HUMAN BiOLOGY AND PUBLiC HEALTH
JOURNAL OF THE AUXOLOGICAL SOCIETY

ISSN 2748-9957 | 2026 | pp. 1–23

Body fat percentage, not early life experiences, predicts blood pressure in children in Utila, Honduras

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Citation:

Merullo, N./Hlay, J.K./Rodríguez-James, I. et al. (2026). Body fat percentage, not early life experiences, predicts blood pressure in children in Utila, Honduras, Human Biology and Public Health. https://doi.org/10.52905/hbph2026.117.

Received: 2025-10-06
Accepted: 2026-01-05
Published: 2026-08-24

Peer review:

Single anonymized

Conflict of Interest:

The authors declare no conflicts of interest related to this research.

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Keywords

Cardiovascular disease, blood pressure, hypertension, stress, adiposity

Abstract

Background Elevated blood pressure distributes metabolic resources through the body, but can also cause pathology. Life history theory predicts that natural selection has acted on energy allocation, leading to strategic adjustments to psychosocial and energetic challenges posed by one's environment.

Objective We test whether greater psychosocial challenges will necessitate increases in mean arterial pressure (MAP), predicting that greater social-economic-political-emotional (SEPE) stress is associated with higher MAP. We also test whether adiposity is positively associated with MAP.

Methods We measured the growth and development of 222 children longitudinally and cross-sectionally from 2023–2025 in Utila, Honduras, where inhabitants experience varying levels of SEPE stressors. We measured standard anthropometrics, blood pressure, and morning salivary hormones. SEPE factors were collected from the primary caregiver at the time of consent to the study.

Results A Saint Nicolas House Analysis network of associations showed a positive correlation between age-adjusted MAP and body fat percentage ($r = 0.29$). Multiple regression analysis showed no significant relationship between SEPE factors and MAP ($\beta = -0.89$ and -0.75; $p = 0.17$ and 0.49) and instead showed a positive relationship between body fat percentage and MAP ($\beta = 3.17$; $p = 0.01$).

Conclusion Body fat percentage strongly predicts higher blood pressure, suggesting that the metabolic status of children is an important predictor of potential cardiovascular risk. In contrast to our predictions, MAP appears relatively robust to variable exposures of stress among children in Utila. These findings underscore the need for cultural and location-specific studies of stress and blood pressure.

Take-home message for students Perturbations to energetic and metabolic status could lead to adaptive developmental strategies in children's cardiovascular function. Here, we measure the blood pressure of children in Utila, Honduras. We find that body fat percentage, and not social-environmental-political-emotional stressors, predicts higher blood pressures, suggesting a greater energy abundance through fat stores increases MAP.

Introduction

The evolution of the cardiovascular system has been driven by the effective and efficient delivery of metabolic substrates and oxygen, which is essential to energy production (Klabunde 2022; Monahan-Earley et al. 2013). Despite this, pathology still occurs in this finely tuned system, with cardiovascular disease (CVD) being the leading cause of human morbidity and mortality globally (Aggarwal et al. 2021; Mills et al. 2020; World Health Organization 2021), representing 32% of all-cause deaths (17.9 million people in 2019; (World Health Organization 2021). Hypertension, or chronic high blood pressure, is the leading risk factor for developing CVD worldwide (Aggarwal et al. 2021; Chaturvedi et al. 2023; Mills et al. 2020). The global burden of hypertension, measured as systolic blood pressure $\geq$ 140 mmHg and diastolic blood pressure $\geq$ 90 mmHg was about 31.1% among adults in 2010 (Mills et al. 2020). Since then, however, the standards for hypertension have been lowered to systolic blood pressure $\geq$ 130 mmHg (Klabunde 2022), suggesting that the hypertension burden could now be even greater.

However, this overall burden of hypertension obscures fundamental disparities in rates of hypertension. Understanding these disparities is critical, as they offer clues to the environmental and social drivers of the disease. Low-to-middle-income countries account for the vast majority of global hypertension cases, with 1.04 billion of the estimated 1.39 billion cases (Mills et al. 2020). Decades of research have identified diverse and interconnected causes of hypertension disparities. While age, sex, and genetics play an important role, extrinsic, environmental factors – especially psychosocial factors (e.g., stress) and lifestyle factors (e.g., obesity and poor diet) – greatly compound intrinsic risks for developing hypertension and limit access to treatment (Chaturvedi et al. 2023).

Social, economic, political, and emotional (SEPE) all influence growth and development trajectories from gestation to adulthood (Bogin 2021; Chaturvedi et al. 2023; Kuzawa and Sweet 2009; Kuzawa and Sweet 2025). SEPE is a construct similar to traditional social determinants of health (Marmot et al. 2001), but it goes beyond socioeconomic status, allowing for a more cross-cultural approach (Bogin 2021). For low-to-middle-income countries, SEPE factors are particularly critical for understanding the rise of hypertension, as they help contextualize the local realities which may become embodied as biological health (Worthman and Costello 2009).

SEPE factors expose individuals to psychosocial stressors that activate the hypothalamic–pituitary–adrenal (HPA) axis, leading to elevated levels of cortisol, its primary hormone (Dickerson and Kemeny 2004; Ellison 2017; Worthman and Kuzara 2005). Stress is generally defined as a state of heightened energetic demand in unpredictable or uncontrollable situations, with cortisol acting as the primary mediator of energy allocation to meet these demands (Koolhaas et al. 2011). During times of unpredictable and uncontrollable energetic shortfalls, the body upregulates these hormonal pathways. This physiological response rapidly increases heart rate and contracts blood vessels, thus increasing blood pressure. This subsequent rise in blood pressure serves a critical function: to forcefully mobilize and deliver energetic resources, such as glucose and fatty acids, to muscles and vital organs quickly (Vera et al. 2017).

An evolutionary life history approach can further elucidate why the body makes these energetic trade-offs (Worthman and Kuzara 2005). Because of the functional link between the cardiovascular system and energy distribution, energetically demanding stressors can pose a selective pressure on cardiovascular function. Cardiac output, a key measure of blood flow, matches metabolic rate throughout the life course (Ríos et al. 2023), reflecting the body's demands for oxygen and substrates. Therefore, understanding the relationship between energetically demanding stressors and blood pressure levels may elucidate a path to pathology. This life history perspective reframes increased blood pressure in childhood not merely as a pathological state but as an adaptive strategy to overcome resource limitation, a biological embodiment of SEPE factors in the early life environment.

In addition to SEPE stress, the burden of overnutrition and metabolic dysfunction plays an important role in driving variation in hypertension in communities experiencing nutritional transition from traditional diets to cheap, processed foods (Chung et al. 2023; Sobers and Samuels 2019). Adiposity has been found as a predictor of primary childhood hypertension in the United States (Falkner et al. 2023). Fat tissue triggers the renin-angiotensin-aldosterone system (RAAS), a hormonal pathway which primarily affects kidney function and volume retention, subsequently raising blood pressure (Lurbe et al. 2001). Both the HPA axis and the RAAS pathway increase blood pressure, but through different upstream processes. Body fat percentage is a necessary factor when considering variation in childhood blood pressure. However, adiposity and SEPE status are intertwined (Chung et al. 2023); therefore, disentangling their unique contribution to CVD risk can be difficult. This research contributes to this resolution by examining a population in nutritional transition where SEPE stress and adiposity are not uniformly coupled. By characterizing these pathways in a rapidly changing, non-Western context, we can better isolate whether early-life blood pressure elevation is primarily a metabolic consequence of adiposity or an independent, embodied response to psychosocial instability.

The present research

The present research focuses on childhood blood pressure. While childhood hypertension was long thought to only be secondary to other pathologies, research now suggests disparities in adult hypertension begin in childhood (Falkner et al. 2023). The risk of developing CVD begins in early life, as evidenced by a prospective study tracking risk factors in childhood and CVD outcomes in adulthood across seven countries (Jacobs et al. 2022). Additionally, in a meta-analysis, high blood pressure in childhood significantly predicts intermediate markers of CVD in addition to adult hypertension: pulse wave velocity, carotid intima-media thickness, and left ventricular hypertrophy (Yang et al. 2020). Childhood blood pressure can be challenging to characterize due to the confounding effects of height (Bell et al. 2019) and lack of clinical screening and prevention in children (Yang et al. 2020). While childhood hypertension in the US is only 2–4% (Bell et al. 2019), we may be fundamentally underestimating true childhood hypertension and pre-CVD rates. This study seeks to both measure childhood blood pressure and characterize early life risks for CVD and health disparities in a culturally specific context.

Research on childhood blood pressure is also lacking in low-to-middle-income countries (Jacobs et al. 2022). In Honduras, poverty is the second most common predictor of adult hypertension, implicated in 51.9% of cases (Paz 2015). Limited medical infrastructure compounds this burden; 83% of Hondurans lack health insurance, and 30% of the country is without healthcare access (Pearson et al. 2012). This is similar to many countries around the world where lower socioeconomic status leads to higher rates of hypertension (Schutte et al. 2023). Yet this is not always the case; for example, the Tsimane (an indigenous population in lowland Bolivia) have very low levels of hypertension despite living in relative poverty and facing discrimination from other Bolivians (Gurven et al. 2012).

The specific pathways by which socioeconomic hardship becomes embodied vary significantly depending on local context and history. In some populations, poverty and food insecurity are associated with overnutrition and the consumption of cheap, processed, energy-dense foods, which drives obesity and related cardiometabolic risk (Chung et al. 2023). In others, particularly those with deep-seated food system instability, poverty may be linked to undernutrition (Sobal and Stunkard 1989). Similarly, the relevant psychosocial stressors are not universal. While one community may face chronic stress from a lack of basic resources and environmental instability, another may experience a greater burden from social marginalization, perceived inequality, or cultural disruption (Mittal and Singh 2010). Therefore, careful attention to the local context is necessary to understand the embodied experience of individuals in the study population (Worthman and Kuzara 2005).

We explore the local context of childhood blood pressure in Utila, Honduras. The island of Utila, in the Bay Islands region, is primarily inhabited by two populations: 1) generational islanders with British, Honduran, and Caribbean ancestry; 2) people born in mainland Honduras with mostly indigenous and European ancestry. Both SEPE and adiposity show high within- and between-group variation. The generational islanders have higher relative economic stability that stems from a longer history on the island and greater ownership of property and businesses. In contrast, mainland Hondurans have been relocating over the last four decades to escape hardship and violence on the mainland. These individuals often reside in a crowded and stigmatized neighborhood that lacks reliable sanitation infrastructure (García et al. 2017; García et al. 2020). Previous research on the island has revealed that those with perceived low socioeconomic status (measured via an Utila-specific lifestyle discrepancy scale) had higher levels of cortisol throughout the day (García et al. 2017). Sanitation access was one of the strongest drivers of cortisol in this sample (García et al. 2017).

This field site provides an opportunity to evaluate health disparities in a non-US population with variation in resource access and psychosocial stressors. Relevant SEPE stressors in Utila include food insecurity, neighborhood instability, home instability, lifestyle discrepancy, sanitation access, and other measures of socioeconomic status (Adair and Cole 2003; Dressler et al. 1998; Dressler and Bindon 1998; Ellis et al. 2009; García et al. 2017; Worthman and Kuzara 2005). In this study, we test the hypothesis that greater psychosocial stress and adiposity will increase mean arterial pressure (a measure of blood pressure calculated with systolic and diastolic pressure; MAP) in children on Utila. First, we predict that children exposed to greater stress from various SEPE factors will exhibit greater MAP. Second, we also predict that higher cortisol will be associated with greater MAP as the pathway for SEPE factor stress. Finally, we predict that those with greater fat stores will have higher MAP. Crucially, our analytical approach includes SEPE and adiposity in the same model. In high-income contexts, low socioeconomic status is often strongly collinear with obesity, making it difficult to determine if blood pressure elevation is driven by stress or body mass. This design allows us to disentangle these typically confounded effects, isolating the independent contribution of psychosocial stress versus adiposity. By examining these relationships in a population with clear socioeconomic and environmental disparities, we aim to provide novel insights into the biocultural drivers of early-life cardiovascular risk.

Sample and Methods

Sample

The data for the present study come from the Utila Child Health Project (UCHP), a longitudinal and cross-sectional study of child health and development in Utila, Honduras. UCHP hosts an annual children's camp in January where the research team collects biological and behavioral measures from participants. Across three years of data collection (2023–2025), there have been 222 total participants ages 6–18 from 136 families. Families were recruited by snowball sampling, word of mouth, and community outreach.

Psychosocial Stressors Measurement

SEPE variables leverage data from existing interviews with caregivers at the time of consent to the study. SEPE factors included in this analysis include measures of home flooding, access to sanitation, perceived home instability, perceived neighborhood instability (McGuire 1997), migration to the island, education level, income level, food insecurity (Bickel et al., 2000), social support, and lifestyle discrepancy (García et al. 2017). Surveys are a combination of standardized and Utila-specific questionnaires. Lifestyle Ain other similar settings (Dressler et al. 2005a; Dressler et al. 2005b; Dressler et al. 1998; Dressler and Bindon 1998). García et al. (2017) created a lifestyle discrepancy measure specific to Utila, and it has thus been adapted for this study, where greater value is associated with a greater unmet material needs.

Anthropometric and Biological Measurements

Blood pressure was measured in the camp setting in both 2024 and 2025. Prior to measurement, participants were asked if they had a caffeinated beverage or if they had eaten that day. A validated oscillometric device with an appropriately sized cuff was used to collect measurements (Falkner et al. 2023; Muntner et al. 2019; OMRON 2024). Participants sat for at least five minutes before collection and were instructed to have their feet flat on the floor, uncrossed, and their measurement arm rested at heart level (Liu et al. 2024). To avoid error, blood pressure was taken two times, and if measures differed by more than 10mmHg systolic or diastolic, a third measure was taken. The latter two measurements were averaged (Corrado 2015; Falkner et al. 2023; Muntner et al. 2019). Finally, MAP was calculated from the average systolic and diastolic pressures using the following formula: (2*diastolic+systolic)/3 (Brzezinski 1990; Klabunde 2022). To assess children's growth, the following anthropometrics were collected: height, weight, body fat percentage, and circumferences of the shoulders, waist, and hips (Lohman et al. 1988). Body fat percentage was determined using a pediatric bioelectric impedance scale (Tanita; (Barreira et al. 2013). These measurements were taken approximately every six months. Cortisol saliva samples were collected in the camp setting when children first arrived in the morning. Caffeine intake, breakfast consumption, and color of the saliva were recorded for each participant (Rosenbaum et al. 2018). Samples were assayed at the Salimetrics' SalivaLab (Carlsbad, CA) using the Salimetrics Salivary Cortisol Assay

Kit (Cat. No. 1–3002), without modifications to the manufacturers' protocol. The present study uses the January 2024 and 2025 camp MAP, anthropometrics, and saliva samples.

Statistics

All statistical analyses were performed in R version 4.5.1 (R Core Team 2025). Z-scores were calculated for height using the World Health Organization (WHO) reference heights for children ages 5–19 matched by age to the closest month (Hermanussen 2013); World Health Organization, n.d.). A Saint-Nicolas House Analysis (SNHA) was performed to assess correlations between MAP, anthropometrics, hormones, and SEPE factors. SNHA is a network of variables which hierarchically ranks correlations (Groth et al. 2019; Hermanussen et al. 2021; Groth 2023). To assess an overall burden of SEPE factor stress, a principal components analysis (PCA) was performed to reduce the dimensionality of caregiver survey results to principal component vectors. All predictor variables were centered and standardized. One individual with a height recorded shorter than in previous years had the 2025 value removed. For four other individuals whose heights were less than half an inch shorter than a previous year's measurement, the 2025 measurement was replaced with the most recent year's measurement.

For the primary analysis, we used multiple regression to test the predictors of MAP for age in the 2025 sample (n=69). The top principal component vectors by statistical weight were then used in multiple regression model construction, along with sex, body fat percentage, WHO z-score height, and cortisol. To control for age in MAP, the residuals were taken from this relationship and used as the outcome variable in these models; therefore, age was not included as an effect. Cortisol typically has direct vasoactive effects, typically acting as a vasoconstrictor that signals for the release of other vasoconstrictive and volume-retaining molecules (Kubzansky and Adler 2010; Vera et al. 2017). Height is one of the determining factors for childhood blood pressure ranges (Bell et al. 2019; Lurbe et al. 2001; U.S. Department of Health and Human Services 2007), so it was included in models as a control. Sex was also included as a control. Body fat percentage was included as adiposity is reported as one of the top contributors to primary childhood hypertension in the United States (Falkner et al. 2023). Testosterone was originally tested as a variable in models due to potential vasodilatory action (Lorigo et al. 2020), but was removed from models due to lack of effect. The top model was determined by the lowest Akaike Information Criterion (AIC).

To validate results and to overcome the limitations of cross-sectional data, we conducted a longitudinal analysis using both 2024 and 2025 data. We conducted a linear mixed effects model using the lme4 package (Bates et al. 2014). These models pooled 2024 and 2025 data and tested the same variables as the primary analysis and used year as a fixed effect and participant ID as a random effect. In the longitudinal analysis, we were able to use 134 observations across 93 individuals, an increase in sample size from our cross-sectional analysis. Finally, we also followed the method described in Adair and Cole (2003) for calculating a community-specific high blood pressure threshold based on the top tenth percentile of residuals of MAP regressed on age and height. Using these categories (normal and high blood pressure), we performed a logistic regression with the same covariates used in the top model from the primary analysis.

Results

Sixty-nine individuals had results from both their caregiver's survey and data from the 2025 camp, and the total number of participants with blood pressure data from 2025 totals 109. Descriptive statistics for the sample are presented in Table 1, and results from the caregiver survey for the corresponding families are presented in Table 2. The mean age of the sample is 11.42 years (SD=2.64), and the mean MAP is 76.13 mmHg (SD=10.50). Both males and females had a mean body mass index under 25, the threshold for being overweight. 74% of the caregivers reported having relocated to the island from the mainland at some point in their lifetime. Most caregivers reported being in low-to-middle income categories, with 31% falling into category two, 5,001 to 10,000 Lempira per month, and 47% reporting an income of 10,001 to 20,000 Lempira per month. Mean lifestyle discrepancy, measured on a scale from zero to 80, is 31 (SD=17). 36% of caregivers completed middle school (category 2), and another 36% reported finishing high school (category 4). 40% of caregivers reported the highest level of food insecurity.

We assessed the 2025 camp participants for hypertension using the United States Department of Health and Human Services' standards for pediatric blood pressure (2007). This reference guide considers sex, age, and height and can be used for children ages 3–17. Accordingly, we found 103 children in the normal range (94.50%), three considered pre-hypertensive (2.75%), two in hypertension stage I (1.83%), and one child considered hypertension stage II (0.92%). Blood pressure for the one child in hypertension stage II was validated on site. To further characterize the development patterns of the sample, we compared the heights of the Utila sample to the WHO references. A mean height 2 standard deviations below the WHO reference indicates stunting (Scheffler and Hermanussen 2022). Though longitudinal heights from the entire study (2023–2025) indicate children on Utila are generally shorter than the WHO reference (Figures 1 and 2) and mean z-score heights for both sexes are negative, there was no significant difference between Utila heights and WHO references in a Welch two sample t-test ($t = -1.06$, $p = 0.49$).

The SNHA networks include correlations between variables with a significance threshold $p < 0.05$ and are thus ranked hierarchically into a network of associations. The first SNHA (Figure 3), which used the original MAP values, showed the only direct correlation was with age ($r = 0.62$). After removing the effect of

Table 1 Means (SD) of the biological measures from the child participants in the 2025 children's camp in Utila, Honduras

Variable	Female Means (SD)	Male Means (SD)
Mean Arterial Pressure (MAP) (mmHg)	77 (11.73)	75.3 (9.24)
Age (years)	11.61 (2.77)	11.27 (2.54)
MAP for Age (MAP ~ Age residuals)	-0.04 (11.78)	-1.26 (7.51)
WHO z-score Standardized Height	-0.32 (1.25)	-0.4 (0.96)
Height Increment 2025–2024 (cm)	5.51 (2.67)	5.69 (1.86)
Body Fat Percentage	25.76 (9.83)	20.51 (8.24)
Body Mass Index (kg/m2)	21.04 (6.24)	19.24 (3.9)
Salivary Cortisol (μg/dL)	0.2 (0.16)	0.19 (0.17)
Sample size	36	33

age by taking the residuals of MAP ∼ age, we created a new SNHA (Figure 4) which showed that MAP only correlated with body fat percentage ($r = 0.29$), though this is a weaker correlation that only presents in 50% of bootstrap iterations. In both SNHA plots, many of the SEPE factors clustered together, with lifestyle discrepancy, home instability, education, and income being central to the network and mediating correlations with other SEPE and biological variables. Immigration status was negatively correlated with height increment in both SNHA plots. Cortisol negatively correlated with lifestyle discrepancy ($r = -0.24$), such that those whose caregivers reported greater lifestyle incongruence were associated with lower salivary cortisol levels. Higher body fat percentage was associated with lower home instability ($r = -0.27$) and greater social support ($r = 0.25$).

A PCA was conducted to reduce the dimensionality of the SEPE factors (Figure 5). All relevant SEPE factors were made numerical and scaled. Nominal variables with more than two categories (i.e., citizenship) were excluded. PC1 accounts for 27.63% of the variation in the sample and PC2 accounts for 14.39%. Though 13 principal component vectors were generated, they accounted for diminishingly less statistical weight and had no interpretable direction of SEPE stress. PC1 is associated with outside or shared latrines, no flushing toilet, no running water in the latrine, more likely to have a home or a bedroom flood, more home instability and neighborhood instability, more likely to have relocated to the island, lower education level, lower income level, higher lifestyle discrepancy, greater food insecurity, and lower social support (Table 3). PC2 is associated with not having a flush toilet, greater home and neighborhood instability, immigration to the island, lower education status, lower income level, higher lifestyle discrepancy, and high food insecurity. Notably, PC2 does not correlate positively with measures of flooding or shared and outside latrines.

Finally, multiple regressions allowed us to assess the effect of the principal component vectors of SEPE factors and cortisol on

Table 2 Caregivers of child participants reports of social-economic-political-emotional factors relevant to Utila, Honduras

Variable	Mean (SD)
Relocated to Island (%)	73.91
Income Category (1, <5,000 Lempira monthly – 6, >80,000 Lempira monthly)	2.64 (0.82)
Lifestyle Discrepancy (0, no discrepancy – 80, high discrepancy)	31.23 (16.54)
Neighborhood Instability (1, low instability – 5, high instability)	2.25 (1.06)
Home Instability (1, low instability – 5, high instability)	2.79 (0.79)
Education (0, no education – 6, university degree)	3.28 (1.45)
Social Support (1, low support – 5, high support)	2.66 (1.18)
Food Insecurity (1, low insecurity – 5, high insecurity)	3.54 (1.44)
Bathroom Outside (%)	18.84
Bathroom Shared (%)	4.35
Bathroom Has Flushing Toilet (%)	75.36
Bathroom Has Running Water (%)	72.46
Home Flood Frequency (0, never floods – 3, floods almost always with rain)	0.39 (0.83)
Bedroom Flood Frequency (0, never floods – 2, bedroom floods with rain)	0.26 (0.59)
Sample size	69

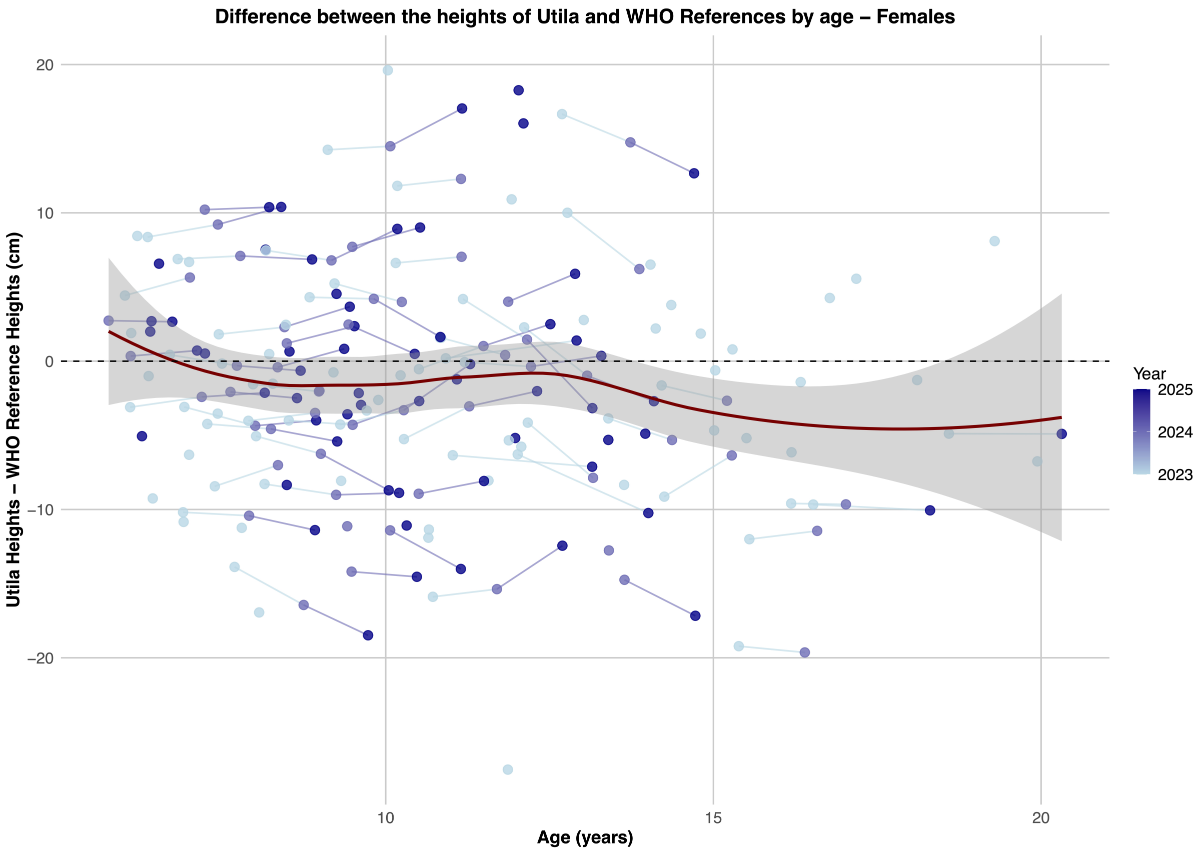

Figure 1 Longitudinal differences between WHO reference heights and Utila heights for children, matched by age in females. Females are not significantly shorter than WHO references and are therefore not showing signs of being stunted. Children in Utila exhibit normal growth patterns

MAP ~ age residuals. We tested the effects of PC1, PC2, cortisol, body fat percentage, sex, and height (Table 4). The top model by lowest AIC was the full model (Table 5). This model shows body fat percentage as a significant positive effect ($\beta = 3.06$, $p = 0.01$), but no other variables were significant. The model itself is not well fit; the F-statistic p-value is not significant ($p = 0.11$), and the adjusted r-squared is low (R2=0.07), showing this model explains very little variance in MAP. The longitudinal mixed effects models confirmed that the full model was the top model by AIC (Figure 6; $\beta = 3.05$, $SE = 0.78$, $t = 3.91$) and that body fat percentage was the best predictor of MAP adjusted for age. Splitting participants into high and normal blood pressure categories based on the Adair and Cole (2003) definition of elevated blood pressure, the best predictor of the high blood pressure category in a logistic regression was also body fat percentage (Figure 7; $\beta = 1.22$, $p = 0.01$). We found no significant relationship between PC1 ($\beta = 0.02$, $p = 0.93$), PC2 ($\beta = -0.26$, $p = 0.61$), or cortisol ($\beta = 0.09$, $p = 0.86$) in the logistic regression. In both cross-sectional and longitudinal analyses, body fat percentage was a significant positive predictor of MAP adjusted for age (Figures 8 and 9).

Discussion

Childhood blood pressure is linked to adult cardiovascular disease across the world, yet we know little about the environmental factors that explain variation in childhood blood pressure, particularly in low-

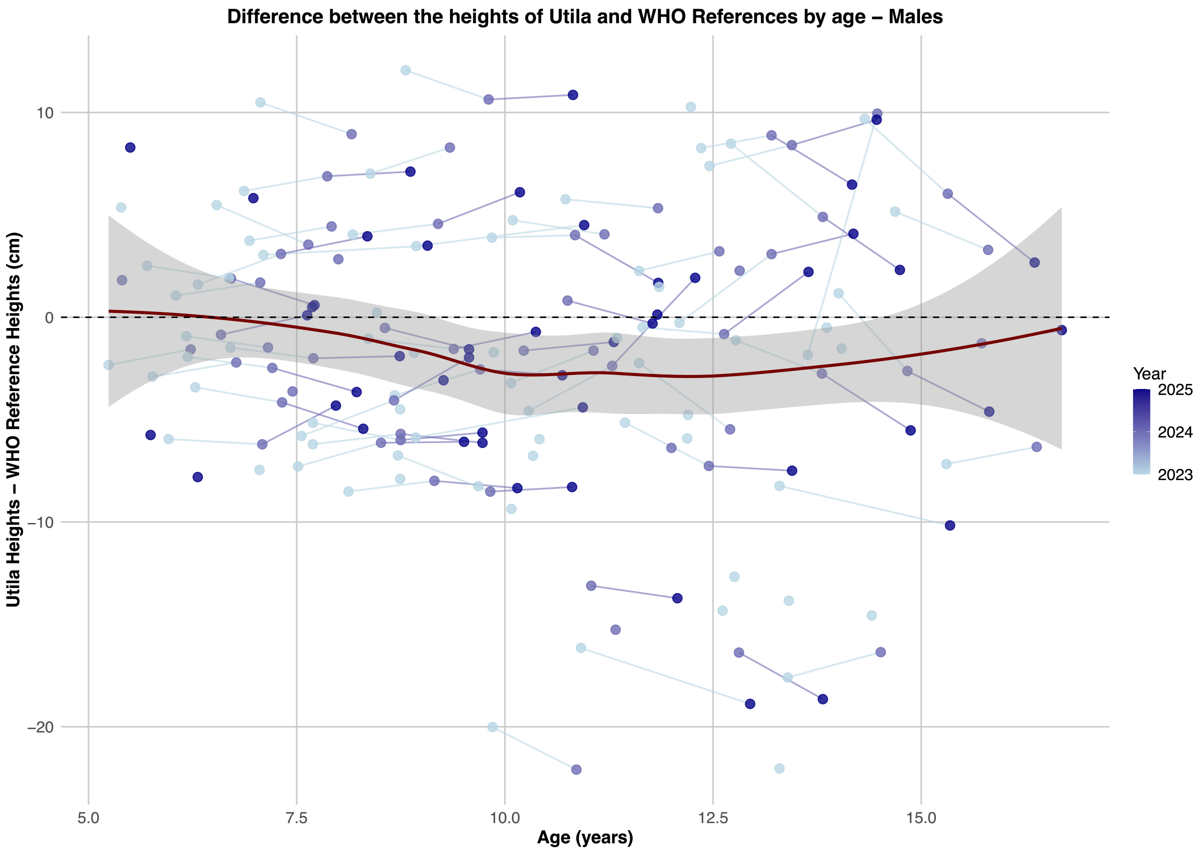

Figure 2 Longitudinal differences between WHO reference heights and Utila heights for children, matched by age in males. Males are not significantly shorter than WHO references and are therefore not showing signs of stunted. Children in Utila exhibit normal growth patterns

to-middle-income countries. In this study, we sought to explain variation in blood pressure (measured via mean arterial pressure; MAP) using SEPE factors, cortisol, and adiposity among children aged 6 to 18 living in Utila, Honduras. While stress has been linked to variation in blood pressure among adults (Chaturvedi et al. 2023; Dressler and Bindon 1998; Kuzawa and Sweet 2009; Kuzawa and Sweet 2025), our findings indicate that neither SEPE factors nor cortisol explained variation in MAP. In contrast, higher body fat percentage was a significant predictor of greater MAP.

Our findings accord with clinical literature, which posits that adiposity is one of the leading causes of primary hypertension in children in the United States (Falkner et al. 2023). Literature that explores the effects of globalization reveals a growing trend of children exposed to more environmental stress or lower socioeconomic status having trended towards lower nutrition but higher prevalence of obesity due to access to low-cost, low-nutrition but calorie-dense foods (Jones-Smith et al. 2011; Monteiro et al. 2007; Shrewsbury and Wardle 2008; Sobal and Stunkard 1989; Wang and Lim 2012). If this were the case on Utila, we would expect to find a positive relationship between SEPE variables, or more stress, and adiposity. However, we find the opposite. Looking at the present data, body fat percentage was negatively correlated with home instability and positively correlated with social support in the SNHA, suggesting preliminarily that children with more adiposity are exposed to less SEPE stress. A regression between body fat percentage and SEPE principal component vectors further confirmed this negative relationship ($\beta = -0.12$, $p = 0.046$, 2.5%, 95% CI [-0.25,

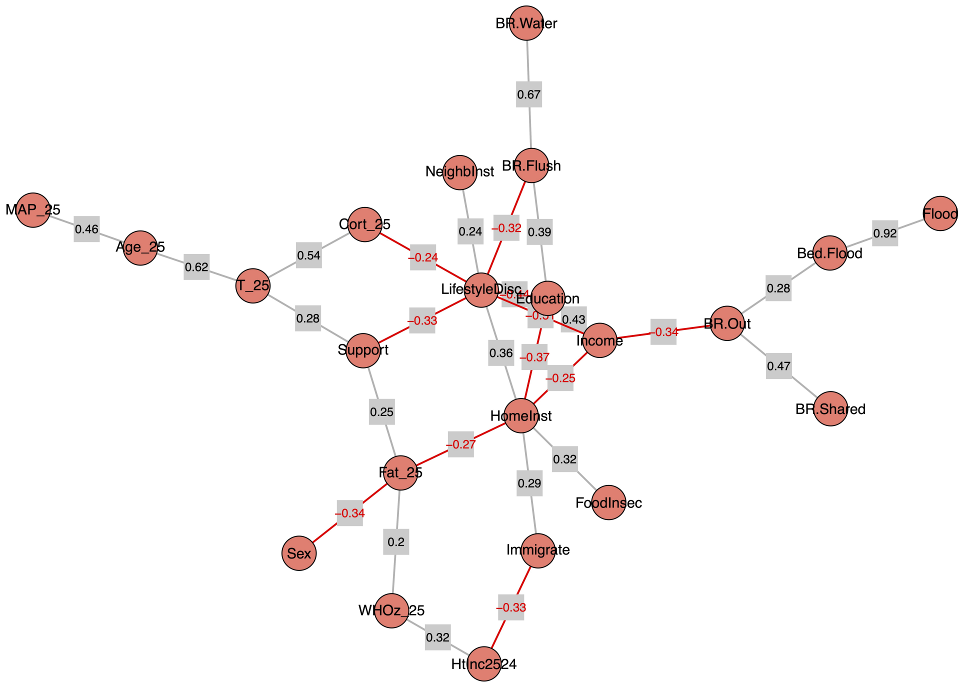

Figure 3 Saint Nicolas House Analysis, a network of hierarchically organized correlations, of Mean Arterial Pressure 2025 (MAP_25) with cortisol 2025 (Cort_25), body fat percentage 2025 (Fat_25), measures of height (WHOz_25, standardized heights; HtInc2524, centimeter change in height from 2024 to 2025), and included SEPE factors (Support: social support, LifestyleDisc: Lifestyle Discrepancy, NeighbInst: Neighborhood Instability; BR.Water: Bath room has running water; BR.Flush: Bath room has flushing water, BR.out: bathroom outside, BR.shared: bathroom shared, Bed.Flood: Bedroom flood frequnecy, Flood: Home flood frequency, HomeInst: Home instability, FoodInsec: Food Insecurity)

0.00]), suggesting instead that children experiencing less social, environmental, political, and emotional stress tend to have greater body fat percentages. Interestingly, this is contrary to the global trend and reinforces the idea that we instead need cultural- and location-specific studies of CVD risk factors.

Previous research has shown that psychosocial stressors predict higher blood pressure in children and adults (Barker and Osmond 1986; Chaturvedi et al. 2023; Dressler and Bindon 1998; Hinz et al. 2025; Kuzawa and Sweet 2009; Kuzawa and Sweet 2025), yet stressors were not adequate in explaining variance in blood pressure in this study. SEPE factors were measured in caregivers of the participants. Our caregiver survey results suggest that there is variation present in the level of exposure to stress through SEPE factors in this population. Despite mean neighborhood and home instability scores near the middle of the range (1–5), a disproportionate number of respondents reported the highest level of food insecurity. Similarly, most respondents also reported being in lower income levels, between the 5,001 to 10,000 Lempira and 10,001 to 20,000 Lempira per month categories (equivalent to approximately 191 to 382 USD and 382 to 764 USD per month). However, we are assuming the status of the caregivers applies directly to their children. Though some of these measures may more easily translate than others, such as hygiene access, food insecurity, home instability, and neighborhood instability, others may

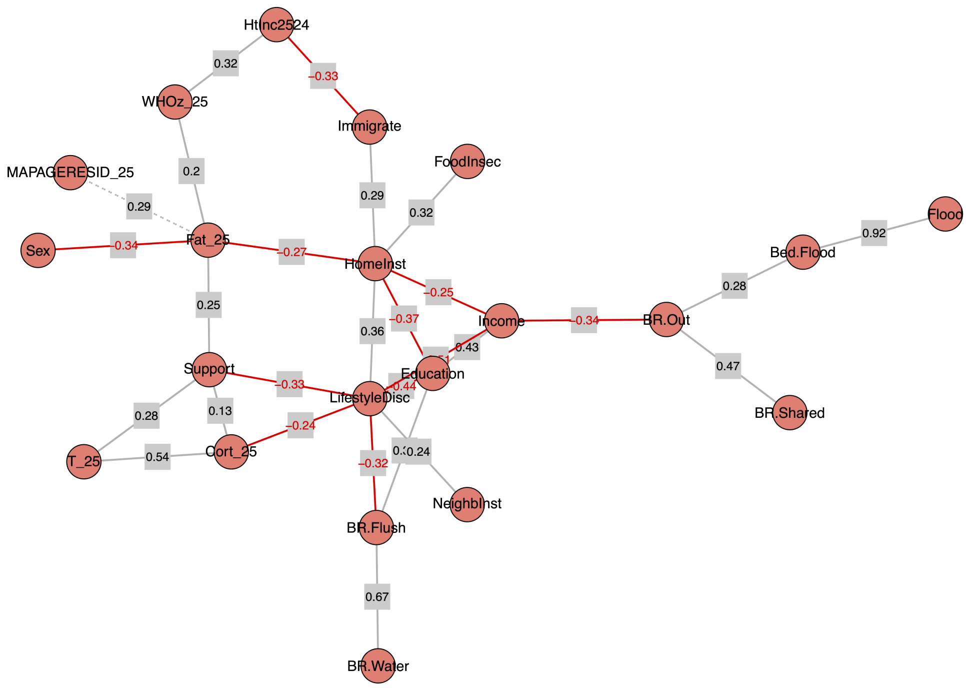

Figure 4 Saint Nicolas House Analysis of Mean Arterial Pressure (MAP) adjusted for age 2025 (MAPAGERESID_25, calculated as the residuals of the MAP ~ Age relationship) with cortisol 2025 (Cort_25), body fat percentage 2025 (Fat_25), measures of height (WHOz_25, standardized heights; HtInc2524, change in height from 2024 to 2025), and included SEPE factors (Support: social support, LifestyleDisc: Lifestyle Discrepancy, NeighbInst: Neighborhood Instability; BR.Water: Bath room has running water; BR.Flush: Bath room has flushing water, BR.out: bathroom outside, BR.shared: bathroom shared, Bed.Flood: Bedroom flood frequnecy, Flood: Home flood frequency, HomeInst: Home instability, FoodInsec: Food Insecurity)

not. Perhaps children on Utila do not feel lifestyle discrepancy the way their parents do. It is possible that while the caregiver is stressed, their children are not. This perspective likely makes sense given families often emigrate from the mainland of Honduras for a better life on Utila.

The high level of food insecurity present on the island could also contribute to the trend of adiposity negatively associated with SEPE factor stress. Even in higher income levels, families could be reporting high food insecurity due to uncertainty of food coming to the island. In general, because of the need to import almost all food to the island, costs are high. Low-nutrient, calorie-dense foods, though usually affordable options, may be out of reach for many families on the island due to fluctuating availability or cost. Though we do not have information about specific diets, these low-nutrient, high-calorie packaged foods may also be increasing the sodium intake compared to those who eat a predominantly traditional diet (He and MacGregor 2006; Rudelt et al. 2014; Urban et al. 2014). High sodium intake similarly triggers the RAAS, seeking to rebalance osmolality by increasing blood volume (Schweda 2015). Additionally, due to the structure of the research project, participants may artificially inflate their need level in the case that the project provides aid. Though this may be a contributing factor to the high level of reported food insecurity, caregivers' perception of their own food insecurity could also be representative of the SEPE stress they experience.

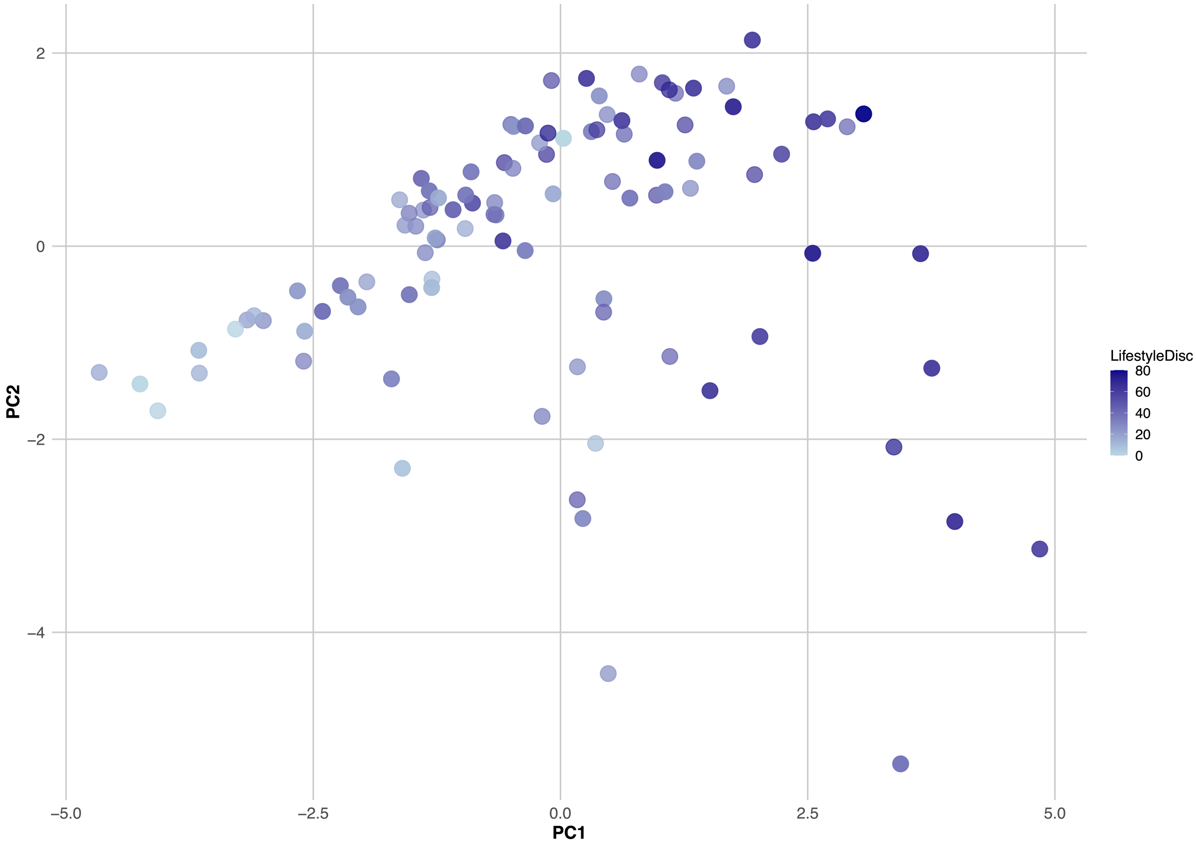

Figure 5 Principal components analysis of SEPE factors. Points shaded with lifestyle discrepancy for legibility. Increasing PC1 (social background) and PC2 (flood frequency) both associated with greater exposure to SEPE stress. PC2 correlates with SEPE factors similarly to PC1, except that it is associated with less home flooding and private, indoor bathrooms

We proposed that the HPA axis was the cellular pathway underlying the relationship between SEPE factor stress and MAP; however, not only did SEPE factors not predict MAP, cortisol also did not have a significant effect on MAP. Both cortisol downstream of HPA axis stimulation and catecholamines downstream of the sympathetic-adrenal-medullary system are important hormonal regulators of blood pressure. Cortisol promotes thirst and sodium reabsorption at the kidneys (Vera et al. 2017), both of which increase blood volume and cardiac output. Additionally, cortisol promotes greater binding of angiotensin in vasculature, leading to vasoconstriction, greater vascular resistance, and thus higher pressure (Kubzansky and Adler 2010; Vera et al. 2017). MAP is a product of cardiac output and vascular resistance; thus both of these increasing due to higher cortisol release is expected to consequently increase MAP. This, however, is not what we found in this study.

Notably, despite previous research on Utila showing that lifestyle discrepancy was associated with higher cortisol levels in adults (García et al. 2017), our Saint Nicolas House Analysis revealed that was not the case in this sample. Instead, we found a negative correlation between lifestyle discrepancy and cortisol, suggesting that children with higher cortisol were associated with lower lifestyle discrepancy. To confirm this relationship, a linear regression model showed a non-significant negative relationship between PC1 and cortisol ($\beta = -0.12$, $p = 0.0.08$, 95% CI [-0.25, 0.01]). While there existed limitations in salivary cortisol collection in this study, samples were collected at the beginning of the camp day and consistently across participants. Instead, discrepancies in our results could be indicative of cortisol being an insufficient measure of longitudinal cardiovascular outcomes. Recent research in allostatic load longitudinally suggests that cortisol in childhood may not be a strong predictor of cardiometabolic outcomes in adulthood and instead may be better suited for capturing short-term health (Hinz et al. 2025).

The prevalence of pathologically high blood pressure was low in this population in 2025. Only six of the 109 (5.5%) children from the 2025 camp had abnormally high blood pressure by U.S. pediatric standards (U.S. Department of Health and Human Services 2007). Following a population-centric approach for defining high blood pressure outlined by Adair and Cole (Adair and Cole 2003), the top tenth percentile of residuals taken between blood pressure and age+height were used in logistic regressions (presence or absence of high blood pressure) to confirm the null relationship between both SEPE factors and cortisol and MAP. Indeed, we found no significant relationship between SEPE factors or cortisol and MAP. However, we did find a significant relationship between high blood pressure and body fat percent-

Table 3 PCA was performed for all available SEPE factors. PC1 and PC2 explain cumulatively 42.02% of the variance in SEPE exposure. Here, the rotations of PC1 and PC2 for each of the included SEPE factor variables are reported. A positive number is a positive correlation between that PC vector and the SEPE variable, while a negative number is a negative correlation between the PC vector and SEPE variable. Names of the PC vectors are given to describe their prominent relationships

SEPE Factor	PC1: Social Background	PC2: Flood Frequency
Bathroom Outside	0.30	-0.22
Bathroom Shared	0.21	-0.32
Bathroom has Flush Toilet	-0.33	-0.21
Bathroom has Running Water	-0.30	-0.01
Home Flood Frequency	0.21	-0.52
Bedroom Flood Frequency	0.27	-0.50
Home Instability	0.28	0.25
Neighborhood Instability	0.13	0.20
Relocated to Utila	0.10	0.29
Education Level	-0.33	-0.22
Income Level	-0.34	-0.08
Lifestyle Discrepancy	0.34	0.14
Food Insecurity	0.26	0.14
Social Support	-0.21	0.05

Table 4 Multiple regression models tested and ranked lowest to highest AIC in the primary analysis. BF=Body Fat, Ht=WHO z-score heights, C=Cortisol

Model	AIC
PC1+PC2+C+Ht+Sex+BF	515.92
PC1+PC2+C+Ht+Sex	521.38
PC1+PC2+Ht+Sex	543.75
C+Ht+Sex	758.34
BF+Ht+Sex	777.87
Ht+Sex	786.79

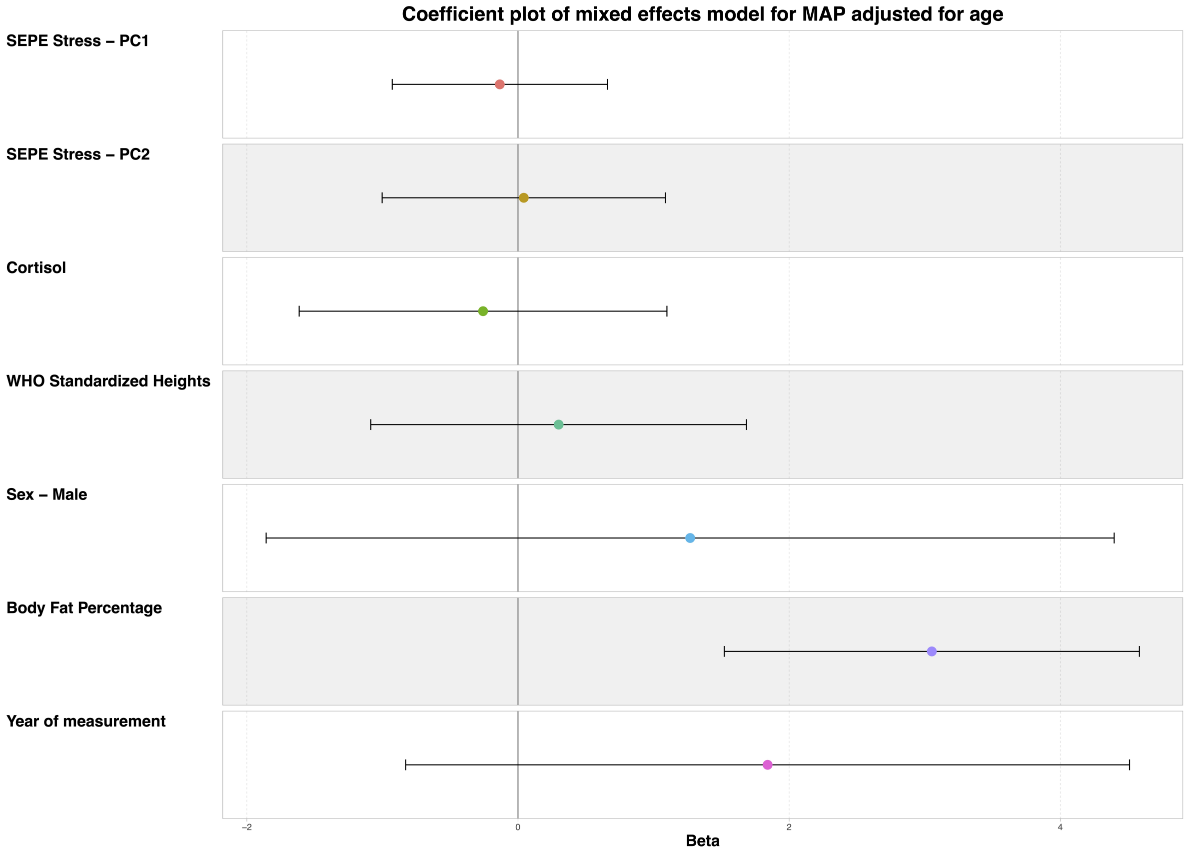

Figure 6 Covariates tested (with 95% confidence intervals) in the mixed effects model in longitudinal analysis of Mean Arterial Pressure (MAP) (2024–2025). Year included as a control and ID as a random effect. Body fat percentage is the best predictor of age adjusted MAP, and the confidence intervals do not overlap with zero

age, confirming the results of the multiple regression. Body fat percentage increases the odds of belonging to the population-specific high blood pressure group by 3.37 times. To confirm that our null results between SEPE factors and MAP were not due to low power, we pooled the 2024 and 2025 data, allowing for a longitudinal perspective on the predictors of MAP across two years. We again found that body fat percentage was the only significant predictor of MAP. Given the size of our sample, stronger trends may emerge with more years of study or a larger pool of participants.

Table 5 Results of the top model from the multiple regression primary analysis. $* = \boldsymbol{p} < \mathbf{0.05}$. CI=confidence interval. Adjusted R-squared=0.07, F-statistic $\boldsymbol{p} = \mathbf{0.11}$

Term	Estimate	Standard Error	Statistic	p-Value	2.5% CI	97.5% CI
Intercept	-1.76	1.8	-0.98	0.33	-5.35	1.84
Body Fat Percentage	3.17	1.19	2.66	0.01*	0.79	5.55
Sex – Male	0.99	2.42	0.41	0.69	-3.86	5.83
WHO z-score Height	-0.39	1.12	-0.35	0.73	-2.63	1.84
SEPE Stress -PC1	-0.89	0.64	-1.39	0.17	-2.16	0.39
SEPE Stress – PC2	-0.75	1.07	-0.7	0.49	-2.89	1.4
Cortisol	-0.46	1.09	-0.42	0.68	-2.64	1.73

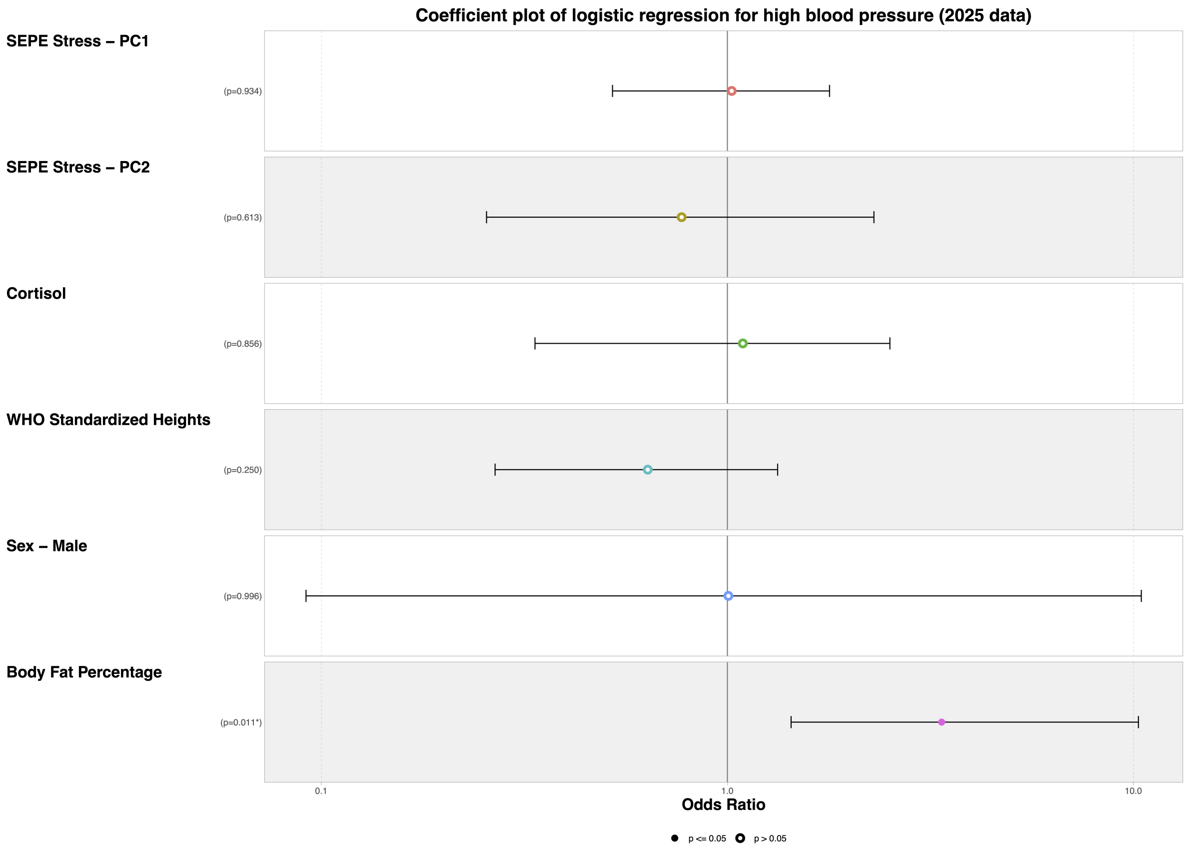

Figure 7 Covariates tested (with 95% confidence intervals) in the logistic regression of 2025 data for high blood pressure category. High blood pressure category are individuals belonging to the top tenth percentile of MAP adjusted for age and height, following Adair & Cole (2003). Body fat percentage is the best predictor of high blood pressure, with a 3.37 odds ratio

Adipocytes trigger blood-volume-elevating hormonal pathways (i.e., the RAAS), thus increasing blood pressure (Lurbe et al. 2001). As MAP is determined by both blood volume and vascular resistance (Klabunde 2022), it is difficult to disentangle which factor is contributing to higher blood pressures without more invasive methods. We hypothesized that children would change their energetic strategy, as measured by MAP, given adverse experiences. Though we did not find this, it is possible that MAP is still a measure of energetic status given energetic abundance through fat stores. This identified pattern could reflect the unique economic context on Utila as a tourist destination within a country still largely reliant on agriculture (Currin 2002; Sohn 2018). Food access on the island is dependent on transport and weather. Those with more resources may have better access to food, though still entirely limited by what is available. Our primary analysis explained little variance in MAP, and though we confirmed these relationships through longitudinal modeling and logistic regression, more work is needed to understand what is contributing to elevated blood pressures in children, especially in understudied populations like those from low-to-middle-income countries.

Finally, the divergence of our results from the standard US phenotype (i.e., high poverty and overweight/obesity) underscores the necessity of this context-specific approach. In industrialized countries, poverty, psychosocial stress, and adiposity are often inextricably linked, creating a collinear cluster of risk factors. However, our data from Utila reveal a decoupling of these traits: children with higher socioeconomic status exhibited greater adiposity

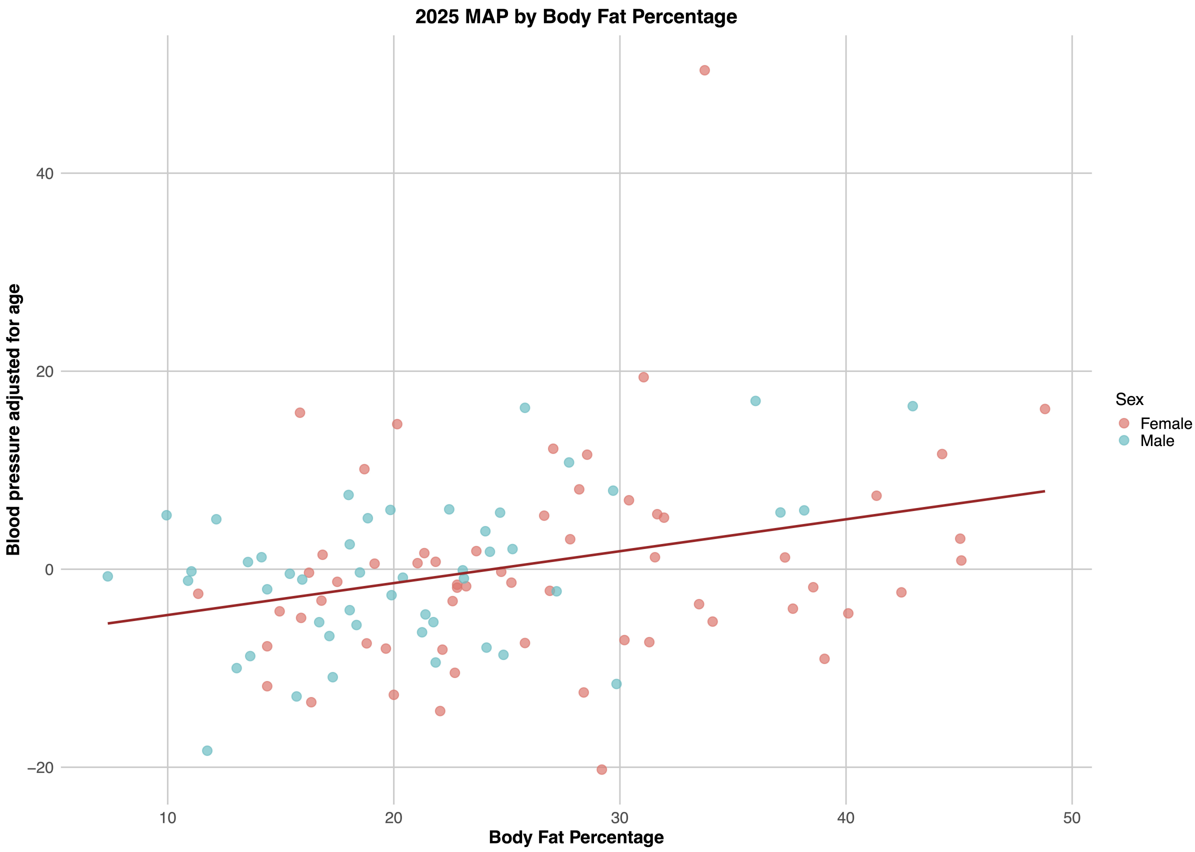

Figure 8 Cross sectional relationship between MAP adjusted for age and body fat percentage from 2025 camp participants in Utila, Honduras

and subsequently higher blood pressure, while those with higher SEPE stress did not exhibit the expected higher MAP. This reversal suggests that the widely observed association between poverty and hypertension in the US and other industrialized countries may be driven more by the specific obesogenic environment that low-income populations are forced to navigate in industrialized nations. By disentangling energetic abundance (adiposity) from energetic scarcity (SEPE stress), this study challenges the generalizability of US-centric models and highlights the importance of a theoretically rich conceptual model paired with local ecological frameworks in defining cardiovascular risk.

Conclusion

The relationship between stress, nutrition, and cardiovascular outcomes is complicated yet an important one to tease out. The cost of treatment for hypertension across the globe has reached several dozen billion dollars, and as the burden grows, this cost will increase (Wierzejska et al. 2020). Hypertension is estimated to make up 10% of the world's healthcare expenditures (Mills et al. 2020). CVD morbidity and mortality disproportionately affect low-to-middle-income countries, meaning they will also disproportionately carry the cost of treatment, pushing their populations further into disability and poverty. Investigating the cultural and socioecological factors that create diverse and unique challenges to treating hypertension is imperative. Blood pressure control remains poor, especially in low-to-middle-income

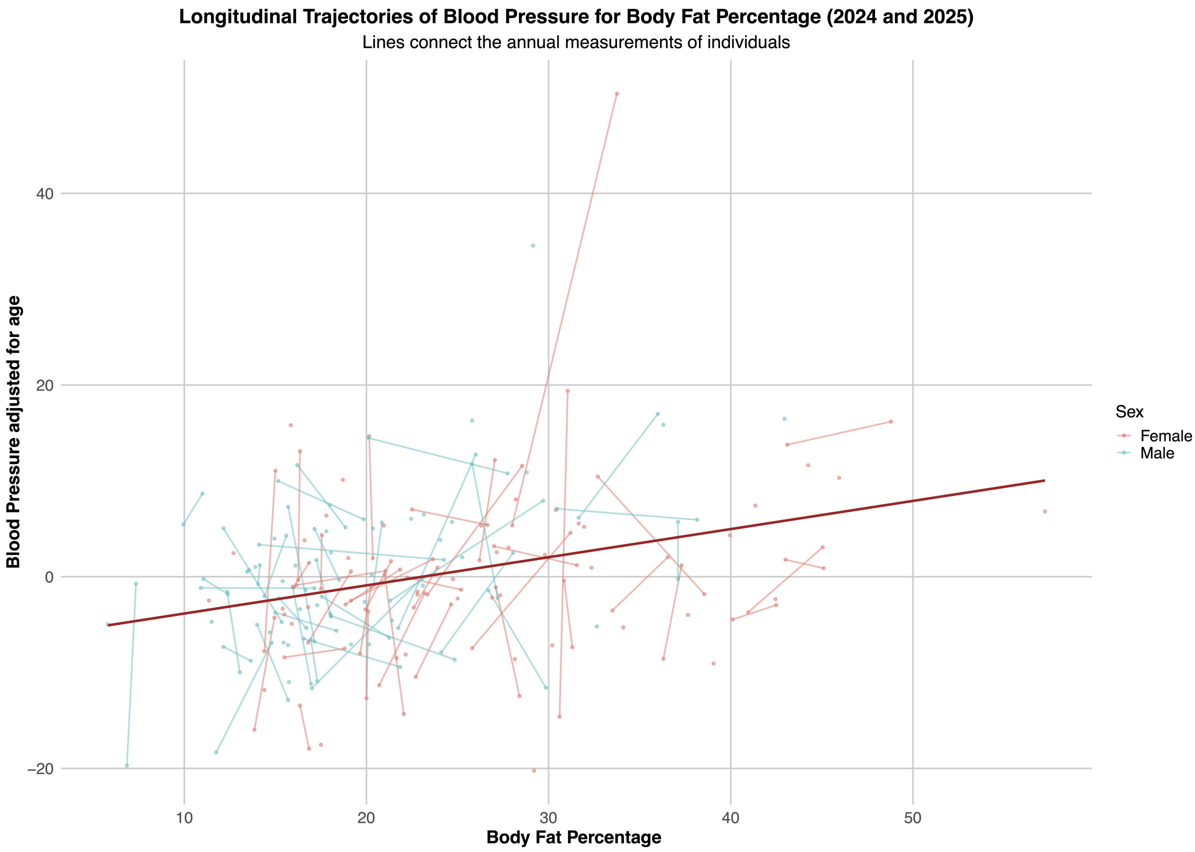

Figure 9 Longitudinal relationship between MAP adjusted for age and body fat percentage, 2024 to 2025 camp participants in Utila, Honduras

countries globally, at around 20% (Aggarwal et al. 2021). Further, mortality due to hypertension is on the rise (Chaturvedi et al. 2023; Mills et al. 2020; Schutte et al. 2023). Honduras has the lowest rate of hypertension awareness among screened countries in the Americas (Schutte et al. 2023). Hypertension and cardiovascular disease create untenable health and economic burdens for those in low-to-middle-income countries (Gheorghe et al. 2018). Blood pressure is a low-cost and non-invasive biomarker that can help predict adult health outcomes and thus can help us learn how social, environmental, political, and emotional factors or structures are impacting children contemporaneously.

An evolutionary perspective helps us frame these not purely as pathological patterns but as necessary coping mechanisms given various early life environments. Future research should interrogate diet quality to better understand how food insecurity, socioeconomic status, and adiposity interact. Additionally, child-centric measures of stress, such as relationship to family and friends, may better capture cardiovascular risk factors. Future research should also increase the sample size to better understand identified trends. If we can identify which early life risk factors are most associated with greater demands on the cardiovascular system, mutual aid and government programs can better target those systemic risk factors early in development.

Ethics Statement

All data collection protocols were approved by the Boston University Institutional Review Board (Protocol #5444E). Informed consent was given by all caregivers prior to involvement in the study, and children assented to research protocols. The study was conducted in accordance with the Declaration of Helsinki ethical principles for the research of human subjects.

Funding Statement

This research was supported by the National Science Foundation Research Experience for Graduates (#1945725) and National Science Foundation Graduate Research Fellowship (#2234657) awarded to N.M., Wenner Gren Post-PhD Grant (#9947) awarded to C.R.H.S., and National Science Foundation Research Grant (#1945725) awarded to A.D.B. and C.R.H.S.

Acknowledgements

We are grateful to the country of Honduras, the island of Utila, and its inhabitants, particularly our participants, and to the Honduran research assistants of the Utila Child Health Project, without whom we would not be able to conduct this research. Thank you to Daniela Mejia for assistance in collecting the caregiver survey. Special thanks to Drs. Christiane Scheffler, Michael Hermanussen, Barry Bogin, and Detlef Groth for helpful comments in the development of this work at the Human Growth and Statistics Summer School, supported by KoUP funding at the University of Potsdam. This research was supported by the National Science Foundation Research Experience for Graduates (#1945725) and National Science Foundation Graduate Research Fellowship (#2234657) awarded to N.M., Wenner Gren Post-PhD Grant (#9947) awarded to C.R.H.S., and National Science Foundation Research Grant (#1945725) awarded to A.D.B. and C.R.H.S.

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