	0.04	1.44
	(0.10)	(0.11)	(0.11)	0.10	(2.25)
R^2	0.76	0.71	0.76	0.75	0.13
[B] Like [A] but with interactions with child's sex (male)					
Stunted	-0.47*	-0.12	-0.10	-0.12	0.54
	(0.24)	(0.08)	(0.06)	(0.07)	(1.48)
Moderately stunted	-0.20	-0.09	-0.07	-0.09	-0.46
	(0.24)	(0.07)	(0.06)	(0.06)	(0.86)
Male	0.16	0.02	-0.09	0.13	6.38*
	(0.38)	(0.17)	(0.13)	(0.11)	(3.46)
Age	0.35***	0.08***	0.06***	0.08***	0.90***
	(0.03)	(0.01)	(0.01)	(0.01)	(0.21)
TAPS	-0.08	0.10	0.76***	0.37***	Not applicable
	(0.18)	(0.06)	(0.05)	(0.06)	
Stunted*male	0.24	-0.006	0.16*	0.01	-1.68
	(0.24)	(0.11)	(0.09)	(0.10)	(1.73)
Moderately stunted*male	0.12	0.04	0.08	0.02	-2.21
	(0.31)	(0.10)	(0.09)	(0.09)	(1.37)
Age*male	0.007	0.006	0.008	-0.003	-0.37
	(0.03)	(0.01)	(0.01)	(0.01)	(0.25)
TAPS*male	-0.12	0.15	-0.01	-0.02	Not applicable
	(0.23)	(0.11)	(0.06)	(0.08)	
Constant	-1.13***	-0.35***	0.42***	-0.32***	-1.80
	(0.36)	(0.12)	(0.12)	(0.09)	(2.83)
R^2	0.76	0.72	0.76	0.75	0.16
Household fixed effects	Yes				No

Table A1.Continued

	Outcome	
	Academic skills	Local plant

Explanatory variables:	Schooling	Math	Reading	Writing	knowledge
[C] Like [A] but with interactions with child's age					
Stunted	-0.28	-0.19	-0.09	-0.27	-6.72**
	(0.53)	(0.20)	(0.19)	(0.18)	(2.92)
Moderately stunted	-0.51	-0.21	-0.21	-0.32**	-5.77
	(0.50)	(0.18)	(0.14)	(0.15)	(6.07)
Male	0.22	0.03	-0.04	0.12	6.46*
	(0.34)	(0.16)	(0.14)	(0.10)	(3.09)
Age	0.33***	0.06***	0.04*	0.06***	0.66
	(0.06)	(0.02)	(0.02)	(0.02)	(0.41)
TAPS	-0.31	0.06	0.66***	0.16	Not applicable
	(0.52)	(0.16)	(0.15)	(0.21)	
Stunted*age	-0.005	0.007	0.007	0.01	0.52*
	(0.05)	(0.02)	(0.02)	(0.01)	(0.26)
Moderately stunted*age	0.03	0.01	0.01	0.02	0.35
	(0.05)	(0.01)	(0.01)	(0.01)	(0.51)
Male*age	0.008	0.01	0.01	-0.0009	-0.48**
	(0.03)	(0.01)	(0.01)	(0.01)	(0.21)
TAPS*age	0.009	0.009	0.006	0.01	Not applicable
	(0.05)	(0.01)	(0.01)	(0.01)	
Constant	-0.94	-0.24	0.31	-0.10	1.73
	(0.62)	(0.21)	(0.21)	(0.18)	(4.78)
R^2	0.76	0.72	0.76	0.75	0.15
Household fixed effects	Yes				No

Table A1.Continued

	Outcome				
		Academic skills			Local plant knowledge
Explanatory variables:	Schooling	Math	Reading	Writing	
[D] Like [A] but with interaction with whether village has road (1=road; 0=road absent)					
Stunted	-0.30	-0.12	-0.01	-0.15	-1.05
	(0.25)	(0.09)	(0.06)	(0.09)	(1.32)
Moderately stunted	-0.12	-0.07	-0.06	-0.11	-2.42***
	(0.21)	(0.08)	(0.05)	(0.07)	(0.72)
Male	0.33**	0.06	0.04	0.04	0.56
	(0.15)	(0.04)	(0.04)	(0.05)	(1.08)
Age	0.33***	0.08***	0.05***	0.08***	0.94**
	(0.04)	(0.01)	(0.01)	(0.01)	(0.30)
Road	2.07***	0.39*	0.12	0.47**	7.17
	(0.76)	(0.19)	(0.21)	(0.20)	(4.99)
TAPS	0.51***	0.48***	0.09***	0.49***	Not applicable
	(0.14)	(0.03)	(0.03)	(0.03)	
Stunted*road	-0.05	-0.01	0.01	0.09	1.34
	(0.31)	(0.13)	(0.12)	(0.13)	(1.76)
Moderately stunted*road	-0.03	-0.01	0.06	0.07	1.57
	(0.29)	(0.11)	(0.08)	(0.09)	(1.18)
Age*road	0.06	-0.0001	0.01	-0.007	-0.53
	(0.05)	(0.01)	(0.01)	(0.01)	(0.39)
Male*road	-0.03	0.19**	0.05	0.14*	-0.27
	(0.19)	(0.09)	(0.06)	(0.07)	(1.66)
TAPS*road	-0.79***	-0.30***	0.62***	-0.10**	Not applicable
	(0.17)	(0.05)	(0.04)	(0.05)	
Constant	-3.56***	-0.85***	-0.72***	-0.83***	-1.78
	(0.66)	(0.15)	0.19	(0.16)	(3.14)
R^2	0.76	0.72	0.76	0.76	0.18
Household fixed effects	Yes				No

Table A1.Continued

	Outcome				
		Academic skills			Local plant knowledge
Explanatory variables:	Schooling	Math	Reading	Writing	
[E] Like [A] but with interactions with household socioeconomic status, using wealth in physical assets as a proxy (see notes for definition of asset wealth)					
Stunted	-0.12	-0.04	0.07	0.04	-2.09
	(0.20)	(0.11)	(0.11)	(0.10)	(2.00)
Moderately stunted	-0.11	-0.02	0.02	0.02	-3.40**
	(0.21)	(0.09)	(0.07)	(0.07)	(1.19)
Male	0.40***	0.11*	0.03	0.11*	-0.31
	0.14	(0.06)	(0.04)	(0.05)	(1.03)
Age	0.39***	0.09***	0.07***	0.09***	0.56**
	(0.05)	(0.01)	(0.01)	(0.01)	(0.22)
Household wealth	2.29e^{-06}	-0.00005**	-0.00002**	-0.00007***	-0.0004*
	(0.00004)	(0.00002)	(0.00001)	(0.00001)	(0.0002)
TAPS	0.80***	0.70***	1.63***	1.18***	Not applicable
	(0.21)	(0.07)	(0.07)	(0.07)	
Stunted*wealth	-0.00003	-0.00001	-0.00001	-0.00002	0.0002
	(0.00002)	(0.00001)	(0.00001)	(0.00001)	(0.0001)
Moderately stunted*wealth	-3.02e^{-06}	-7.44e^{-06}	-6.96e^{-06}	-0.00001	0.0002**
	(0.00002)	(0.00001)	(8.36e^{-06})	(9.40e^{-06})	(0.0001)
Male*wealth	-0.0001	4.11e^{-06}	5.54e^{-06}	-3.26e^{-07}	0.0001
	(0.00001)	(8.16e^{-06})	(6.26e^{-06})	(6.65e^{-06})	(0.0001)
Age*wealth	-5.92e^{-06}	-6.75e^{-07}	-1.70e^{-06}	-1.45e^{-06}	0.00001
	(5.41e^{-06})	(2.16e^{-06})	(1.50e^{-06})	(1.96e^{-06})	(0.00002)
TAPS*wealth	-0.0002***	-0.00007***	-0.0001***	-0.0001***	Not applicable
	(0.00002)	(0.00001)	(9.80e^{-06})	(0.00001)	
Constant	-1.14**	-0.84***	-0.69***	-0.95***	4.54
	(0.50)	(0.14)	(0.13)	(0.14)	(2.39)
R^2	0.76	0.72	0.76	0.76	0.16
Household fixed effects	Yes				No

Table A1. Continued

Explanatory variables:	Outcome				
	Schooling	Academic skills			Local plant knowledge
		Math (n=1,039)	Reading (n=939)	Writing (n=1024)	
[F] Like [A] but with interactions with schooling using academic skills as outcome					
Stunted		-0.14	-0.08	-0.13	
		(0.09)	(0.07)	(0.08)	
Moderately stunted		-0.06	-0.07	-0.07	
		(0.08)	(0.05)	(0.07)	
Male		0.12**	0.02	0.13**	
		(0.06)	(0.03)	(0.05)	
Age		0.07***	0.03**	0.08***	
		(0.01)	(0.01)	(0.01)	
Schooling		0.21**	0.01	0.21***	
		(0.08)	(0.08)	(0.07)	
TAPS		0.15*	0.77***	0.35***	
		(0.08)	(0.07)	(0.10)	
Stunted*schooling	Not applicable	0.03	0.04	0.03	Not applicable
		(0.03)	(0.03)	0.02)	
Moderately stunted*schooling		0.01	0.02	0.007	
		(0.03)	(0.02)	(0.03)	
Male*schooling		-0.003	0.008	-0.02	
		(0.02)	(0.01)	(0.02)	
Age*schooling		-0.01**	0.002	-0.01**	
		(0.006)	(0.006)	(0.005)	
TAPS*schooling		0.006	-0.01	-0.007	
		(0.03)	(0.02)	(0.03)	
Constant		-0.51***	-0.30**	-0.44***	
		(0.15)	(0.14)	(0.13)	
R^2		0.74	0.78	0.77	
Household fixed effects	Yes				No

Notes: Same notes as in Table 2.Household wealth is the total value in *bolivianos* (1 US dollar≈7.46 bolivianos during 2002-2010) of three types of physical assets: *(i)* five goods made from local material (e.g., dug-out canoes, bows), *(ii)* 13 commercial assets (e.g., metal cooking pots, machetes, axes), and *(iii)* domesticated animals (e.g., chickens, pigs, ducks).

Appendix 3. Robustness analysis of regressions from Table 2, all with household fixed effects: Summary of coefficients for stunted and moderately stunted

Table A2 contains the results of robustness analysis to ensure the results of Table 2 hold up after changing the method of analysis of Table 2.Recall that schooling was censored at zero, with 23.6% of children having no schooling (Table 1) and that scores of academic skills were transformed into binary variables. In section B of the table below we use a lowered-censored Tobit regression for schooling and Poisson regressions for raw measures of academic skills. The results confirm the findings presented earlier, with all previously significant coefficients becoming more negative. For instance, in the regression of Table 2, stunting was associated with 0.3 fewer completed grades of schooling, but with the Tobit regression stunting was associated with 0.5 fewer completed grades of schooling (p=0.001).In the regressions of Table 2, moderate stunting never bore a significant negative association with completed grades of schooling or academic skills, but with the Poisson count regressions moderate stunting bore a statistically significant negative association with math (p=0.001) and with writing (p=0.05). Including only the stunting variable (section C), reduced the size of the coefficients for the stunting variable, but still showed that stunting was associated with significantly fewer completed grades of schooling (from 0.34 in Table 2 to 0.23 in the table below (p=0.05)) and with a lower probability of having any math skills (7 percentage points; p=0.09), compared with non-stunted and moderately-stunted children. In section D we used a logit regression for academic skills, and found statistically stronger results than when using OLS, with previously insignificant coefficients becoming significant. For example, moderate stunting was negatively associated with math skills and stunting was negatively associated with reading skills.

Last, we use household random effect models. For the main results we opted to use a household fixed-effect model over a household random-effect model for substantive and technical reasons. On the substantive side, we wanted to control for important confounds such as household socioeconomic status and parental attributes. Particularly in the cross-sectional survey, much of the bias from these confounds would be swept away by the use of a household fixed-effect model. On the technical side, the random-effect model assumes that the error terms are uncorrelated with the explanatory variables, which is unlikely to be true in our data. The random effect models will have smaller standard errors, but the coefficients are more likely to be biased. We used the Hausman test to check for the technical adequacy of the random versus the fixed-effect model. These results are reported in section [E] and suggest that, on technical grounds, we can reject random-effect specification in favor of the fixed-effect specification. The use of a household random-effect model (Section E) shows slightly larger negative coefficients for the stunting variable and shows that moderately stunted children had less schooling (p=0.06) and lowers scores in tests of math (p=0.01) and writing (p=0.02), but not in reading tests (p=0.37).

Table A2. Robustness analysis of regressions from Table 2, all with household fixed effects: Summary of coefficients for stunted and moderately stunted

Height category:	Outcome			
	Schooling	Math	Reading	Writing
[A] Basic regression [Eq 1] from Table 2				
Stunted	-0.34*	-0.12*	-0.01	-0.11*
	(0.18)	(0.06)	(0.05)	(0.06)
Moderately stunted	-0.14	-0.07	-0.02	-0.08
	(0.15)	(0.05)	(0.04)	(0.04)
N	1,262	1,060	953	1,045
[B] Tobit and censored Poisson count regressions[a]				
Stunted	-0.52***	-0.41***	-0.23	-0.29**
	(0.16)	(0.12)	(0.23)	(0.15)
Moderately stunted	-0.23	-0.28***	-0.25	-0.23*
	(0.14)	(0.10)	(0.19)	(0.12)
[C] Like [A] but only stunted included as an explanatory variable, with non-stunted and moderate stunting used as reference				
Stunted	-0.23*	-0.07*	0.001	-0.05
	(0.12)	(0.04)	(0.04)	(0.04)
[D] Logit regressions for academic skills with odds ratio & 95% CI also reported				
Stunted		-0.80***	-0.58**	-0.67**
		(0.29)	(0.28)	(0.29)
Odds ratio		0.44***	0.55**	0.50**
95% CI		(0.24-0.79)	(0.32-0.97)	(0.28-0.91)
Moderately stunted	Not applicable	-0.54**	0.81	-0.34
		(0.25)	(0.17)	(0.25)
Odds ratio		0.57**	0.81	0.71
95% CI		(-0.34-0.94)	(0.53-1.25)	(0.43-1.17)
[E] Like [A] but with household random-effects				
Stunted	-0.36***	-0.13***	-0.04	-0.11***
	(0.09)	(0.03)	(0.03)	(0.03)
Moderately stunted	-0.16*	-0.08**	-0.02	-0.07**
	(0.08)	(0.03)	(0.02)	(0.02)
Hausman test [$\chi 2$, (p)]	7.16 (0.12)	5.50 (0.23)	2.28 (0.68)	4.32 (0.36)

Notes: Same notes as in Table 1 and same regressions as in Table 2, except where noted.[a] Lower-censored Tobit for schooling and lower-censored Poisson regressions for math, reading, and writing, with raw scores of academic skills used as outcome variables (see Table 1 for raw scores). CI = confidence interval.