Received: 7 June 2019 | Revised: 14 May 2020 | Accepted: 19 May 2020
DOI: 10.1002/ajhb.23452

ORIGINAL RESEARCH ARTICLE

American Journal of Human Biology WILEY

Trekking and toddlers: Towards a biocultural analysis of growth among infants and young children in a rural region of the Himalayas

Elizabeth A. Quinn | **Geoff Childs**

Department of Anthropology, Washington University in St. Louis, Saint Louis, Missouri, USA

Correspondence
Elizabeth A. Quinn, Department of Anthropology, Washington University in St. Louis, Box 1114, 1 Brookings Drive, Saint Louis, MO 63130.
Email: equinn@wustl.edu

Funding information
Division of Behavioral and Cognitive Sciences, Grant/Award Number: #1518013

Abstract

Objectives: Rapid socioeconomic change, associated with development and a growing tourism industry is occurring across the Himalayas. The health impact of this rapid economic development is poorly understood, especially for infants and young children. This study investigated the associations between village level economic differences as indexed by economic development and tourism engagement on infant and young child growth and health in a population of ethnic Tibetans living in the western Himalayas of Nepal.

Methods: One hundred and fifty nine infants and young children (ages 1-24 months) were enrolled. Anthropometric data (height, weight, triceps skinfold thickness) were collected at a single time point. Village level measurements of tourism and market engagement were incorporated into a scale measuring tourism, healthcare, trail access, agriculture, and involvement in medicinal trade. Village level disease patterns were calculated from morbidity and mortality recalls collected since 2003.

Results: There were no significant associations between infant weight for age z-score (WAZ), length for age z-score (LAZ), or weight-for-length for age z-score (WLZ) and village altitude, village economic development score, or engagement in tourism. Males had significantly higher LAZ, WAZ, and WLZ compared to females; only females showed a decline in LAZ with age. Triceps skinfold thickness z-score (ZTSF) was inversely associated with village level economic development score in male but not female infants; females ZTSF was positively associated with IYC age.

Conclusions: While overall size for age indices (WAZ, LAZ, WLZ) were not associated with altitude or village economic development in this population, ZTSF was inversely associated with village economic development in males but not females.

1 | INTRODUCTION

Hypoxia has long been argued to be a primary selective pressure on child height, weight, and other measures of growth for high altitude adapted children from the Andes and Himalayas. Although some of the earliest studies focused on hypoxia as the primary driver for short stature among high altitude adapted populations (Newman, 1961; Mazess & Baker, 1964), later studies recognized that hypoxia was just one selective pressure associated with high altitude living that contributed to atypical patterns of childhood growth (Frisancho, 1969; Frisancho, 2013; Frisancho & Baker, 1970). Quickly, marginal nutrition, high infectious disease burdens, and political marginalization from healthcare and trade emerged as important considerations (Beall, 1981; Beall, 2013; Frisancho, 2013; Leonard, Leatherman, Carey, & Thomas, 1990).

Some of the most telling evidence that hypoxia was not the exclusive driver of altered infant and young child growth comes from longitudinal research on child size at high altitude over the last several decades. In the Andes, improvements in child growth occurred in individuals from the 1960s to the 1980s but then declined in some, but not all areas, following political instability and guerrilla warfare associated with *Sendero Luminoso/Shining Path* (Leatherman, Carey, & Thomas, 1995; Leonard et al., 1990). The trend suggests that growth restriction had as much to do with the biology of poverty as with physiological challenges associated with high altitude (Varela-Silva & Santinho, 2016). More recently, Hoke and Leatherman (2019) demonstrated significant recent improvements in child size for age among children in Nuñoa compared to both pre- and post-*Sendero Luminoso* periods but not the declines reported during the *Sendero Luminoso* period. Oths, Smith, Stein, and Lazo Landivar (2018), working elsewhere in the Andes, have also documented recent increases in child size for age among mobile populations moving between high altitude and coastal areas of Peru. These increases occurred despite recent crop failures; the authors hypothesize that contemporary mobility and market integration may be driving child size increase. Comparatively large, temporal studies of child size for age in the Himalayas also show marked increases in child size for age across the Himalayas and Tibetan plateau (Argnani, Cogo, & Gualdi-Russo, 2008; Dang, Yan, & Yamamoto, 2008; Tripathy & Gupta, 2007; Wang et al., 2016).

As Oths et al. (2018) recently described, size for age data for infants and young children is comparably rare for high altitude populations. Hoke (2017) in a longitudinal study of infant and young child growth in Nuñoa, Peru, reported significant differences in size and growth trajectory by the zone of employment the family lived in. They found that children from the camelid herding zone had decreased growth compared to children from the dairying zone, reflecting differences in access to animal based sources of dietary protein. Collectively, such data suggest that secular trends in child size for age and changes to the underlying processes of growth are highly sensitive to nutritional improvement and household resources (Leonard 1990), although access to healthcare is also a strong potential factor as well (Oths et al., 2018).

Pictures of biocultural impacts on child growth and measures of size for age among high altitude populations is emerging in both the Andes (Hoke & Leatherman, 2019; Oths et al., 2018) and Himalayas (Wiley, 2004). In this biocultural framework, high altitude adaptation is the result not only of selective pressures associated with high altitude hypoxia and increased ultraviolet radiation but also social pressures such as poverty, political marginalization, marginal nutrition associated with shortened growing seasons and a limitation on crop diversity.

High altitude populations have developed myriad ecological and cultural strategies that act to ameliorate these pressures. However, long standing biological and cultural practices are impacted by rapid, recent economic development in these mountainous regions with variable impacts on child health and growth. In some instances, as Hoke and Leatherman (2019) illustrate, new economic strategies, such as changes in subsistence practices and increased engagement in the market economy, act not only to mediate these physiological constraints but may also create new constraints on child growth. While studies have shown that altitude and high altitude ancestry does have some influence on child size, especially long bone length (Bailey et al., 2007; Pomeroy et al., 2015), overall secular trends and the strong associations documented for the last 25 years between child size and poverty would argue that both matter, with poverty, malnutrition, and possibly infectious disease exposures having greater impacts on infant and young child growth and survivorship (Beall, 1981; Hoke & Leatherman, 2019; Leatherman et al., 1995; Leonard, 1989; Leonard et al., 1990; Wiley, 2004). Both Hoke (2017) and Oths et al. (2018) echo trends described earlier by demonstrating that improved economic conditions associated with dairying or coastal living predict increased size for age in Andean populations.

The links between recent economic development and child size have not been as extensively explored in the Himalayas, where tourism associated with mountaineering and trekking has dramatically altered community wealth, subsistence patterns, and economic development (Childs and Choedup 2018). Such economic development has long been hypothesized to contribute to a decrease in fertility and childhood morbidity and mortality, as evidenced by reports from the Everest region where access to healthcare, education, and other new economic resources has followed the popularity of Everest as a mountaineering and trekking destination (Pawson, 1977); and more recent data on demographic trends and contraceptive use from the Western Himalayas (Craig, Childs, & Beall, 2016). What is unknown however is how the economic and social differences associated with increased engagement in tourism and trekking impact infant and young child growth at the community level and if direct vs indirect engagement in tourism matters for infant and young child growth.

Here, we report on characteristics of growth in infants and young children ages two and under from an ethnic Tibetan population living in rural villages in a single valley at altitudes from 8500 to 12 500 ft in the central Himalayas of Nepal. We investigated three primary research questions: (a) is there an association between infant/young child (IYC) size for age (weight, length, BMI, triceps skinfold thickness, mid-upper arm circumference) and altitude of residence, (b) is there an association between growth (as defined above) and village level economic development (as indexed by village level engagement in tourism, agriculture, and trade in medicinal plants). These associations will then be contextualized within larger frameworks of infectious disease burdens which may contribute to patterns of growth faltering seen in this community.

2 | METHODS AND PARTICIPANTS

2.1 | Location and participants

Study participants live in the Nubri Valley of Nepal. The approximately 3000 individuals living in Nubri identify for the most part as ethnically Tibetan: they wear Tibetan dress, speak a Tibetan dialect, adhere to many Tibetan norms of social organization, and practice Buddhism. Historical records identify at least 700 years of continual occupation by settlers from the Tibetan plateau and regions to the south (Childs, 2004). The population is concentrated into 11 main and several additional satellite villages. Villages are within a few hours walk of one another, with altitudes from 1980 to 3875 m.

In 2015, as part of longitudinal research into children's health and growth at high altitude, we recruited all families with children ages 1 month to 17 years living in 11 main and several satellite villages to participate in a cross-sectional study of child size for age. Those younger than 1 month were enrolled in a longitudinal study that would follow them monthly for the first 18 months of life and are thus excluded from this sample (n = 3); an older infant with an inborn error of metabolism (based on maternal reports of medical diagnosis) was also excluded. The final sample size for this study was 159 children from 1 to 24 months of age; 77 females and 82 males recruited from 12 villages in the Nubri Valley. The sample here contains approximately 95% of all eligible children 24 months or younger in the Nubri Valley. Missing individuals were outside of Nubri during the study period; community members living in small outlying villages would walk upwards of several hours to villages where data collection were occurring and grandparents and other caregivers would bring children to the data collection sites (often health clinics) if parents were unavailable.

2.2 | Anthropometric methods

Basic anthropometrics of recumbent length, weight, mid-upper arm circumference (MUAC), head circumference, and triceps skinfold thicknesses were collected using standard anthropometric techniques used by the World Health Organization and UNICEF (de Onis et al., 2004; WHO Multicentre Growth Reference Study Group, 2006). Infants and young children were measured wearing light clothing with average clothing weight subtracted from overall measurements following common practice in colder climates (Roche, Gyorkos, Sarsoza, & Kuhnlein, 2015). All measurements were done in triplicate by one of three trained researchers (EQ, JS, NS) with inter-observer reliability tested every other day; inter-observer error for skinfold thickness was 4.3%-4.6% between researchers over the course of the study; error was lower for measurements of height and weight.

At the time of anthropometric collection, mothers were asked for the birth order and the birth date of the child. Data entry, cleaning, and cross checking against WHO standards and child age information was completed daily by the research team allowing for real time error capture. Birth date was provided according to the Tibetan calendar and converted to the Gregorian calendar during data cleaning using a method validated in other studies (Beall & Leslie, 2014; Fricke, 1994). Birth weight was not available for participants; as such we cannot know what percentage of children may have started out as low birth weight. However, only one child in the sample was below the standard low birth weight cut-off of 2500 g at 1 month of age and no older children were below 2500 g. In a separate study of longitudinal growth among infants in this population, we have only three instances of low birth weight infants reported, suggesting that low birth weight may be uncommon in this population.

The Z-anthro program for Stata 12.1 was used to calculate weight for age, length for age, weight for length, and MUAC for age z-scores for infants and young children (Vidmar, Cole, & Pan, 2013), following the World Health Organization growth standards (de Onis et al., 2004). Stunting, wasting, and underweight were calculated using the WHO cut-offs. In addition to calculating the standard WHO measures to facilitate comparisons with other populations, body surface area (BSA) and ponderal index (PI) were also calculated for all children following Frisancho (2013). BSA was calculated by multiplying the length (in centimeters) times the weight (in kilograms) of the individual and dividing this number by 3600; the square root of the product was then taken as the BSA. Ponderal index was calculated by dividing the weight (kg) of each individual by the length (m) cubed. BSA and PI were calculated to further test associations between body composition, altitude, and village economic development score.

2.3 | Health recall data

Health recall data for the infants and young children included in this study were not collected at the time of anthropometric measurement. As such, we use two alternative sources of health information as proxies for direct health recalls—maternal recall of infant and young child mortality, by cause, from 2000 to2013 and survey data collected in 2013 from a cohort of 70 infants and young children (under age two) where mothers were asked to recall all illnesses the child had experienced in the prior month. These data are extensively described elsewhere in earlier work by this team; data were collected using the OWN child method (Craig et al., 2016; Quinn, Diki Bista, & Childs, 2016). Reflecting the nature of these data, we cannot make specific statements about individual illnesses and their impacts on child health but we can use these as relative measures for community morbidity and mortality trends.

2.4 | Village characteristics

Archeologists (Aldenderfer, 1998; Bender & Wright, 1988), cultural ecologists (Rhoades & Thompson, 1975; Stevens, 1993), agricultural specialists (Partap, 1999), and geographers (Bjønness, 1983; Zurich & Karan, 1999) have pointed to a combination in mountainous areas of high altitude, climatic conditions, and steeply sloped landscapes that constrain agricultural productivity. People use various practices to offset limitations on production, ranging from pastoralism to trade. For example, cold stress constrains agricultural production by truncating the growing season and limiting the crops that can thrive. This is evident along the altitude gradient in Nubri where villages above 3500 m yield only a single crop per year as opposed to two per annum in lower villages; maize and beans grow in the lower but not the higher villages. Altitude-related constraints on agricultural productivity will impact nutrition, which is one reason why so many mountain dwellers across the globe rely on a mixed subsistence strategy that includes pastoralism (Brush & Guillet, 1985; Netting, 1981; Stevens, 1993). Pastoralism increases and diversifies the food supply, but also places humans in close contact with animals and their waste which can increase exposure to pathogens and consequently child size through increased infectious disease exposure (Pearce-Duvet, 2006).

In Nubri's highest villages people acknowledge their agricultural shortfalls through the oft-repeated phrase, "We trade or we starve" (Childs, 2004). High altitude dwellers in Nubri, and elsewhere augment their food supply by profiting as middle-men in trans-montane trade (Fisher, 1986; Fürer-Haimendorf, 1974). Trade in medicinal plants has become especially important to local economies in recent years. Pastures owned by the highest villages in Nubri (and elsewhere in Nepal, Bhutan, and across the Tibetan Plateau) are now prime collection grounds for *yartsa gunbu* (*Ophiocordyceps sinensus*; a caterpillar fungus complex), a medicinal substance prized in China since the early 2000s for its perceived efficacy in improving longevity and virility (Childs & Choedup, 2014). Income generated by the sale of *yartsa gunbu* is available only to residents of the highest villages in Nubri.

This new source of income and opportunities to purchase market foods may buffer nutritional stressors associated with high altitude from impacting child growth. Families living in the highest communities may earn more half their household income from *yartsa gunbu* (Childs & Choedup, 2014), opening up new avenues for income and wealth. Tourism is also emerging as an important source of income for villages along the trekking trail as families increasingly build trekking lodges, restaurants, and shops to meet the growing demands of trekkers and mountaineers.

2.5 | Village economic development score

The examples presented above help illustrate the importance of developing an index of village-level characteristics that are useful for explaining any inter-village differences in infant and child growth. This starts with a fixed geographical variable, altitude of the village. A seven level economic development score was then generated for each village using the following village-level characteristics: the location of the village on or off the main tourist trekking trail (determined from published trekking routes), the number of trekking lodges/tea houses in the village (based on a count collected during the field season), opportunities to work as paid mountain porters, participation in the collection and sale of *yartsa gunbu*, the presence of a health clinic in the village, the presence of a boarding school in the village, and the number of annual crop cycles (1 or 2). All characteristics were evenly ranked for the scale; this may not be an accurate representation of the weight of that characteristic on village economic development. For example, being on the main trail with access to tourist money may have a greater influence on economic development than a boarding school - but the two are often coupled in that villages with greater access to income from tourism and yartsa gunbu tend to have boarding schools and health clinics. Even a variable such as on the main trekking route can be problematic to interpret as some villages may be on the trekking routes but not have overnight stays, while other villages may have stays of two or more days. Yartsa gunbu income is often invested in tea houses/trekking lodges but both are sensitive to economic fluctuations in a way that seasonal crops are not. Access to portering jobs may impact individual households more than the number of lodges in a village, as these jobs are rotated through all households in the villages whereas yartsa gunbu income is frequently tied to household size. Boarding school presence in villages is often tied to greater nongovernment organization (NGO) activity which may have an impact on health but this can be highly variable between villages. As such, all variables were ranked evenly in the scale, although this is an oversimplification of a much more complex set of economic differences between villages.

Not all community members in each village are directly involved in trekking and tourism and this may create disparities within a village that these indexes will not capture. Overall however, the measures index community-wide benefits and engagement with development initiatives and accords well with our long-standing observations of relative wealth and external exposure by village that began in 1995. Mean village development score for the Nubri Valley was 3; one village had a score of 6 (highest), three villages had a score of 4, 2 villages had a score of 3, 3 villages had a score of 2.5, three villages had a score of 2, and two villages had a score of 1.

2.6 | Statistical analysis

ANOVA was used to test for differences in infant size for age by village and altitude, after adjustment for infant age and birth order. Multivariate linear regression was used to test for associations between weight for age z-score (WAZ), length for age z-score (LAZ), mid-upper arm circumference z-score (MUACZ), weight for length z-score (WLZ), triceps skinfold thickness for age z-score (ZTSF), body surface area (BSA), and ponderal index (PI) and secondary predictors of age, sex, birth order, and village of residence in the first set of models. In the second set of models, in addition to age, village characteristics of a health post, being on the main trail, and the village economic development score described previously were tested as secondary predictors of WAZ, LAZ, WLZ, MUACZ, ZTSF, BSA, and PI. All models were run independently by sex. Akaike information criteria was used to differentiate between regression model fit (Akaike, 1974). Regression models for village economic development score were secondary analyses to ANOVA, which better modeled the nonlinear association between each unit of change in the development score.

2.7 | Human subjects' protection

Approval for this study was obtained from the human subjects' approval board at Washington University in St. Louis and from the Nepal Health Research Council. Additionally, the study teams met with community leaders and mothers' groups in each community to discuss the research and obtain local permission. Caregivers were provided with immediate feedback on the child's size and any child identified as stunted or wasted was referred to local health clinics for enrollment in nutritional counseling or, if appropriate, for enrollment in community-based supplemental nutritional programs.

3 | RESULTS

The overall prevalence of stunting was 30.2%, underweight 11.7%, and wasting 4.9%. Females were more likely to be wasted or underweight compared to males although the differences were not significant (stunting $P < .184$; underweight $P < .294$; wasting $P < .204$). Males were more likely to be stunted than females, although rates varied by age (Figure 1).

3.1 | Age, sex, and anthropometrics

Prior to testing any of the primary research questions, we first tested for an association between age and infant size characteristics (regression outputs summarized in Tables 2 and 3). Current age (in months) was not significantly associated with WAZ (Figure 2), WLZ, or MUACZ. Conversely, age was significantly and inversely associated with LAZ for female infants (Figure 3) and approached significance for male infants (Figure 3). For females, each additional month of age was associated with a loss of 0.062 ± 0.021 z-scores of length ($R^2 = 0.164$; $P = .003$), with age explaining 10.1% of the variation in z-scores. By comparison, male length for age a-scores declined by

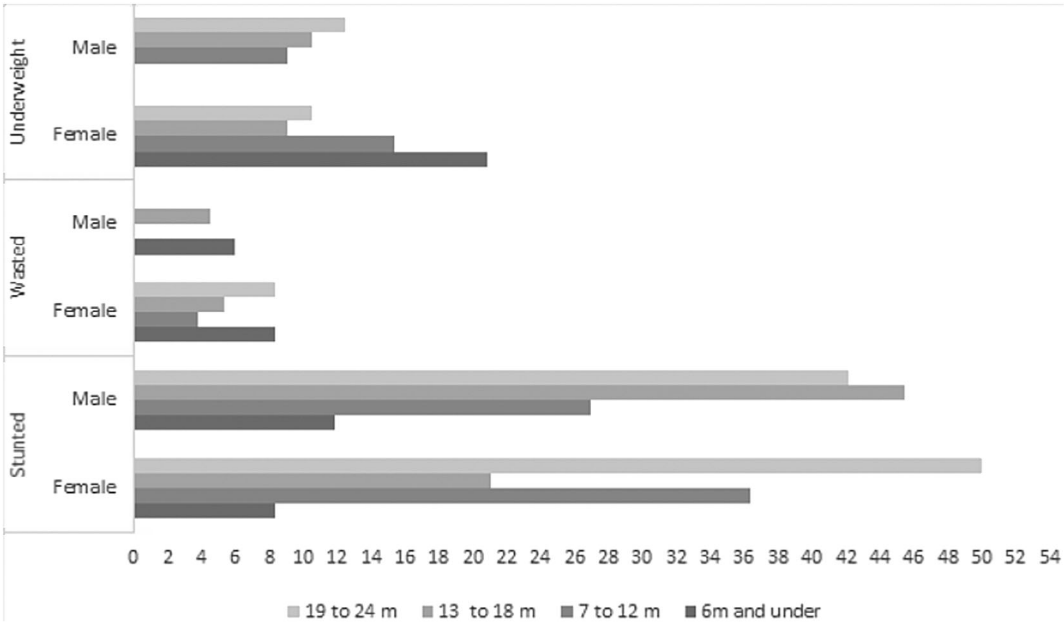

FIGURE 1 Stunting, wasting, and underweight frequency, by age category and child sex, for children ages 2 years and younger in Nubri, Nepal. Children were more likely to be wasted or stunted after 12 months of age, but underweight was more common in children under 12 months. There were no significant differences in rates of stunting, wasting, or underweight by infant sex

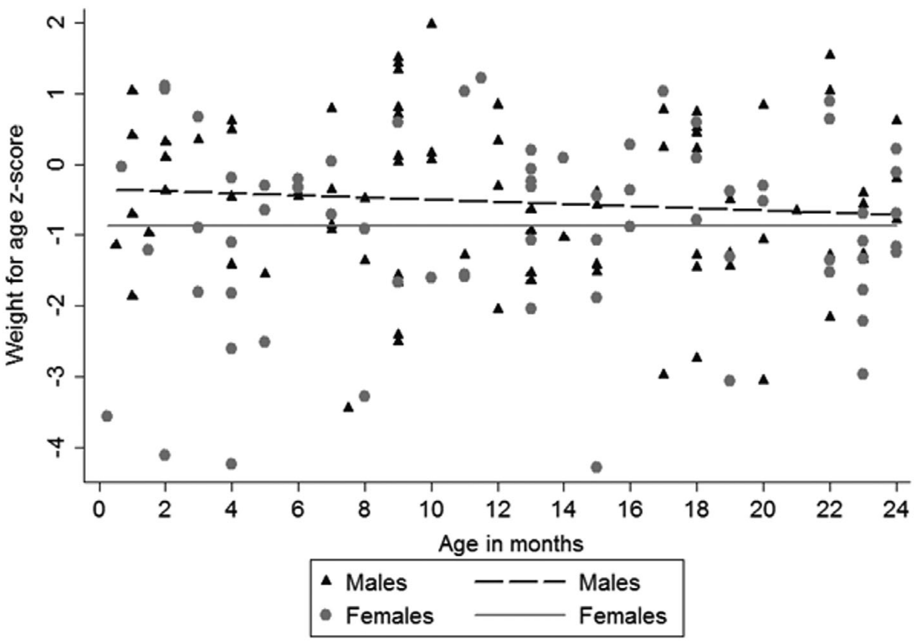

FIGURE 2 Weight for age z-score for male and female children under the age of two from Nubri, Nepal. There was no association between age and WAZ in females and only a modest association for males

0.044 (0.024) with each additional month of age ($R^2 = 0.03$; $P = .069$), although age explained only 1.9% of the variation in males. ZTSF was positively associated with age in females but not males (Figure 4).

Males had greater WAZ and WLZ compared to females. There were no significant differences in LAZ, MUACZ, and ZTSF between male and female infants (Table 1). Males had significantly higher PI (25.03 ± 4.65 vs 23.76 ± 4.04; $P < .033$) and BSA (0.426 ± 0.082 vs 0.403 ± 0.084; $P < .044$) compared to females.

3.2 | Altitude and anthropometrics

For each village, a reference altitude was used to assign all infants in that village a standard altitude; analyses

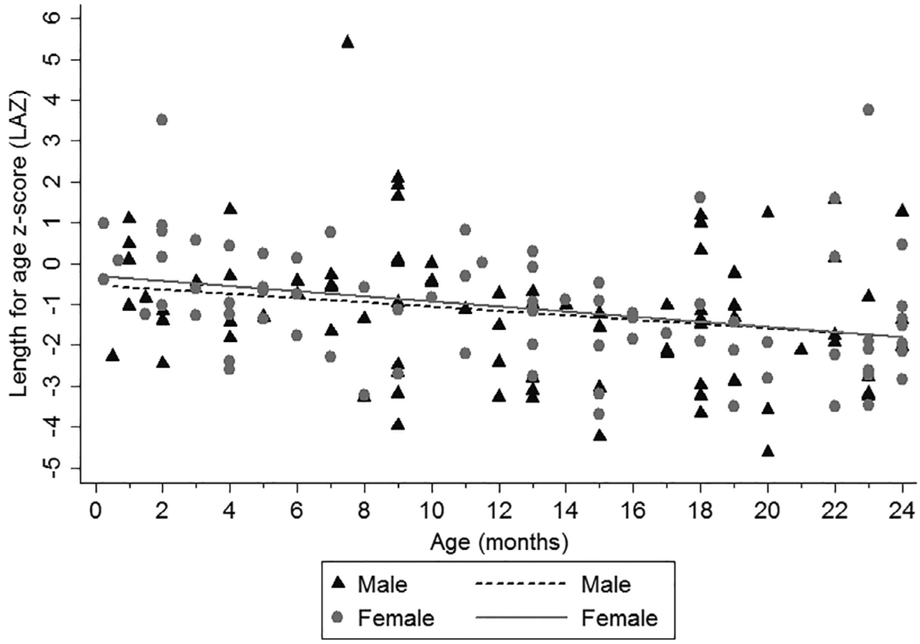

FIGURE 3 Length for age z-score for male and female children under the age of two. While both males and females had declines in LAZ with age, the trend was only statistically significant for females

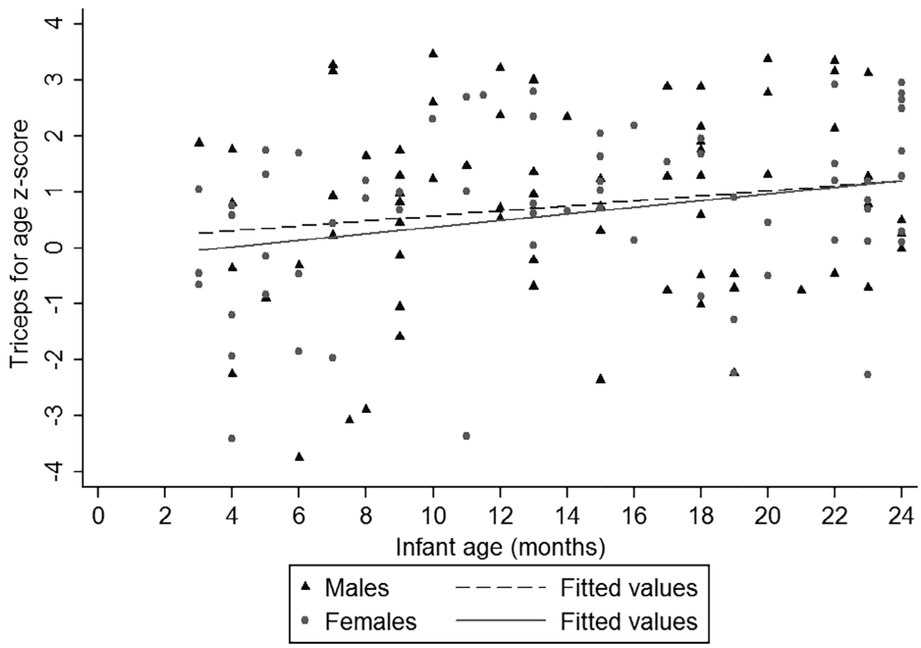

FIGURE 4 Triceps skinfold thickness for age z-score for male and female children under the age of two. Females, but not males, showed age associated increases in ZTSF

were conducted using both altitude and village as discrete predictors, as some villages were closely paired in altitude (only altitude results are shown in Tables 2 and 3). There was also no significant association between altitude of residence and LAZ, WAZ, WLZ, or MUACZ for infants and young children. Village of residence was not significantly associated with WAZ, LAZ, WLZ, or MUACZ for either male or female infants. However, among male infants, village of residence but not altitude was positively associated with ZTSF score; for females the association approached significance. BSA did not differ between low and high altitude living infants. PI was slightly lower among infants living below 3050 m/10 000 ft compared to infants living above 3,50 m/10 000 ft. ($P < .056$). These findings suggest that characteristics of the village besides its altitude have important implications for infant and young child adiposity but not linear growth.

3.3 | Village economic development and infant and young child growth

There were no differences in mean WAZ, LAZ, WLZ, ZTSF, or MUACZ by villages on the main trail compared

TABLE 1 Differences in primary characteristics of the sample between male and females under the age of two

	Male n = 83		Female n = 75		
	Mean	Std.	Mean	Std.	*P* value
Infant age (months)	12.48	6.91	12.89	7.92	.721
Weight (kg)	9.18	2.39	8.37	2.35	.017
Length (cm)	71.64	9.07	70.21	9.57	.333
Mid-upper arm circumference (cm)	15.25	1.98	14.88	1.92	.231
Triceps skinfold thickness (mm)	9.83	3.07	9.66	2.58	.698
Length for age z-score (LAZ)	−1.19	1.69	−1.1	1.49	.724
MUAC for age z-score (ZMUAC)	0.66	1.39	0.58	1.27	.717
Triceps for age z-score (ZTSF)	0.75	1.66	0.64	1.47	.674
Weight for age z-score (WAZ)	−0.54	1.15	−0.87	1.27	.043
Weight for length z-score (WLZ)	0.21	1.29	−0.22	1.22	.017

Note: Only weight was significantly different, with males heavier than female infants. Consequently, both WAZ and WLZ were significantly higher in male compared to females.

TABLE 2 Regression models for primary outcomes for males under the age of 2 years in this study

Outcome	Predictor	Model 1	Model 2	Model 3
Weight for age z-score	Age	−0.015 (0.018)	−0.015 (0.018)	−0.008 (0.019)
	Altitude		0.000 (0.000)	
	Dev. Score			0.085 (0.082)
	Constant	−0.354 (0.262)	−0.039 (0.791)	−0.667 (0.388)
	R^2	0.000	0.000	0.000
Length for age z-score	Age	−0.045 (0.024)*	−0.045 (0.024)*	−0.037 (0.025)
	Altitude		0.000 (0.000)	
	Dev. Score			0.046 (0.107)
	Constant	−0.704 (0.340)	−1.086 (1.015)	−0.935 (0.509)
	R^2	0.03	0.02	0.00
Weight for length z-score	Age	−0.007 (0.021)	−0.009 (0.020)	−0.004 (0.022)
	Altitude		0.000 (0.000)	
	Dev. Score			0.039 (0.094)
	Constant	0.300 (0.294)	1.592 (0.877)	0.192 (0.443)
	R^2	0.00	0.01	0.00
Mid upper arm circum	Age	−0.019 (0.027)*	−0.019 (0.027)	−0.016 (0.028)
	Altitude		0.000 (0.000)	
	Dev. Score			−0.088 (0.104)
	Constant	0.927 (0.407)	1.444 (1.067)	1.278 (0.548)
	R^2	0.00	0.00	0.00
Triceps skinfold z score	Age	0.044 (0.032)	0.043 (0.029)	0.034 (0.031)
	Altitude		0.000 (0.000)	
	Dev. Score			−0.358 (0.116)**
	Constant	0.133 (0.479)	4.341 (1.142)	1.396 (0.608)
	R^2	0.01	0.18	0.11

Note: Numbers shown are β (SE).
*$P < .05$.
**$P < .01$.
***$P < .001$.

TABLE 3 Regression models for primary outcomes for females under the age of 2 years in this study

Outcome		Model 1	Model 2	Model 3
Weight for age z-score	Age	0.000 (0.020)*	0.002 (0.019)	−0.001 (0.019)
	Altitude		0.000 (0.000)	
	Dev. Score			−0.123 (0.085)
	Constant	−0.875 (0.286)	0.329 (0.873)	−0.477 (0.389)
	R^2	0.01	0.001	0.000
Length for age z-score	Age	−0.067 (0.017)***	−0.068 (0.017)***	−0.070 (0.017)***
	Altitude		0.000 (0.000)	
	Dev. Score			−0.073 (0.079)
	Constant	−0.317 (0.259)	0.241 (0.822)	−0.066 (0.357)
	R^2	0.164	0.158	0.185
Weight for length z-score	Age	0.014 (0.019)	0.016 (0.019)	−0.070 (0.017)
	Altitude		0.000 (0.000)	
	Dev. Score			−0.073 (0.079)
	Constant	−0.410 (0.286)	0.298 (0.846)	−0.371 (0.393)
	R^2	0.00	0.000	0.000
Mid upper arm circum	Age	0.003 (0.022)	0.003 (0.022)	0.003 (0.022)
	Altitude		0.000 (0.000)	
	Dev. Score			−0.066 (0.089)
	Constant	0.535 (0.349)	0.535 (0.349)	0.856 (0.455)
	R^2	0.00	0.00	0.02
Triceps skinfold z score	Age	0.060 (0.024)*	0.060 (0.024)*	0.060 (0.024)*
	Altitude		0.000 (0.000)	
	Dev. Score			−0.142 (0.096)
	Constant	−0.223 (0.384)	1.266 (1.020)	0.189 (0.489)
	R^2	0.07	0.09	0.09

Note: Numbers shown are β (SE).
*$P < .05$.
**$P < .01$.
***$P < .001$.

to villages off the main trail (models not shown). The presence of a health clinic in the village was also not associated with increased WAZ, LAZ, WLZ, ZTSF, or MUACZ (models not shown). The overall village economic development score was not associated with any measure of child size except triceps skinfold thickness in males (Table 2), where it was inversely associated with the village economic development score ($R^2 = 0.112$; $P < .003$); for each one level increase in village economic development score, male ZTSF declined by 0.358 ± 0.119 z-scores; female z-scores (Table 3) showed modest but nonsignificant declines (-0.142 ± 0.096; $R^2 = 0.09$; $P < .143$); all models were adjusted for age. Overall, there was minimal evidence in this population for an association between village economic development score, engagement in the trekking industry, access to healthcare, and size for age of children under the age of two (Table 4).

3.4 | Under two mortality and infectious disease burden

Based on reproductive history surveys collected as part of this study, under-two mortality rates for Nubri from 2000-2013 were 11.3% (excluding stillbirths). The most common reported cause of death for children under the age of two was diarrhea (36.3%). Fevers accounted for 9.7% of mortality, followed by accidents (6.4%), respiratory infections (4.8%), and other infectious diseases such as measles and chicken pox (4%), and unspecific "swelling" (1.6%). Additional common causes of infant and

TABLE 4 Mean anthropometric indexes for combined males and females by village development score

	1	2	2.5	3	4	6
	n = 21	n = 15	n = 24	n = 43	n = 23	n = 34
WAZ	−0.70 (1.25)	−0.65 (1.43)	−0.43 (1.15)	−0.87 (0.93)	−0.48 (1.24)	−0.79 (1.50)
LAZ	−1.39 (1.54)	−1.00 (1.51)	−0.94 (1.29)	−1.41 (1.26)	−0.90 (1.61)	−1.40 (1.48)
WLZ	−0.04 (1.39)	0.002 (1.68)	0.19 (1.03)	−0.05 (0.81)	−0.10 (1.51)	0.09 (1.53)
MUACZ	0.52 (1.55)	1.65 (1.24)	0.33 (1.55)	0.68 (1.11)	0.92 (1.39)	0.34 (1.20)
ZTSF	1.17 (1.23)	0.16 (1.56)	1.41 (1.40)	0.32 (1.25)	0.81 (1.51)	0.09 (1.78)
BSA	0.44 (0.09)	0.41 (0.11)	0.41 (0.08)	0.40 (0.08)	0.42 (0.08)	0.42 (0.09)
PI	23.86 (5.19)	24.61 (6.21)	25.31 (4.24)	25.37 (3.82)	24.44 (3.70)	23.61 (4.44)

young child mortality were locally expressed as spiritually related and thus difficult to categorize (11.3%). For 22.6% of all infant and young child deaths, the cause of death was unknown. As evidenced by long term demographic data for the population, infant and young child mortality rates have declined precipitously since 1990 (Childs & Choedup, 2018).

From the second source of infant health data, collected from 70 mother-infant dyads aged 0-2 in 2013, mothers reported illnesses (diarrhea, fever, respiratory infection, or other illness type) at the time of the survey in 27 of 70 (38.5%) of infants. There were 46 total illness events reported by mothers with 18 infants having more than one illness at a time. The most common illnesses reported were respiratory infections with 89.3% of all infants and young children who were ill suffering from a respiratory infection. 64.3% of all sick children were sick with diarrhea. Diarrheal and respiratory infections co-occurred in 15 of these children (53.5%).

4 | DISCUSSION

4.1 | Growth at high altitude in a biocultural framework

While LAZ is often used as the primary measure of determining secular trends in child size, given its sensitivity to nutritional improvement in other developmental contexts (Cameron, 2007), ecological factors associated with high altitude stressors may continue to select for adiposity at the expense of height among high altitude living children. Adiposity, as indexed here by weight, WLZ, and triceps skinfold thicknesses showed no age-associated decline in z-scores after adjustment for infant age; female ZTSF actually increased with age. Earlier studies among ethnic Tibetans living on the Tibetan plateau have reported similar protection from age associated declines in WAZ (Wang et al., 2016). Compared to Han children living at similar altitudes, Tibetan children had consistently higher WAZ and incremental weight gain over the first year of life (Wang et al., 2016), suggesting that Tibetan infants may conserve weight at the expense of length; a pattern that has long been described for infants and young children from high altitude adapted populations (Bailey et al., 2007).

In a challenging environment characterized by chronic cold stress, a high infectious disease burden, and a long history of marginal nutrition, maintaining weight—especially adipose tissue—at the expense of height may be an adaptive strategy for infants and young children. This may reflect both the function of adipose tissue in the regulation of temperature, as infants and young children cannot fully self-regulate temperature the way older children and adults can. Hoke (2017) has hypothesized that increased adiposity in high altitude infants may also be an energetic reservoir for brown adipose tissue useful for dealing with chronic cold stress. Consistently, studies from high altitude adapted populations from the Himalayas and Andes have shown these trends: rates of wasting and underweight decline at much faster rates than stunting similar to the low rates we find here for underweight and wasting compared to stunting (de Meer et al., 1995). Pomeroy et al. (2015) recently showed that indigenous surnames predicted shorter tibia length at high altitude compared to children with nonindigenous surnames. However, in a comparative study of Tibetans and Han living at 3100 m, Bailey et al. (2007) reported that Tibetan children had consistently longer tibia length across quartiles of oxygen saturation and body fat compared to Han children, with tibia length sensitive to oxygen saturation as shown by the finding that children who had lower oxygen saturation had shorter tibias than those with higher oxygen saturation. Overall, it appears that there is evidence for multiple selective pressures on child height in Tibetan populations, with genes and hypoxia possibly limiting lower leg/tibia growth but other environmental factors, such as infectious diseases, poverty, and malnutrition also influencing child size for age.

4.2 | Rates of stunting, wasting, and undernutrition

In a study of urban and rural children living on the Tibetan Plateau, Dang, Yan, Yamamoto, Wang, & Zeng, 2004 reported incidence of stunting at 39.1% with 23.7% of children underweight. In comparison, we found much lower levels of stunting (30.2%) and underweight children (11.7%) (Figure 1). There were no significant differences in rates of stunting, underweight, or wasting by IYC sex. Nubri stunting rates were modestly lower but underweight rates were less than half of that reported for children on the Tibetan plateau 15 years prior. Studies have consistently found that rates of wasting and underweight in children decline faster than rates of stunting in association with improvements in nutrition, healthcare, and the diversification of income sources in both high altitude and sea level populations (Hoke & Leatherman, 2019; Leonard 1989; Cameron, 2007; Adair & Guilkey, 1997). One hypothesis is that the adaptive phenotypes for high altitude have always prioritized weight, and adipose tissue especially, as a strategy for dealing with chronic cold and nutritional stress associated with high altitude living. Therefore, nutritional and economic improvements enhance this adaptive phenotype—with adipose tissue prioritized as future energetic reserves for brains or somatic growth. Elsewhere, we have argued that hormones contained in human milk received by infants living at high altitude may promote weight gain as part of an adaptive strategy during infancy to prioritize weight gain and the construction of adipose tissue reserves to deal with high altitude stressors (Quinn et al., 2016), and that growth in length lags behind growth in weight and adiposity.

4.3 | Height loss among infant and young children in high altitude populations

It has been previously reported in many ecologically sensitive populations that infant growth during the first 6 months of life is characterized by improved WAZ and LAZ scores compared to later infancy (Cameron, 2007).

This decrease in growth starting at 6 months has been hypothesized to be the result of decreased nutritional intakes from nutritionally poor weaning foods starting at 6 months (Sellen, 2007), or from increased rates of injury and infection following the emergence of independent motor skills including walking and crawling that increase infant exposure to injuries and pathogens (Wiley & Pike, 1998). Such patterns of growth faltering are quite common in human populations—regardless of altitude.

In this sample of ethnic Tibetans, female infants and young children in Nubri, age was inversely associated with LAZ while ZTSF was positively associated. Although young female infants (1-3 months) had positive LAZ, older female infants (3-6 months) had inverse associations between age and LAZ (Figure 3). Male infants, by comparison, had lower LAZ in early infancy compared to female infants but almost no change in mean LAZ by 6 months; older male infants had inverse associations between age and LAZ. Prior studies in high altitude populations have found similar results with height loss primarily occurring in early life. Among Andean infants, Leonard, DeWalt, Stansbury, and McCaston (1995) reported that most height loss occurs by 6 months. While we did find evidence of a inverse association between age and LAZ from birth to 24 months, the associations were most pronounced from 1 to 6 months of age in female infants and after 6 months in male infants.

4.4 | Nutrition and infant growth

Nutrition as a cause of reduced growth in size among high altitude living children has been the source of considerable debate. Dang et al. (2004) reported no association between diet and WAZ, WLZ, wasting, or underweight among the infants and young children in their study and suggested that hypoxia was the primary factor contributing to the high rates of stunting and underweight they reported from the Tibetan plateau. However, other studies among Tibetan infants and young children have found significant evidence for nutrition as an important factor influencing infant WAZ and risk of underweight among young children (Beall, 1981; Wang et al., 2016). Among Peruvian infants, Hoke (2017) showed that infants living in the dairying zone of Nunoa had greater growth velocity over 6 months than infants living in urban or herding zones which they hypothesized reflected improved nutritional conditions that facilitated length and weight gain. Similar to the positive associations between ZTSF and age reported here, Hoke (2017) also reported minor increases ZTSF associated with age in female infants. Hoke (2017) also reported that economic strategy predicted significant differences in ZTSF, with infants from dairying regions having greater ZTSF compared to urban or herding infants for both sexes while we found inverse associations between village economic development score and ZTSF in male infants. Hypotheses proposed for these findings were (a) improved nutrition for dairying infants and increased adiposity in herding infants as energy stores for brown adipose tissue or (b) a reduction in the use of fats as energy substrates, resulting in increased body fat as the body preferentially utilizes carbohydrate substrates for metabolism.

Dietary recall data were not available for the children in this study, but earlier food frequency recalls identified infant diets based primarily on human milk to 4 to 6 months. After 6 months human milk is supplemented by aam (roasted barley flour mixed with butter tea to a thin pap/gruel), tsampa (roasted barley flour usually consumed with butter tea), and butter tea (black tea churned with butter, water, and salt); among older toddlers food included potatoes, prepackaged noodles, noodle soup, rice, and lentils/beans. Vegetables and apples are incorporated seasonally, especially in communities below 10 000 ft/3050 m. Meat and packaged sweets (candy, crackers, cookies) were occasionally consumed by older toddlers. As this study was conducted immediately after the 2015 earthquake, emergency relief supplies of rice and lentils were plentiful across all communities and no villages in Nubri were reporting food storages.

4.5 | Village of residence: altitude and tourism

As described earlier, altitude was not significantly associated with WAZ, LAZ, WLZ, or ZMUAC for male or female infants in this sample. We then tested for differences by village characteristics. As previously described, a village economic development score was calculated for each community. LAZ, WAZ, WLZ, and ZMUAC had no significant association with level of village economic development or proximity to the trail. For each one level increase in the six level village economic development score described previously, male infant triceps skinfold thickness decreased by 0.358 (0.119) z-scores, with village economic development score and age explaining 11.2% of the variance in ZTSF ($P < .003$). Age was associated with an increase in ZTSF for females, but females also showed a trend in decreasing ZTSF with village economic development score ($\beta = -0.142$ [0.095]; P, .143). These associations are in the opposite direction of our predictions as we predicted that increased village economic development score, as a marker of increased access to inexpensive, low quality commercial foods (such as cookies and instant noodles) would be associated with increased ZTSF and overall adiposity. Increased consumption of these foods may displace more nutritionally dense foods such as potatoes, beans/lentils, and vegetables resulting in the loss of ZTSF shown here, although this is speculative at best.

Village level economic development should also not be mistaken for individual economic conditions. Agricultural intensity, access to *yartsa gunba*, and tourism engagement vary dramatically between families even within the same village. For example, some families may own lodges or shops putting them directly in contact with tourists while others may have much more limited and casual interactions, such as serving as porters. Intra-village income variation is primarily associated with the fact that larger households can deploy more labor to gather *yartsa gunba* during its short harvest period and may garner more economic resources, although this source of income is heavily dependent on fluctuations in the price of *yartsa gunba* each year (Childs & Choedup, 2014); birth order number however was not associated with any measure of infant size for age in this sample.

An important point to consider is that villages with high economic development scores often have other community-level benefits that can translate into differences in infant and young child health and growth. While villages with more than one growing season will have better food supplies, villages with access to *yartsa gunba* will have greater access to cash and market goods (Childs & Choedup, 2014). At the household level, *yartsa gunbu* income is often used to purchase food via trans-Himalayan trade networks, while at the community level the tax on *yartsa gunbu* collectors can be invested in infrastructure that directly affects health outcomes, such as piped water and pour-flush latrines with septic tanks, including household latrines (Childs & Choedup, 2014). Villages with higher economic development scores also tend to have greater access to nongovernment organizations (NGOs) which promote local development and health initiatives. This translates to increased access to healthcare for individuals, especially those living in or near villages with health clinics although no community is presently more than a few hours walk from a health clinic. While we did not include access to NGOs in the developmental index score, villages do differ significantly in the degree of NGO activity. Such unequal village level economic developments may affect infectious disease exposures, severity, and mortality rates. However, as much of the mortality data described here was collected prior to the wide-spread availability of health clinics, their overall impact on infant mortality cannot be accurately estimated at this time.

4.6 | Infectious diseases and child growth

The common causes of infant and young child mortality discussed previously are also common causes of infant illness that do not result in death. In 2013, we did household surveys of all mothers with nursing infants (Quinn et al., 2016). Mothers were asked to recall all infant illnesses for the last 24 hours. Among the 70 infants in the sample, 38.5% were ill at the time of the survey. Respiratory infections were the most common, followed by diarrheal illness with numerous infants experiencing both conditions. The morbidity data collected as part of these surveys provides insight into the mortality data collected as part of the reproductive histories. Diarrheal illnesses were the most common cause of death reported for infants and young children in this population since 2000 but not the most common illness, suggesting that there may be complex relationships between diarrheal illness, respiratory infections, and mortality in this sample.

Infant mortality declined from 220 to 44/1000 over the last three decades (Childs & Choedup, 2018). This decline in infant and young child mortality has likely been driven by numerous factors accumulating over time: NGO health training workshops and support for traditional Tibetan medical practitioners, NGO sponsored health posts staffed by nurse midwives, and vaccination campaigns. Vaccine preventable illnesses, such as measles, have dramatically declined in Nubri following government vaccine initiatives that regularly send government health workers into communities to vaccinate children against measles, polio, and other illnesses, and it is now well documented that vaccination against measles translates into overall lower infectious disease rates in vaccinated communities (Welaga, Hodgson, Debpuur, Aaby, & Binka, 2018). The Nepali government has also trained, in each village, older women as Female Community Health Volunteers (FCHV) who serve as lay health workers and have access to basic medications (such an anti-helminths), vitamins, safe birthing kits, and birth control; the benefit of FCHV to maternal and child health has been well documented across Nepal (Kandel & Lamichhane, 2019).

Wiley (2004) has described high rates of respiratory infections among infants living in Ladakh, particularly with respiratory syncytial virus (RSV). Although respiratory infections are the most common cause of illness reported among infants and young children in Nubri, we do not have data to quantify RSV infection prevalence.

Chronic immune activation to prevent RSV infections and other diarrheal and respiratory infections will force a reallocation of energy towards immune activation instead of growth; chronic immune activation is a known risk factor for adverse growth trajectories (Blackwell, Snodgrass, Madimenos, & Sugiyama, 2010; McDade, 2003; Urlacher et al., 2018, 2019). Prior research across multiple populations have shown that chronic immune activation, as suggested here by the high rates of illness in the subset of children 2 years and younger measured in 2013, may act to limit the energy available for growth and thereby constrain growth, especially as measured by length/height (McDade, Georgiev, & Kuzawa, 2016). As adipose tissue can be a somatic reserve for increased energetic demands associated with infections, weight prioritization could be considered an adaptive trait for managing potential infections during the first 2 years of life (Kuzawa, 1998). Infections were most common in older infants aged 6 to 12 months, with 66.7% in this age category identified as having been ill in the prior 7 days. This is generally considered a period of high infectious disease morbidity from the introduction of nonmilk foods with associated potential pathogens and the emergence of independent locomotor skills (crawling, walking) that act to increase infant environmental contact (Sellen, 2007; Wiley & Pike, 1998).

Non-nutritional factors that may contribute to differences in child size relate to chronic cold stress, indoor air pollution, and infectious disease exposures. Frigid temperatures force people to spend more time indoors. In Nubri, this means more time sitting beside an open hearth in a one-room house that is not well-ventilated. While smokeless stoves are becoming more common in Nubri, they are often modified for use with available fuel and may not reduce smoke exposure as much as designed. Seasonal and inter-village variation in fuel type (yak dung, pine seasoned for less than a year, older dried birch) may also modulate smoke exposure across households and villages. Since women primarily perform domestic chores including food preparation, the infants and small children under their charge are continuously exposed to a smoke inundated environment. Wiley (2004) suggests that high altitude infants may be especially prone to respiratory problems because of the interplay between biocultural practices related to heating and food production and the hypoxic environment. A study in Pakistan found a much higher prevalence of pneumonia among children in high altitude than low altitude areas of the country (Khan et al. 2009). While this study did not suggest what factors may underlie the trends, chronic smoke exposure is a plausible hypothesis, especially when linked to the higher rates of RSV hypothesized by Wiley (2004) for infants in Ladakh and other high altitude communities.

5 | LIMITATIONS OF THE CURRENT STUDY

The current study has several key limitations. As a cross sectional study, we cannot accurately pinpoint when growth faltering is most likely to occur and what factors are most likely to predispose infants and young children to growth faltering; however longitudinal work is underway investigating these questions both monthly in younger children and on a yearly basis for all older children living in Nubri. We also did not collect nutritional information or illness data on the children in the study which limits our ability to identify what may be major potential causes of child malnutrition and suboptimal growth. Rather, what it presented here is a community level investigation into the ways in which village economic development may or may not contribute to changing patterns of growth during the first 2 years of life in high altitude living infants from the Himalayas.

High altitude populations are generally small, and as such sample sizes for these populations tend to be correspondingly small; the sample size here represents 95% of eligible children under the age of 2 years from the Nubri valley. There is also frequent concern about generalizability of these results, as high altitude is characterized by a unique set of ecological challenges not shared by other location and while these results may not be generalizable to all populations they may shed additional light on growth in high altitude adapted populations.

Individual level information on health and household construction were not available. As such, this study cannot provide insights into how infectious disease histories or household differences such as stove type (smokeless, open hearth) were also not available for all households. These analyses are focused on community level characteristics. Future research collecting longitudinal data on individuals will be necessary to better understand how village economic development is experienced at the individual and household level and the potential health impacts these differences may have.

6 | CONCLUSIONS

In this study into the biocultural contributors to infant and young child growth and development in a high altitude community in the Himalayas, we investigated environmental, social, and economic contributors to child growth and development. Three primary research questions were tested. We found, as many other prior studies have also reported, no association between size for age measures and altitude of the village the child lived in. We also found age associated declines in LAZ for females but not males, and no age associated declines for WAZ, WLZ, or ZMUAC. ZTSF increased in females, but not males, with age.

There were no direct associations between individual size for age measurements and village level economic development or proximity to the main trail, except for triceps skinfold thickness. Triceps skinfold thickness was inversely associated in males with degree of tourism involvement. These results are contradictory to expectations, as we predicted that higher village economic development scores and associated increased access to commercially produced foods (especially noodles and sweets) would be associated with increased ZTSF.

While direct measures of infections were unavailable for these children, 1990-2013 mortality data collected by reproductive history surveys and health recall data for 70 children under age two collected in 2013 consistently identified respiratory illness and diarrheal infections as the most common conditions experienced by infants and young children in this population. Respiratory infections were most common in illness histories but diarrhea was a more common cause of mortality, with infections peaking from 6to 12 months of age. It is quite possible that infectious disease, and not malnutrition, may act to limit the energy available for growth in this, and other, high altitude adapted populations.

Further work, specifically using longitudinal research of child growth that can includes regular nutritional and health histories will be necessary to fully understand the ways in which ecological factors contribute to differences in growth among high altitude living children. The findings here point to a conclusion reached by others (eg, Leatherman et al., 1995; Leonard et al., 1990; Hoke & Leatherman, 2019; Oths 2018): it is imperative to situate child growth and community health processes within large political, economic, and social measures because environmental factors alone cannot provide the answers.

ACKNOWLEDGEMENTS

The authors would like to thank the mothers, children, and families who participated in this research. The authors would also like to thank the research team members who assisted with data collection in Nubri: Jhangchuk Sangmo, Nyima Sangmo, Tsewang Palden, and Thinley Lama. The work was funded by the National Science Foundation BCS #1518013, the Leakey Foundation, and the Wenner Gren Foundation for Anthropological Research.

AUTHOR CONTRIBUTIONS

Elizabeth A. Quinn and Geoff Childs participated equally in all research activities. Elizabeth A. Quinn conducted data analysis and did the first draft of this manuscript. Geoff Childs created the indexes and contributed significantly to the revisions.

ORCID

Elizabeth A. Quinn https://orcid.org/0000-0001-7212-8271

REFERENCES

Adair, L. S., & Guilkey, D. K. (1997). Age-specific determinants of stunting in Filipino children. *The Journal of Nutrition*, *127*(2), 314–320. https://doi.org/10.1093/jn/127.2.314

Akaike, H. (1974). A new look at the statistical model identification. *IEEE Transactions on Automatic Control*, *19*(6), 716–723.

Aldenderfer, M. (1998). *Montane Foragers: Asana and the south-central Andean Archaic*, Iowa City: University of Iowa Press.

Argnani, L., Cogo, A., & Gualdi-Russo, E. (2008). Growth and nutritional status of Tibetan children at high altitude. *Collegium Antropologicum*, *32*(3), 807–812.

Bailey, S. M., Xu, J., Feng, J. H., Hu, X., Zhang, C., & Qui, S. (2007). Tradeoffs between oxygen and energy in tibial growth at high altitude. *American Journal of Human Biology*, *19*(5), 662–668. https://doi.org/10.1002/ajhb.20667

Beall, C. M. (1981). Growth in a population of Tibetan origin at high altitude. *Annals of Human Biology*, *8*(1), 31–38.

Beall, C. M. (2013). Human adaptability studies at high altitude: Research designs and major concepts during fifty years of discovery. *American Journal of Human Biology*, *25*(2), 141–147. https://doi.org/10.1002/ajhb.22355

Beall, C. M., & Leslie, P. W. (2014). Collecting women's reproductive histories: Women's reproductive histories. *American Journal of Human Biology*, *26*(5), 577–589. https://doi.org/10.1002/ajhb.22543

Bender, S. J., & Wright, G. A. (1988). High-altitude occupations, cultural process, and high plains prehistory: Retrospect and prospect. *American Anthropologist*, *90*(3), 619–639. https://doi.org/10.1525/aa.1988.90.3.02a00060

Bjønness, I. M. (1983). External economic dependency and changing human adjustment to marginal environment in the high Himalaya, Nepal. *Mountain Research and Development*, *3*(3), 263–272.

Blackwell, A. D., Snodgrass, J. J., Madimenos, F. C., & Sugiyama, L. S. (2010). Life history, immune function, and intestinal helminths: Trade-offs among immunoglobulin E, C-reactive protein, and growth in an Amazonian population. *American Journal of Human Biology*, *22*(6), 836–848. https://doi.org/10.1002/ajhb.21092

Brush, S., & Guillet, D. (1985). Small-scale agro-pastoral production in the Central Andes. *Mountain Research and Development*, *5*(1), 19–30.

Cameron, N. (2007). Growth patterns in adverse environments. *American Journal of Human Biology*, *19*(5), 615–621. https://doi.org/10.1002/ajhb.20661

Childs, G. (2004). *Tibetan diary: From birth to death and beyond in a Himalayan Valley of Nepal*. Berkeley, CA: University of California Press.

Childs, G., & Choedup, N. (2014). Indigenous management strategies and socioeconomic impacts of Yartsa Gunbu (Ophiocordyceps sinensis) harvesting in Nubri and Tsum, Nepal. *HIMALAYA, The Journal of the Association for Nepal and Himalayan Studies*, *34*(1) https://digitalcommons.macalester.edu/himalaya/vol34/iss1/7

Childs, G., & Choedup, N. (2018). *From a trickle to a torrent*, (247). Berkeley: University of California Press.

Craig, S. R., Childs, G., & Beall, C. M. (2016). Closing the womb door: Contraception use and fertility transition among culturally Tibetan women in Highland Nepal. *Maternal and Child Health Journal*, *20*(12), 2437–2450. https://doi.org/10.1007/s10995-016-2017-x

Dang, S., Yan, H., & Yamamoto, S. (2008). High altitude and early childhood growth retardation: New evidence from Tibet. *European Journal of Clinical Nutrition*, *62*(3), 342–348.

Dang, S., Yan, H., Yamamoto, S., Wang, X., & Zeng, L. (2004). Poor nutritional status of younger Tibetan children living at high altitudes. *European Journal of Clinical Nutrition*, *58*(6), 938–946. https://doi.org/10.1038/sj.ejcn.1601915

de Meer, K., Heymans, H. S. A., & Zijlstra, W. G. (1995). Physical adaptation of children to life at high altitude. *European Journal of Pediatrics*, *154*, 263–272.

de Onis, M., Garza, C., Victora, C. G., Onyango, A. W., Frongillo, E. A., & Martines, J. (2004). The WHO multicentre growth reference study: Planning, study design, and methodology. *Food and Nutrition Bulletin*, *25*(1 Suppl), S15–S26.

Fisher, J. (1986). *Trans-Himalayan Traders*, Delhi: Motilal Banarsidass.

Fricke, T. (1994). *Himalayan households: Tamang demography and domestic processes*, New York: Columbia University Press.

Frisancho, A. R. (1969). Human growth and pulmonary function of a high altitude Peruvian Quechua population. *Human Biology*, *41*(3), 365–379.

Frisancho, A. R. (2013). Developmental functional adaptation to high altitude: Review: Developmental functional adaptation to high altitude. *American Journal of Human Biology*, *25*(2), 151–168. https://doi.org/10.1002/ajhb.22367

Frisancho, A. R., & Baker, P. T. (1970). Altitude and growth: A study of the patterns of physical growth of a high altitude Peruvian Quechua population. *American Journal of Physical Anthropology*, *32*(2), 279–292. https://doi.org/10.1002/ajpa.1330320217

Fürer-Haimendorf, C. (1974). The changing fortunes of Nepal's high altitude dwellers. In *Contributions to the anthropology of Nepal*, (98–113). Liverpool: Aris and Phillips.

Hoke, M. K. (2017). Economic activity and patterns of infant growth in a high altitude district of Peru. *American Journal of Human Biology*, *29*(6), e23038. https://doi.org/10.1002/ajhb.23038

Hoke, M. K., & Leatherman, T. L. (2019). Secular trends in growth in the high-altitude district of Nuñoa, Peru 1964-2015. *American Journal of Physical Anthropology*, *168*(1), 200–208. https://doi.org/10.1002/ajpa.23736

Kandel, N., & Lamichhane, J. (2019). Female health volunteers of Nepal: The backbone of health care. *The Lancet*, *393*(10171), e19–e20. https://doi.org/10.1016/S0140-6736(19)30207-7

Khan, A. (2009). High incidence of childhood pneumonia at high altitudes in Pakistan: a longitudinal cohort study. *Bulletin of the World Health Organization*, *87*(3), 193–199. http://dx.doi.org/10.2471/blt.07.048264

Kuzawa, C. W. (1998). Adipose tissue in human infancy and childhood: An evolutionary perspective. *American Journal of Physical Anthropology, Suppl*, *27*, 177–209.

Leatherman, T. L., Carey, J. W., & Thomas, R. B. (1995). Socioeconomic change and patterns of growth in the Andes. *American Journal of Physical Anthropology*, *97*(3), 307–321. https://doi.org/10.1002/ajpa.1330970305

Leonard, W. R. (1989). Nutritional determinants of high-altitude growth in Nuñoa, Peru. *American Journal of Physical Anthropology*, *80*(3), 341–352. https://doi.org/10.1002/ajpa.1330800308

Leonard, W. R., DeWalt, K. M., Stansbury, J. P., & McCaston, M. K. (1995). Growth differences between children of highland and coastal Ecuador. *American Journal of Physical Anthropology*, *98*(1), 47–57. https://doi.org/10.1002/ajpa.1330980105

Leonard, W. R., Leatherman, T. L., Carey, J. W., & Thomas, R. B. (1990). Contributions of nutrition versus hypoxia to growth in rural Andean populations. *American Journal of Human Biology*, *2*(6), 613–626. https://doi.org/10.1002/ajhb.1310020605

Mazess, R. B., & Baker, P. T. (1964). Diet of Quechua Indians living at high altitude: Nunoa, Peru. *American Journal of Clinical Nutrition*, *15*, 341–351.

McDade, T. W. (2003). Life history theory and the immune system: Steps toward a human ecological immunology. *American Journal of Physical Anthropology*, *122*(S37), 100–125. https://doi.org/10.1002/ajpa.10398

McDade, T. W., Georgiev, A. V., & Kuzawa, C. W. (2016). Trade-offs between acquired and innate immune defenses in humans. *Evolution, Medicine, and Public Health*, *2016*(1), 1–16. https://doi.org/10.1093/emph/eov033

Netting, R. (1981). *Balancing on an alp: Ecological change and continuity in a Swiss Mountain community*, Cambridge: Cambridge University Press.

Newman, M. T. (1961). Biological adaptation of man to his environment: Heat, cold, altitude, and nutrition. *Annals of the new York Academy of Sciences*, *91*, 617–633.

Oths, K. S., Smith, H. N., Stein, M. J., & Lazo Landivar, R. J. (2018). A decade of rapid change: Biocultural influences on child growth in highland Peru. *American Journal of Human Biology*, *30*(2), e23072. https://doi.org/10.1002/ajhb.23072

Partap, T. (1999). Sustainable land management in marginal mountain areas of the Himalayan region. *Mountain Research and Development*, *19*(3), 251–260.

Pawson, I. G. (1977). Growth characteristics of populations of Tibetan origin in Nepal. *American Journal of Physical Anthropology*, *47*(3), 473–482. https://doi.org/10.1002/ajpa.1330470320

Pearce-Duvet, J. (2006). The origin of human pathogens: Evaluating the role of agriculture and domestic animals in the evolution of human disease. *Biological Reviews*, *81*(3), 369–382.

Pomeroy, E., Wells, J. C. K., Stanojevic, S., Miranda, J. J., Moore, L. G., Cole, T. J., & Stock, J. T. (2015). Surname-inferred Andean ancestry is associated with child stature and limb lengths at high altitude in Peru, but not at sea level. *American Journal of Human Biology*, *27*(6), 798–806. https://doi.org/10.1002/ajhb.22725

Quinn, E. A., Diki Bista, K., & Childs, G. (2016). Milk at altitude: Human milk macronutrient composition in a high-altitude adapted population of Tibetans. *American Journal of Physical Anthropology*, *159*(2), 233–243. https://doi.org/10.1002/ajpa.22871

Rhoades, R., & Thompson, S. (1975). Adaptive strategies in alpine environments: Beyond ecological particularism. *American Ethnologist*, *2*(3), 535–551.

Roche, M. L., Gyorkos, T. W., Sarsoza, J., & Kuhnlein, H. V. (2015). Adjustments for weighing clothed babies at high altitude or in cold climates. *Global Public Health*, *10*(10), 1227–1237. https://doi.org/10.1080/17441692.2015.1037326

Sellen, D. W. (2007). Evolution of infant and young child feeding: Implications for contemporary public health. *Annual Review of Nutrition*, *27*, 123–148. https://doi.org/10.1146/annurev.nutr.25.050304.092557

Stevens, S. (1993). *Claiming the high ground*, Berkeley: University of California Press.

Tripathy, V., & Gupta, R. (2007). Growth among Tibetans at high and low altitudes in India. *American Journal of Human Biology*, *19*(6), 789–800. https://doi.org/10.1002/ajhb.20638

Urlacher, S. S., Ellison, P. T., Sugiyama, L. S., Pontzer, H., Eick, G., Liebert, M. A., … Snodgrass, J. J. (2018). Tradeoffs between immune function and childhood growth among Amazonian forager-horticulturalists. *Proceedings of the National Academy of Sciences of the United States of America*, *115*(17), E3914–E3921. https://doi.org/10.1073/pnas.1717522115

Urlacher, S. S., Snodgrass, J. J., Dugas, L. R., Sugiyama, L. S., Liebert, M. A., Joyce, C. J., & Pontzer, H. (2019). Constraint and trade-offs regulate energy expenditure during childhood. *Science Advances*, *5*(12), eaax1065. https://doi.org/10.1126/sciadv.aax1065

Varela-Silva, M. I., & Santinho, C. (2016). Human biology of poverty. *Annals of Human Biology*, *43*(2), 99–101. https://doi.org/10.3109/03014460.2016.1150158

Vidmar, S. I., Cole, T. J., & Pan, H. (2013). Standardizing anthropometric measures in children and adolescents with functions for egen: Update. *Stata Journal*, *13*(2), 366–378.

Wang, W., Liu, F., Zhang, Z., Zhang, Y., Fan, X., Liu, R., & Dang, S. (2016). The growth pattern of Tibetan infants at high altitudes: A cohort study in rural Tibet region. *Scientific Reports*, *6*, 34506. https://doi.org/10.1038/srep34506

Welaga, P., Hodgson, A., Debpuur, C., Aaby, P., Binka, F., & Azongo, O. A. (2018). Measles vaccination supports millennium development goal 4: Increasing coverage and increasing child survival in Northern Ghana, 1996–2012. *Frontiers in Public Health*, *6*, 28.

WHO Multicentre Growth Reference Study Group. (2006). Reliability of anthropometric measurements in the WHO Multicentre Growth Reference Study. *Acta Paediatrica (Oslo, Norway: 1992) Supplement*, *450*, 38–46.

Wiley, A. S. (2004). *An ecology of high-altitude infancy: A biocultural perspective*, Cambridge: Cambridge University Press.

Wiley, A. S., & Pike, I. L. (1998). An alternative method for assessing early mortality in contemporary populations. *American Journal of Physical Anthropology*, *107*(3), 315–330. https://doi.org/10.1002/(SICI)1096-8644(199811)107:3<315::AID-AJPA8>3.0.CO;2-4

Zurich, D., & Karan, P. (1999). *Himalaya: Life at the edge of the world*, Baltimore: The John Hopkins University Press.

How to cite this article: Quinn EA, Childs G. Trekking and toddlers: Towards a biocultural analysis of growth among infants and young children in a rural region of the Himalayas. *Am J Hum Biol*. 2020;32:e23452. https://doi.org/10.1002/ajhb.23452