The Effect of Lifestyle Change on Health and Early Childhood Growth in Daasanach Pastoralists Living in Northern Kenya

by

Zane Shea Swanson

Department of Evolutionary Anthropology
Duke University

Date:_______________________
Approved:

____
Herman Pontzer, Advisor

____
Charles L. Nunn

____
Susan C. Alberts

____
Steven E. Churchill

____
Asher Y. Rosinger

Dissertation submitted in partial fulfillment of
the requirements for the degree of Doctor
of Philosophy in the Department of
Evolutionary Anthropology in the Graduate School
of Duke University

2021

ABSTRACT

The Effect of Lifestyle Change on Health and Early Childhood Growth in Daasanach Pastoralists Living in Northern Kenya

by

Zane Shea Swanson

Department of Evolutionary Anthropology
Duke University

Date:_______________________
Approved:

____
Herman Pontzer, Supervisor

____
Charles L. Nunn

____
Susan C. Alberts

____
Steve E. Churchill

____
Asher Y. Rosinger

An abstract of a dissertation submitted in partial
fulfillment of the requirements for the degree
of Doctor of Philosophy in the Department of
Evolutionary Anthropology in the Graduate School of
Duke University

2021

Abstract

Understanding the relationships between lifestyle, ecology and physiology is essential for understanding variation in health, life history, and subsistence practice among populations. Previous work has investigated human behavioral ecology and life history across a wide range of human populations, but study with populations experiencing changes to their lifeways remains particularly important. Work with populations that traditionally practice nomadic pastoralism as a subsistence strategy and are experiencing encroaching market pressures offers the opportunity to investigate the effects of stark subsistence and market transitions across a variety of lifestyle factors (e.g., nutrition, physical activity, healthcare, socioeconomic status).

Using data collected with the Daasanach Health and Life History Project, this dissertation applies a broad approach to test whether changes in lifestyle (e.g., market integration and sedentarization) affect health and patterns of early childhood growth within a human population through the framework of life history theory. Health, physical activity, growth, nutrition, reproduction, and community composition data have been synthesized to test the effects of life history tradeoffs that arise through socioecological variation. As semi-nomadic pastoralists who currently face the encroaching pressure of sedentarization, the Daasanach living in and around the town of Illeret are well suited to test this hypothesis. In addition, this project will expand the existing body of work concerning life history and health variation in non-industrial populations, specifically adding a population with a subsistence pattern that is currently underrepresented. This addition allows for a new level comparison between the variation in ecology, life history, health, and behavior that characterize our species, advancing our understanding of difference between industrialized and non-industrialized populations, and the breadth of variation in the variables across human populations.

Dedication

For my family.

Contents

List of Tables

List of Figures

Acknowledgements

This work would not have been possible without the support and guidance of so many friends, family members, and colleagues. I found my first academic home as an undergraduate in the DeSilva Lab at Boston University, and then my next when starting my graduate career as a member of the Pontzer Lab at the New York Consortium in Evolutionary Primatology (NYCEP), before continuing as a member of the Evolutionary Anthropology Department at Duke University. The abundance of generosity that I've received from students, faculty, and staff at every step in my career has helped shape me and my work for the better. I must also thank the numerous members of the Daasanach Health and Life History Project, and more broadly, the Koobi Fora Field School, for the opportunity to participate in this exciting work. To have taken part in shaping the conception of such a research endeavor has been one of the highlights of my life. Additionally, and most importantly, I thank the members of the Daasanach community in northern Kenya, including the staff of the Illeret Health Clinic and community health volunteers. I would not have had this opportunity if not for their incredible generosity. It is with immense gratitude that I thank them for their continued kindness and openness over the year. Finally, I would like to thank my family. All that I've been able to accomplish comes from their support and encouragement.

1. Introduction

1.1 Dissertation Chapter Overview

This dissertation in organized in five chapters. This first chapter serves to provide important background on the work in life history theory, evolutionary mismatch, and early childhood growth patterns in populations suffering malnutrition and increased disease risk. This chapter also describes the sample population, Daasanach semi-nomadic pastoralists living in northern Kenya (n = 572), with whom all data were collected. In Chapter Two, patterns of early childhood growth among Daasanach children (n = 8669; age = 0-59 months) are compared to WHO growth standards to better understand the pattern of growth faltering experienced across Daasanach communities relative to both 'Western' industrialized growth reference and other populations experiencing growth faltering due to malnutrition and disease. Additionally, Generalized Additive Models of Location, Shape, and Scale (GAMLSS) are used to create Daasanach specific descriptions of growth (i.e., height-for-age, weight-for-age, and weight-for-height) in Daasanach children under the age of five years old. These analyses then allow for the discussion of the relationship between linear growth and weight gain experienced by Daasanach children relative to expectations based on international references, identifying potentially distinct patterns in this population. Chapter Three describes the observed relationships between variables of lifestyle change and cardiometabolic health in adults. This chapter builds upon work investigating both the effects of sedentarization on traditionally nomadic and semi-nomadic populations, as well as the effects of market integration among populations that previously relied primarily on traditional subsistence strategies (e.g., hunting and gathering, pastoralism, farming and horticulture). These analyses investigate the relationships between socioecological condition and health that results in disparities among non-communicable disease risk in a relatively genetically homogenous population in the early stages of lifestyle change that results from myriad market pressures. In Chapter Four, the analytical foundation created by the two preceding chapters are used to test the proximate causes of early childhood growth variation at the community and household level. In this way, the results from this chapter describe the effect of relative health and socioecological condition on Daasanach-specific early childhood growth parameters at the level of the household. Finally, Chapter Five serves to summarize the results found across the preceding three chapters.

1.2 Theoretical Background

1.2.1 Early Childhood Growth Variation

The relationships between the environment, demography, behavior, nutrition, and metabolic investment are fundamental to understanding evolved life history strategies in humans. Growth in humans, particularly in early childhood, is sensitive to variation in environmental conditions, with reaction norms responding to proximate factors, such as disease, stress, nutrition, and physical activity that affect growth patterns and achieved adult heights and weights (Little & Gray, 1990; Schell, 1991; Bhan et al., 2001; Barclay & Weaver, 2006; Blackwell et al., 2010; Maggi, 2010; Bogin, 2009; Snodgrass, 2012; Stinson, 2012, Urlacher et al., 2018; Urlacher & Kramer, 2018). Additionally, the plasticity of early childhood growth is also influenced by variation in familial structure, and household socioeconomic condition, as competition for energetic availability can fluctuate when either changes (Schell, 1991; Ulijaszek, 2006; Gurven & Walker, 2006). For example, important work with the Ache of eastern Paraguay and the Dobe Ju/'hoansi of Botswana and Namibia found that children of mothers with more dependents grew more slowly, which in turn supports the hypothesis that the relatively slow childhood growth expressed by humans increases fitness by reducing feeding competition between multiple dependent offspring and adults (Gurven & Walker, 2006).

Interspecific comparisons of growth are representative of evolved responses to varied ecological conditions. Such comparisons can elucidate differences in the evolutionary histories and selective pressures that lead to species differences. Intraspecific comparisons of early childhood growth, on the other hand, allow for the investigation of phenotypic plasticity, providing context for the relationship between ecological condition and life history traits (Stearns, 1992; Walker et al., 2006). Historically, such comparisons are assessed using international growth standards derived from a large international survey, like those established by the World Health Organization (WHO, 2006). Reliance on these growth standards can be dubious, however, as they do not account for differences in the timing and pattern of somatic growth that results from genetic variation at the population level (Cole, 2007; Ziegler & Nelson, 2012; Martin et al, 2019). Therefore, population specific comparisons provide an increased degree of resolution when trying to resolve the proximate and ultimate causes of growth and life history variation. The unique suite of human life history traits, marked by an extended period of juvenile dependence and relatively increased fertility may result in particular constraints on early childhood growth patterns and rates (Hill & Kaplan, 1999; Kaplan et al., 2000, Alberts et al., 2013). Differences in these patterns and rates as they relate to lifestyle change within a population can be used to better understand our evolutionary history, as well as contemporary struggles with malnutrition, disease, and social inequity.

1.2.2 Life History Theory

Life history theory describes the patterning of energy allocation to growth, reproduction, and somatic maintenance as a function of mortality risk. Variation in the timing and amount of energy allocated to any of these processes results from evolved strategies to maximize fitness with limited energetic resources (Charnov, 1986; Charnov, 1991; Charnov & Berrigan, 1993; Stearns, 1989; Stearns, 1992; Hill & Kaplan, 1999; Ellison, 1994, 2014, 2017). The evolutionary interpretations of human life history characteristics are complicated by the variety of lifestyles expressed by modern human populations, and a relatively recent departure from the ecological and behavioral contexts in which our species evolved.

Much work has been done to identify patterns of intra- and interspecific variation among ecological, physiological, and life history characteristics (Read & Harvey, 1989; Charnov, 1991; Charnov & Berrigan, 1993; Stearns, 1989; Stearns, 1992; Brown et al, 2004; Sibley & Brown, 2007; Kaplan et al., 2000; Hill & Kaplan, 1999; Mace, 2000; Speakman, 2005; Pontzer et al., 2014; Pontzer et al., 2015; Gurven et al., 2016). Additionally, the relationships between ecology and the phenotypic expression of life history traits, specifically growth, have been studied across a wide range of human populations (Little et al., 1983; Little & Gray, 1990; Little et al., 1993; Hill & Hurtado, 1996; Strassman & Gillespie, 2002; Pike, 1999; Pike, 2000; Hagen et al., 2006; Blackwell et al., 2017; Urlacher et al., 2016; Urlacher and Kramer, 2018; Gurven et al. 2017). A species' evolved life history strategy can be viewed as a response to the inherent energy trade-offs among different tasks (e.g., growth versus reproduction, reproduction versus maintenance). Changes in environmental condition, like those that occur as a function of lifestyle change (e.g., sedentarization, market integration) can have broad and cascading effects on life history patterns in a population.

The study of human life history, and in particular growth during early childhood, is important because of the relatively wide ecological breadth of our species. As humans occupy a variety of environments and practice a wide range of subsistence strategies, intraspecific variation among human populations can inform the way in which life history variables are both adaptive and adaptively plastic, thereby informing our understanding of hominin evolution and the emergence of the suite of life history features that characterize our species (Froehle & Churchill, 2009).

1.3 Study Population

1.3.1 Daasanach of Northern Kenya

Daasanach are a semi-nomadic pastoral group living in semi-arid and arid regions of southwestern Ethiopia and northwestern Kenya (Carr, 1977; Almagor, 1978). About 48,000 Daasanach live in Ethiopia, while about 19,300, live in Kenya (Mwamidi et al., 2018; KNBS, 2019). A majority of the Daasanach population in Kenya live in or around the town of Illeret (4.314° N, 36.227° E), located in the most northwestern region of Marsabit county, bordering Lake Turkana to the west and Ethiopia to the north (KNBS, 2019). The region around Illeret experiences a bimodal seasonal cycle with mean temperatures ranging from 20°C and 37°C and yearly average rainfall of about 217mm (Opiyo et al., 2014; Liebmann et al., 2014). The increased threat of drought, flash flooding, and climate variability, as well as historical economic and political isolation, have led to health issues related to long-term water and food insecurity for Daasanach living in Kenya (Little et al., 2001; VSF RSIPA, 2011-2013; Boru & Koske, 2014; MoALF, 2017; Bethancourt et al., 2021).

Traditionally, Daasanach lifestyles are highly physically demanding. Men are typically in charge of protecting and caring for livestock, with herding responsibilities falling to boys beginning in young adolescence (Figure 1). Women and girls are responsible for most other subsistence labor tasks. These responsibilities include water gathering, childcare, cooking, and home building/maintenance. Daasanach also practice polygyny, with men often having multiple wives who typically serve as individual female heads of household once they have had their first child. Subsistence labor for both men and women varies as a function of household mobility and engagement in pastoral activity.

Figure 1: Examples of pastoral activities. Left: young man leading herd of cattle while in the fora (pastureland), near the Gerem nomadic community site. Right: young children providing water for herd of goats from a hand-dug well located in a dry riverbed near Illeret. Water from such wells is used both for livestock animals and for human consumption (see Figure 3).

Though considered semi-nomadic, Daasanach in and around Illeret engage in a variety of movement patterns. Those living in Illeret tend to be more settled, living more often in permanent living structures and with increased access to organizational infrastructure. Daasanach living in the upper Turkana Basin have a heterogenous settlement pattern, with some communities, specifically those closer to the town of Illeret, being more settled than the semi-nomadic communities in surrounding areas (Mwamidi et al, 2018). These semi-nomadic and nomadic communities travel into what is called the fora, or undeveloped pastureland to the South and East of Illeret (Figure 2). Daasanach are part of the greater East African Cattle Complex, with the central importance of cattle demonstrated in the linguistic import with which cattle are characterized – the bestowing of an "Ox-name" to men after the birth of their first daughter a primary example (Carr, 1977). While Daasanach are often classified as agropastoralists, this distinction is largely a function of ethnographic work conducted with the Daasanach residing in the Omo River Valley of Ethiopia, and results as a function of the relative flexibility of pastoralism as a subsistence strategy (Almagor, 1978; Gray et al., 2002).

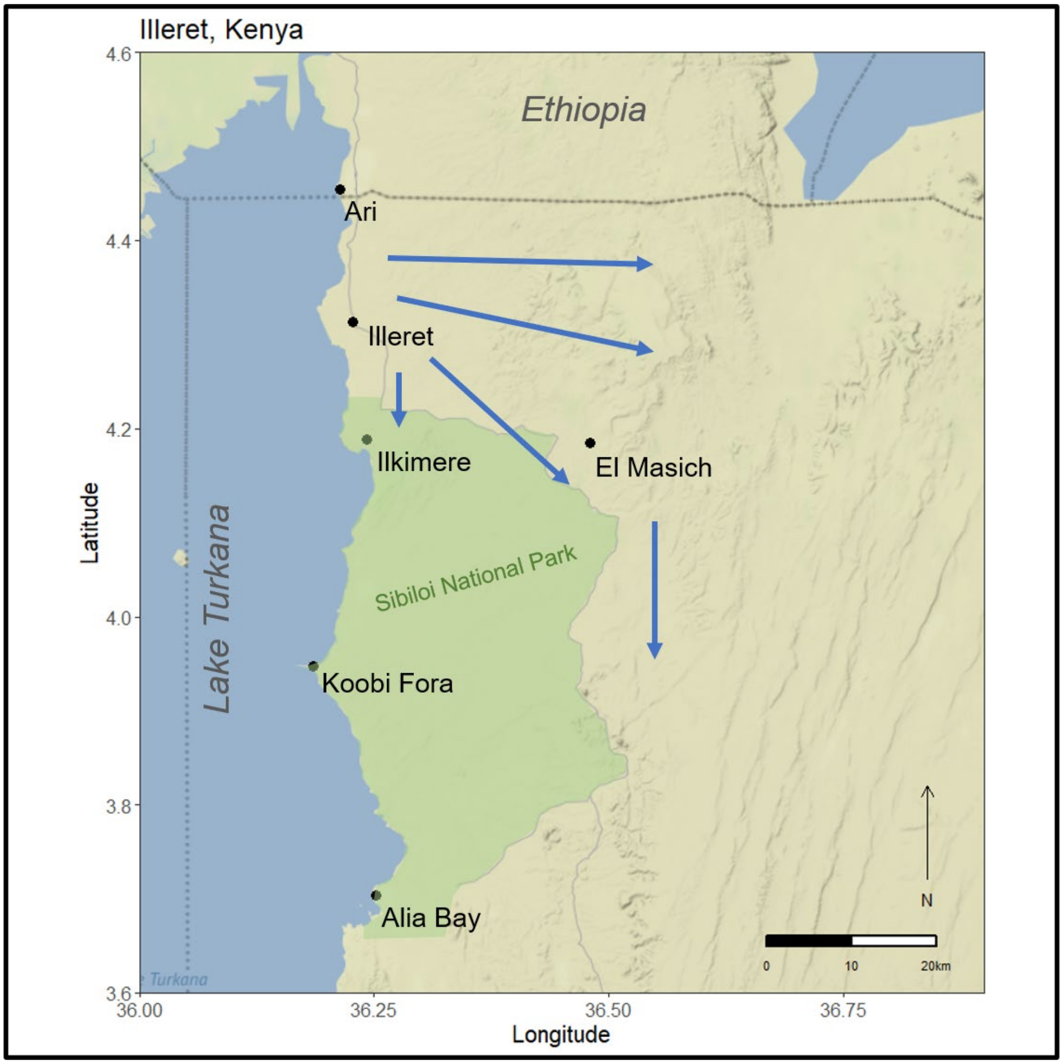

Figure 2: Landmarks and Daasanach movement into the fora. Blue arrows indicate travel into the fora and away from more developed/settled zones. (Adapted from Mwamidi et al., 2018).

Daasanach in and around Illeret are far more reliant on herding practices and access to market food staples, such as beans, rice, and maize, with very little ability to perform sustainable agriculture. Due to the severity of water and food insecurity, which has recently been measured at the household-level across several Daasanach communities, childhood malnutrition is a major concern in the area (Bethancourt et al., 2021, Rosinger et al., 2021). Though several standpipes can be found in Illeret, retrieving water from hand-dug wells – which can measure nearly 2 meters in depth – in dry riverbeds (lagas) is often preferred due to its ease of access, the quality of water, and the cost of piped water (Figure 3; Bethancourt et al., 2021; Rosinger et al., 2021). This way of collecting water can be very labor intensive and female heads of household surveyed by the Daasanach Health and Life History Project reported about 42 hours of total household time spent for water collection per week, calculated as the product of the reported number of weekly water collection trips and reported time spent per trip by all members of a household. Daasanach living in northern Kenya have had numerous multiyear relationships with NGOs operating in the region. With varying degrees of success, these NGOs have focused primarily on increasing maternal health standards, supplying sources of clean water, and combating childhood malnutrition. Despite this, and unlike members of the neighboring Turkana tribe, Daasanach community members living in and around Illeret had little involvement in scientific or medical research.

Figure 3: Water gathering for livestock and household use. Left: Man collecting water from a hand-dug well (~1.5m deep) in dry riverbed. Water shown to be used simultaneously for livestock and human consumption. Right: Woman filling multiple jerrycans with water collected from a hand-dug well (~1.5m deep) for household use.

1.3.2 Pastoralism as a subsistence strategy

Pastoralism, though not the ancestral subsistence mode for humans, has been practiced for at least 10,000 years, with archaeological evidence for pastoralist behavior in East Africa dating to ~4.5-5 kya (Little, 1989; Little, 2015; Lane, 2013, Zinstagg et al., 2016). Defined primarily by the keeping and herding of domesticated animals, pastoralism encompasses a range of both movement and subsistence patterns. Present and historical pastoralist communities exhibit movement strategies that range from nomadism to semi-nomadism to permanent settlement, and subsistence strategies ranging from exclusive herding to mixed cultivation and herding to agropastoralism. These two continua, movement pattern and subsistence pattern, are distinct but related, with communities being more likely to be characterized by combinations of nomadism and exclusive herding, or settlement and agropastoralism (Müller et al., 2007; Pedersen & Benjaminsen, 2008; Lane, 2013). Underlying this variation is a third variable, environmental uncertainty, which influences the ability of pastoral communities to practice particular movement and subsistence patterns. Generally, as environmental uncertainty increases so will the likelihood that a pastoral community practices nomadic and exclusive herding behavior, as evidenced by nomadic pastoralism being practiced at higher frequency in more arid environments (Little, 2015). Recent desertification and increasing climatic volatility may have also led some groups to shift towards increased herding of small ruminants to offset the disproportionate effect of drought on cattle (Rufino et al., 2013).

1.3.3 Sedentarization as a vector for changes in lifestyle and health

Sedentarization is a process through which populations that have historically been nomadic become increasingly settled (Little & Leslie, 1999). Though there appears to be an increasing trend towards sedentary lifestyles among non-industrialized populations, sedentarization is not a new phenomenon (Fratkin et al., 2004; Dounias & Froment, 2006). Today, sedentarization is often instigated by the encroachment of larger settled populations, erratic climate, governmental initiatives, or some combination of the three (Fratkin et al., 2004; Little, 2015, Catley et al., 2016). However, populations have been settling since the Neolithic Transition, some 10,000 years ago (Bocquet-Appel, 2011).

Currently, many NGOs and governmental agencies encourage the transition of nomadic populations to more sedentary ways of life. The health consequences of this process remain in question, however (Table 1). In East Africa, health outcomes for settled members of pastoral populations have been found to be consistently worse than those for the more nomadic members (Barkey et al., 2001; Fratkin et al., 2004; Campbell et al., 2005). The disparity in health has been suggested to be the result of changes in diet, increased exposure to pathogens due to higher population and waste densities, and lower physical activity. The process of sedentarization is often thought to lead to deleterious effects in individuals for whom subsistence context has rapidly changed away from the one in which their populations have gained biological and behavioral adaptations (Schell, 1986; Eaton et al., 1988; Galvin, 1992; Little & Leslie, 1999). This process can be understood as an ultimate cause of more proximate factors that can affect human health and life history, such as nutrition, stress, and disease.

One way to assess the potential life history, health, and behavioral consequences of lifestyle transitions is to perform intragroup comparisons with a population currently undergoing such changes. This project will investigate the process of lifestyle change for the Daasanach as it affects early childhood growth and health. This investigation will both serve to enhance our understanding of the effects of sedentarization on childhood life history and health variation as a function of energetics, with application to ancient lifestyle transitions (e.g., the Neolithic Demographic Transition) as well as contemporary lifestyle changes associated with industrialization.

Table 1: Reported variation in nutrition, physical activity, growth, body composition, and disease in East African pastoral populations experiencing sedentarization. (Adapted from Little & Leslie, 1999)

Category	Nomadic	Settled	References
Nutrition	High protein and milk intake, relatively low calorie	Decreased protein and milk intake, decreased milk consumption, increased starch consumption, greater reliance on relief foods	Glavin, 1992; Brainard, 1991; Fratkin et al., 2004; Fujita et al., 2004
Activity	Early subsistence labor requirements for both boys and girls	Increased sedentism due to lower engagement in subsistence activities and increased likelihood of school attendance	Brainard, 1991; Little & Gray, 1990
Child Growth	Infants and children less than 5 are slightly taller and heavier than settled children	Schoolchildren aged 5-10 years are taller and heavier than nomadic children	Brainard,1991; Little & Gray, 1990; Little et al. 1993
Adult Body Composition	Taller achieved height	Increased weight and body fat, though results are variable	Ellis et al., 1987; Little et al., 1983; Little et al., 1993
Disease	Acute respiratory infection is major risk for child morbidity, increased rate of anemia	Increased rates of respiratory infection, eye infection, malaria, and white blood cell activity, increased blood pressure, increased childhood mortality	Shell-Duncan, 1995; Brainard, 1991; Little et al. 1983; Little et al., 1983; Adongo et al., 2013; Barkey et al., 2001; Page et al., 2016, 2018

1.3.4 Data collection

Data was collected over the course of two field seasons – June to July of 2019 and February to March of 2020 – in association with the Daasanach Health and Life History Project, the Koobi Fora Field School, and the Turkana Basin Institute. Collection of anthropometric, health, interview, GPS data took place across 11 communities in the greater Illeret region (Figure 4, Figure 7, & Table 2). Data from all households (n = 166) were collected in an opportunistic semi-random manner, with subjects selected for participation from every third household from a central community point to minimize family clusters. Participation included the collection of anthropometric and cardiometabolic biomarker data in coordination with a semi-structured interview to collect survey data related to lifestyle, health, and food/water insecurity.

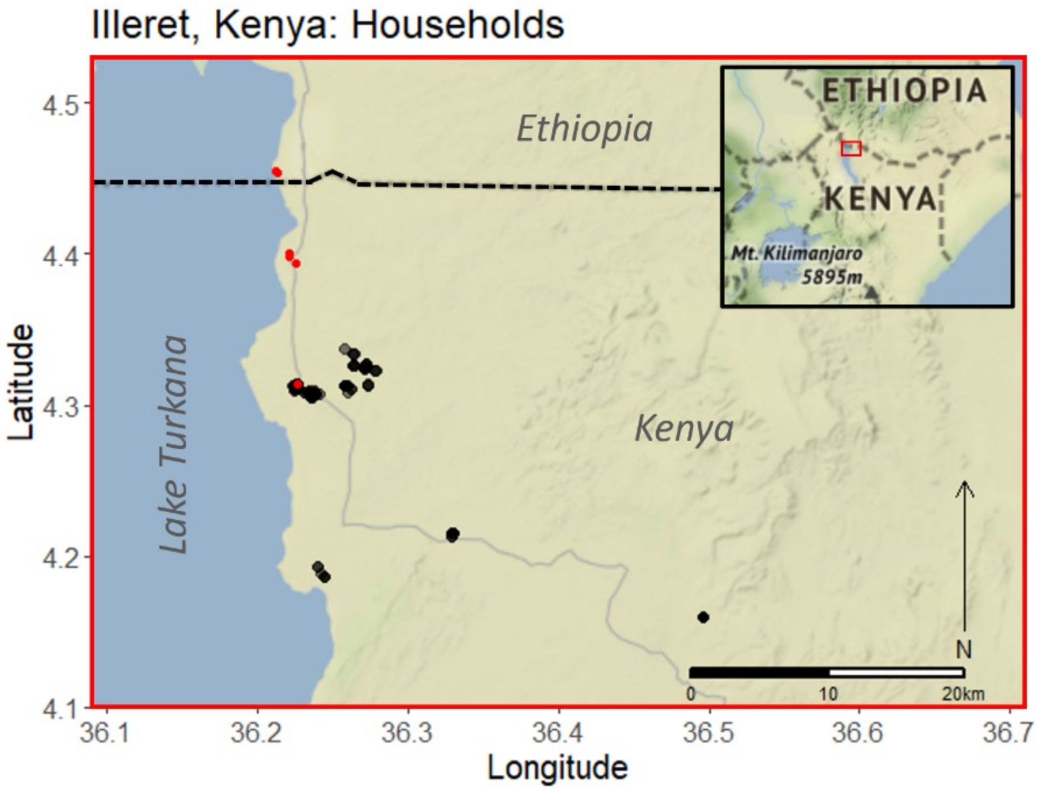

Figure 4: Map of northwestern Marsabit County, Kenya. Black dots indicate location of households (n = 166) sampled by the Daasanach Health and Life History Project. Red dots indicate market centers (IHC, Sieslucho fish market, and Ari trading post) in and around Illeret.

Table 2: Daasanach communities sampled by the Daasanach Health and Life History Project.

Community	Centroid of Households	Mobility Status	Mean Distance to Nearest Market (km)
Hocholoch	(4.313° N, 36.226° E)	Settled	0.11 ± 0.06
Namugusie	(4.311° N, 36.227° E)	Settled	0.28 ± 0.13
Kerech	(4.308° N, 36.236° E)	Settled	1.21 ± 0.21
Nangole	(4.330° N, 36.220° E)	Settled	1.92 ± 0.36
Baulo*	(4.301° N, 36.245° E)	Settled	2.3
Telesgaye	(4.394° N, 36.243° E)	Settled	2.47 ± 0.06
Watalii	(4.306° N, 36.248° E)	Settled	3.59 ± 0.16
El Bokoch	(4.320° N, 36.276° E)	Settled	4.93 ± 0.47
Ilkimere	(4.190° N, 36.242° E)	Nomadic	11.27 ± 0.31
Aiybete	(4.214° N, 36.230° E)	Settled	14.44 ± 0.05
Gerem*	(4.160° N, 36.496° E)	Nomadic	32.88

*based on single GPS point

All households sampled were located between 0.05 km and 32.88 km from one of three market centers – the Illeret Health Clinic (4.314° N, 36.227° E), the Sieslucho fish market (4.398° N, 36.221° E), and the Ari trading post (4.454° N, 36.213° E), located on the border of Kenya and Ethiopia (Figure 5). Nine of the communities sampled were permanent, while two were temporary settlements used by individuals practicing nomadic pastoralism (Table 2). Such temporary settlements are typically used for several days to several weeks and vary in location based upon seasonal and climatic changes (Mwamidi, 2018). Semi-permanent household residences – manyattas – are typically constructed in a dome-like fashion, with metal sheeting covering an internal wooden structure created by a lattice of tree boughs. Additionally, they are sometimes patched with cured animal hides and other materials, like plastics or cardboard. Conversely, non-permanent households utilize lightweight plastic sheeting to cover an internal wooden structure. By comparison, and necessity, non-permanent structures are typically much smaller in size than permanent household manyattas (Figure 6).

Figure 5: Market centers in northwestern Marsabit County, Kenya. Top left: Ari (4.354° N, 36.213° E) – trading post and small village at the southern Ethiopian border. Pictured is a small bar/restaurant with wood and mud construction typical of the commercial structures in the area. Ari serves as the primary trading center for the collection of market goods (e.g., sacks of beans, rice, coffee husks) transported from Ethiopia. Top right: Illeret Health Clinic (4.314° N, 36.227° E) – primary healthcare facility in the immediate vicinity. The Illeret Health Clinic consists of four primary buildings – the main intake facility (exterior wall pictured here), a laboratory, a maternity ward, and housing for the head nurse and nutritionist. Bottom: Sieslucho (4.399° N, 36.222° E) – fish market pictured here. Not pictured is the nearby medical dispensary.

Figure 6: Examples of Daasanach home structures (manyattas). Left: A typical semi-permanent Daasanach residence, constructed out of sheet metal, wood, and animal hides. Dirt floors will sometimes be covered by animal hides and plastic rugs but are otherwise unfinished. Most cooking is performed inside the dwelling. Right: A nomadic community, Gerem, setting up camp in the fora near the El Masich well complex (4.184° N, 36.481° E). Pictured are typical nomadic residences, some still under construction, made of wooden boughs and black plastic sheeting.

Large-scale early childhood growth data was synthesized from anthropometric records generated by the Illeret Health Clinic (IHC). Since May of 2018, the Illeret Health Clinic (IHC) has conducted systematic collections of anthropometric data for children aged 0-5 years (n=8669) as part of a large-scale multiyear malnutrition survey of children living across 11 communities in the greater region surrounding Illeret, Kenya (Figure 7). The distance between the IHC and communities sampled ranges from >1km to 16km. This work has been led by the IHC's governmentally contracted nutritionist working in conjunction with the head nurse of the IHC. Families with children aged 59 months and younger were encouraged to participate, but free to decline participation. Anthropometric measures were collected at the IHC for communities living within a short distance, typically those located within a 2km radius. Communities located farther from the IHC were visited for data collection. When ages were not available through IHC records, ages were estimated to the month by the IHC nutritionist. Height/length was measured to the nearest 1 mm using UNICEF provided stadiometers/infantometers, weight was measured to the 0.1kg using a digital scale (Tanita), and middle-upper arm circumference (MUAC) was measured to the nearest 1 mm using a fabric measuring tape. IHC health records were used to determine deworming status, micronutrient powder (MNP) supplementation status, and disability status. Additionally, the date of data collection, the first and last names of the subject, sex, the community of residence, and malnutrition survey re-measure status were collected. All anthropometric data were transcribed into digital form from the hand-written IHC's malnutrition survey records between the dates of May 2018 and December 2019.

Figure 7: Examples of data collection stations. Left: Data collection performed by the Daasanach Health and Life History Project research team was partly conducted out of the laboratory facility at the Illeret Health Clinic. Pictured is a portion of the anthropometric data collection set up. Right: Mass screening for malnutrition effort led by the Illeret Health Clinic. Pictured is a young child having their MUAC measured using a UNICEF provided measuring tape. Heights, weights, and MUACs for children 59 months of age and younger have been collected across 11 Daasanach communities in northern Kenya by the Illeret Health Clinic since May 2018.

The following chapters describes the work completed to investigate the effects of lifestyle change on health and early childhood growth among Daasanach living in northern Kenya. These chapters establish a Daasanach-specific model of somatic growth for those between 0-59 months, investigate variation in adult cardiometabolic health as a function of sedentarization and market integration, before finally testing household health, demography, socioeconomic status, and market integration as proximate causes for early childhood growth within Daasanach communities.

2. Early childhood growth in Daasanach pastoralists of Northern Kenya: Distinct patterns of faltering in linear growth and weight gain

2.1 Introduction

Patterns of somatic growth are important indicators of health and nutritional status in children and have significant consequences for adaptive variation in adult stature (Waterlow, 1994; Bogin, 1999; Cole, 2007). The detection of growth faltering as measured against large international growth standards is common among non-industrialized populations suffering malnutrition and disease (Frisancho et al., 2008; de Onis et al., 2007; Saha et al., 2009; de Onis & Branca; 2016; Spencer et al., 2017; Zhang et al., 2017; Martin et al. 2019). The causes of growth faltering, either in linear growth or weight gain, are multifactorial and most commonly attributed to inadequate nutrition and disease, with linear growth serving as a measure of long-term status and weight gain as a measure of short-term status (WHO, 2006; Spencer et al., 2017; Gonzalez-Viana et al, 2017; Urlacher et al., 2018; Urlacher & Kramer, 2018). The importance of growth as an indicator of malnutrition, which itself is associated with myriad negative short- and long-term health conditions, such as reduced muscle or organ function, cognitive developmental deficits, and increased psychosocial stress, has helped proliferate the use of such international growth references with which large number of individuals can be easily assessed (Saunders & Smith, 2010; Adair et al., 2013; Sudfeld et al., 2015). The

World Health Organization’s (WHO) Growth Standards are one of the most widely accepted and used growth references for comparison across populations.

Derived from large multi-national surveys, these standards have been commonly used for inter-population comparison since their establishment in 2006 (WHO, 2006). Age stratified z-scores (standard deviation values) can then be used to compare across mixed cross-sectional samples. For example, the identification of wasting, underweight, and stunting is assessed by using a threshold of ≤ -2 standard deviations (SD) for measures of weight-for-height (WFH), weight-for-age (WFA), and height-for-age (HFA), respectively. Despite the reliance on the WHO standards for these assessments, significant issues remain with the analysis of population-specific growth, particularly in small-scale and genetically isolated populations, as these standards do not account for potential genetic variation that could lead to differences in somatic growth pattern and timing (Cole, 2007; Ziegler & Nelson, 2012; Martin et al, 2019; Hruschka, 2020).

To address some of the limitations of international growth standards, large cross-population analyses to assess region specific variation in timing and magnitude of growth faltering from populations in developing nations have been employed (Shrimpton et al., 2001; Victoria et al., 2010; Alderman & Headley, 2018). Such work has found that most growth faltering begins at about 3 months of age and continues over the first 23 months of life, suggesting that the effects of poor nutrition and immune stress are most acutely felt in the first 1000 days of life (Shrimpton et al., 2001; Alderman &

Headley, 2018). Specifically, work by Shrimpton et al. (2001) has found that when analyzing data derived from nationally representative samples of 39 developing nations weight-for-age declined significantly between the ages of 3 and 12 months, with catch-up weight gain not occurring until about 18-19 months. Simultaneously, weight-for-height faltering was found to be more tightly restricted to the first 15 months of life. Linear growth faltering, as defined by measures of height-for-age, was also found to occur in the first two years of life. However, little evidence was found for positive changes to linear growth between 2-5 years of age, and evidence for linear catch-up growth among these large-scale datasets from populations in developing nations remains disputed (Shrimpton et al., 2001; Leroy et al., 2015; Alderman & Headley, 2018). As these large-scale multinational analyses provide insight into global trends of somatic growth failure, they can be used for comparative investigations of variation in growth pattern and timing within distinct populations.

The objectives of this study are two-fold. First, we seek to characterize early childhood growth among children living in a relatively remote and low-nutrition environment, identifying the potential presence and severity of growth faltering over the early childhood age-course. Second, we aim to analyze the Daasanach-specific pattern of growth, both in timing and magnitude, to identify distinct differences relative to large-scale studies of early childhood growth faltering. Such growth variation, identified within a genetically homogenous population, may shed light on the broader adaptive variation in adult body size and shape that is expressed across human populations, the study of which has been central to human evolutionary biology since the 19th century (Bergmann, 1847; Allen, 1877; Ruff, 1994).

2.1.1 Study population: Daasanach

Semi-nomadic pastoral Daasanach communities live in the semi-arid and arid regions of southwestern Ethiopia and northwestern Kenya (Almagor, 1978). Based on the most recent national Kenyan census, about 19,300 Daasanach live in Kenya (KNBS, 2019). A majority of Daasanach, about 48,000, live in the Omo River Valley region of Ethiopia (Mwamidi et al., 2018). Most Daasanach in Kenya live in Illeret (4.314° N, 36.227° E) or the surrounding area. Illeret is in the northwestern corner of Marsabit County, and borders Lake Turkana to the west and Ethiopia to the north (Figure 8). Encroaching markets and the phenomenon of sedentarization has led some Daasanach to live more settled lifestyles, living in permanent structures with greater access to market goods and infrastructure. Despite this, many Daasanach continue to practice a traditional semi-nomadic movement strategy and pastoral subsistence strategy (Mwamidi, 2018).

The region around Illeret experiences a bimodal seasonal cycle with mean temperatures ranging from 20°C and 37°C and yearly average rainfall of about 217mm (Opiyo et al., 2014; Liebmann et al., 2014; Mwamidi et al., 2018). The historical classification of agropastoralism given to Daasanach communities (Alamgor, 1987), results largely as a function of ethnographic work conducted with Daasanch living in Ethiopia, as they have increased agricultural access. Daasanach in and around Illeret are far more reliant on herding practices and access to market food staples, such as beans, rice, and maize, with very little ability to perform sustainable agriculture. Health issues related to long-term water and food insecurity caused by increased threat of drought, flash flooding, and climate variability have also been exacerbated by longstanding economic and political isolation (Little et al., 2001; VSF RSIPA, 2011-2013; Boru & Koske, 2014; MoALF, 2017). Childhood malnutrition remains a major concern in the region, and recent work has found high levels of both food and water insecurity across Daasanach communities at the household level (Bethancourt et al., 2021). The challenges facing Daasanach living in northern Kenya have led to a number of relationships with NGOs, though they operate with varying degrees of success. To date, NGOs have focused primarily on increasing the quality of maternal healthcare, increasing access to clean water, and supplying nutritional supplementation to combat childhood malnutrition. Despite such efforts, Daasanach community members living in and around Illeret had little involvement in scientific or medical research.

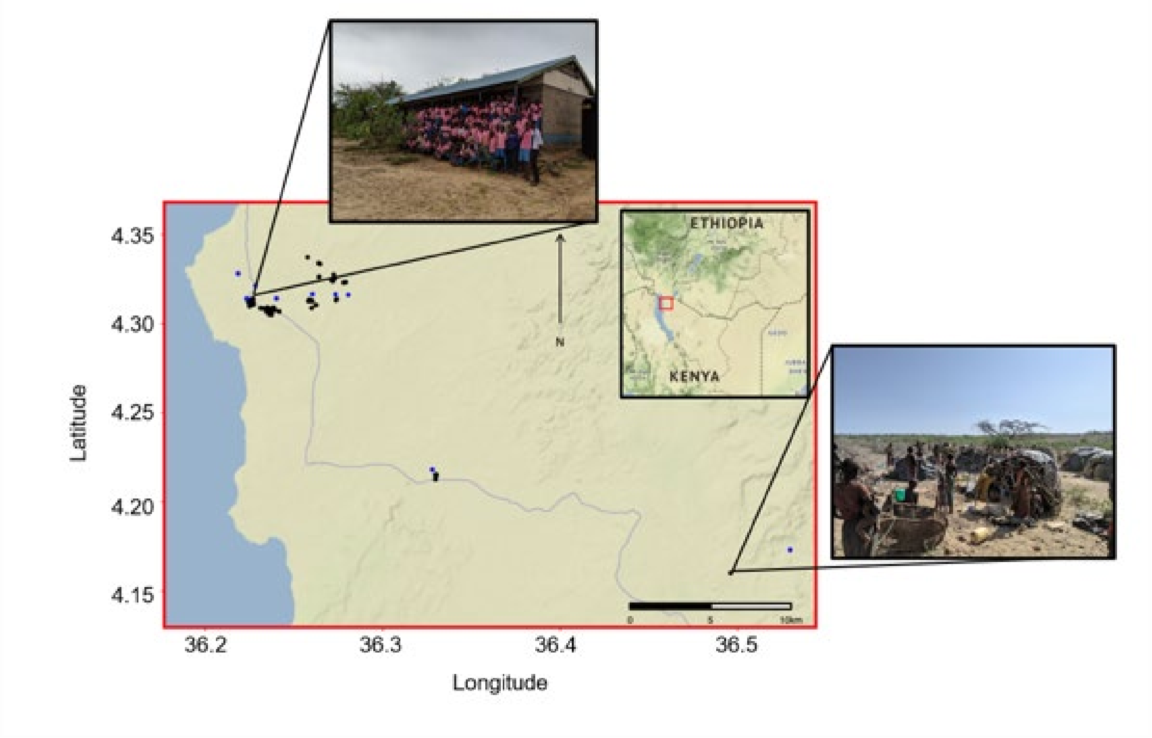

Figure 8: Map of Illeret and surrounding region. Black dots = households sampled. Blue dots = water sources. Inlays display the Illeret Primary School above and the nomadic community of Gerem below.

2.2 Methods

2.2.1 Data collection

Since May of 2018, the Illeret Health Clinic (IHC) has conducted systematic collections of anthropometric data for children aged 0-5 years as part of a large-scale multiyear malnutrition survey of children living across 11 communities in the greater region surrounding Illeret, Kenya (n = 8669). The distance between the IHC and communities sampled ranges from >1km to 16km. This work has been led by the IHC's governmentally contracted nutritionist working in conjunction with the head nurse of the IHC. Families with children aged 59 months and younger were encouraged to participate, but free to decline participation. Anthropometric measures were collected at the IHC for communities living within a short distance, typically those located within a 2km radius. Communities located farther from the IHC were visited for data collection. When ages were not available through IHC records, ages were estimated to the month by the IHC nutritionist. Height/length was measured to the nearest 1 mm using UNICEF provided stadiometers/infantometers, weight was measured to the 0.1kg using a digital scale (Tanita), and middle-upper arm circumference (MUAC) was measured to the nearest 1 mm using a fabric measuring tape. IHC health records were used to determine deworming status, micronutrient powder (MNP) supplementation status, and disability status. Additionally, the date of data collection, the first and last names of the subject, sex, the community of residence, and malnutrition survey re-measure status were collected. All anthropometric data were transcribed into digital form from the hand-written IHC's malnutrition survey records between the dates of May 2018 and December 2019.

2.2.2 Analysis

All statistical analyses were completed in R (4.0.2). Height-for-age (HFA) was calculated as cm/month, weight-for-age (WFA) as kg/month, and weight-for-height (WFH) as kg/cm for male and female subjects. Values were plotted against WHO standards to identify the relative shape of growth among Daasanach infants and young children. WHO specific z-scores for WFH, WFA, and HFA were generated using the R package ‘*localgrowth*’, which was previously developed and used for growth analyses of Shuar and Tsimane populations (Urlacher et al., 2016; Blackwell et al., 2017; Martin et al., 2017). To control for age estimation, age-correction based on difference in date from previous measurement was employed and individuals with z-scores ≥ 5 or ≤ -5 for any of the three measures were dropped. This reduced our sample to only those individuals from whom multiple measures were available, a reduction of 4082. The sample for these analyses includes 4587 measures from 1753 subjects (Table 3). To examine growth faltering as a function of change in cross-sectional z-score over the early childhood age-course, sex-specific local polynomial regression (LOESS) models (α=0.25) of z-scores for WFH, WFA, and HFA were generated as a function of age. Following procedures similar to those previously used for large-scale analysis of early childhood growth faltering, subjects were also binned by age to the nearest month and means for HFA, WFA, and WFH z-scores were generated for each age cohort (Shrimpton et al., 2001; Victoria et al., 2010). Additionally, height-for-age differences (HAD) were calculated for males and females by assessing the difference, in centimeters, between a child’s height and the median height standard for their age. This follows a similar procedure previously used for the identification of potential population-level catch-up growth among children less than five years old (Leroy et al., 2015).

Table 3: IHC Sample statistics – Ages (months) of subjects by community.

	Male (Age)			**Female (Age)**			**Total (Age)**		
Community	N	Mean	SD	N	Mean	SD	N	Mean	SD
Aiybete	72	32.30	13.99	99	30.34	14.66	171	31.16	14.37
Blachaloki	13	29.97	15.38	16	34.42	16.38	29	32.42	15.81
Baulo	161	30.02	14.10	152	32.57	14.56	313	31.26	14.36
El Bokoch	146	29.84	14.30	120	31.83	14.79	266	30.74	14.53
Guoro	160	27.94	15.77	156	27.93	14.19	316	27.94	14.98
Ilgele	204	31.45	12.90	179	31.95	13.00	383	31.68	12.93
Ilolo	216	32.89	14.52	208	31.46	13.69	424	32.19	14.12
Kerech	247	32.85	12.57	191	32.86	12.88	438	32.85	12.69
Lomadang	259	34.86	13.36	222	33.25	14.22	481	34.11	13.77
Namugusie	170	30.74	14.21	133	31.00	14.13	303	30.85	14.16
Nangolei	230	29.82	13.94	210	27.33	14.90	440	28.63	14.45
Sieslucho	166	28.13	13.56	156	28.24	13.99	322	28.18	13.75
Telesgaye	137	32.68	13.71	182	29.73	14.35	319	31.00	14.14
Watalii	183	33.05	14.60	199	29.95	14.55	382	31.43	14.64
Total	*2364*	*31.44*	*14.03*	*2223*	*30.70*	*14.23*	*4587*	*31.08*	*14.13*

Centile curves for HFA, WFA, and WFH were generated for sex-specific samples between the ages of 0-59 months using Generalized Additive Models of Location, Shape, and Scale (GAMLSS) as part of the '*GAMLSS*' package in R (4.0.2) (Rigby and Stasinopoulos, 2005). Modeling procedures were based on previous work modeling the growth of the Shuar and Tsimane farmer-horticulturist populations in South America (Urlacher et al., 2016; Blackwell et al., 2017). All models were fit with Box-Cox Power Exponential (BCPE) distributions with varying model parameters with samples that fell outside ±5 standard deviations of the Daasanach-specific curve being dropped (Cole & Green, 1992). GAIC scores were used to determine the best fit model for the sample populations and centile models were produced using the best fit GAMLSS model parameters. Additionally, pseudo-velocity curves were produced from the 1st derivate of mu (median) of the GAMLSS models of male and female linear and weight growth. These models allow for the identification quantification of age-related changes in growth across early childhood. WHO pseudo-velocity reference was added to facilitate comparisons in timing and magnitude of growth variation between Daasanach subjects and international standards.

2.2.3 Ethical approvals

Study protocols were approved by Penn State Institutional Review Board (IRB#STUDY00009589) and the Kenya Medical Research Institute (#KEMRI/RES/7/3/1) prior to all data collection. These approvals include permissions for the collection of health records from the Illeret Health Clinic, in addition to anthropometric, survey, and biological sample collection. In-person consent for data collection was also obtained from all relevant sources, including community elders, the Illeret Ward, and medical officials from the IHC. Additionally, permitting for human biology research was obtained from the National Commission for Science, Technology and Innovation (NACOSTI).

2.3 Results

Daasanach boys and girls display patterns of early childhood growth that are not congruent with those established by the WHO. Rates of stunting (≤-2SD HFA) between the ages of 0-5 years are 18.6% and 11.4% for males and females, respectively. Rates of underweight (≤-2SD WFA) are higher, with 43.1% of males and 35.1% of females at or below the threshold, while rates of wasting (≤-2SD WFH) are highest, with 56.3% of males and 51.4% observed to be wasted (Figure 9 & Table 14-15). Severe wasting, marked by those who fall at or below -3SD for WFH relative to WHO standards, was observed in 19.1% of males and 16.1% of females (Table 15-16).

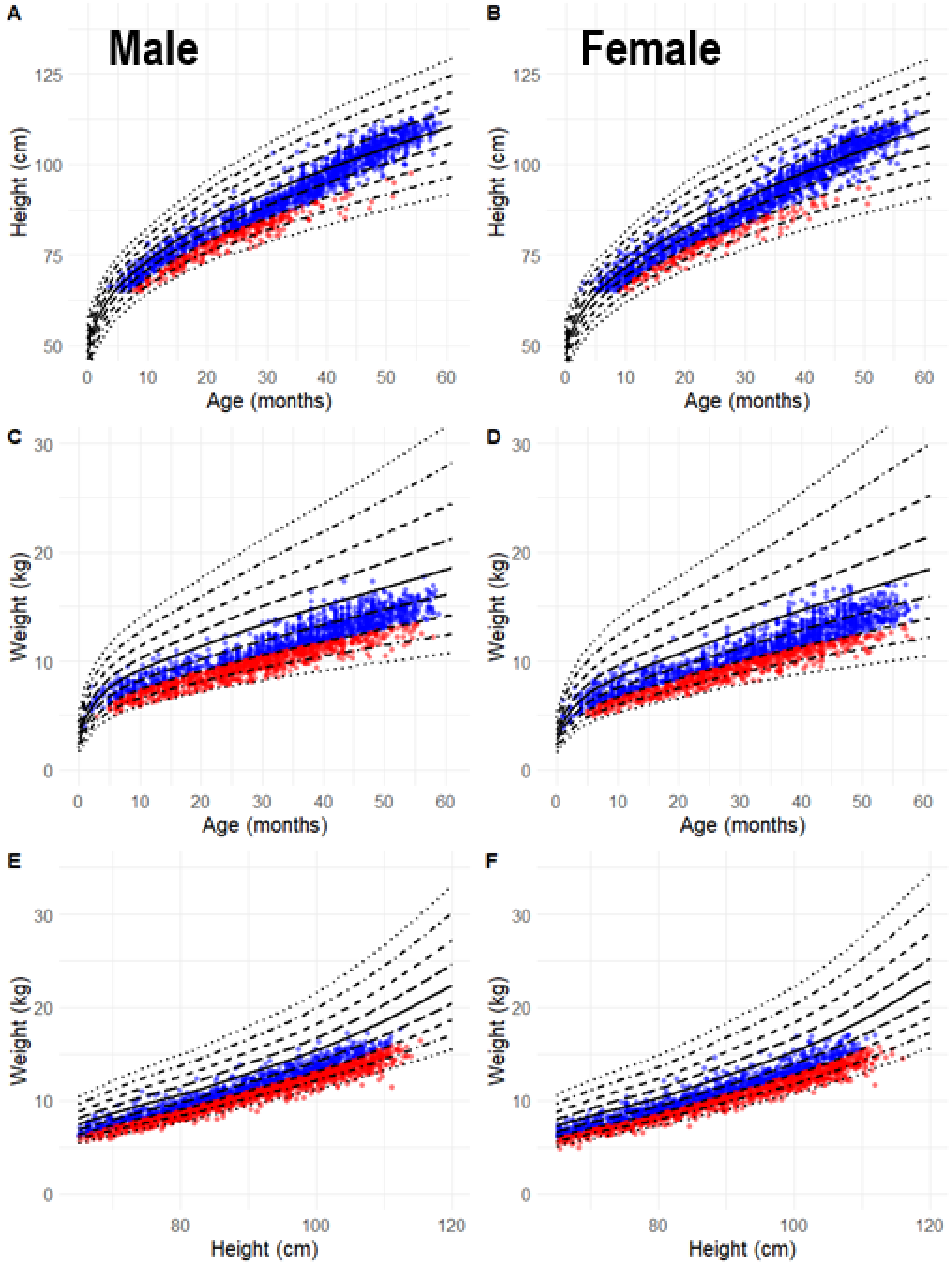

Figure 9: Daasanach growth relative to WHO standards. Height-for-age (A-B), weight-for-age (C-D), and weight-for-height (E-F). Black lines represent WHO standards. Solid black line = 0SD, long dashed = ± 1SD, short dashed = ± 2SD, dash dot = ± 3SD, dotted = ± 4SD. Blue dots = individuals above -2SD, red dots = subjects at or below -2SD (stunted, underweight, or wasted).

Relative to WHO standards, Daasanach children are born at or near normal lengths and weights, with mean z-scores for children aged 0-5 months >-0.5 for both length-for-age and weight-for-age (Table 15-16). However, Daasanach children then experience significant growth faltering beginning shortly after birth. Like previous work examining growth faltering across global populations, Daasanach faltering begins before 6 months of age and is most severe between the ages of 18-24 months (Figure 10 & 11) (Shrimpton et al., 2001; Alderman & Headley, 2018). In this age range, the prevalence of stunting is 50.5% for males and 28.8% for females, with rates of underweight being 70.2% and 58.0% for males and females, respectively. Contrary to previous findings, however, mean HFA z-scores for males and females return to and exceed the 0SD standard for the WHO between by about 4 years of age, while prevalence of faltering continues to increase beyond the third year of life (Figure 10 & Figure 11).

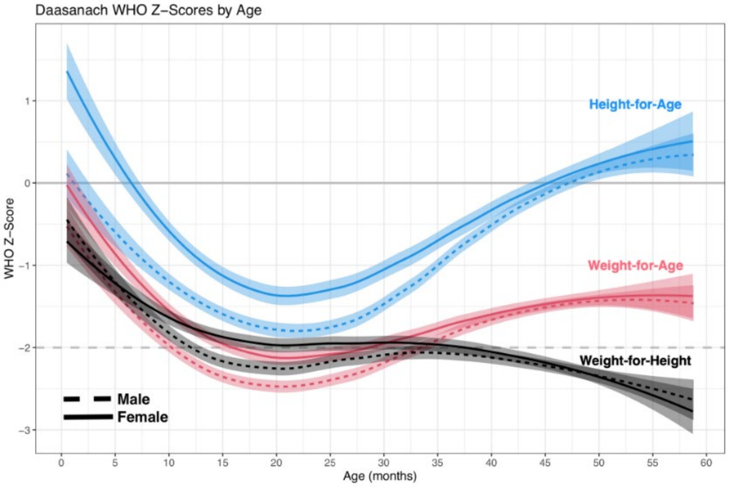

Figure 10: LOESS modeling of HFA, WFA, WFH z-scores by age for Daasanach children (0-59 months). Solid grey line = 0SD standard, dashed grey line = -2SD standard (WHO threshold for stunting, underweight, and wasting).

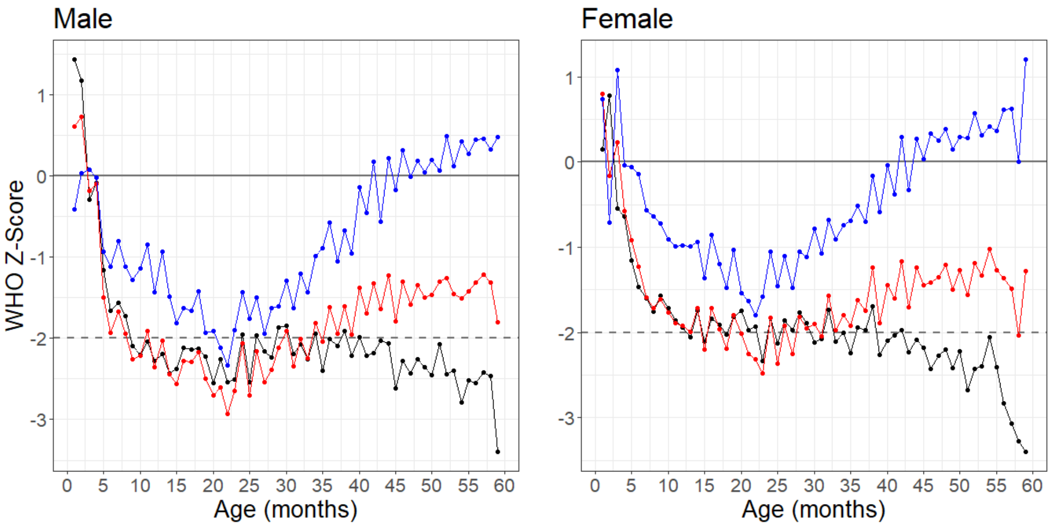

Figure 11: Mean WHO z-scores by month of age for males and females between the age of 0-59 months. Blue = HFA z-score, red = WFA z-score , black = WFH z-score.

When examining mean z-score by 6-month age cohorts, the mean z-score for HFA for males reaches 0.06 ± 0.89 for those aged 48-53 months, rising to a mean of 0.38 ±0.93 for males aged 54-59 months. Prevalence of male stunting drops to its lowest rate for this age cohort as well, with only 2.4% being found to be stunted. For females, mean HFA z-score becomes positive (0.09 ± 0.98) for the 42-47 months cohort, slightly earlier than found in males. Mean z-score for HFA amongst the oldest female age cohort, 54-59 months old, is 0.45 ± 0.60 and there are no observed instances of stunting (Table 4; Figure 12). These results are consistent with the polynomial regressions of HFA z-scores by age, which finds females and males surpassing the 0SD threshold at about 45 and 47.5 months of age, respectively (Figure 10). Polynomial regressions for height-for-age differences (HAD), calculated as the difference in centimeters to the median height-for-age standard showed a similar pattern to HFA analyses, with boys and girls aged 59 months having median HAD values ~2 cm and ~2.5 cm greater than the median standard values, respectively (Figure 13).

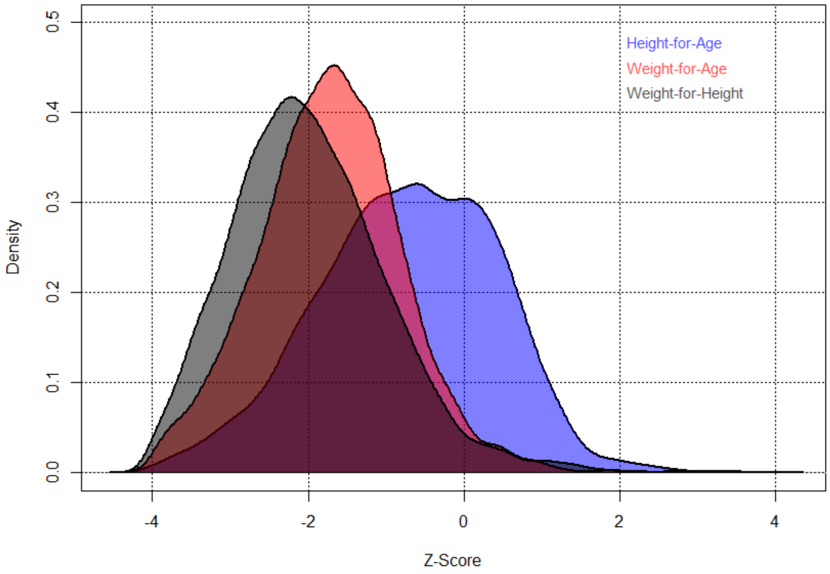

Figure 12: Combined sex density distribution of WHO z-scores for Daasanach children aged 0-59 months.

While mean HFA z-scores increase dramatically among Daasanach children over the course of early childhood, mean z-scores for WFA only increases slightly from the lowest observed means of -2.54 ± 1.05 for males aged 18-23 months and -2.20 ± 0.96 for similarly aged females to -1.40 ± 0.67 males and -1.29 ± 0.60 for females in the 54-60 months cohort. However, this change of about +1SD for males and females is matched by a large decrease in underweight prevalence, from 70.2% to 14.1% for males aged 18-23 months and 54-59 months, respectively, and from 58.0% to 9.8% for similarly aged females.

While mean z-score for HFA and WFA both increase after initial growth faltering in the first 18-24 months of life, mean WFH z-scores decrease over the course of early childhood, matched by a marked increase in wasting prevalence after 41 months of age (Figure 10 & 11). Mean z-scores of WFH among males and females aged 54-59 months (male = -2.58 ± 0.86; female = -2.52 ± 1.13) are the lowest observed for any sex-specific age group across all measures (Table 14; Table 15; Figure 12). Similarly, wasting prevalence increases to 72.6% and 75.4% for males and females, respectively, after a period of relative stability in wasting prevalence between 12-41 months (male = 56.1% ± 2.0%; female = 49.5% ± 3.7%) (Table 14; Table 15).

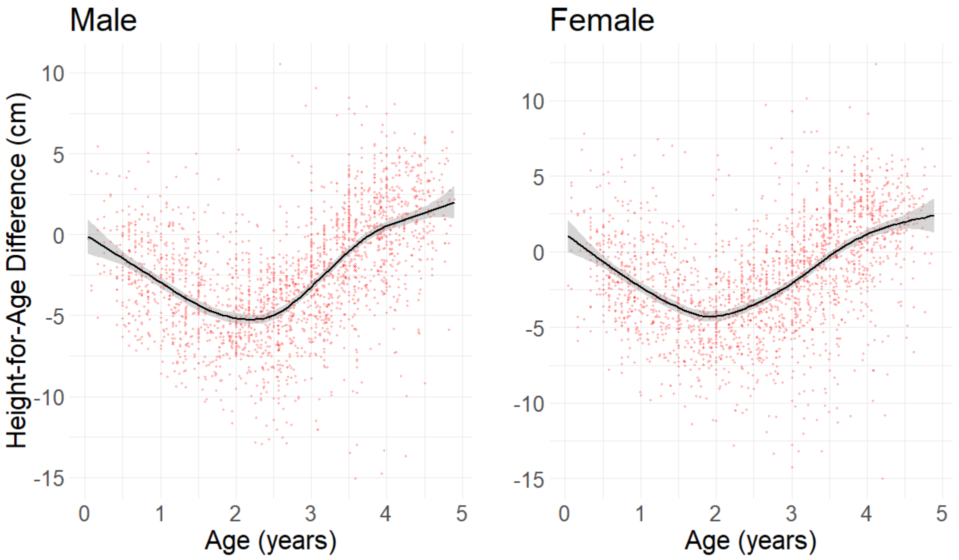

Figure 13: Height-for-age differences (WHO standards) for male and female Daasanach children under five years of age.

Sex-specific centile curves for Daasanach height, weight, and weight-for-height for children aged 0-5 years are presented in Figure 14. Pseudo-velocity curves of linear growth and weight gain constructed using GAMLSS found positive acceleration for linear growth between ~22-36 months old for males and ~20-36 months old for females (Figures 15). Likewise, there was an increase in weight gain velocity for males between the ages of 18-35 months and females between the ages of 17-34 months (Figure 16). Linear growth velocity peaked at ~0.98cm/month for boys and girls aged ~36 months, a rate greater than the median WHO velocity standards for children aged 22-24 months (WHO, 2006). Weight gain velocity peaked slightly earlier than linear growth, at a value of nearly 0.20 kg/month for boys and girls aged ~ 35 months.

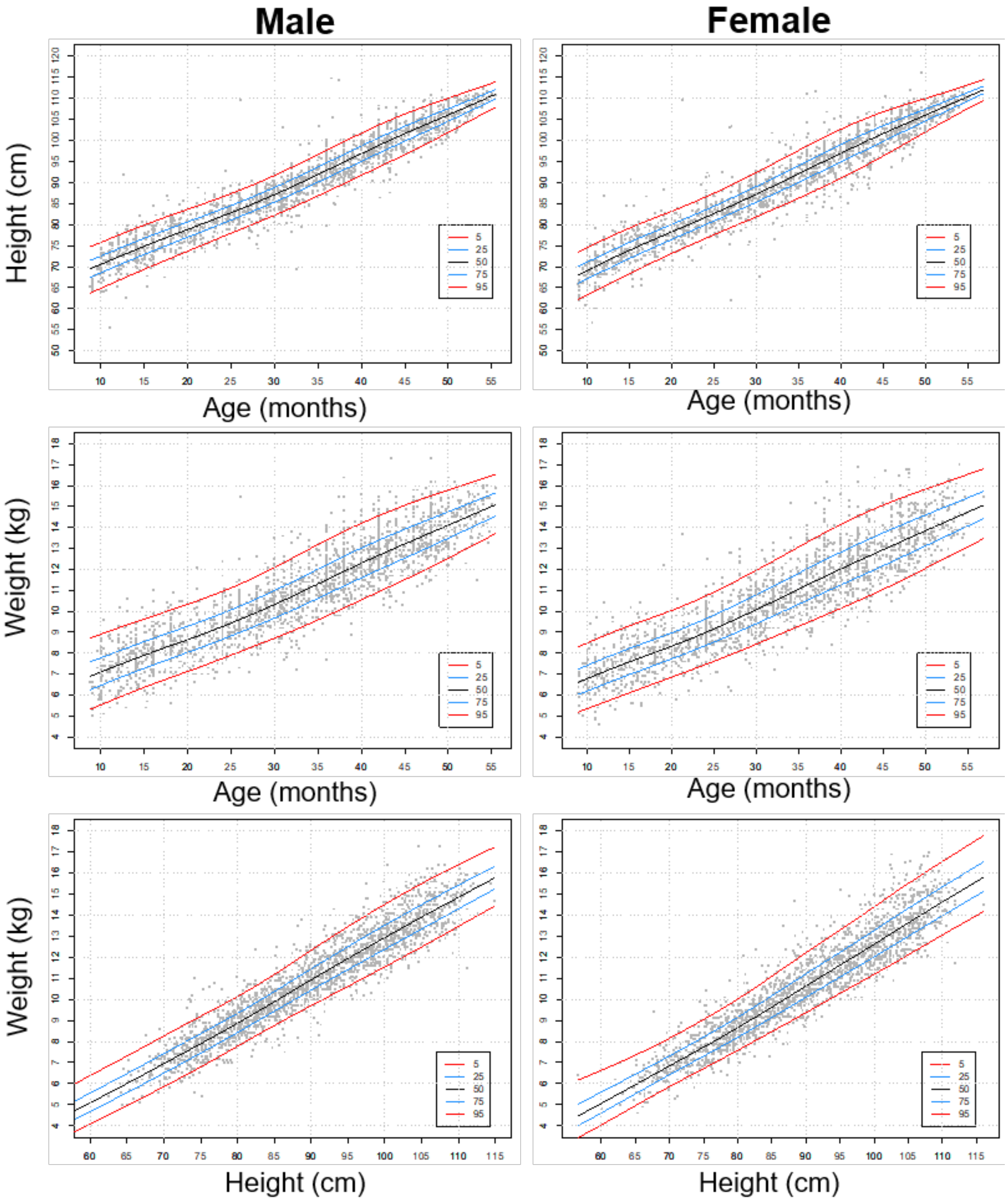

Figure 14: Centile curves for Daasanach children aged 0-5 years (male=2361; female=2208). Red lines = 5th and 9th centiles; Blue lines = 25th and 75th centiles; Black = 50th centile. Measures from the Illeret Health Clinic malnutrition survey.

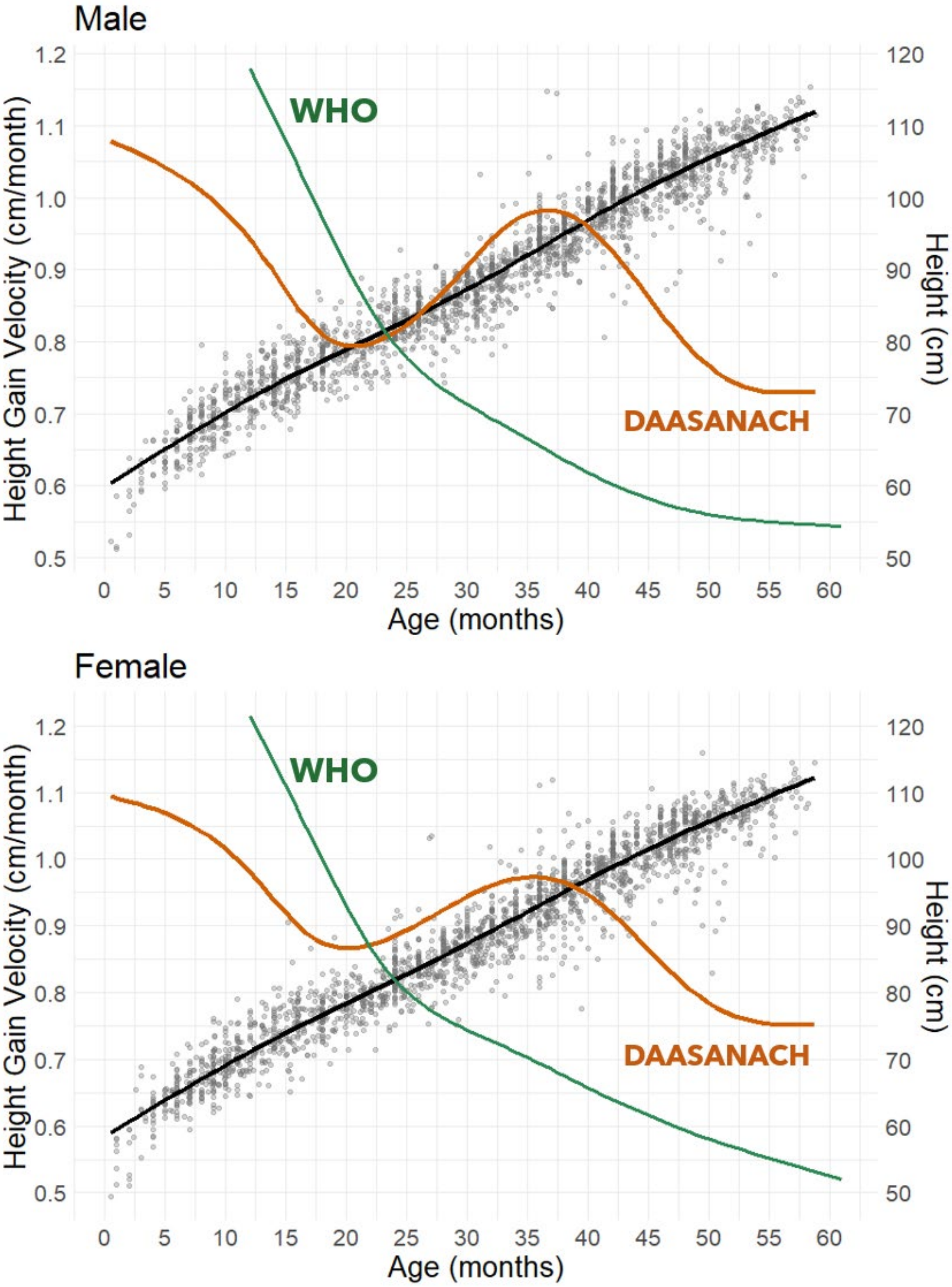

Figure 15: Pseudo-velocity curves produced from GAMLSS modeling of linear growth for Daasanach children (0-59 months). Purple line = median of spline model of linear growth (HFA), orange line = 1st derivative of median linear growth spline parameter, green line = loess model of WHO 1st derivative of median HFA.

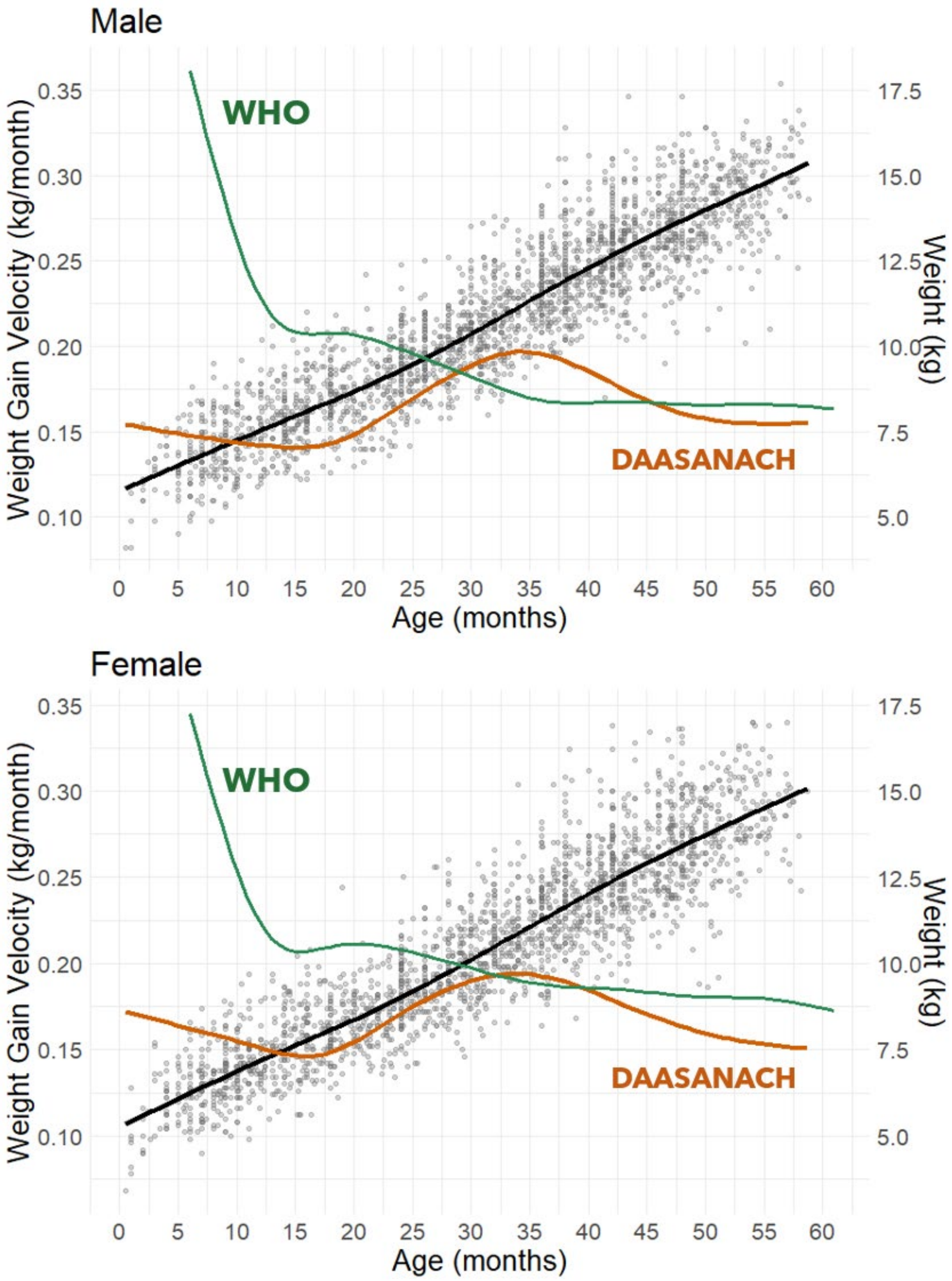

Figure 16: Pseudo-velocity curves produced from spline modeling of weight gain for Daasanach children (aged 0-59 months). Purple line = median of spline model of linear growth (WFA), orange line = 1st derivative of median weight gain spline parameter, green line = loess model of WHO 1st derivative of median WFA.

2.4 Discussion

The patterns of faltering in Daasanach children in the first 24 months of life largely match those described for other populations in developing regions of the world (Dewey, 1997; Victoria et al.; 2008; Hermanussen et al., 2016; Alderman & Headley, 2018). Daasanach children are born at relatively normal heights and weights relative to WHO standards, but quickly begin to show both linear and weight growth faltering before 6 months of age (Figure 10 & 11). As linear faltering and weight gain faltering continue throughout the first 24 months of life, cross-sectional prevalence for stunting and underweight peaks between the ages of 18-23 for both males and females. While high prevalence of stunting and underweight are observed, particularly in the first 36 months of life, Daasanach achieve relatively tall adult height, with mean adult males (n = 131) and female (n = 180) heights of 172.3 ± 6.3cm and 163.5 ± 6.2cm, respectively. Mean adult weights were observed to be 53.1 ± 9.3kg for males and 49.0 ± 8.7kg for females. These measures for height and weight are similar to, and in some cases larger than, those measured in the neighboring Turkana population (male: 174.3cm & 49.8kg; female: 161.6cm & 47.4kg) (Little et al., 1983).

Unlike other populations in developing nations, both Daasanach boys and girls show significant gains in linear growth relative to WHO standards after about 24 months of age and throughout the rest of early childhood. This results in Daasanach children achieving cross-sectional mean HFA z-scores greater than 0 SD relative to

WHO standards by 5 years of age, and stunting rates below 5% after 42 months of age. These results are in opposition to the widely observed pattern of faltering, which sees weight gain increasing after about two years of age when faltering is present, but consistent with rates of stunting continuing through early childhood. This pattern also contrasts with the growth observed among young children in the neighboring Turkana (Little et al., 1983; Galvin, 1992).

Daasanach children continue to have relatively low cross-sectional mean WFH z-scores across the first 59 months of life (male = -1.90 ± 1.03; female = -1.69 ± 1.11) and have a particularly high prevalence of wasting throughout early childhood (male = 56.3%; female = 51.4%). Rates of wasting are at their most severe between 54-59 months of age, the last age cohort measured here, with 72.6% of males wasted (31.0% severely wasted) and 75.4% of females wasted (41.0% severely wasted) (Table 4). This remarkably high rate of wasting may be the result of patterns of growth in Daasanach children that are not consistent with WHO standards, however. Despite wasting among nearly three quarters of all children aged 54-59 months, rates of underweight for those same children are 14.1% and 9.8% for males and females, respectively. Overall prevalence of stunting in our sample is less than half the estimated stunting prevalence for preschool children in the UN sub-region of East Africa as predicted based on global trends in 2010 (mean = 43.9%). In fact, only the prevalence of stunting for male children aged 18-23 months (50.5%) falls within the 95% confidence interval for this prediction (conf. int. = 38.0, 50.0) (de Onis et al., 2012). These results suggest that patterns of wasting in Daasanach children is likely a result of their unusually high linear growth outcomes.

Daasanach-specific growth patterns exhibit an increase in both linear growth velocity and weight gain at ~24 months of age which continues until about 48 months of age in both males and females (Figure 15 & 16). At its peak at ~40 months for both males and females, linear growth velocity reaches ~1cm/month, which is above the median expected velocity for a 24-month-old using WHO velocity standards (WHO, 2007). Additionally, this pattern is temporally distinct from the mid-childhood growth spurt, which is generally associated with adrenarche and a moderate increase to growth velocity between the ages of 6-8 (Katz et al., 1985; Bogin, 1999). This increase in velocity may be associated with weaning, though one might expect the opposite effect on growth velocity (Rehman et al., 2009). Though both linear growth velocity and weight gain velocity increase similarly across males and females, additional data on relative z-score change suggests a larger increase in linear growth velocity relative to expectations established by WHO standards. This increase in linear growth relative to weight gain also explains the high prevalence of wasting across Daasanach children, especially those between 42-59 months of age.

Though undernutrition is surely a concern for Daasanach children living in a relatively calorically sparse environment with high rates of water and food insecurity, investigation into Daasanach early childhood growth patterns suggest differences in energetic allocation to linear growth versus weight gain than expected among populations sampled for WHO and other international growth standards (Bethancourt et al., 2021). These differences provide potential evidence for the broader forces of adaptive variation in body shape, as outlined by Bergmann's and Allen's "rules" (Bergmann, 1847; Allen, 1877). These "rules" consider the ecological relationship between body size (Bergmann) and body proportionality (Allen) variation as a function of thermoregulatory adaptation and suggests those that live in warmer climates evolved slimmer bodies with longer limbs, while humans living in colder climates evolved bodies with relatively higher mass and shorter limbs (Ruff, 1991; Ruff, 1994). The square-cube law, which describes the relationship between the surface area and volume of a three-dimensional object as it changes size, dictates the physiological basis for the fitness advantages of differing body sizes and shapes (Schmidt-Nielson, 1984). Daasanach adults match the adaptive expectations of both Bergmann's and Allen's rules, being relatively tall in adult stature (Male = 172.7 ± 6.3cm | Female = 163.7 ± 6.0cm), with very low adult body mass indices (Male = 17.9 ± 2.8 kg/m^2 | Female = 18.5 ± 3.3 kg/m^2), while living in a hot and very arid environment (Opiyo et al., 2014; Wells et al., 2019; Bethancourt et al., 2021). Given the trajectory of linear growth relative to weight gain in the latter half of early childhood, as well as the achieved body size and shape of Daasanach adults, the patterns of growth that results in relatively tall and lean children by the age of 59 months is suggestive of an adaptive trend towards a trade-off for increased height rather than weight.

A major limitation of this work is the use of age estimation, which can lead to error in age-dependent growth measures (Diekmann et al., 2017). To reduce the effect of this factor, all age estimations were made by a single observer who was a government sponsored nutritionist familiar with the local population. This limitation was also mitigated through the use of age-correction that produces new age estimates based on the difference in dates between multiple samples. This method requires the use of subjects with multiple samples, reducing our overall sample by about half. Patterns of growth for this sample were also analyzed in combination with anthropometric data collected by the Daasanach Health and Life History Project, finding that the IHC sample falls within expected ranges for LMS analysis.

This study identifies a unique pattern of early childhood growth faltering, in which growth outcomes both height and weight differ significantly from expectations based on WHO growth standards and previous work identifying faltering patterns over the early childhood age-course. Additionally, the results of this study provide insight into a distinct relationship between the timing and magnitude of early childhood linear growth and weight gain that may have broader implications for public health through the identification of nutritional and health disparities in small-scale populations. These results are also potentially indicative of an adaptive growth strategy, which prioritizes linear growth rather than weight gain during early childhood and results in adult body sizes and proportions that match expectations based on environmental condition (Bergmann, 1847; Allen, 1877). As linear growth and weight gain remain important indicators of infant and childhood health, comparisons with international growth standards are still crucial, however, understanding the limitations of these standards is key to identifying population-specific variation in growth (Waterlow, 1994; Bogin, 1999; Ziegler & Nelson 2012). Without such investigation, the proper identification of growth faltering that results as a consequence of undernutrition or disease may be impossible.

3. The effects of lifestyle change on indicators of cardiometabolic health in semi-nomadic pastoralists: Daasanach sedentarization and market integration in northern Kenya

3.1 Introduction

Understanding the relationships between health and lifestyle is of growing global importance as populations around the world transition towards states of industrialization and urbanization that characterize "western" lifestyles, with distinct importance for a rapidly changing East Africa (Little, 1983; Little & Leslie, 1999; Fratkin et al., 2004; Fujita et al., 2004; Fratkin & Roth, 2005; Lea et al., 2020). Shifts away from traditional subsistence and movement strategies create potential mismatches between evolved physiology and the ecological and behavioral environments populations create (Gurven et al., 2017; Pontzer et al., 2018; Manus, 2018). Research investigating the repercussions of evolutionary discordance on cardio-metabolic health for populations currently experiencing lifestyle transition has historically focused on inter-population variation between "western" populations in developed countries and small-scale populations in developing countries, and the intra-population variation found within groups that express a gradient of lifestyle variables (e.g. market integration, urbanization, subsistence/movement strategy) (Byron, 2003; Godoy et al., 2005; Zeng et al., 2013; Liebert et al., 2013; Gurven et al., 2017; Page et al., 2018; Pontzer et al., 2018; Jaeggi et al., 2020; Lea et al., 2020). The investigation of non-communicable diseases, such as cardio-metabolic disease, is central to interpretations of these potential mismatches within the study of evolutionary health.

Sedentarization, or the transition from a previously mobile lifestyle to a settled one, is a phenomenon that has existed since the Neolithic Transition, some 10,000 years ago. However, increased rates of geographic encroachment by larger settled populations, climate change, governmental intervention, or a combination of the three has led to an escalating trend towards sedentary and market-integrated lifestyles among non-industrialized populations (Little & Leslie, 1999; Fratkin et al., 2004; Fratkin et al., 2004; Dounias & Froment, 2006; Bocquet-Appel, 2011; Adongo et al., 2013; Little, 2015; Catley et al., 2016). Currently, many NGOs and governmental agencies encourage the transition of nomadic populations to more sedentary ways of life. However, health outcomes of individuals who have become more settled have often been found to be worse than those of more nomadic individuals in a population (Barkey et al., 2001; Fratkin et al., 2004; Page et al., 2018). Explanations for the disparity in health has been suggested to be the result of changes in dietary environment, increased exposure to pathogens due to higher population and waste densities, and lower levels of physical activity. Some of these changes are additionally influenced by increased market access, which has been associated with becoming more settled (Page et al., 2018). The negative implications of sedentarization and lifestyle changes have often been explained by evolutionary mismatch in which deleterious effects arise among individuals for whom subsistence contexts have rapidly changed away from the one in which their populations have gained biological and behavioral adaptations (Schell, 1986; Eaton et al., 1988; Little, 1989; Galvin, 1992; Little & Leslie, 1999; Manus, 2018). This process can be understood as an ultimate cause of more proximate factors that can affect human health and life history, such as nutrition, stress, and disease. One way to assess the potential life history, health, and behavioral consequences of lifestyles in flux is to perform intra-group comparisons with a population currently undergoing this transition.

Work with populations that exhibit varying lifestyles provides insight into the associations between diet, activity, and health outcomes, such as hypertension, diabetes, overweight/obesity, and heart disease. However, studies that identify intra-population variation in health often do so through the framework of an 'urban-rural divide', which precludes the ability to specifically investigate the effects on a population as it actively transitions away from traditional lifestyle characteristics. Here we work with traditionally semi-nomadic Daasanach pastoralists living in northern Kenya to investigate the effects of lifestyle change on cardio-metabolic health in a population experiencing a relatively recent transition toward more sedentary lifestyles in a remote non-urban area. Daasanach in northern Kenya provide the unique opportunity to understand the ways in which bio-behavioral health variation occurs at a level more finite than the 'urban-rural divide'. This investigation will both serve to enhance our understanding of the effects of market integration and sedentarization on health variation within a genetically homogenous population in the early stages of lifestyle change, and serve to provide additional context for comparative study of evolutionary health across global populations.

3.2 Methods

3.2.1 Data collection

To test the associations between lifestyle variables with indicators of health, anthropometric, survey, and GPS data were collected over the course of two field seasons between June-July of 2019 and February-March of 2020 in the region surrounding Illeret in Marsabit County, Kenya (Figure 7; Figure 8). Collection took place across eleven communities located between 0.05 km and 32.87 km from the nearest market centers – the Illeret Health Clinic (4.314° N, 36.227° E), the Sieslucho fish market (4.398° N, 36.221° E), and the Ari trading post (4.454° N, 36.213° E), located on the border of Kenya and Ethiopia. Nine of the communities sampled were permanent, while two were temporary settlements used by individuals practicing nomadic pastoralism. Such temporary settlements are typically used for several days to several weeks and vary in location based upon seasonal and climatic changes (Mwamidi, 2018). Data from all subjects (n = 311; age = 18-79) were collected in an opportunistic semi-random manner, with subjects selected for participation from every third household from a central community point to minimize family clusters. Participation included the collection of anthropometric and cardiometabolic biomarker data in coordination with a semi-structured interview to collect survey data related to lifestyle variable (e.g., labor, mobility, market interaction), socioeconomic status, health, female reproductive variation, psychosomatic stress, diet, demography, and food/water insecurity. All interviews were completed with the help of a local research assistant and translator.

Participants had their weight (to the nearest 0.1 kg) and body fat percentage (to the nearest 0.1%) measured using a Tanita BF-680W bioelectronic impedance scale (Tanita; Arlington Heights, Illinois). Height was measured without shoes (to the nearest 0.1 cm) using a portable Seca stadiometer, which was placed on a hard, smooth surface. Four skinfold measurements – triceps, biceps, suprailiac, and subscapular - were taken using Lange skinfold calipers following standard technique (Lukaski et al., 1986). Systolic and diastolic blood pressure was measured twice using an Omron Series 7 upper-arm digital blood pressure monitor (Omron; Kyoto, Japan). Participants were seated for both measurements, with a seated rest of several minutes between each measurement. Analyses were completed with the second measured blood pressure to account for potential effects of unfamiliarity with the procedure, sometimes referred to as white coat hypertension (James & Gerber, 2018; Unger et al., 2020). Dried blood spot samples and fingerstick blood samples were also taken concurrently, and the latter were analyzed for blood glucose, triglycerides, cholesterol (total, HDL, and LDL) using a Cardiochek Plus analyzer (PTS Diagnostics; Whitestone, IN).

3.2.2 Data analysis

All statistical analyses were completed in R (4.0.2). Generalized linear models, which controlled for age and sex, were used to test for the effects of lifestyle (e.g., market integration and household mobility) on health across Daasanach communities. When significant sex interactions were detected with lifestyle variables, models for males and females were conducted separately. The log of distance to the nearest market (in meters), a proxy for market integration, and the square root of household moves in the previous year, a proxy for engagement in traditional nomadic activity, were used to account for heteroscedasticity in the data that occurred as a function of the scale over which these variables varied in the sample. Additionally, to investigate the effects of sedentarization, subjects were binned into mobility categories based on the number of times their household moved in the previous year – settled (0), non-settled (1-9), nomadic (10+). Logistic regression was also used to test the relationship between lifestyle and odds of hypertension (diastolic blood pressure ≥140 and/or systolic blood pressure ≥90) in our sample.

To identify the relationships between lifestyle variables, Pearson pairwise correlation matrices were constructed. These models specifically compared variables related to diet, behavior, wealth, experienced nutritional insecurity, and market integration. All comparisons were done with Pearson pairwise testing and the significance of observed relationships were established at p-values less than 0.05. The specific relationships between dietary variables and the lifestyle variables of market integration and household mobility were also separately assessed using linear models, which again controlled for the effects of age and sex.

3.2.3 Ethical Approvals

Study protocols were approved by Penn State Institutional Review Board (IRB#STUDY00009589) and the Kenya Medical Research Institute (#KEMRI/RES/7/3/1) prior to all data collection. These approvals include permissions for the collection of health records from the Illeret Health Clinic, in addition to anthropometric, survey, and biological sample collection. In-person consent for data collection was also obtained from all relevant sources, including community elders, the Illeret Ward, and medical officials from the IHC. Additionally, permitting for human biology research was obtained from the National Commission for Science, Technology and Innovation (NACOSTI).

3.3 Results

3.3.1 Age-related variation in cardiometabolic health and body composition

To identify variation across indicators of cardiometabolic health in Daasanach adults, variables related to cardiovascular health and body composition were first evaluated across the adult age-course. Measurements collected include body fat percentage, body mass index (BMI), skinfolds (triceps, biceps, supra-iliac, and subscapular), blood pressure (BP), cholesterol (total, HDL, and LDL), triglycerides, blood glucose, and urine specific gravity. The mean age of males sampled (n=124) was 47.6 ± 15.5 years, while the mean age for females (n=157) was 35.1 ± 12.3 years. Systolic and diastolic blood pressure were found to increases with age (systolic: $\beta=0.28$, SE=0.07, $p<0.001$ | diastolic: $\beta=0.18$, SE=0.05, $p<0.001$) among adult Daasanach men and women (Figure 17, Table 4). Despite these age-related increases in blood pressure, Daasanach men and women aged 40 years and older have relatively low rates of hypertension (diastolic BP ≥140 and/or systolic BP ≥90), 28.9% and 31.7% for men and women, respectively (Table 4; Unger et al., 2020).

Body fat percentage also increases significantly with age for both men and women (male: $\beta=0.08$, SE=0.02, $p<0.001$ | female: $\beta=0.15$, SE=0.05, $p=0.003$), though body fat percentage only increases moderately after the age of ~30 for women and ~45 for men (Figure 17). Interestingly, despite this change in body fat, there is not a likewise increase in BMI over time, as BMI remained low throughout adulthood for men and women. Mean ± SD BMI was 17.9 ±2.8 kg/m^2 for males and 18.5 ±3.3 kg/m^2 for females (Table 5). As a result of these relatively low BMI values in subjects, there was a high prevalence of adult underweight (BMI < 18.5 kg/m^2) based on US Centers of Disease Control (CDC) standards. 77.1% of males sampled between the ages of 18-39 years were found to be underweight, which decreased to a rate of 68.1% for men 40 years and older. Women aged 18-39 years of age were found to have an underweight prevalence of 56.4%, while women aged 40 years and older had an underweight prevalence of 65.1% (Table 5). Only

33.5% of adults sampled were found to have BMI values within the range of ‘normal weight’ (BMI = 18.5-24.9 kg/m^2), while fewer than 3% of all adults sampled were found to be overweight (BMI ≥ 25.0 kg/m^2) by CDC standards.

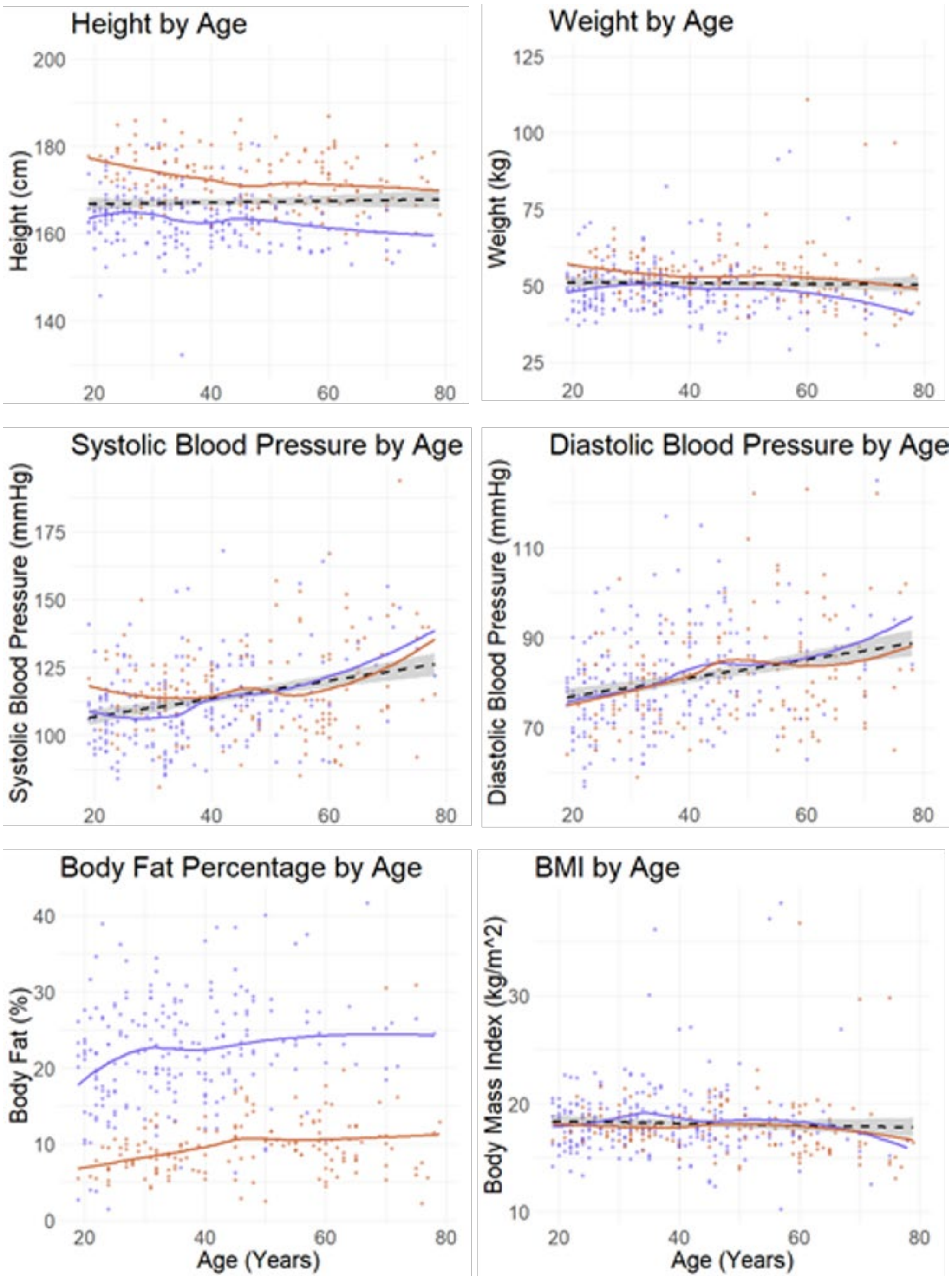

Figure 17: Age-related change in indicators of cardiometabolic health. Sex-specific relationships are represented by loess regression (male = orange; female = purple). Black dashed line represented sex-pooled linear regression model.

Table 4: Blood Pressure Statistics & Hypertension Rates. Blood Pressure (BP) values represent means and standard deviations in mmHg.

Sample (Age)	*N*	Systolic BP (mmHg)	Diastolic BP (mmHg)	% Hypertensive
Female (18-39)	129	107.7 (±13.4)	78.3 (±10.3)	14.7%
Male (18-39)	60	114.6 (±12.2)	78.5 (±8.3)	10.0%
Total (18-39)	**189**	**109.9 (±13.4)**	**78.4 (±9.7)**	**13.2%**
Female (40+)	82	117.3 (±16.4)	84.4 (±11.2)	31.7%
Male (40+)	97	118.6 (±19.1)	84.1 (±12.6)	28.9%
Total (40+)	**179**	**118.0 (±17.9)**	**84.2 (±12.0)**	**30.2%**

Hypertension defined as systolic BP ≥140 mmHg and/or diastolic bp ≥90 mmHg (Unger et al., 2020).

Table 5: Body composition & prevalence of underweight. Values represent means and standard deviations.

Sample (Age)	*N*	Body Fat (%)	BMI (kg/m²)	% Underweight
Female (18-39)	133	21.2 (±6.9)	18.5 (±2.8)	56.4%
Male (18-39)	61	8.2 (±2.2)	17.9 (±1.3)	77.1%
Total (18-39)	**194**	**17.1 (±8.4)**	**18.3 (±2.5)**	**62.9%**
Female (40+)	86	23.4 (±7.2)	18.3 (±4.2)	65.1%
Male (40+)	99	10.7 (±4.6)	17.8 (±3.3)	68.7%
Total (40+)	**185**	**16.6 (±8.7)**	**18.1 (±3.7)**	**67.0%**

Underweight and overweight defined as having a BMI ≤18.5 and ≥ 25.0, respectively.

3.3.2 The effects of market integration and lifestyle variation on health

To investigate the effects of market integration on cardiometabolic health and body composition, household distance to the nearest market center and engagement in nomadic movement patterns, determined by number of household moves in the previous year, were measured against biomarkers of cardiometabolic health. Mean ± SD market distance was 6.2 ± 8.9km, while subjects moved an average of 3.5 ± 5.6 times in the previous year (Figure 18). Multiple linear regression controlling for age and sex was used to test for the effects of market distance and household mobility on biomarkers for cardiometabolic health (Table 6). Diastolic blood pressure was both found to be significantly negatively correlated with household distance to the nearest market center for both men and women (male diastolic BP: $\beta = -5.31$, $p < 0.001$, SE = 1.43 | female diastolic BP: $\beta = -2.23$, $p = 0.03$, SE = 1.02). This relationship was also significant for systolic blood pressure among men (systolic BP: $\beta = -7.28$, $p < 0.001$, SE = 2.21), but not among women (Figure 19). To further investigate the effects of market integration on blood pressure, risk of hypertension as a consequence of market distance was tested. Logistic regression suggests a 44% less likely chance of having hypertension per unit of distance from a market center (Figure 20; OR = 0.56; 95% CI = [0.37-0.83]).

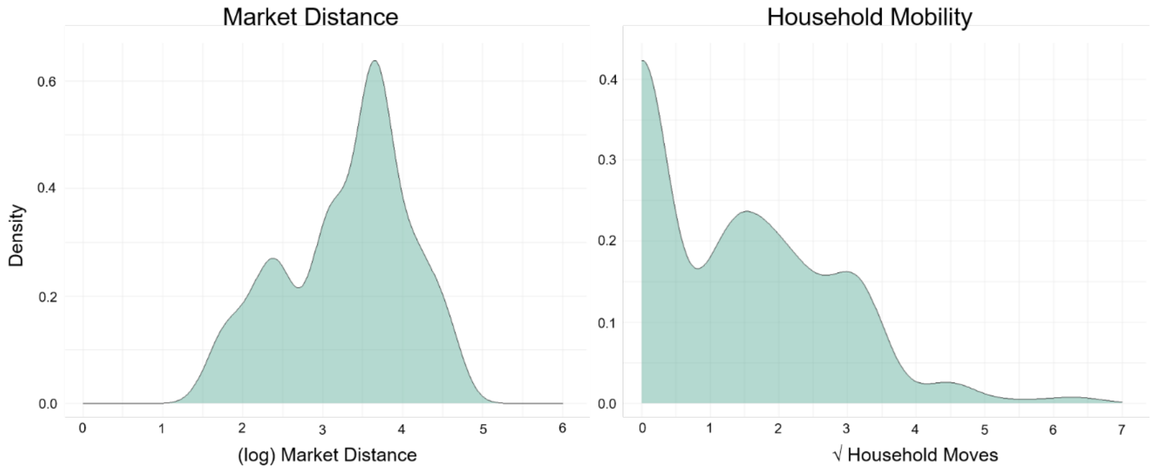

Figure 18: Density representation of market distance and household mobility.

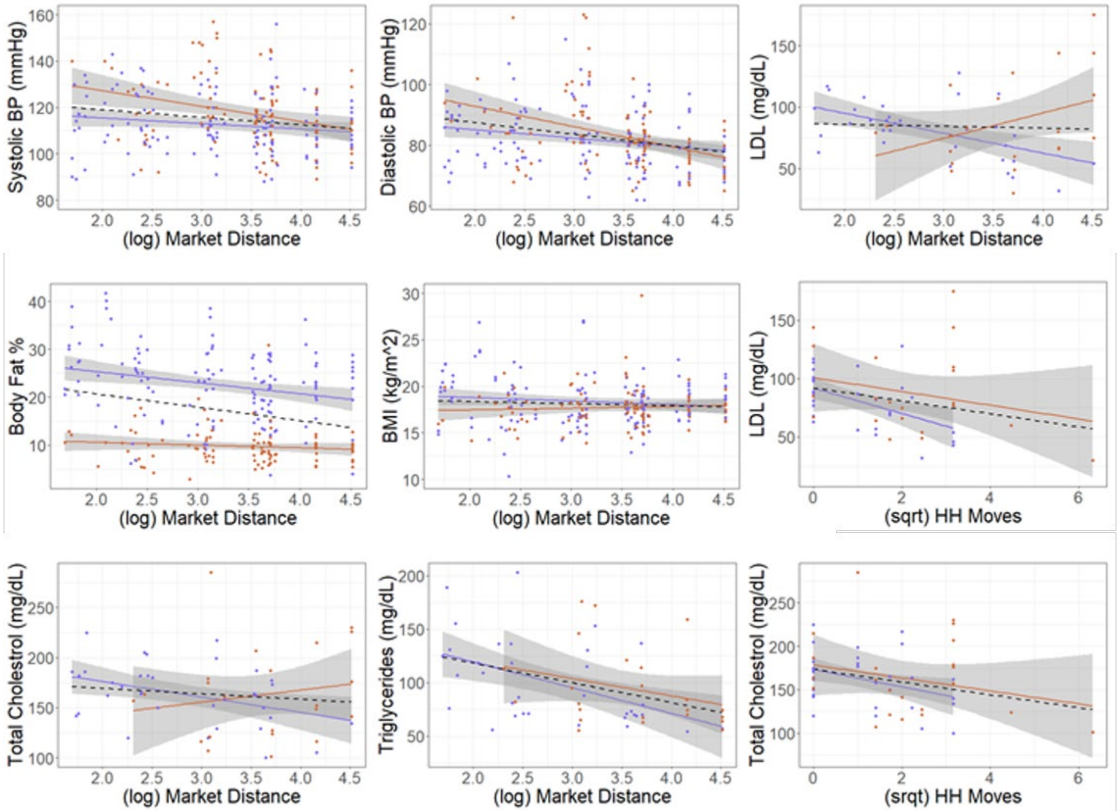

Figure 19: Indicators of cardiometabolic health as a function of distance from household location to the nearest market center. Models representing biomarker relationship to individual mobility, as measured by the number of household moves in the last season, are shown for total cholesterol and LDL. Black dashed line represented sex-pooled linear regression model.

Table 6: Indicators of cardiometabolic health by (log) distance to nearest market.

	Dependent variable:											
	Diastolic BP		**Systolic BP**		**Body Fat %**		**Sum of Skinfolds**		**BMI**		**Hypertension**	
	(Female)	(Male)	(Female)	(Male)	(Female)	(Male)	(Female)	(Male)	(Female)	(Male)	(Female)	(Male)
Age	0.146**	0.072	0.267***	0.134	0.122**	0.085***	-0.146	0.167*	0.007	-0.003	0.004	0.003
	(0.069)	(0.065)	(0.094)	(0.100)	(0.051)	(0.024)	(0.152)	(0.099)	(0.024)	(0.017)	(0.003)	(0.003)
(log) Market Distance	**-2.233****	**-5.315*****	-1.574	**-7.277*****	**-1.849****	0.148	-3.775	-0.681	**-0.698***	-0.107	-0.072	**-0.139****
	(1.021)	(1.429)	(1.407)	(2.211)	(0.783)	(0.531)	(2.292)	(2.179)	(0.363)	(0.382)	(0.046)	(0.057)
Constant	83.834***	97.661***	108.519***	136.366***	24.142***	5.355**	56.171***	17.788*	20.555***	18.384***	0.349*	0.570**
	(4.583)	(6.402)	(6.312)	(9.903)	(3.498)	(2.388)	(10.270)	(9.859)	(1.629)	(1.728)	(0.205)	(0.254)
Observations	134	121	134	121	135	119	137	124	138	124	134	121
R^2	0.085	0.131	0.080	0.116	0.102	0.102	0.022	0.028	0.031	0.001	0.037	0.074
Adjusted R^2	0.071	0.116	0.066	0.101	0.089	0.086	0.008	0.012	0.017	-0.016	0.022	0.058
Residual Std. Error	9.570 (df = 131)	10.617 (df = 118)	13.179 (df = 131)	16.422 (df = 118)	7.180 (df = 132)	3.957 (df = 116)	21.451 (df = 134)	16.448 (df = 121)	3.416 (df = 135)	2.883 (df = 121)	0.428 (df = 131)	0.421 (df = 118)
F Statistic	6.111*** (df = 2; 131)	8.911*** (df = 2; 118)	5.696*** (df = 2; 131)	7.704*** (df = 2; 118)	7.537*** (df = 2; 132)	6.581*** (df = 2; 116)	1.516 (df = 2; 134)	1.731 (df = 2; 121)	2.159 (df = 2; 135)	0.045 (df = 2; 121)	2.494* (df = 2; 131)	4.702** (df = 2; 118)

Cont.	**USG**		**Total Cholesterol**		**HDL**		**LDL**		**Triglycerides**		**Blood Glucose**	
	(Female)	(Male)	(Female)	(Male)	(Female)	(Male)	(Female)	(Male)	(Female)	(Male)	(Female)	(Male)
Age	-0.0001	0.0001	0.768	-0.209	-0.016	-0.034	0.603	-0.785*	1.175*	0.224	0.179	0.151
	(0.0001)	(0.0001)	(0.489)	(0.621)	(0.366)	(0.223)	(0.378)	(0.456)	(0.618)	(0.454)	(0.208)	(0.261)
(log) Market Distance	0.001	0.001	**-13.608****	8.839	5.893	-2.222	**-14.355*****	4.821	**-21.543*****	-9.003	**-6.043***	-2.848
	(0.001)	(0.001)	(6.124)	(11.936)	(4.609)	(4.411)	(4.632)	(9.045)	(7.470)	(8.999)	(3.254)	(5.768)
Constant	1.010***	1.006***	174.989***	140.765**	45.990**	64.287***	100.599***	109.089**	118.674***	115.319**	112.853***	105.534***
	(0.005)	(0.005)	(26.924)	(57.578)	(20.922)	(21.157)	(21.286)	(43.213)	(33.397)	(42.786)	(12.542)	(24.214)
Observations	111	104	35	26	34	24	32	25	34	27	47	40
R^2	0.036	0.013	0.219	0.035	0.054	0.012	0.348	0.150	0.315	0.061	0.093	0.017
Adjusted R^2	0.018	-0.006	0.171	-0.049	-0.007	-0.082	0.303	0.072	0.271	-0.018	0.052	-0.036
Residual Std. Error	0.008 (df = 108)	0.008 (df = 101)	27.467 (df = 32)	46.153 (df = 23)	19.796 (df = 31)	16.410 (df = 21)	19.622 (df = 29)	34.943 (df = 22)	33.497 (df = 31)	35.121 (df = 24)	17.275 (df = 44)	27.147 (df = 37)
F Statistic	1.996 (df = 2; 108)	0.684 (df = 2; 101)	4.499** (df = 2; 32)	0.422 (df = 2; 23)	0.887 (df = 2; 31)	0.127 (df = 2; 21)	7.742*** (df = 2; 29)	1.937 (df = 2; 22)	7.125*** (df = 2; 31)	0.776 (df = 2; 24)	2.250 (df = 2; 44)	0.319 (df = 2; 37)

Note: *p<0.1; **p<0.05; ***p<0.01

Body fat percentage decreased significantly with increased distance from market centers among females (β = -1.85, p = 0.02, SE = 0.78), while BMI followed a similar trend (β = -0.70, p = 0.056, SE = 0.36). Neither body fat percentage, nor BMI were significantly affected by market distance in males. Sum of skinfolds were found to significantly decrease with increased household mobility, however (β = -2.10, p = 0.02, SE = 0.91). Additional biomarkers were collected from finger prick blood samples for a subset of individuals. Total cholesterol, LDL, and triglyceride levels were all found to significantly decrease as a function of increased household distance from the nearest market center, but only among women. Household mobility (number of moves in the previous year) was also significantly negatively associated with sum of skinfolds, total cholesterol, and LDL (Figure 19).

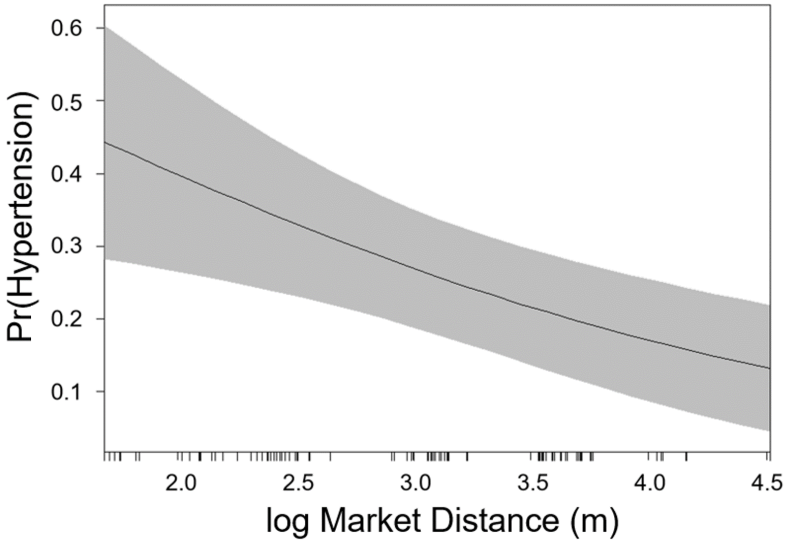

Figure 20: Logistic regression of hypertension presence as a function of market integration. Regression suggests that the probability of having hypertension decreases with distance to nearest market centers.

3.3.3 Market and lifestyle correlates

The relationships between lifestyle variables were assessed using Pearson's pairwise correlation analysis (Figure 21). Variables tested included market distance and household mobility, as well as household size, as measured by total number of individuals living in the household, food/water insecurity, water labor, consumption of protein items (e.g., meat and fish), education, socioeconomic status (SES) perception, household income, as measured by reported income earned in the previous month, and livestock wealth, which was calculated as the product of the number of livestock owned and the reported market value of livestock in the region. Analyses found that distance to market is significantly positively correlated with household mobility and livestock wealth, as households farther from market centers engage in more traditional semi-nomadic pastoral activities. Market distance and household mobility are both negatively correlated with education, while market distance is surprisingly negatively correlated with protein consumption. Both water and food insecurity are positively correlated with household mobility and market distance, with individuals living farther from sources of infrastructure finding themselves at higher risk of malnutrition (Figure 21).

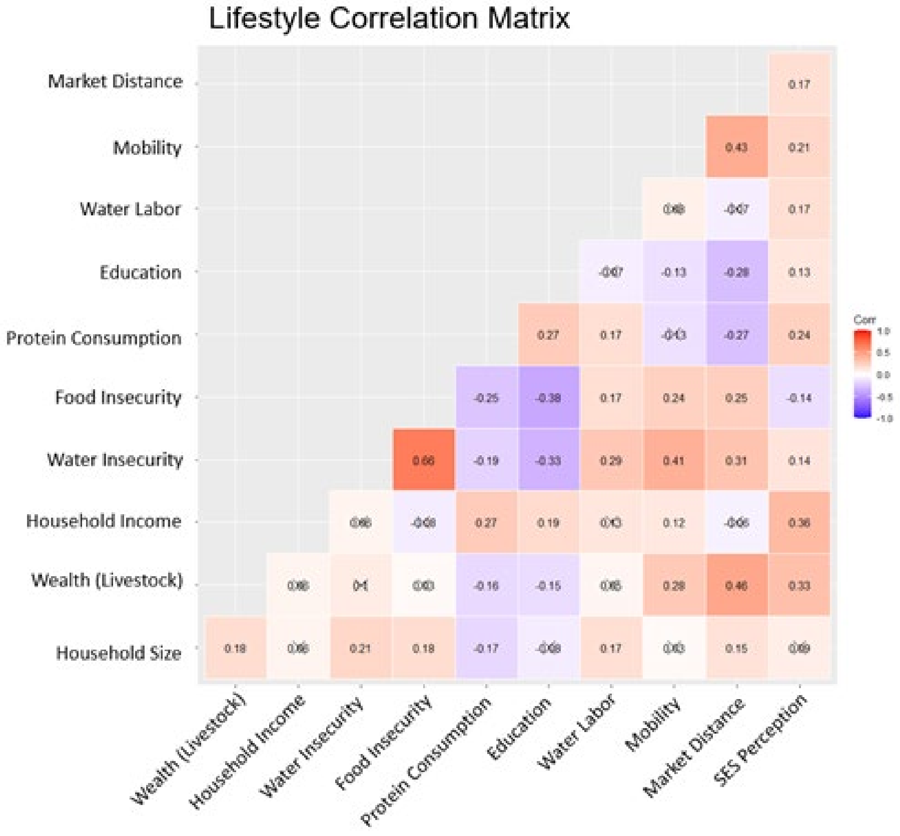

Figure 21: Correlation matrix of lifestyle, socioeconomic, and socioecological measures.

Additional multiple regression models were constructed to probe more specifically into the effects of market distance and household mobility on dietary variation (Table 7). After controlling for age and sex, distance to market was found to be significantly positively associated with milk consumption (β = -0.41, p=0.022, SE = 0.17), but negatively associated with protein consumption, as measured by the combined frequency of weekly meat and fish consumption (β = -1.2, $p < 0.001$, SE = 0.31). This result is likely driven by the increased consumption of fish by those living in market areas, as fish consumption is negatively associated with market distance but not meat consumption. Additionally, individuals who reported ten or more household moves in the previous year were also found to drink significantly more milk than those who moved between one and nine times in the previous year, or those who had been completely settled for the previous year. Soda consumption, while relatively infrequent in the sample, was found to decrease significantly with increased distance to markets.

Table 7: Nutritional variation by distance from market and movement strategy.

	Dependent variable:						
	Milk	Tea w/ Sugar	Fruit Water	Soda	Meat	Fish	Protein
Age	-0.010	-0.025*	0.002***	-0.009	0.001	-0.003	-0.024
	(0.009)	(0.013)	(0.001)	(0.006)	(0.006)	(0.010)	(0.015)
Sex	0.029	0.333	-0.045*	0.203	0.987***	-0.306	0.525
	(0.256)	(0.396)	(0.026)	(0.170)	(0.181)	(0.296)	(0.433)
(log) Market Distance	**0.407****	**-1.617*****	-0.027	**-0.419*****	0.016	**-0.809*****	**-1.187*****
	(0.172)	(0.267)	(0.018)	(0.115)	(0.126)	(0.205)	(0.313)
Movement Pattern (Semi-Nomadic=1)	**-1.554*****	**-0.844***	-0.023	-0.281	-0.100	-0.474	-0.604
	(0.328)	(0.508)	(0.034)	(0.218)	(0.235)	(0.385)	(0.540)
Movement Pattern (Settled=2)	**-1.409*****	-0.434	0.015	**-0.428***	-0.044	-0.098	0.293
	(0.360)	(0.557)	(0.037)	(0.239)	(0.258)	(0.423)	(0.592)
Constant	1.844**	9.372***	0.046	2.314***	0.250	4.388***	7.144***
	(0.798)	(1.236)	(0.082)	(0.531)	(0.591)	(0.964)	(1.445)
Observations	217	217	217	217	214	212	187
R^2	0.189	0.172	0.079	0.065	0.154	0.108	0.110
Adjusted R^2	0.169	0.153	0.057	0.043	0.133	0.086	0.086
Residual Std. Error	1.693 (df = 211)	2.624 (df = 211)	0.173 (df = 211)	1.127 (df = 211)	1.197 (df = 208)	1.952 (df = 206)	2.663 (df = 181)
F Statistic	9.805*** (df = 5; 211)	8.786*** (df = 5; 211)	3.621*** (df = 5; 211)	2.948** (df = 5; 211)	7.549*** (df = 5; 208)	4.994*** (df = 5; 206)	4.485*** (df = 5; 181)
Note:							*p<0.1; **p<0.05; ***p<0.01

3.4 Discussion

This study sought to test the effects of lifestyle change on biomarkers of non-communicable disease health. The effects of lifestyle change, namely market integration (as measured by a household's distance to the nearest market) and sedentarization (as measured by the number of times a household moved in the previous year), on biomarkers for cardiometabolic health were large enough to detect across subjects (Table 17; Table 18). The directionality of these effects is clear. Systolic and diastolic blood pressure in adults both decrease as a function of market distance when controlling for age, as well as the log-odds of hypertension (Figure 19 & 20). These associations match expectations based on previous work that has found that individuals living in small-scale subsistence societies who are less market integrated tend to have lower blood pressure (Little et al., 1989; Fratkin et al, 2004; Fratkin & Roth, 2005). For Daasanach, results are also influenced by environmental factors, as recent work found that groundwater nearer to Illeret contains higher levels of salt, which likely contributes to increased hypertension risk for more settled and market integrated communities (Rosinger et al., 2021). Like results found in previous work with small-scale populations living in developing nations, however, Daasanach present with hypertension rates that are markedly lower than those of adult US men and women (Gurven et al., 2012; Liebert et al, 2013; Raichlen et al., 2017; CDC, 2019; Lea et al., 2020).

While previous work has found significant difference in BMI across market integrated and non-market integrated, or urban and rural individuals, market distance and household mobility had no significant effect on BMI for men or women in our sample (Barkey et al., 2001; Fratkin et al., 2004; Lea et al., 2020). BMI for men and women was found to be consistently very low across our sample, with a majority of adults having a BMI < 18.5 kg/m^2, a commonly used threshold for underweight. While BMI did not vary significantly, body fat percentage, as measured by bioelectrical impedance, did significantly decrease as distance to market increased among women. This result matches expectations based on previous work with East African pastoralist populations, which found that body fat, as measured by skinfolds, was significantly higher among more market integrated and settled women (Little & Leslie et al., 1999; Barkey et al., 2001; Fujita et al., 2004). Interestingly, the biomarkers of total cholesterol, LDL, and triglycerides all decreased as a function of increased market distance among women sampled, and both total cholesterol and LDL were significantly negatively associated with engagement in increased nomadism. Neither market distance nor household mobility were found to significantly affect HDL in men or women.

While several biomarkers for non-communicable disease health were found to vary as a function of lifestyle change, the effect of market integration and mobility on nutritional, behavioral, and socioeconomic variation could also be assessed. Previous work with Maasai pastoralists found that nutritional status remained poor despite increased market integration and level of sedentarization (Galvin et al., 2015). Food and water insecurity were both negatively correlated with proxies for market integration and sedentarization, but overall prevalence of insecurity remained very high across the entire sample (Bethancourt et al., 2021). Similarly, levels of educational achievement were higher among those who were closer to market centers and more settled, but educational achievement was low across both men and women, with most subjects having never attended any level of schooling. There is some indication, however, that variation in market integration and engagement in traditional pastoral activities do affect nutrition beyond levels of nutritional security. Typically, African pastoralists have diets that are high in protein, low in fat, with relatively little access to sugar (Eaton et al., 2002; Fratkin et al., 2004; Galvin et al., 2015). Expectedly, milk consumption is significantly higher among non-settled individuals and those living farther from the market, suggesting higher milk intake among those engaged in more traditional pastoral activities (Table 7; Table 19). This result is similar to those previously found that suggest deceasing milk consumption with increasing sedentarization among pastoral communities (Fujita et al., 2004). Sugar consumption, in the form of tea with sugar and soda, is significantly positively associated with living nearer to market centers, which is congruous with previous studies among small-scale communities across the globe (Gurven et al, 2017; Lea et al., 2020). Interestingly, meat consumption does not vary across our sample, but fish consumption is found to be significantly higher in those living nearer to markets. The increased frequency of consuming fish, which is not traditional for Daasanach, among those closer to markets results in a significantly higher rate of protein consumption overall in those nearer to market centers (Table 7). This has potentially significant nutritional and health consequences among Daasanach, who already suffer from high levels of malnutrition, as expectations based on previous work with East African pastoralists would be for decreased protein consumption with increased market integration and sedentarization (Fujita et al., 2004). Access to Lake Turkana and fishing may buffer some of the nutritional effects of lifestyle change.

Though variation in body composition and cardiovascular health across Daasanach is suggestive of the effects of evolutionary mismatch, determinations about the detrimental effects of lifestyle change on Daasanach at a population level are more difficult to assess. Typical biomarkers for cardiometabolic disease, like BMI, body fat percentage, and blood pressure are all low across adult Daasanach in our sample. While previous work has suggested that sedentarization has negative effects on nutritional, reproductive, and health outcomes, the findings here represent trends towards expected outcomes, but not explicit variation in cardiometabolic disease outcomes themselves (Leslie et al., 1993; Little & Leslie, 1999; Pike, 1999; Pike, 2000; Barkey et al., 2001; Fratkin et al., 2004; Pike & Williams, 2006; Page et al., 2016; Page et al.; 2018). As Daasanach communities in northern Kenya continue to settle, move away from traditional semi-nomadic pastoral practices, and become more exposed to market goods and services, it is essential that work is done to understand the complex dynamics underlying the effects of these trends on health and wellbeing. In this way, both practical and theoretical findings can be used to improve outcomes for Daasanach and other communities affected by socioecological change.

4. Household causes of growth differences: Variation in health and market integration affect early childhood growth in Daasanach pastoralists living in northern Kenya

4.1 Introduction

Globally, small-scale populations with traditional subsistence practices are experiencing the growing pressures of market integration and sedentarization, resulting in significant consequences for health (Fratkin et al., 2004; Liebert et al., 2013; Urlacher et al., 2016; Urlacher et al., 2021; Gurven et al., 2017; Page et al., 2018; Pontzer et al., 2018; Jaeggi et al., 2020; Lea et al., 2020). Such changes are felt acutely in East Africa, where economic, political, and environmental pressures have led to the increased market integration and practice of settled agriculture among formerly nomadic or semi-nomadic pastoralist communities (Little, Gray, & Leslie, 1993; Little & Leslie, 1999; Barkey et al., 2001; Fujita et al., 2004; Fratkin et al., 2004; Fratkin & Roth, 2005; Adongo et al., 2013; Rufino et al., 2013). Changes in environmental condition, like those that occur as a function of sedentarization or market integration, can have broad and cascading effects on life history patterns in a population.

Growth is particularly sensitive to variation in environmental conditions, with reaction norms affected by proximate factors, such as disease, stress, nutrition, and physical activity resulting in varying growth patterns and achieved adult body size (Waterlow, 1994; Ulijaszek et al., 1998; Ulijaszek, 2006; Hagen et al., 2006; Bogin & Smith, 2012; Snodgrass, 2012; Stinson, 2012; Spencer et al., 2016; Blackwell et al., 2017). Additionally, the plasticity of early childhood growth can be influenced by social factors, such as variation in familial structure or maternal marital status ((Janson & Van Schaik, 1993; Sellen, 1999b; Gurven & Walker, 2006; Ulijaszek, 2006). The effects on growth of broader forces, such as market integration and sedentarization, remain mixed, however. For example, previous work with Turkana pastoralists found higher rates of childhood stunting and wasting in settled children under the age of six compared to similarly aged pastoral children, but other investigations found that among Turkana children aged 4-9 years old settled children tended to be larger in most measures of body size relative to their nomadic counterparts (Little & Gray, 1990; Fratkin et al, 2004; Roth et al., 2005). Additionally, work with Shuar farmer-horticulturalists found that childhood body size increased with increasing market access, likely as a result of positive effects of market integration on nutritional status (Urlacher et al., 2016).

While intraspecific comparisons of early childhood growth can be used for the investigation of phenotypic plasticity and provide context for the relationship between ecological condition and life history traits, population-specific comparisons allow for an increased level of resolution when trying to resolve the proximate and ultimate causes of growth variation. This is particularly the case when working with genetically homogenous populations. Additionally, investigations of growth variation, even within a population, often relies on international growth standards (Little et al., 1983; Galvin, 1992; Little, Gray, & Leslie, 1993; Fratkin et al., 2004). However, such applications can be fraught, as the use of such growth models can be affected by the variation in the demographic makeup of communities and households, particularly in populations with patterns of growth discordant with those populations from which international growth standards are derived (Ziegler & Nelson, 2012; Martin et al, 2019). Differences observed in these patterns and rates of growth, as they relate specifically to lifestyle change within such populations, can be used to better understand our evolutionary history, as well as contemporary struggles like food insecurity.

Here we test the potential proximate causes of early childhood growth variation at the level of the household. A combination of anthropometric, demographic, and socioeconomic status (SES) data have been complied for households across 11 Daasanach communities, with such data providing insight into the specific factors that underlie the broader forces of lifestyle change. Analysis of within group differences in measures of early childhood growth – height-for-age (HFA), weight-for-age (WFA), and weight-for-height (WFH) – that have been assessed with robust population-specific growth models for a genetically homogenous population then allows for the testing of models of household variation that may drive patterns of growth.

4.2 Methods

4.2.1 Data collection

To create models of Daasanach-specific growth, data were analyzed from previously collected anthropometric records generated by the Illeret Health Clinic (IHC). Having conducted systematic collection of anthropometric measures of children under the age of 5 since May 2018 as part of a large-scale multiyear malnutrition survey, the IHC had non-digitized records of 8,669 measures for 4,624 individuals spanning 11 Daasanach communities within 16 km of the IHC. Data collection involved both traveling to more distant communities and running data collection out of the IHC facility in Illeret for communities located within about 2 kilometers. Families with children aged 59 months and younger were encouraged to participate, but free to decline participation.

Ages were estimated to the month by the IHC nutritionist when family member did not know, and ages were not available through IHC records. Subject height/length was measured to the nearest 1 mm using UNICEF stadiometers/infantometers. Weight was measured to the nearest 0.1kg using a digital scale (Tanita), while middle-upper arm circumference (MUAC) was measured to the nearest 1 mm using a fabric measuring tape. IHC staff also collected and registered the deworming, micronutrient powder (MNP) supplementation, and disability status of subjects. Additionally, the date, subjects’ first and last names, sex, community of residence, and re-measurement status were also collected and documented. To create growth models, all anthropometric data available (May 2018 – December 2019) were first transcribed into digital form.

To test the associations between lifestyle variation and early childhood growth, the Daasanach Health and Life History Project collected health biomarker, anthropometric, survey, and GPS data over the course of two field seasons between June-July of 2019 and February-March of 2020 in region surrounding Illeret in Marsabit County, Kenya (Figure 4). Communities were approached prior to the collection of any data, ensuring the Daasanach Health and Life History Project first received consent and support from community members. To date, 11 communities in and around Illeret have participated in data collection efforts. These communities varied between 0.05 and 32.9 km from the nearest market center – the Illeret Health Clinic (4.314° N, 36.227° E), the Sieslucho fish market (4.398° N, 36.221° E), and the Ari trading post (4.454° N, 36.213° E). Of these communities, a majority were settled and semi-permanent. Two communities were nomadic and located in the fora (undeveloped pastureland). Daasanach nomadic settlements, like the ones visited, are typically used for several days to several weeks and vary in location based upon seasonal and climatic changes (Mwamidi, 2018).

Data from adults (n = 311; age = 18-79) across all households (n = 166) were collected in an opportunistic semi-random manner, with subjects selected for participation from every third household from a central community point to minimize family clusters. Anthropometric and cardiometabolic biomarker data collection included weight and body fat percentage, measured to the nearest 0.1 kg and nearest 0.1%, respectively (Tanita BF-680W bioelectronic impedance scale – Tanita; Arlington Heights, Illinois). Height, without shoes, was measured to the nearest 0.1 cm using a portable Seca stadiometer, which was first placed on a hard, smooth surface. Four skinfold measurements – triceps, biceps, suprailiac, and subscapular - were taken using Lange skinfold calipers following standard technique (Lukaski et al., 1986; Lange; 2007). Blood pressure was measured twice using an Omron Series 7 upper-arm digital blood pressure monitor (Omron; Kyoto, Japan). Participants were seated for both measurements, with a seated rest of several minutes between each measurement. Analyses were completed with the second measured blood pressure to account for potential effects of unfamiliarity with the procedure, sometimes referred to as white coat hypertension (James & Gerber, 2018; Unger et al., 2020). Dried blood spot samples and fingerstick blood samples were also taken concurrently, and the latter were analyzed for blood glucose, triglycerides, cholesterol (total, HDL, and LDL) using a Cardiochek Plus analyzer (PTS Diagnostics; Whitestone, IN). In coordination with anthropometric data collection, a semi-structured interview was conducted, which collected survey data related to lifestyle variable (e.g., labor, mobility, market interaction), socioeconomic status, health, female reproductive variation, psychosomatic stress, diet, demography, and food/water insecurity. All interviews were completed with the help of a local research assistant and translator.

4.2.2 Data analysis

All statistical analyses were completed in R (4.0.2). Daasanach-specific centile curves for height-for-age, weight-for-age, and weight-for-height were generated for sex-specific samples between the ages of 0-59 months (Figure 22) using the '*GAMLSS*' package in R (Rigby and Stasinopoulos, 2005). All models were fit with Box-Cox t distributions (BCTo) with varying model parameters (Cole & Green, 1992; Shinde & Kakade, 2019). GAIC scores were used to determine the best fit models. WHO specific z-scores for WFH, WFA, and HFA were also generated (Figure 23) using the R package '*localgrowth*', which was previously developed and used for growth analyses of Shuar and Tsimane populations (Urlacher et al., 2016; Blackwell et al., 2017; Martin et al., 2017).

To control for age estimation, age-correction based on difference in date from previous measurement was employed and individuals with z-scores ≥ 5 or ≤ -5 relative to WHO reference for any of the three measures were dropped. This reduced our sample to only those individuals from whom multiple measures were available. The sample used for the creation of the Daasanach-specific LMS models includes 4587 measures from 1753 subjects (Table 8). To identify whether meaningful differences in childhood growth were present across the larger IHC sample, Tukey's HSD was used to test for variation in HFA, WFA, and WFH across communities for which household-level data were also available – Namugusie, Kerech, El Bokoch, Watalii, and Aiybete (Figure 24). Subsequently, Daasanach-specific z-scores for HFA, WFA, and WFH were generated from the Daasanach LMS models for individuals (n=99) for whom household health, anthropometric, demographic, and socioeconomic data were available (Table 9). Generalized linear models were used to test for the biobehavioral effects of household variation on early childhood growth in the Daasanach. To identify variation in household characteristics, the variables of market distance, as measured by distance of a household to the nearest market center, household mobility, as measured by the number of times a household moved in the previous year, as well as composite variables of socioeconomic status (SES), demography, and health were measured. Composite SES scores were created as the summed sex-specific z-score values (observed value – mean / standard deviation) for household income earned in the previous month, livestock wealth, and education, as measured by the number of grades achieved. Livestock wealth was calculated as the product of the number of livestock owned and the reported market value of livestock in the region. Similarly, composite demography scores were calculated as summed sex-specific z-scores for overall household size, the number of children (>8 years old) living in a household, the number of adolescents (8-16 years old) living in the household, and number of adults (>16 years old) living in the household. Composite health scores were created using thresholds for cardiometabolic health, which identified the presence of hypertension (diastolic BP ≥140 and/or systolic BP ≥90), underweight or overweight (BMI <18.5 or >24.9), and high body fat (male: >24%; female; >35%) across adults sampled (Unger et al., 2020; CDC, 2020; Gallagher et al., 2000). In the cases where both the male and female heads of household were present for data collection, composite values were averaged to create a singular household value. Daasanach-specific z-scores for height and weight among children under the age of five were then compared these household characteristics in households that included children between the ages of 0-5 years old were identified and were averaged at the household-level (n=51). Like composite scores, z-scores for HFA, WFA, and WFH were averaged within households that had more than one child to create mean household values for growth comparison. Logistic regression was also used to test the relationship between household characteristics and the odds of a child having a z-score for growth above the median (z-score = 0) in our sample.

To identify the relationships between household variables, Pearson pairwise correlation matrices were constructed. These models specifically compared the variables the were used to construct the composite scores for health, SES, and demography, as well as the relationships between the composite scores themselves. All comparisons were done with Pearson pairwise testing and the significance of observed relationships were established at p-values less than 0.05. The specific relationships between each composite variable and both market integration and household mobility were also separately assessed using linear models while controlling for the effects of age and sex.

4.2.3 Ethical approvals

Study protocols were approved by Penn State Institutional Review Board (IRB#STUDY00009589) and the Kenya Medical Research Institute (#KEMRI/RES/7/3/1) prior to all data collection. These approvals include permissions for the collection of health records from the Illeret Health Clinic, in addition to anthropometric, survey, and biological sample collection. In-person consent for data collection was also obtained from all relevant sources, including community elders, the Illeret Ward, and medical officials from the IHC. Additionally, permitting for human biology research was obtained from the National Commission for Science, Technology and Innovation (NACOSTI).

4.3 Results

4.3.1 Community-level variation in early childhood growth

Initial investigation into community-level differences in early childhood growth across sampled Daasanach communities found several comparisons that varied significantly in HFA, WFA, and WFH metrics constructed from Daasanach-specific growth models (Figure 24; Table 16). Boys and girls in Aiybete were found to have significantly larger z-scores for HFA than counterparts living in Namugusie, Kerech, and Watalii, with males in El Bokoch also have significantly higher HFA z-scores compared to Watalii. This trend held for male values for WFA, with young boys from Aiybete having significantly larger WFA values than those from all other communities tested – Namugusie, Kerech, Watalii, and El Bokoch. Girls from Aiybete were significantly heavier for their age than those living in El Bokoch and Kerech, while girls aged 0-59 months living in Namugusie and Watalii had significantly larger WFA z-scores than those from Kerech. Once again, boys and girls from Aiybete were found to have significantly greater WFH z-scores than children sampled from Kerech, but boys from Aiyebete were significantly heavier for their height than those from Namugusie, as well. WFH z-scores for girls were significantly higher among those living in Namugusie and Watalii than Kerech, and this relationship was also found to be significant between boys from Watalii and Kerech.

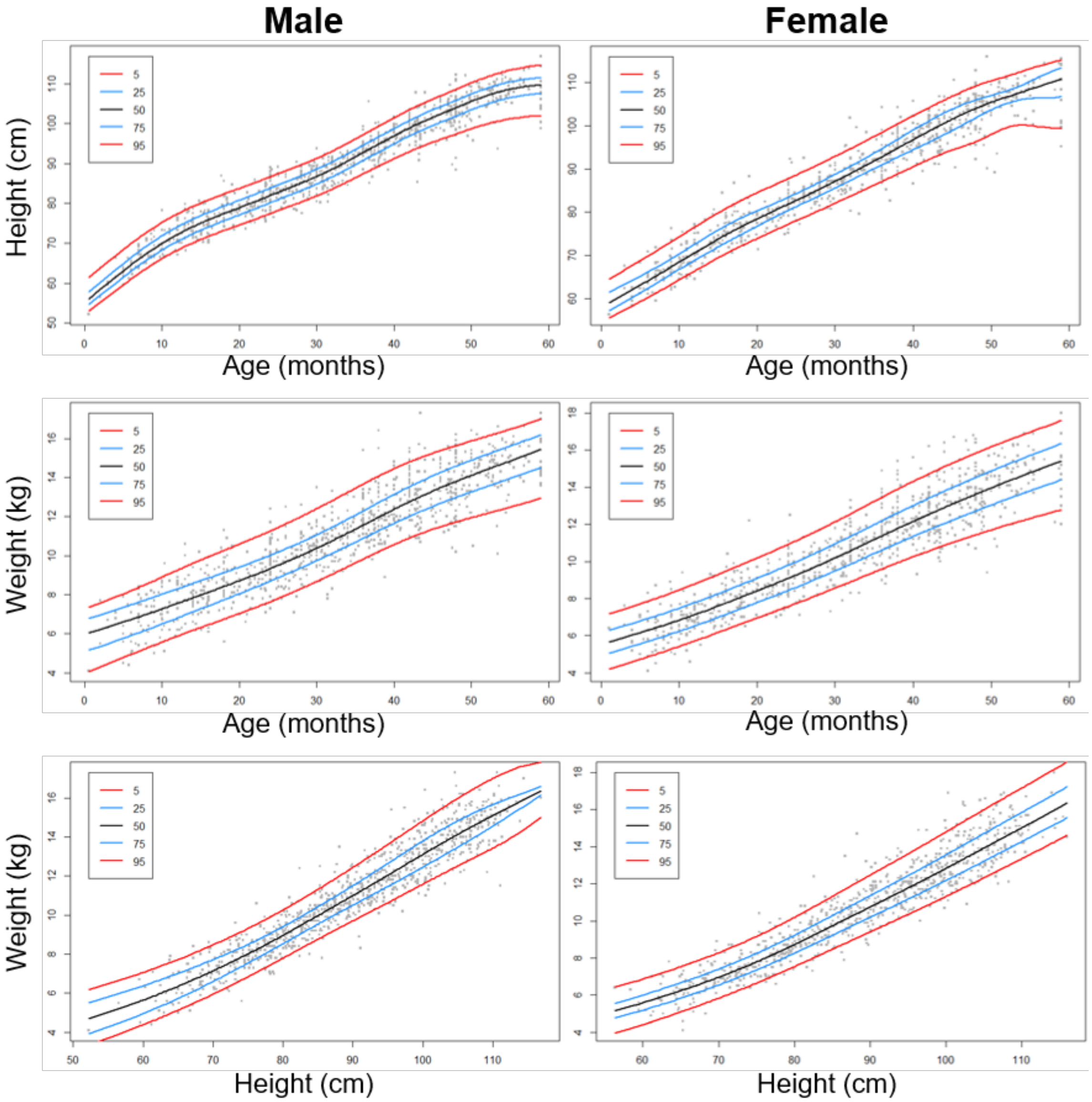

Figure 22: Daasanach-specific centile curves of height-for-age, weight-for-age, and weight-for-height for males and females aged 0-59 months.

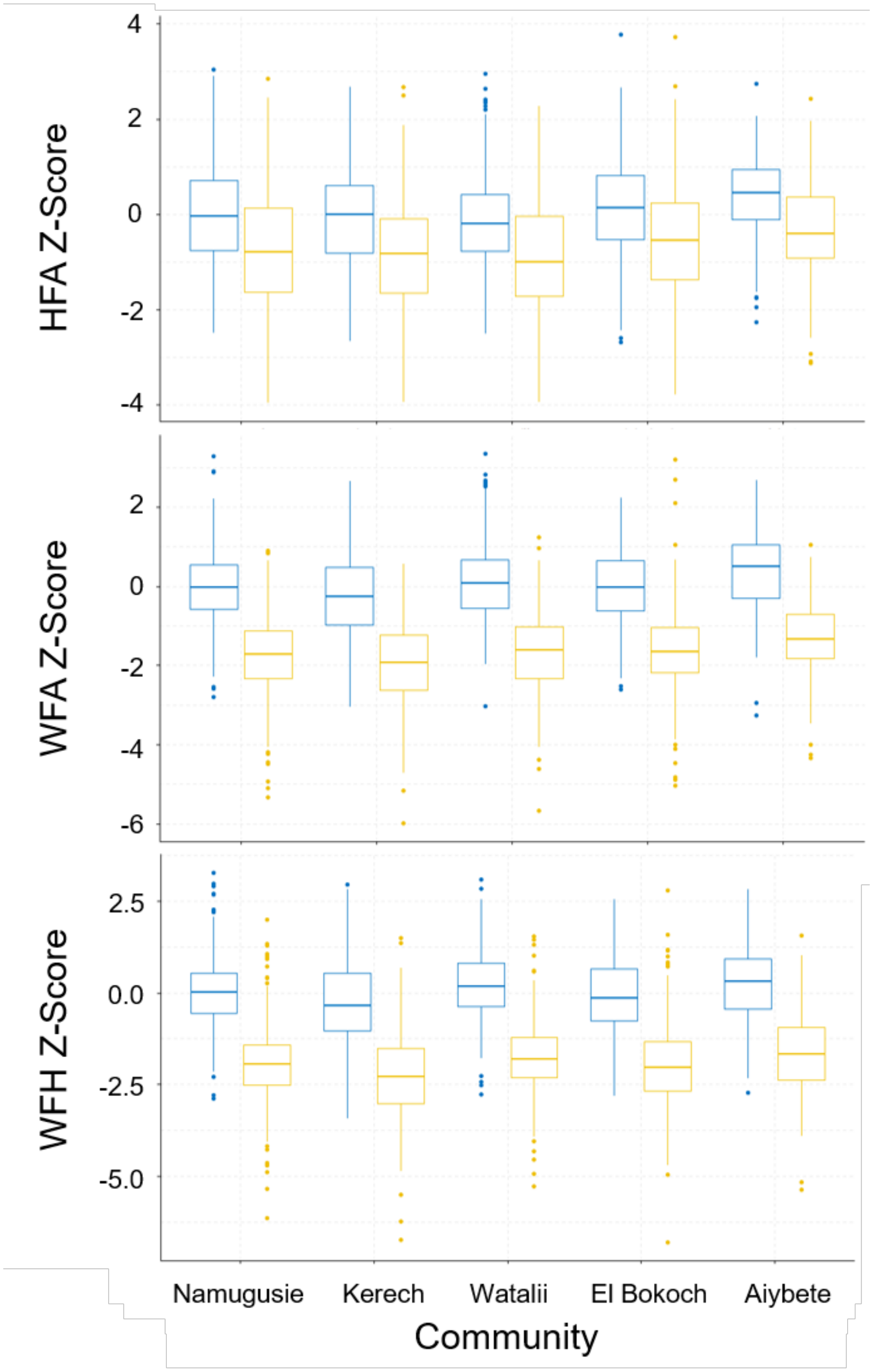

Figure 23: Z-score comparisons for children aged 0-59 months by village based on Daasanach-specific (blue) and WHO (yellow) growth references.

Table 8: Sample statistics – Ages (months) of subjects by community.

	Male (Age)			Female (Age)			Total (Age)		
Community	N	Mean	SD	N	Mean	SD	N	Mean	SD
Aiybete*	72	32.30	13.99	99	30.34	14.66	171	31.16	14.37
Blachaloki	13	29.97	15.38	16	34.42	16.38	29	32.42	15.81
Baulo	161	30.02	14.10	152	32.57	14.56	313	31.26	14.36
El Bokoch*	146	29.84	14.30	120	31.83	14.79	266	30.74	14.53
Guoro	160	27.94	15.77	156	27.93	14.19	316	27.94	14.98
Ilgele	204	31.45	12.90	179	31.95	13.00	383	31.68	12.93
Ilolo	216	32.89	14.52	208	31.46	13.69	424	32.19	14.12
Kerech*	247	32.85	12.57	191	32.86	12.88	438	32.85	12.69
Lomadang	259	34.86	13.36	222	33.25	14.22	481	34.11	13.77
Namugusie*	170	30.74	14.21	133	31.00	14.13	303	30.85	14.16
Nangolei	230	29.82	13.94	210	27.33	14.90	440	28.63	14.45
Sieslucho	166	28.13	13.56	156	28.24	13.99	322	28.18	13.75
Telesgaye	137	32.68	13.71	182	29.73	14.35	319	31.00	14.14
Watalii*	183	33.05	14.60	199	29.95	14.55	382	31.43	14.64
Total	*2364*	*31.44*	*14.03*	*2223*	*30.70*	*14.23*	*4587*	*31.08*	*14.13*

Table 9: Sample Statistics – Children aged 0-59 months sampled by the Daasanach Health and Life History Project

	Male (n=54)		Female (n=44)	
	Mean	*SD*	*Mean*	*SD*
Age (months)	43.9	12.4	43.5	12.8
Height (cm)	98.0	10.8	97.5	11.5
Weight (kg)	13.1	2.4	12.7	2.6
Market Distance (km)	4.0	4.8	4.9	5.8

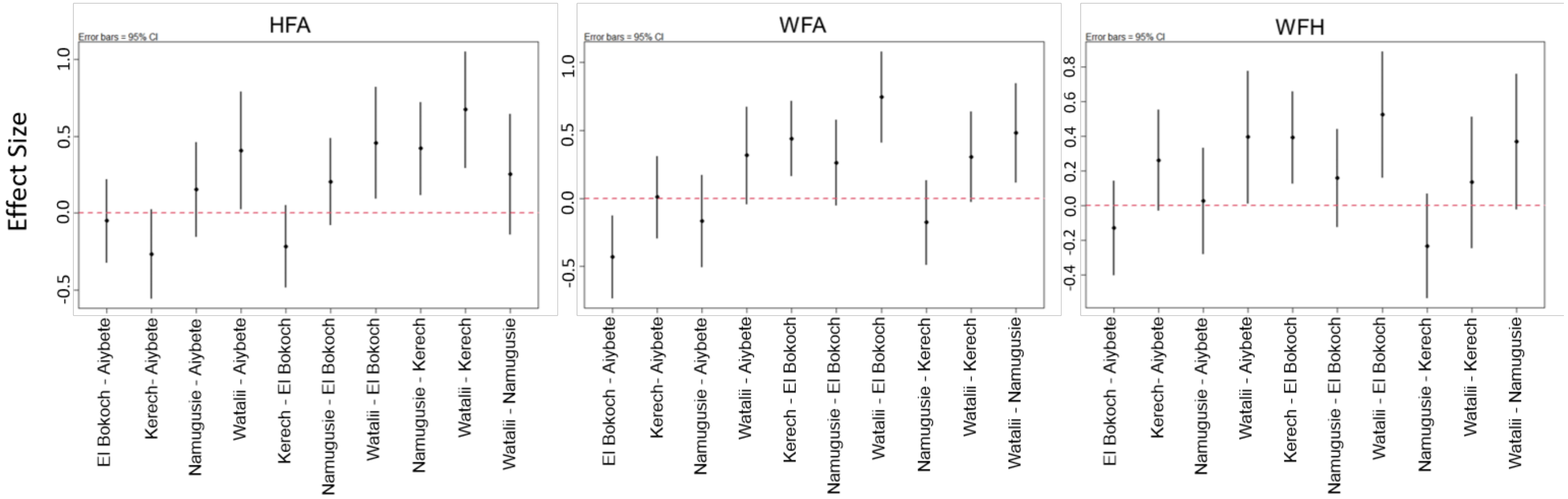

Figure 24: Tukey's HSD comparison of HFA, WFA, and WFH z-scores for Daasanach-specific growth across communities for which household samples were collected.

4.3.2 The effects of household health, demographic structure, and socioeconomic status on early childhood growth

To test the relationships between variation in household characteristics and early childhood growth, mean household values of HFA, WFA, and WFH expressed by children aged 0-59 months were measured against indicators of household health, demography, and SES. Additionally, indicators of lifestyle variation, namely market integration, were also tested for their effects on growth at the household-level. Mean ± SD market distance of household sampled was 4.6 ± 6.5km, while households moved an average of 4.1 ± 6.5 times in the previous year. Multiple linear regression was used to test for the effects of market distance, household mobility, and sex-specific composite scores for household health, demography, and SES on measure of linear and weight growth (Table 10; Figure 25). HFA was significantly positively correlated with household distance to nearest market center ($\beta = 0.916$, $p < 0.001$, SE = 0.276). To further investigate the effect of market distance on linear growth, the likelihood of being relatively tall for one's age – having a Daasanach-specific z-score >0 – was tested. Logistic regression suggests a 24% more likely chance of having a positive HFA z-score per kilometer distance from the nearest market center (OR = 1.24; 95% CI = [1.04-1.63]).

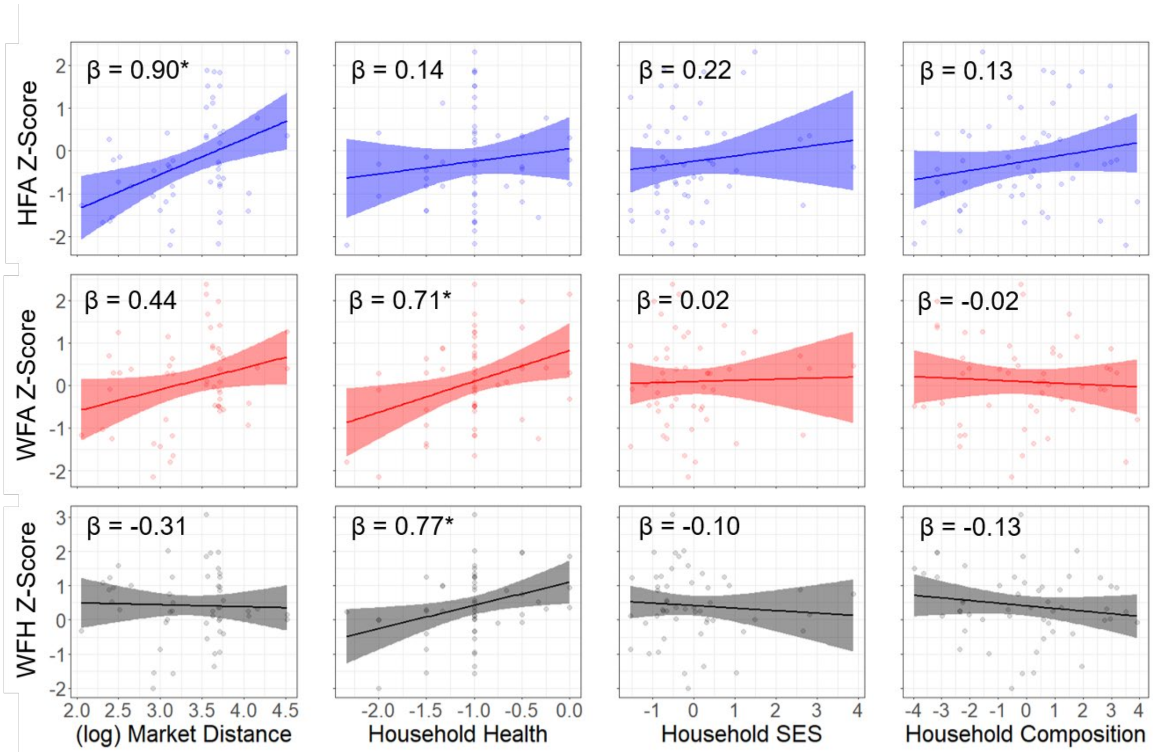

Figure 25: Mean Daasanach-specific household HFA, WFA, and WFH z-scores by household lifestyle variation.

Neither WFA, nor WFH, were significantly affected by market distance within multiple regression models. No significant relationships were found between any of the three measures of growth and household mobility, demographic score, or SES score. Similarly, logistic regression found no significant change in the likelihood of having positive WFA or WFH z-score based on market distance or household mobility. However, a more specific investigation of the effect of co-dependents found that the mean WFH of young children within a household was significantly negatively correlated (β = -0.358, p = 0.011, SE = 0.134) with the number of children under the age of seven living in that household (Figure 26). Additionally, household composite health score was found to be significantly negatively correlated with both WFA and WFH at the household-level, with children living in households with less healthy parents having lower weights for age and height compared to other Daasanach children. HFA was unaffected by household health score.

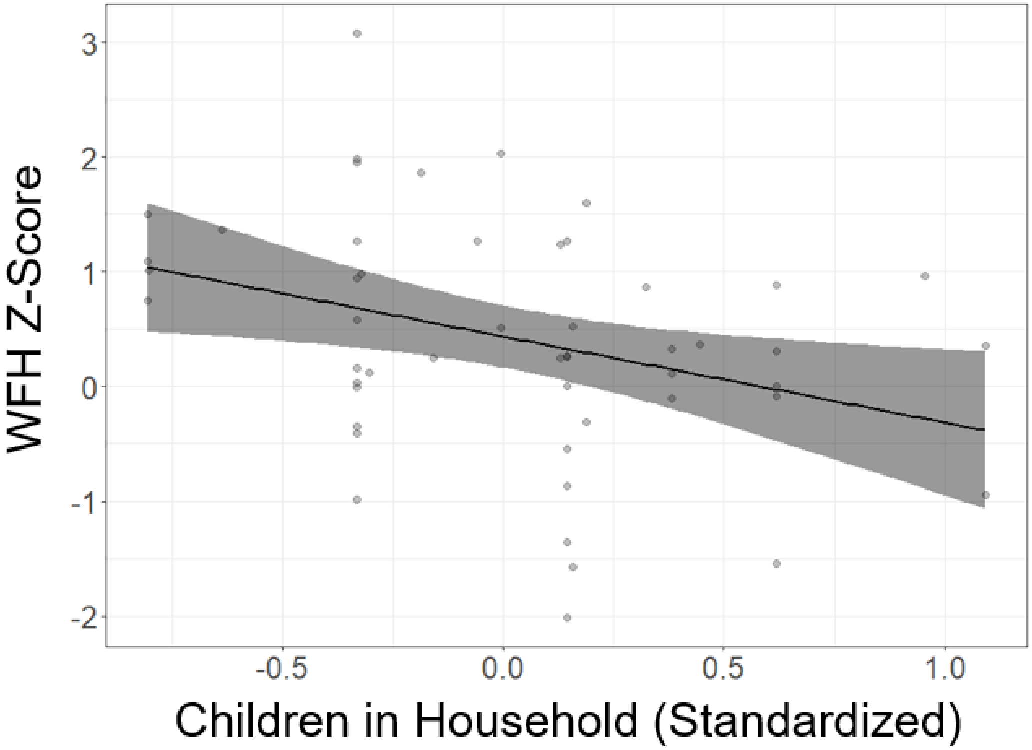

Figure 26: Mean Daasanach-specific household WFH z-scores by number of co-dependent children.

Table 10: Household values of early childhood growth by indicator of household variation.

	Dependent variable:		
	Height-for-Age (1)	Weight-for-Age (2)	Weight-for-Height (3)
(log) Distance to Nearest Market	**0.916*****	0.354	-0.306
	(0.276)	(0.268)	(0.262)
(sqrt) Household Moves	0.040	0.118	0.138
	(0.117)	(0.113)	(0.111)
Household Health Score	-0.217	**-0.732****	**-0.751****
	(0.300)	**(0.291)**	**(0.285)**
Household Demographic Score	0.132*	-0.023	-0.092
	(0.073)	(0.071)	(0.070)
Household SES Score	0.173	0.019	-0.119
	(0.130)	(0.127)	(0.124)
Constant	-3.146***	-0.540	1.971**
	(0.980)	(0.951)	(0.931)
Observations	51	51	51
R^2	0.282	0.199	0.171
Adjusted R^2	0.202	0.110	0.079
Residual Std. Error (df = 45)	1.020	0.990	0.969
F Statistic (df = 5; 45)	3.532***	2.241*	1.855
Note:			$^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$

4.3.3 Correlates of household health, demographic structure, and socioeconomic status

The relationships between household variables used to construct composite measures of household health, demography, and SES were assessed using Pearson's pairwise correlation analysis (Figure 27). Composite SES scores were generated from household values of income, livestock wealth, and educational achievement. Livestock wealth and household income were not significantly correlated, but livestock wealth was positively correlated with both household mobility and distance to the nearest market. Alternatively, household income was significantly positively correlated with educational achievement, and educational achievement was negatively correlated with distance to market.

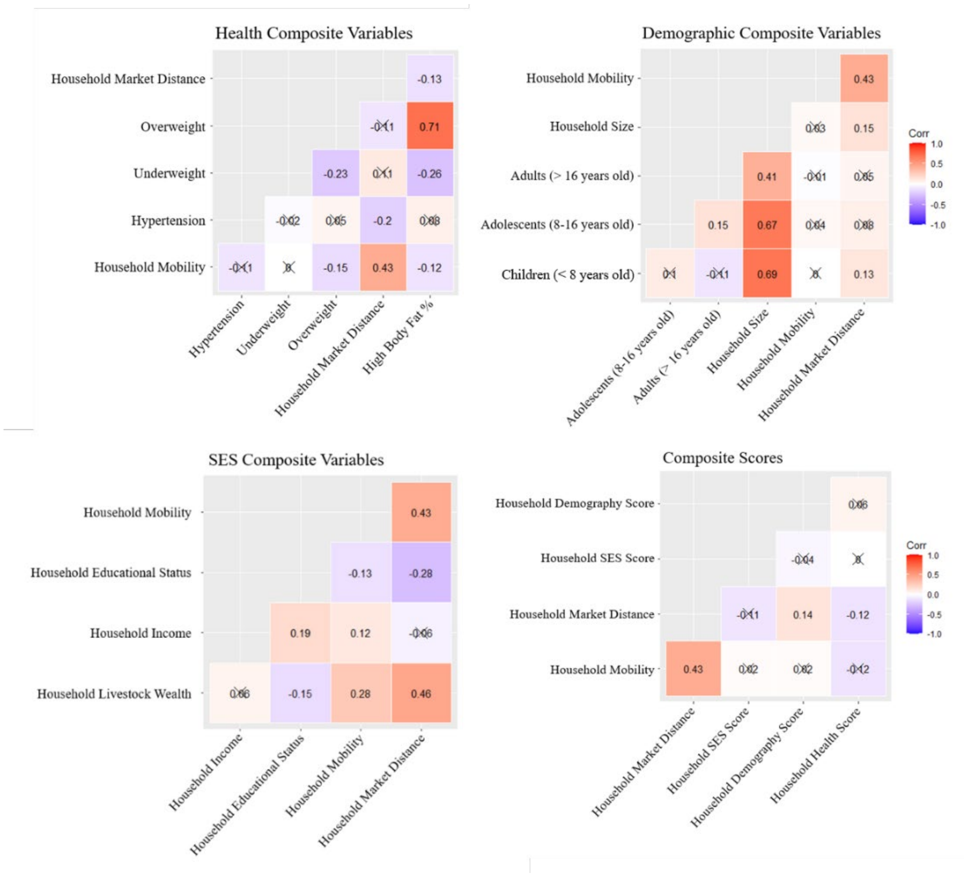

Figure 27: Correlation matrices of composite variables analyzed using Pearson pairwise comparisons.

When investigating the relationships between the variables used to construct household demographic scores, overall household size was expectedly correlated with the number of children, number of adolescents, and number of adults present in the household. Interestingly, number of children was not correlated to either the number of adolescents or number of adults living in a single household and was only marginally positively correlated with market distance. Household mobility was not correlated with any measure of household size. Unsurprisingly, when testing the relationships between health variables, the largest correlation existed between the prevalence of overweight and high body fat. However, tests of the correlations between hypertension and all other household measures for health were not significant. A final comparison between the composite household scores themselves found that none were significantly correlated with each other.

Additional multiple regression models were constructed to investigate the relationship between the household composite variables and the variables of lifestyle variation – market integration and household mobility (Table 11). After controlling for the age and sex of heads of household, distance to the nearest market was found to significantly positively correlated with household demographic score. This is driven by a significant increase in household size across most demographic categories with decreased market integration. Alternatively, household SES score was significantly negatively correlated with distance to the nearest market center. Though less market integrated households, those that are farther from market centers, have significantly larger livestock wealth, the negative association between overall SES score and market distance is due to decreased access to sources of earned income and education outside of market centers.

Table 11: Composite scores for household variation by indicators of lifestyle.

	Dependent variable:		
	Household Health Score	Household Demographic Score	Household SES Score
	(1)	(2)	(3)
Age	**0.010*****	**0.063*****	**-0.025*****
	(0.003)	**(0.012)**	**(0.008)**
Sex	0.042	**-0.942*****	0.404
	(0.091)	**(0.359)**	(0.248)
(log) Distance to Nearest Market	-0.045	**0.745*****	**-0.449*****
	(0.060)	**(0.235)**	**(0.165)**
(sqrt) Household Moves	-0.030	0.022	0.076
	(0.033)	(0.131)	(0.090)
Constant	0.719***	-4.619***	2.230***
	(0.234)	(0.931)	(0.650)
Observations	263	278	269
R^2	0.071	0.106	0.049
Adjusted R^2	0.056	0.093	0.035
Residual Std. Error	0.652 (df = 258)	2.647 (df = 273)	1.801 (df = 264)
F Statistic	4.904*** (df = 4; 258)	8.109*** (df = 4; 273)	3.436*** (df = 4; 264)
Note:			*p<0.1; **p<0.05; ***p<0.01

4.2 Discussion

This study tests the proximate causes that might affect growth during early childhood within and across communities experiencing lifestyle change. To account for population-specific patterns of early childhood growth, all growth values – HFA, WFA, and WFH – were derived from LMS models created using a large dataset of anthropometric measures of children between the ages of 0-59 months from eleven communities located within 16 km of the IHC (Table 8). Multivariate regression analyses found meaningful differences in early childhood growth at both the community and household levels, with associations being found between specific household characteristics and growth among young children in our sample (Figure 25-26; Table 10-11; Table 14). Household values for HFA among children under five years old increased significantly with a decrease in household market integration ($\beta = 0.916$, $p < 0.001$, SE = 0.276), as measured by increasing household distance to the nearest market center, with 24% higher odds that a household would have children whose mean HFA was above the Daasanach-specific median per kilometer increase in distance to the nearest market. Likewise, household values of WFA did appear to increase with increased market distance, but the results of multivariate linear regression models were not significant ($\beta = 0.354$, $p > 0.05$, SE = 0.268).

Like members of other small-scale societies, Daasanach living in and around Illeret have low risks of cardiometabolic diseases, with low rates of hypertension and overweight among adult males and females (Table 12; Liebert et al, 2013; Raichlen et al., 2017; Lea et al., 2020). However, Daasanach communities have been found to experience very high prevalence of both food and water insecurity (Bethancourt et al., 2021). Of adults between the ages of 18-49 years, 62.9% were found to suffer from clinical underweight, with BMIs falling below the CDC threshold of 18.5 kg/m^2 (Table 13). When comparing growth measures to household health status, composite health scores constructed from biomarkers of non-communicable disease risk found that children of parents with poorer relative health had significantly lower weights for their age and height (Figure 25). In addition, these relationships held when isolating the comparison to only maternal health. Interestingly, HFA was not significantly associated with variation in household health scores.

Table 12: Adult Daasanach blood pressure statistics and hypertension rates.

Sample (Age)	*N*	Systolic BP (mmHg)	Diastolic BP (mmHg)	% Hypertensive
Female (18-39)	129	107.7 (±13.4)	78.3 (±10.3)	14.7%
Male (18-39)	60	114.6 (±12.2)	78.5 (±8.3)	10.0%
Total (18-39)	**189**	**109.9 (±13.4)**	**78.4 (±9.7)**	**13.2%**
Female (40+)	82	117.3 (±16.4)	84.4 (±11.2)	31.7%
Male (40+)	97	118.6 (±19.1)	84.1 (±12.6)	28.9%
Total (40+)	**179**	**118.0 (±17.9)**	**84.2 (±12.0)**	**30.2%**

Hypertension defined as systolic BP ≥140 mmHg and/or diastolic bp ≥90 mmHg (Unger et al., 2020).

Table 13: Adult Daasanach body composition and prevalence of underweight.

Sample (Age)	*N*	Body Fat (%)	BMI (kg/m^2)	% Underweight
Female (18-39)	133	21.2 (±6.9)	18.5 (±2.8)	56.4%
Male (18-39)	61	8.2 (±2.2)	17.9 (±1.3)	77.1%
Total (18-39)	**194**	**17.1 (±8.4)**	**18.3 (±2.5)**	**62.9%**
Female (40+)	86	23.4 (±7.2)	18.3 (±4.2)	65.1%
Male (40+)	99	10.7 (±4.6)	17.8 (±3.3)	68.7%
Total (40+)	**185**	**16.6 (±8.7)**	**18.1 (±3.7)**	**67.0%**

Underweight and overweight defined as having a BMI ≤18.5 and ≥ 25.0, respectively.

After controlling for market distance, household mobility, and household health, neither household demographic scores nor household SES were found to significantly affect any metric of early childhood growth. Surprisingly, overall household size was positively associated with HFA among young children, but not significantly so ($\beta = 0.13$, $p = 0.052$, SE = 0.067). A more specific investigation found that this result was not driven by the number of co-dependents, however, as the number of children under 7 years old in a household did not significantly affect mean household HFA for young children. These results differ from previous work that has suggested that both the demographic structure and SES can affect life history characteristics and health in children (Sellen, 1999b; Hagen et al., 2006; Gurven & Walker, 2006; Larrea & Kawachi, 2005). Some support was found for the effect of co-dependents on weight, though, as households with more co-dependent children under the age of seven had lower mean household values for WFH among children less than five after controlling for other household differences (Figure 26). Relative to many other studies, which investigate growth and health differences across larger lifestyle divides (e.g., urban/rural, industrial/non-industrial), Daasanach express a smaller magnitude of variation between households and communities (Little, Gray, & Leslie, 1993; Fratkin et al., 2004; Blackwell et al., 2017; Lea et al, 2020; Jaeggi et al., 2020). This relatively low level of variation, which results from recent transitions to settled lifestyles and market integration, likely accounts for the inability to detect meaningful differences in growth associated with either household composition or SES.

Unexpectedly, household mobility, a measure of how settled a household is, had no significant effect on HFA, WFA, or WFH in our sample (Table 10). Previous work with nomadic and semi-nomadic pastoralist communities in East Africa has often focused on the biosocial effects of sedentarization (Little & Gray, 1990; Little, Gray, & Leslie, 1993; Sellen, 1999a; Barkey et al., 2001; Fratkin et al., 2004; Fratkin & Roth, 2005; Roth et al., 2005; Fujita et al., 2004; Campbell et al., 2005). Like market integration, and most other types of behavioral or socioeconomic transition, both the causes and effects of sedentarization are multifactorial and heterogenous within and between populations. For this reason, observing life history and health variation at the level of the individual and/or household is essential for the investigation of the proximate effects of such changes. Many studies have assessed these effects at the community-level, testing differences observed between groups of settled and non-settled individuals (Little & Gray, 1990; Little, Gray, & Leslie, 1993; Fratkin et al., 2004; Roth et al., 2005; Fujita et al., 2004; Page et al., 2018). The use of this methodology risks obscuring potential covariates of sedentarization, which themselves might drive the differences in growth and health between communities in transition. This is supported by the heterogenous effects of household variation on different measures of growth in our sample. Additionally, when testing the relationships between household mobility and composite characteristics of household health, demography, and SES, no significant relationships were found (Table 11). This suggests that sedentarization exist within a complex system of lifestyle variation not easily assessed simply by household mobility status. One other consideration to be made when investigating differences within and between communities is that the dichotomization of comparative populations – whether as urban and rural, or settled and nomadic – can lead to the collapsing of the temporal component of transitional phenomenon. In this way, the process of becoming more settled, or urbanized, or market integrated may have particular biobehavioral consequences not readily observable in already distinctly defined communities.

Age estimations remains a major limitation of this work (Diekmann et al., 2017). While all estimates were made by a single observer, error was reduced by using age-correction calculations that incorporated cross-comparisons of dates for which subjects had previously been sampled to produces new age estimates. As this method requires the exclusive use of subjects with multiple samples, the overall sample for growth analyses is reduced by about half. Patterns of growth for this sample were also analyzed in combination with anthropometric data collected by the Daasanach Health and Life History Project, finding that the IHC sample falls within expected ranges for LMS analysis. Another limitation of this study is that only the effects of household differences could only be assessed among those household for which young children were able to participate. This significantly reduced the number of households available for analysis from 166 to 51 households.

5. Conclusion

Investigating the relationships between socioecological, biobehavioral, and physiological variation is central to understanding the implications of lifestyle change for health and life history in humans. As growth is particularly sensitive to variation in environmental conditions, questions of metabolic investment and evolutionary mismatch can be integrated through testing the response of growth in early childhood to proximate causes of variation, such as disease, stress, nutrition, and physical activity that affect growth patterns and achieved adult heights and weights (Little & Gray, 1990; Schell, 1991; Bhan et al., 2001; Barclay & Weaver, 2006; Blackwell et al., 2010; Maggi, 2010; Bogin & Smith, 2012; Snodgrass, 2012; Stinson, 2012, Urlacher et al., 2018; Urlacher & Kramer, 2018). Therefore, comparisons of early childhood growth within and across populations allow for the investigation of phenotypic plasticity and provides context for the relationship between ecological condition and the life history traits of growth and development.

This dissertation uses anthropometric and survey data collected from Daasanach individuals (n = 572) from 166 households and 11 communities in conjunction with a large dataset of anthropometric measures (n = 8669) to test the effects of lifestyle change within a life history framework. Daasanach communities in northern Kenya are well suited to investigate the questions posed by this dissertation as they practice a physically demanding subsistence strategy in a hot and arid environment. As semi-nomadic pastoralists, Daasanach rely heavily on livestock and the labor required for herding. Daasanach living in the upper Turkana Basin have a heterogenous settlement pattern, with some communities, specifically those closer to the town of Illeret, being more settled than the semi-nomadic communities in surrounding areas (Mwamidi et al, 2018). This continuum of lifestyle allows for the direct testing of hypotheses concerning the effects of transitions to more sedentary and market integrated lifestyles on early childhood growth.

5.1 Summary: Chapter Two

Chapter Two sought to characterize growth in early childhood (age = 0-59 months) using General Additive Models of Location, Shape, and Size (GAMLSS) and compare patterns of somatic growth among Daasanach children to both WHO standards and growth faltering patterns observed in populations from developing regions of the world (Rigby & Stasinopoulos, 2005; WHO, 2006; DeOnis, 2007; Dewey, 1997; Victoria et al.; 2008; Hermanussen et al., 2016; Alderman & Headley, 2018). Comparisons found that the patterns of faltering in Daasanach children largely matched expectations of growth faltering based on other populations affected by malnutrition for the first 24 months of life (Dewey, 1997; Victoria et al.; 2008; Hermanussen et al., 2016; Alderman & Headley, 2018). Daasanach children also matched faltering patterns as described for neighboring Turkana pastoralists during this same period (Little et al., 1993). Born at or near expectation for WHO height and weight standards, Daasanach children experienced both linear and weight growth faltering before 6 months of age. Both linear faltering and weight gain faltering continued most dramatically throughout the first 24 months of life. However, unlike growth patterns from other populations in developing nations, both Daasanach boys and girls showed significant and continued linear growth gain after about 24 months of age, with higher than expected linear growth velocities.

This pattern of linear growth resulted in very low rates of stunting as measured by WHO standards for height-for-age. By the age of 5 years old, less than 5% of Daasanach children were found to be stunted. Overall prevalence of stunting was less than half the predicted estimated value for preschool children in East Africa based on global trends in 2010 (de Onis et al., 2012). Conversely, rates of wasting were exceedingly high among children aged 54-59 months, with nearly three quarters experiencing wasting. This result comes in spite of relatively low rates of underweight for the same age group – 14.1% and 9.8% for males and females, respectively. The discontinuity in growth faltering prevalence within the early childhood age course highlights the difficulty of applying growth references across global populations, especially those that are genetically homogenous and historically underrepresented in human biological study. Though likely driven in part by food insecurity, malnutrition, and disease, the high rates of wasting in Daasanach children are also an artifact of the low rates of stunting, especially after about 42 months of age.

To further investigate Daasanach specific patterns of growth, GAMLSS was used to generate pseudo-velocity growth curves. As previously observed by decreased prevalence of stunting and underweight, Daasanach-specific growth patterns exhibited an increase in both linear growth velocity and weight gain at ~24 months of age. This positive velocity then continued through the first 48 months of life for boys and girls, peaking at a linear growth velocity of ~1 cm/month at ~40 months. Both linear growth velocity and weight gain velocity increased similarly across boys and girls, though linear growth gain achieved a higher relative pseudo-velocity than weight gain. This was additionally evidenced by the difference in change between height-for-age and weight-for-age z-scores across the age course. These results again suggest that the relative difference in linear growth relative to weight gain also explains the high prevalence of wasting across Daasanach children, regardless of socioecological condition.

Undernutrition is surely a concern for Daasanach children living in a relatively calorically sparse environment with high rates of water and food insecurity, however, investigation into Daasanach early childhood growth patterns suggest distinct differences in energetic allocation to linear growth versus weight gain. The Daasanach pattern is neither temporally analogous to a mid-childhood growth spurt, which typically occurs between the ages of 6-8, nor does it match the expected effects of weaning (Katz et al., 1985; Bogin, 1999; Rehman et al., 2009). Additionally, despite experiencing early growth faltering, Daasanach adults (n = 311) achieved relatively tall adult stature (male = 172.7 ± 6.3cm | female = 163.7 ± 6.0cm), with very low adult body mass indices (male = 17.9 ± 2.8 kg/m^2 | female = 18.5 ± 3.3 kg/m^2). When examined through the lens of life history theory, an adaptive explanation for the Daasanach early childhood growth patterns becomes apparent.

These distinct patterns of Daasanach early childhood growth provide evidence for climatic effects on adaptive variation in body shape and size. Initially suggested by Bergmann (1847) and Allen (1877), Bergmann's and Allen's "rules" consider the ecological relationship between body size and body proportion as a function of thermoregulatory adaptation. Further work has found a negative correlation between body size and regional mean annual temperature, as well as a positive correlation between limb length and temperature (Schreider, 1950; Roberts, 1953; Schreider, 1957; Ruff, 1991; Ruff, 1994). This is further supported by work finding that the relative surface area of the body increases with increasingly hot climates (Schreider, 1964; Ruff, 1994). The importance of the body's surface area can be understood as function of the square-cube law, which describes the dynamic relationship between the surface area and volume of a three-dimensional object and dictates the physiological basis for the thermoregulatory fitness advantages of differing body sizes and shapes (Schmidt-Nielson, 1984; Ruff; 1994). Daasanach adults, who live in both a very hot and very arid environment, match the adaptive expectations of the relationships between climate and body size and shape. Given the achieved body size and shape of Daasanach adults, the trajectory of linear growth relative to weight gain in the latter half of early childhood that results in tall and lean children is suggestive of an adaptive trend towards an energetic trade-off that prioritizes increased somatic investment in height rather than weight.

5.2 Summary: Chapter Three

Chapter Three tested the relationships between lifestyle variables (e.g., market integration, household mobility, socioeconomic status) and biomarkers of non-communicable disease health. Overall, Daasanach adults had lower rates of hypertension, overweight, and obesity than industrialized populations (Liebert et al, 2013; Raichlen et al., 2017; Lea et al., 2020). While there was a significant positive association between body fat percentage and age for both men and women, BMI remained low across the sample and the age-course, with mean values of 17.9 ± 2.8 kg/m^2 for men and 18.5 ± 3.3 kg/m^2 for women, respectively.

Despite the relative homogeneity in Daasanach lifestyle as compared to populations previously studied to investigate cardiometabolic variation between rural and urban populations, the effects of lifestyle change on biomarkers for cardiometabolic health were large enough to detect across our sample. Both systolic and diastolic blood pressure are negatively correlated with market distance after controlling for age in adults. Likewise, logistic regression suggested a 44% less likely chance of having hypertension per log kilometer that a household is located from a market center (OR =

0.56; 95% CI = [0.37-0.83]). These results matched expectations from work with small-scale populations that found that less market integrated individuals tended to have lower blood pressures (Little et al., 1989; Fratkin et al, 2004; Fratkin & Roth, 2005). Alternatively, no significant differences in BMI were detected across Daasanach individuals with varying degrees of market integration or household mobility. This contrasts with previous work investigating market integration and sedentarization in some East African pastoralist populations (Barkey et al., 2001; Fratkin et al., 2004; Lea et al., 2020). However, body fat percentage, as measured by bioelectrical impedance, was significantly negatively correlated with market distance among women. Likewise, biomarkers of total cholesterol, LDL, and triglycerides are all negatively correlated with market distance among women, and total cholesterol and LDL were significantly negatively associated with engagement in increased household mobility.

In addition to testing the relationship between market integration and household mobility on biomarkers for cardiometabolic, the effects of these lifestyle variables on nutritional, behavioral, and socioeconomic variation were investigated. While food and water insecurity remained high across the sample, both were found to be negatively correlated with proxies for market integration and sedentarization. Beyond nutritional security, milk consumption was significantly increased among non-settled individuals and those living farther from the market relative to those who are more settled and market integrated. This result suggests that those who engaged in more traditional pastoral activities also consumed more milk, matching previous results that found that milk consumption was negatively correlated with sedentarization among pastoral communities (Fujita et al., 2004). As has been found in previous work, sugar consumption – in the form of tea with sugar and soda for Daasanach – was significantly positively associated with living nearer to market centers (Gurven et al, 2017; Lea et al., 2020). Meat consumption did not vary across our sample, but fish consumption was found to be significantly higher in those living nearer to markets, which has potentially significant nutritional and health consequences among Daasanach who settle because of the impacts of increased climate variability on their livestock. Access to Lake Turkana and the ability to obtain fish through nearby markets may help to buffer some of the negative nutritional effects of lifestyle change.

While variation in biomarkers of cardiometabolic health can be used to assess the potential effects of evolutionary mismatch, it is important to keep in mind that the typical thresholds for biomarkers, like BMI, body fat percentage, and blood pressure, are largely determined based on studies of populations living in industrialized contexts. Previous work that suggests relationships between sedentarization and variation in nutritional, reproductive, and health outcomes, represent trends towards expected outcomes rather than experienced difference in cardiometabolic disease prevalence (Little et al. 1983; Little & Leslie, 1999; Barkey et al., 2001; Fratkin et al., 2004; Page et al., 2016; Page et al.; 2018). Therefore, it is even more important to work with populations like Daasanach pastoralists to better understand the complex dynamics underlying health and life history variation that arise out of increased market reliance and decreased engagement in traditional subsistence. Such work can be used both for the betterment of Daasanach communities and for the increased understanding of evolutionary mismatch at a global scale.

5.3 Summary: Chapter Four

Chapter Four investigated proximate causes of early childhood growth variation across Daasanach households. GAMLSS was once again employed to generate population-specific early childhood growth curves from a large age-corrected dataset (n = 1753; measures = 4587) of children between the ages of 0-59 months living in communities within 16 km of the IHC. Household values for Daasanach-specific height-for-age, weight-for-age, and weight-for-height were calculated for household (n = 51) for whom at least one child under the age of 5 years was present for data collection. Using multivariate regression analyses, significant associations were then identified between early childhood growth and household characteristics related to lifestyle change. Using market distance as a proxy for market integration, household values for early childhood height-for-age were significantly negatively correlated with household market integration ($\beta = 0.916$, $p < 0.001$, SE = 0.276). This result was also supported by logistic regression, finding 24% higher odds of a household having children with a mean height-for-age greater than the Daasanach-specific median per log kilometer increase in market distance.

To further investigate the relationships between growth and household variation composite health, demography, and socioeconomic status score were constructed and standardized from all sampled Daasanach households (n = 166). Comparisons between growth measures and household health status found that children of parents with poorer relative health had significantly lower weights for their ages and heights but did not significantly vary in height-for-age. These relationships also remained significant when restricting the comparison to just to maternal health status. When controlling for market distance, household mobility, and household health in multivariate regression models, neither demography nor socioeconomic status were found to significantly affect any measure growth in children under five years of age. A more specific investigation found that the number of co-dependents, defined here as the number of children under 8 years old living in the same household, did not significantly affect mean household height-for-age. This differs from previous work that has found household demographic structure to affect life history characteristics and health in children (Gurven & Walker, 2006; Sellen, 1999b). However, some support was found for the effect of co-dependents on weight gain, as households with more co-dependent children had lower mean household values of weight-for-height after controlling for other household differences.

The causes and effects of sedentarization are multifactorial and heterogenous both within and between populations. For this reason, observing life history and health variation at the level of the individual and/or household is essential for the investigation of the proximate effects of such differences. Low variance in the population due to the relatively recent impact of sedentarization and market integration likely accounts for the relatively similar patterns of growth in Daasanach communities despite differences in demography or SES. While other studies have assessed the effects of lifestyle change on life history characteristics at the community-level, they often do so by testing differences between exclusively settled and non-settled individuals, which risks obscuring potential differences caused by the process of sedentarization itself (Little & Gray, 1990; Little et al., 1993; Leslie et al., 1993; Fratkin et al., 2004; Roth et al., 2005; Fujita et al., 2004; Page et al., 2018). These processes of change also have an important, but often overlooked, temporal component. Investigating the relationships between health, life history, and socioecology over time allows for the testing of questions not only of the rates of change, but the patterns of change that ultimately drive the differences observed in populations that have already gone through demographic, nutritional, and/or lifestyle transitions. In this way, work with Daasanach communities is an ideal opportunity to address how such relationships change and develop as a temporal phenomenon.

5.4 Future Directions

The relationships and protocols established by the Daasanach Health and Life History Project ensure that data collection with Daasanach communities in northern Kenya will be sustained well into the future. Having only been initially established in 2017, with the first human subject involvement beginning in the summer of 2019, work with Daasanach in northern Kenya has just begun. As the Daasanach Health and Life History Project grows, so too will the scope and depth of the questions that can be addressed. To date, much work has already been completed to lay the foundation for further investigation. Moving forward within an evolutionary framework, novel and continuing collection of data pertaining to infectious disease risk and response, female reproductive variation, and nutritional landscape will be essential for further exploration of the relationships between changing lifestyles, health, and life history among Daasanach pastoral communities (Figure 28).

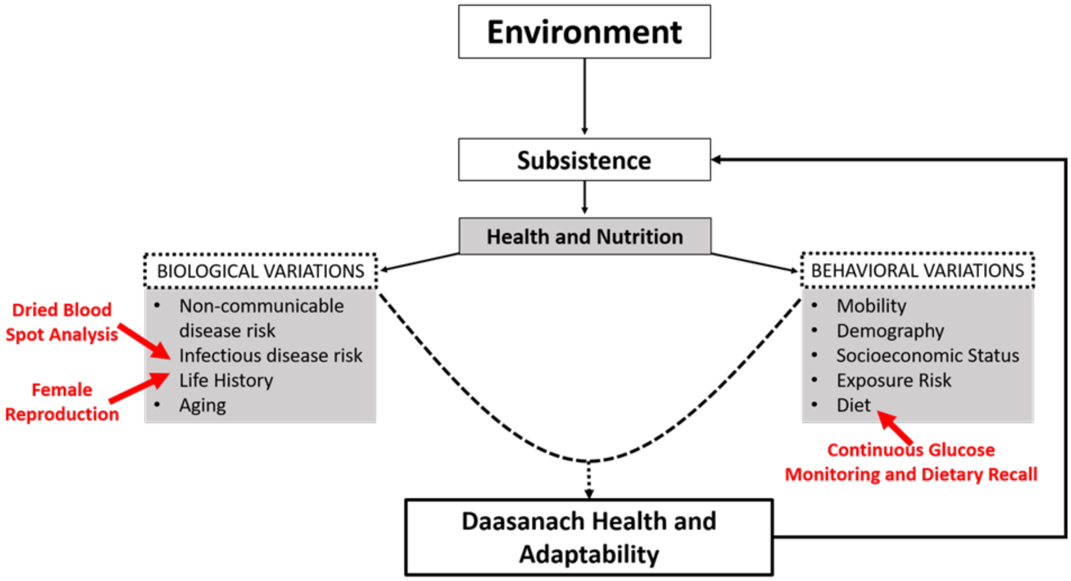

Figure 28: Conceptual model of relationships between biobehavioral health, life history, lifestyle (e.g., subsisitence strategy, mobility, and market intergration, and the environment). Red text indicates the methods by which future research will address and expand upon the goals of the Daasanach Health and Life History Project (adapted from Little & Leslie, 1999).

5.4.1 Biomarkers of inflammation and immune activity

To date, a subset of individuals (n = 400) from whom anthropometric and survey data have been collected also provided minimally invasive dried blood spot (DBS) samples. The DBS samples were collected concurrently with anthropometric data collection using a disposable micro-lancet to create a drop of free-flowing blood from the finger that was applied to standardized filter paper. At least 3 drops were collected per participant (McDade et al. 2007). These samples are scheduled to be analyzed via ELISA assay techniques to obtain data regarding biomarkers of inflammation: C-reactive protein (CRP), and antibody activity: immunoglobulin G (IgG), immunoglobulin E (IgE). These measures will allow for the assessment of short, medium, and long-term immune responses and health status (McDade et al., 2005: McDade et al., 2007; Adongo et al., 2013; Brindle et al., 2010; Shanahan et al., 2013; Andersen et al., 2014; Urlacher et al., 2018). Previous work with East African pastoralist populations have often relied on variation in type and frequency of health complaints to investigate the effect of sedentarization on infectious disease health, however, these DBS data will allow for the investigation of communicable disease variation within a population in transition through physiological proxies of inflammation and immune response (Barkey et al., 2001). Further data collection involving DBS will allow for the increase of sample size in the coming years.

5.4.2 Female reproductive variation

Preliminary data regarding female reproductive data has already been collected with Daasanach women through the Daasanach Health and Life History Project. Further data collection will allow for the testing of tradeoffs in fertility and reproductive success across communities and household experiencing the effects of sedentarization and market integration. This work will build upon work investigating reproductive variation generally, and among East African populations specifically, and will do so through the framework of life history theory (Leslie et al., 1993; Strassmann & Gillespie, 2002; Lawson et al., 2012; Adongo et al., 2013, Page et al., 2018). In this way, tradeoffs dictated by energy investment and availability can be assessed within a population currently experiencing the beginning of a major lifestyle transition.

5.4.3 Nutritional variation

Assessment of nutritional landscapes and diet are notoriously difficult to quantify but are essential to understanding the effects of lifestyle change that involve transitions in subsistence practice and variation in market integration. Further work with Daasanach communities will involve the implementation of more rigorous dietary recall surveys to test the relationships between diet, market integration, and engagement in traditional subsistence practices. These data will then be used to inform the already observed variation in early childhood growth and health expressed within and between Daasanach communities.

Additionally, a novel technique for collecting nutritional data in the field has already been piloted through the Daasanach Health and Life History Project. Continuous glucose monitoring (CGM), using continuous glucose monitoring patches (Freestyle Libre Pro) can be worn for up to 14 consecutive days (Klonoff et al., 2017). Typically used for tracking blood sugar among individuals suffering from diabetes, use of CGM in healthy adults can provide information regarding the patterning of food intake throughout the day and the approximate amount of carbohydrate intake for individuals (Aronoff et al., 2004). When assessing this data in the context of nutritional survey information, blood glucose levels can provide insight into survey accuracy and additional information regarding dietary composition.

5.5 Final Thoughts

The relationships between the environment, demography, behavior, nutrition, and metabolic investment are fundamental to understanding evolved life history strategies in humans. Human cardiometabolic health and growth are sensitive to variations in environmental conditions, and the relationships between the magnitude and temporal patterns of growth and socioecological condition can be used to test the hypotheses of life history theory and metabolic tradeoffs.

This dissertation takes a broad approach to the investigation of relationships between life history, health, and lifestyle transitions in Daasanach pastoralist living in northern Kenya. The use of an evolutionary and life history framework to test and investigate these relationships enables a greater understanding of variation of experienced biobehavioral consequences that occur due to metabolic tradeoffs affected by socioecological condition. The Daasanach population in northern Kenya is ideal for these research endeavors. They practice a physically demanding subsistence and movement strategy while living in a remote, hot, and arid environment, and they are currently experiencing the increasing pressure of encroaching markets. The urgency with which this work must be done is felt in the pace at which these market pressures are growing. Through the involvement of NGOs and research organizations, like the Turkana Basin Institute, market/aid goods and services continue to become more accessible for those living in Illeret and the surrounding region. Importantly, this includes increased access to electrical infrastructure, which prior to December 2019 was totally absent (Figure 29).

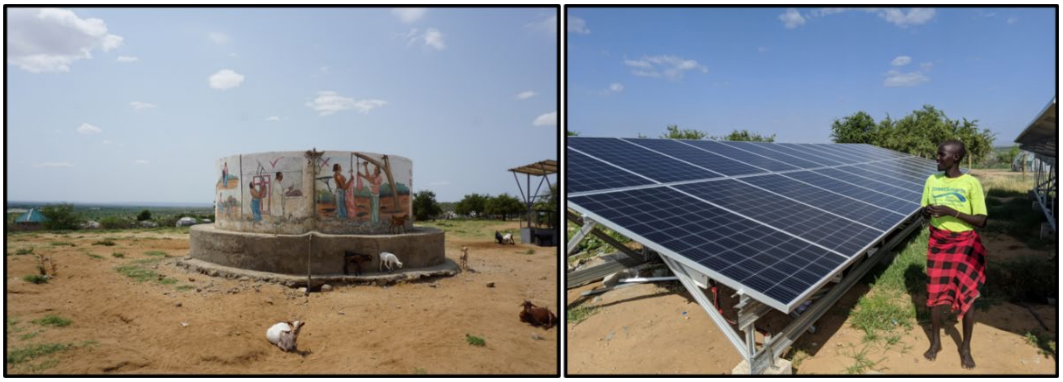

Figure 29: Examples of market infrastrucature in Illeret. Left: Water cistern with solar pump located in the Kerech community. Right: Solar array installed in December 2019 and turned on in Janauary 2020 through a partnership between Kenya Power and German energy company, GIZ. This array provides moderate power to small businesses, households, and community buidlings that are constructed in a permament fashion. Expansions to the solar grid planned in the near future.

This dissertation expands the existing body of research investigating health and growth variation within small-scale non-industrialized populations through an evolutionary and life history framework in non-industrial communities to a population with a subsistence pattern that is currently underrepresented in the literature. This addition allows for a new level of comparison between the variation in ecology, life history, health, and behavior that characterize our species, advancing our understanding of difference between industrialized and non-industrialized populations, and the breadth of variation in the characteristics across human populations.

Appendix A

Table 14: WHO Z-Scores and growth faltering rates among male children aged 0-59 months.

Male

	Age (months)		**HAZ - WHO**					**WAZ - WHO**					**WHZ - WHO**				
Age (months)	μ	SD	N	μ	SD	% < -2	% < -3	N	μ	SD	% < -2	% < -3	N	μ	SD	% < -2	% < -3
0-5	3.56	1.42	41	-0.39	1.34	7.3% (3)	0% (0)	41	-0.45	1.37	12.2% (5)	2.4% (1)	41	-0.18	1.52	4.9% (2)	2.4% (1)
6-11	8.54	1.58	209	-1.02	1.77	24.4% (51)	6.2% (13)	209	-2.01	1.30	49.3% (103)	19.6% (41)	209	-1.91	1.37	42.1% (88)	17.7% (37)
12-17	14.44	1.56	241	-1.55	1.35	34.9% (84)	10.8% (26)	241	-2.36	1.14	65.6% (158)	26.1% (63)	241	-2.25	1.25	56.0% (135)	27.0% (65)
18-23	20.38	1.91	218	-1.91	1.11	50.5% (110)	17.0% (37)	218	-2.54	1.05	70.2% (153)	28.9% (63)	218	-2.31	1.08	59.6% (130)	23.9% (52)
24-29	26.40	1.76	311	-1.60	0.96	29.6% (92)	5.2% (16)	311	-2.28	0.85	62.7% (195)	17.4% (54)	311	-2.09	0.99	54.7% (170)	15.1% (47)
30-35	32.24	1.58	294	-1.34	0.96	20.1% (59)	4.1% (12)	294	-2.12	0.90	53.4% (157)	16.0% (47)	294	-2.12	1.06	55.4% (163)	17.7% (52)
36-41	38.30	1.77	375	-0.66	0.96	4.5% (17)	1.6% (6)	375	-1.71	0.79	33.6% (126)	5.3% (20)	375	-2.06	0.99	54.9% (206)	16.0% (60)
42-47	44.33	1.88	339	-0.06	0.89	3.0% (10)	1.8% (6)	339	-1.50	0.72	19.8% (67)	3.2% (11)	339	-2.25	0.86	62.2% (211)	18.0% (61)
48-53	50.25	1.83	251	0.06	1.17	3.2% (8)	2.0% (5)	251	-1.46	0.86	16.7% (42)	3.2% (8)	251	-2.31	0.88	65.7% (165)	20.3% (51)
54-59	55.57	1.38	85	0.38	0.93	2.4% (2)	1.2% (1)	85	-1.40	0.67	14.1% (12)	2.4% (2)	84	-2.58	0.86	72.6% (61)	31.0% (26)
0-59 (Total)	*31.44*	*14.03*	*2364*	*-0.90*	*1.33*	*18.6% (439)*	*5.2% (122)*	*2364*	*-1.90*	*1.03*	*43.1% (1018)*	*13.1% (310)*	*2363*	*-2.14*	*1.09*	*56.3% (1331)*	*19.1% (452)*

Table 15: WHO Z-Scores and growth faltering rates among female children aged 0-59 months.

Female

	Age (months)				**HAZ - WHO**					**WAZ - WHO**					**WHZ - WHO**		
Age (months)	μ	SD	N	μ	SD	% < -2	% < -3	N	μ	SD	% < -2	% < -3	N	μ	SD	% < -2	% < -3
0-5	3.44	1.35	57	0.85	3.61	8.8% (5)	0% (0)	57	-0.09	1.46	5.3% (3)	0% (0)	57	-0.62	1.79	17.5% (10)	8.8% (5)
6-11	8.65	1.69	241	-0.54	2.16	12.9% (31)	4.6% (11)	241	-1.64	1.47	36.5% (88)	11.2% (27)	241	-1.70	1.45	40.7% (98)	12.0% (29)
12-17	14.51	1.65	196	-0.97	1.56	20.9% (41)	7.1% (14)	196	-1.88	1.21	44.4% (87)	16.8% (33)	196	-1.92	1.11	49.5% (97)	15.3% (30)
18-23	20.39	1.77	212	-1.51	1.11	28.8% (61)	4.2% (9)	212	-2.20	0.96	58.0% (123)	17.9% (38)	212	-2.00	0.95	50.9% (108)	13.2% (28)
24-29	26.39	1.82	292	-1.18	1.09	15.1% (44)	3.8% (11)	292	-2.00	0.98	47.3% (138)	13.0% (38)	292	-1.89	1.00	43.5% (127)	11.3% (33)
30-35	32.44	1.64	273	-0.88	1.08	9.2% (25)	1.8% (5)	273	-1.90	0.94	43.6% (119)	8.8% (24)	273	-2.01	0.99	53.5% (146)	13.2% (36)
36-41	38.38	1.77	349	-0.52	1.31	8.6% (30)	4.6% (16)	349	-1.67	1.07	31.0% (108)	7.7% (27)	349	-1.98	1.03	50.1% (175)	15.8% (55)
42-47	44.39	1.88	307	0.09	0.98	2.3% (7)	0.3% (1)	307	-1.42	0.87	22.1% (68)	2.6% (8)	307	-2.19	0.91	58.6% (180)	19.2% (59)
48-53	50.12	1.73	235	0.21	1.08	3.8% (9)	3.0% (7)	235	-1.42	0.86	17.4% (41)	4.3% (10)	235	-2.37	0.90	66.0% (155)	24.3% (57)
54-59	55.39	1.33	61	0.45	0.60	0% (0)	0% (0)	61	-1.29	0.60	9.8% (6)	0% (0)	61	-2.52	1.13	75.4% (46)	41.0% (25)
0-59 (Total)	*30.70*	*14.23*	*2223*	*-0.56*	*1.54*	*11.4% (253)*	*3.3% (74)*	*2223*	*-1.69*	*1.11*	*35.1% (781)*	*9.2% (205)*	*2223*	*-1.99*	*1.11*	*51.4% (1142)*	*16.1% (357)*

Table 16: Tukey's HSD community comparisons for Daasanach-specific early childhood growth.

Male: Height-for-Age

			95 % Conf. Int.		
		Mean Difference	Lower	Upper	p-value
Namugusie	Kerech	0.08	-0.18	0.35	0.92
	El Bokoch	-0.15	-0.45	0.14	0.60
	Watalii	0.24	-0.05	0.52	0.15
	Aiybete	-0.43	-0.81	-0.06	0.02*
Kerech	Namugusie	-0.08	-0.35	0.18	0.92
	El Bokoch	-0.24	-0.50	0.03	0.11
	Watalii	0.16	-0.10	0.42	0.46
	Aiybete	-0.51	-0.87	-0.16	< 0.01*
El Bokoch	Namugusie	0.15	-0.14	0.45	0.60
	Kerech	0.24	-0.03	0.50	0.11
	Watalii	0.39	0.11	0.68	< 0.01*
	Aiybete	-0.28	-0.66	0.10	0.26
Watalii	Namugusie	-0.24	-0.52	0.05	0.15
	Kerech	-0.16	-0.42	0.10	0.46
	El Bokoch	-0.39	-0.68	-0.11	< 0.01*
	Aiybete	-0.67	-1.04	-0.30	< 0.01*
Aiybete	Namugusie	0.43	0.06	0.81	0.02*
	Kerech	0.51	0.16	0.87	< 0.01*
	El Bokoch	0.28	-0.10	0.66	0.26
	Watalii	0.67	0.30	1.04	< 0.01*

Female: Height-for-Age

			95 % Conf. Int.		
		Mean Difference	Lower	Upper	p-value
Namugusie	Kerech	0.02	-0.28	0.32	0.99
	El Bokoch	-0.14	-0.47	0.19	0.76
	Watalii	0.05	-0.25	0.35	0.99
	Aiybete	-0.41	-0.76	-0.05	0.01*
Kerech	Namugusie	-0.02	-0.32	0.28	0.99
	El Bokoch	-0.16	-0.46	0.14	0.59
	Watalii	0.03	-0.24	0.30	0.99
	Aiybete	-0.43	-0.76	-0.10	< 0.01*
El Bokoch	Namugusie	0.14	-0.19	0.47	0.76
	Kerech	0.16	-0.14	0.46	0.59
	Watalii	0.19	-0.11	0.49	0.40
	Aiybete	-0.27	-0.62	0.09	0.24
Watalii	Namugusie	-0.05	-0.35	0.25	0.99
	Kerech	-0.03	-0.30	0.24	0.99
	El Bokoch	-0.19	-0.49	0.11	0.40
	Aiybete	-0.46	-0.79	-0.13	< 0.01*
Aiybete	Namugusie	0.41	0.05	0.76	0.01*
	Kerech	0.43	0.10	0.76	< 0.01*
	El Bokoch	0.27	-0.09	0.62	0.24
	Watalii	0.46	0.13	0.79	< 0.01*

Male: Weight-for-Age			95 % Conf. Int.		
		Mean Difference	Lower	Upper	p-value
Namugusie	Kerech	0.14	-0.13	0.41	0.61
	El Bokoch	-0.09	-0.39	0.20	0.90
	Watalii	-0.10	-0.38	0.19	0.89
	Aiybete	-0.51	-0.89	-0.13	< 0.01*
Kerech	Namugusie	-0.14	-0.41	0.13	0.61
	El Bokoch	-0.23	-0.50	0.03	0.12
	Watalii	-0.24	-0.50	0.02	0.10
	Aiybete	-0.65	-1.01	-0.26	< 0.01*
El Bokoch	Namugusie	0.09	-0.20	0.39	0.90
	Kerech	0.23	-0.03	0.50	0.12
	Watalii	0.00	-0.29	0.29	1.00
	Aiybete	-0.42	-0.80	-0.04	0.02*
Watalii	Namugusie	0.10	-0.19	0.38	0.89
	Kerech	0.24	-0.02	0.50	0.10
	El Bokoch	0.00	-0.29	0.29	1.00
	Aiybete	-0.42	-0.79	-0.04	0.02*
Aiybete	Namugusie	0.51	0.13	0.89	< 0.01*
	Kerech	0.65	0.26	1.01	< 0.01*
	El Bokoch	0.42	0.04	0.80	0.02*
	Watalii	0.42	0.04	0.79	0.02*

Female: Weight-for-Age			95 % Conf. Int.		
		Mean Difference	Lower	Upper	p-value
Namugusie	Kerech	0.39	0.09	0.69	< 0.01*
	El Bokoch	0.11	-0.22	0.43	0.90
	Watalii	-0.04	-0.34	0.26	0.99
	Aiybete	-0.30	-0.65	0.06	0.15
Kerech	Namugusie	-0.39	-0.69	-0.09	< 0.01*
	El Bokoch	-0.29	-0.59	0.01	0.06
	Watalii	-0.44	-0.71	-0.17	< 0.01*
	Aiybete	-0.69	-1.02	-0.36	< 0.01*
El Bokoch	Namugusie	-0.11	-0.43	0.22	0.90
	Kerech	0.29	-0.01	0.59	0.06
	Watalii	-0.15	-0.44	0.15	0.65
	Aiybete	-0.40	-0.75	-0.05	0.01*
Watalii	Namugusie	0.04	-0.26	0.34	0.99
	Kerech	0.44	0.17	0.71	< 0.01*
	El Bokoch	0.15	-0.15	0.44	0.65
	Aiybete	-0.25	-0.58	0.07	0.21
Aiybete	Namugusie	0.30	-0.06	0.65	0.15
	Kerech	0.69	0.36	1.02	< 0.01*
	El Bokoch	0.40	0.05	0.75	0.01*
	Watalii	0.25	-0.07	0.58	0.21

Male: Weight-for-Height

			95 % Conf. Int.		
		Mean Difference	Lower	Upper	p-value
Namugusie	Kerech	0.13	-0.14	0.40	0.66
	El Bokoch	-0.07	-0.36	0.23	0.97
	Watalii	-0.28	-0.57	0.00	0.06
	Aiybete	-0.39	-0.77	-0.01	0.04*
Kerech	Namugusie	-0.13	-0.40	0.14	0.66
	El Bokoch	-0.20	-0.47	0.07	0.26
	Watalii	-0.41	-0.67	-0.15	< 0.01*
	Aiybete	-0.52	-0.88	-0.16	< 0.01*
El Bokoch	Namugusie	0.07	-0.23	0.36	0.97
	Kerech	0.20	-0.07	0.47	0.26
	Watalii	-0.22	-0.50	0.07	0.24
	Aiybete	-0.33	-0.70	0.05	0.13
Watalii	Namugusie	0.28	0.00	0.57	0.06
	Kerech	0.41	0.15	0.67	< 0.01*
	El Bokoch	0.22	-0.07	0.50	0.24
	Aiybete	-0.11	-0.48	0.26	0.93
Aiybete	Namugusie	0.39	0.01	0.77	0.04*
	Kerech	0.52	0.16	0.88	< 0.01*
	El Bokoch	0.33	-0.05	0.70	0.13
	Watalii	0.11	-0.26	0.48	0.93

Female: Weight-for-Height

			95 % Conf. Int.		
		Mean Difference	Lower	Upper	p-value
Namugusie	Kerech	0.47	0.17	0.77	< 0.01*
	El Bokoch	0.20	-0.12	0.53	0.44
	Watalii	-0.08	-0.38	0.22	0.95
	Aiybete	-0.13	-0.48	0.22	0.85
Kerech	Namugusie	-0.47	-0.77	-0.17	< 0.01*
	El Bokoch	-0.27	-0.56	0.03	0.11
	Watalii	-0.54	-0.81	-0.27	< 0.01*
	Aiybete	-0.60	-0.92	-0.27	< 0.01*
El Bokoch	Namugusie	-0.20	-0.53	0.12	0.44
	Kerech	0.27	-0.03	0.56	0.11
	Watalii	-0.28	-0.58	0.02	0.08
	Aiybete	-0.33	-0.68	0.02	0.08
Watalii	Namugusie	0.08	-0.22	0.38	0.95
	Kerech	0.54	0.27	0.81	< 0.01*
	El Bokoch	0.28	-0.02	0.58	0.08
	Aiybete	-0.05	-0.38	0.28	0.99
Aiybete	Namugusie	0.13	-0.22	0.48	0.85
	Kerech	0.60	0.27	0.92	< 0.01*
	El Bokoch	0.33	-0.02	0.68	0.08
	Watalii	0.05	-0.28	0.38	0.99

Table 17: Supplement: Anthropometric and lifestyle characteristics by categorized movement strategy.

Male	**Settled (n=37)**		**Semi-nomadic (n=48)**		**Nomadic (n=22)**	
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**
Age	50.41	16.26	45.50	14.99	41.82	15.85
BMI	18.18	4.21	17.66	1.63	17.92	1.52
Body Fat %	10.32	5.04	9.52	2.92	9.39	2.99
Sum of Skinfolds	27.86	24.93	20.71	6.47	19.82	5.94
Systolic BP	121.89	21.40	117.74	16.04	117.33	12.93
Diastolic BP	86.39	13.52	83.34	11.14	78.48	6.49
HH Size	7.76	3.91	7.63	2.95	6.82	2.48
Ind. Income (Ksh)	3424.32	6501.77	1547.92	2976.34	1177.27	1397.51
HH Income (Ksh)	4100.54	7515.40	3573.71	13094.79	1513.64	1536.24
Livestock	30.03	70.74	27.19	90.62	59.41	120.22
Education	2.43	3.44	1.38	1.75	1.09	0.43
Times Moved	NA	NA	3.54	1.80	13.18	7.16
SES Ladder	7.97	2.14	7.79	2.19	6.18	2.54
HWISE	24.59	8.77	27.94	7.82	34.77	7.74
HFIAS	20.08	6.39	21.80	3.87	22.39	4.19

Female	**Settled (n=53)**		**Semi-nomadic (n=54)**		**Nomadic (n=28)**	
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**
Age	38.30	13.30	32.89	10.07	29.29	8.84
BMI	18.99	4.75	17.93	1.93	18.52	1.77
Body Fat %	23.54	7.76	21.46	6.57	20.57	5.80
Sum of Skinfolds	39.35	24.76	35.68	15.27	34.46	14.98
Systolic BP	116.20	14.53	111.61	15.32	108.75	11.10
Diastolic BP	84.20	9.69	80.98	11.72	78.39	9.53
HH Size	7.19	3.76	7.76	2.65	7.07	2.36
Ind. Income (Ksh)	1923.46	7135.64	2010.15	12344.52	807.41	1935.09
HH Income (Ksh)	3900.38	8879.72	3247.00	12361.54	1703.57	2150.49
Livestock	30.87	71.77	25.04	85.59	53.29	107.08
Education	1.70	1.93	1.33	1.53	1.39	1.55
Times Moved	NA	NA	3.39	1.89	13.57	7.31
SES Ladder	8.22	1.70	8.21	2.01	6.59	2.71
HWISE	25.13	9.84	27.24	7.73	34.14	7.37
HFIAS	20.45	6.51	21.19	4.20	22.10	3.93

Table 18: Supplement: Prevalence of hypertension, underweight, and overweight by categorized movement strategy.

Male (n = 107)	**Settled (n = 37)**	**Semi-Nomadic (n = 48)**	**Nomadic (n = 22)**
Age	50.4 ±16.3	45.5 ±15.0	41.8 ±15.8
Hypertension (%)	36.1%	27.7%	4.8%
Underweight (%)	73.0%	77.1%	68.2%
Overweight (%)	5.4%	0.0%	0.0%

Female (n = 135)	**Settled (n = 53)**	**Semi-Nomadic (n = 54)**	**Nomadic (n = 28)**
Age	38.3 ±13.3	32.9 ±10.1	29.3 ±8.8
Hypertension (%)	31.4%	21.6%	14.3%
Underweight (%)	54.7%	61.1%	50.0%
Overweight (%)	7.5%	0.0%	0.0%

Hypertension defined as systolic BP ≥140 mmHg and/or diastolic bp ≥90 mmHg (Unger et al., 2020). Underweight and overweight defined as having a BMI ≤18.5 and ≥ 25.0, respectively.

Table 19: Models of the relationships between milk consumption, lifestyle variation, and hypertension.

	Dependent variable:		
	Milk Consumption (per/day)		Hypertensive (=1)
	OLS		*logistic*
	(1)	(2)	(3)
Age	-0.012	-0.010	0.023*
	(0.009)	(0.009)	(0.012)
Sex	-0.0005	0.029	-0.167
	(0.267)	(0.256)	(0.370)
(log) Market Distance	**0.685*****	**0.407****	**-0.574****
	(0.164)	(0.172)	(0.235)
Movement Pattern (Semi-Nomadic=1)		**-1.554*****	
		(0.328)	
Movement Pattern (Settled=2)		**-1.409*****	
		(0.360)	
Milk Consumption			**-0.255****
			(0.106)
Constant	-0.143	1.844**	0.294
	(0.694)	(0.798)	(0.920)
Observations	217	217	210
R^2	0.100	0.189	
Adjusted R^2	0.087	0.169	
Log Likelihood			-110.668
Akaike Inf. Crit.			231.336
Residual Std. Error	1.775 (df = 213)	1.693 (df = 211)	
F Statistic	7.853*** (df = 3; 213)	9.805*** (df = 5; 211)	
Note:			*p<0.1; **p<0.05; ***p<0.01

References

Adair, L.S., Fall, C.H., Osmond, C., Stein, A.D., Martorell, R., Ramirez-Zea, M., Sachdev, H.S., Dahly, D.L., Bas, I., Norris, S.A., et al. (2013). Associations of linear growth and relative weight gain during early life with adult health and human capital in countries of low and middle income: findings from five birth cohort studies. The Lancet *382*, 525–534.

Adongo, A.O., Shell-Duncan, B., and Prisca Tuitoek, J. (2013). Effect of settlement on nutrition and health status of pastoral Gabra women of reproductive age in Kalacha Location, Marsabit County, Kenya. Public Health Nutrition *16*, 1622–1630.

Alberts, S.C., Altmann, J., Brockman, D.K., Cords, M., Fedigan, L.M., Pusey, A., Stoinski, T.S., Strier, K.B., Morris, W.F., and Bronikowski, A.M. (2013). Reproductive aging patterns in primates reveal that humans are distinct. Proceedings of the National Academy of Sciences of the United States of America *110*, 13440–13445.

Alderman, H., and Headey, D. (2018). The timing of growth faltering has important implications for observational analyses of the underlying determinants of nutrition outcomes. PLoS ONE *13*, e0195904.

Almagor, U. (1978). Pastoral partners: affinity and bond partnership among the Dassanatch of South-West Ethiopia. Manchester: Manchester University Press.

Andersen, N.J., Mondal, T.K., Preissler, M.T., Freed, B.M., Stockinger, S., Bell, E., Druschel, C., Buck Louis, G.M., and Lawrence, D.A. (2014). Detection of immunoglobulin isotypes from dried blood spots. Journal of Immunological Methods *404*, 24–32.

Aronoff, S.L., Berkowitz, K., Shreiner, B., and Want, L. (2004). Glucose Metabolism and Regulation: Beyond Insulin and Glucagon. Diabetes Spectrum *17*, 183–190.

Barclay, A. and Weaver, L. (2006). Feeding the normal infant, child and adolescent. Medicine *34*, 551-556.

Barkey, N.L., Campbell, B.C., and Leslie, P.W. (2001). A Comparison of Health Complaints of Settled and Nomadic Turkana Men. Medical Anthropology Quarterly *15*, 391–408.

Bethancourt, H.J., Swanson, Z.S., Nzunza, R., Huanca, T., Conde, E., Kenney, W.L., Young, S.L., Ndiema, E., Braun, D., Pontzer, H., Rosinger, A.Y. (2020). Hydration in relation to water insecurity, heat index, and lactation status in two small-scale populations in hot-humid and hot-arid environments. *American Journal of Human Biology.*

Bhan, M.K., Bahl, R., and Bhandari, N. (2001). Infection: how important are its effects on child nutrition? In *Nutrition and Growth*, Martorell, R. and Haschke, F. Philadelphia. Lippincott Williams and Wilkins, 197-217.

Blackwell, A.D., Snodgrass, J.J., Madimenos, F.C., and Sugiyama, L.S. (2010). Life history, immune function, and helminths: trade-offs among immunoglobulin E, C-reactive protein, and growth in an Amazonian population. American Journal of Human Biology *22*, 836–848.

Bocquet-Appel, J.-P. (2011). When the World's Population Took Off: The Springboard of the Neolithic Demographic Transition. Science *333*, 560–561.

Bogin, B. & Smith, B.H. (2012). *Evolution of the Human Life Cycle*, in Stinson, S., Bogin, B., O'Rouke, D. Human Biology (eds.): An Evolutionary and Biocultural Perspective, Second Edition. Wiley, 515-586.

Bogin, B. (1999). Patterns of Human Growth (2nd Ed.). Cambridge University Press.

Bogin, B. (2009). Childhood, adolescence, and longevity: A multilevel model of the evolution of reserve capacity in human life history. American Journal of Human Biology *21*, 567–577.

Boru, H.J., and Koske, J.K.A. (2014). Climate Variability and Response Strategies among the Gadamoji Agro-Pastoralists of Marsabit County, Kenya. International Journal of Humanities and Social Science *4*, 10.

Brainard, J.M. (1991). Health and Development in a Rural Kenyan Community. New York. Peter Lang Publishing.

Brindle, E., Fujita, M., Shofer, J., and O'Connor, K.A. (2010). Serum, plasma, and dried blood spot high-sensitivity C-reactive protein enzyme immunoassay for population research. Journal of Immunological Methods *362*, 112–120.

Brown, J.H., Gillooly, J.F., Allen, A.P., Savage, V.M., and West, G.B. (2004). Toward a Metabolic Theory of Ecology. Ecology *85*, 1771–1789.

Byron, E.M. (2003). Market integration and health: the impact of markets and acculturation on the self-perceived morbidity, diet, and nutritional status of the Tsimane'Amerindians of lowland Bolivia. University of Florida.

Campbell, B., Gray, P.B., and Leslie, P. (2005). Age-related changes in body composition among Turkana males of Kenya. American Journal of Human Biology *17*, 601–610.

Carr, C.J.. (1977). Pastoralism in Crisis: The Dasanetch and their Ethiopian Lands. The University of Chicago, Chicago, Illinois.

Catley, A., Lind, J., and Scoones, I. (2016). The futures of pastoralism in the Horn of Africa: pathways of growth and change. Revue Scientifique et Technique de l'OIE *35*, 389–403.

Centers for Disease Control and Prevention (CDC). (2019). Hypertension Cascade: Hypertension Prevalence, Treatment and Control Estimates Among US Adults Aged 18 Years and Older Applying the Criteria from the American College of Cardiology and American Heart Association's 2017 Hypertension Guideline—NHANES 2013–2016. Atlanta, GA: US Department of Health and Human Services.

Charnov, E.L. (1986). Life History Evolution in a "Recruitment Population": Why Are Adult Mortality Rates Constant? Oikos *47*, 129.

Charnov, E.L. (1991). Life history invariants: some explorations of symmetry in evolutionary ecology. Oxford, UK: Oxford University Press.

Charnov, E.L., and Berrigan, D. (1993). Why do female primates have such long lifespans and so few babies? or Life in the slow lane. Evolutionary Anthropology: Issues, News, and Reviews *1*, 191–194.

Cole, T. (2007). Babies, bottles, breasts: is the WHO growth standard relevant? Significance *4*, 6–10.

Cole, T.J., and Green, P.J. (1992). Smoothing reference centile curves: The lms method and penalized likelihood. Statistics in Medicine *11*, 1305–1319.

de Onis, M. (2007). Development of a WHO growth reference for school-aged children and adolescents. Bulletin of the World Health Organization *85*, 660–667.

de Onis, M., and Branca, F. (2016). Childhood stunting: a global perspective. Matern Child Nutr *12*, 12–26.

de Onis, M., Blössner, M., and Borghi, E. (2012). Prevalence and trends of stunting among pre-school children, 1990–2020. Public Health Nutrition *15*, 142–148.

Dewey, K.G., Mayers, D.R. (2011). Early child growth: how do nutrition and infection interact? *Maternal & Child Nutrition 7*, 129-142.

Diekmann, Y., Smith, D., Gerbault, P., Dyble, M., Page, A.E., Chaudhary, N., Migliano, A.B., and Thomas, M.G. (2017). Accurate age estimation in small-scale societies. Proceedings of the National Academy of Sciences *114*, 8205–8210.

Dounias, E., and Froment, A. (2006). When forest-based hunter-gatherers become sedentary: consequences for diet and health. *57*, 8.

Eaton, S.B., Konner, M.J., Shostak, M. (1988). Stone Agers in the Fast Lane: Chronic Degenerative Diseases in Evolutionary perspective. The American Journal of Medicine *84*, 739–747.

Eaton, S.B., Strassman, B.I., Nesse, R.M., Neel, J.V., Ewald, P.W., Williams, G.C., Weder, A.B., Eaton, S.B., Lindeberg, S., Konner, M.J. (2002). Evolutionary Health Promotion. Preventive Medicine *34*, 109–118.

Ellis, J.E., Galvin, K., McCabe, J.T., and Swift, D.M. (1987). Pastoralism and drought in Turkana District, Kenya. A report to Norad. Bellevue, CO.

Ellison, P.T. (1990). Human Ovarian Function and Reproductive Ecology: New Hypotheses. American Anthropologist *92*, 933–952.

Ellison, P.T. (1994). Advances in Human Reproductive Ecology. Annual Review of Anthropology *23*, 255–275.

Ellison, P.T. (2003). Energetics and reproductive effort. American Journal of Human Biology *15*, 342–351.

Ellison, P.T. (2014). Evolutionary Tradeoffs. Evol Med Public Health *2014*, 93.

Ellison, P.T. (2017). Endocrinology, energetics, and human life history: A synthetic model. Hormones and Behavior *91*, 97–106.

FAO/WHO/UNU (2001). Human energy requirements. FAO Food and Nutrition Technical Report Series 1.

Fratkin, E., and Roth, E.A. (2005). As Pastoralists Settle: social, health, and economic consequences of the pastoral sedentarization in Marsabit District, Kenya. Kluwer Academic / Plenum Publishers, New York.

Fratkin, E., Roth, E.A., and Nathan, M.A. (2004). Pastoral Sedentarization and Its Effects on Children's Diet, Health, and Growth Among Rendille of Northern Kenya. Human Ecology *32*, 531–559.

Frisancho A.R. (2008). Anthropometric standards: an interactive nutritional reference of body size and body composition for children and adults. - Ann Arbor: University of Michigan Press, 2011.

Froehle, A.W., and Churchill, S.E. (2009). Energetic Competition Between Neandertals and Anatomically Modern Humans. PaleoAnthropology, 96-116.

Fujita, M., Roth, E.A., Nathan, M.A., and Fratkin, E. (2004). Sedentism, seasonality, and economic status: A multivariate analysis of maternal dietary and health statuses between pastoral and agricultural Ariaal and Rendille communities in northern Kenya. American Journal of Physical Anthropology *123*, 277–291.

Gallagher, D., Heymsfield, S.B., Heo, M., Jebb, S.A., Murgatroyd, P.R., and Sakamoto, Y. (2000). Healthy percentage body fat ranges: an approach for developing guidelines based on body mass index. The American Journal of Clinical Nutrition *72*, 694–701.

Galvin, K.A. (1992). Nutritional ecology of pastoralists in dry tropical Africa. American Journal of Human Biology *4*, 209–221.

Galvin, K.A., Beeton, T.A., Boone, R.B., and BurnSilver, S.B. (2015). Nutritional Status of Maasai Pastoralists under Change. Hum Ecol Interdiscip J *43*, 411–424.

Godoy, R., Reyes-Garcıa, V., Byron, E., Leonard, W.R., Vadez, V. (2005). The effect of market economies on the well-being of indigenous peoples and on their use of renewable natural resources. Annu Rev Anthropol 34:121–138

Gonzalez-Viana, E., Dworzynski, K., Murphy, M.S., and Peek, R. (2017). Faltering growth in children: summary of NICE guidance. BMJ j4219.

Gurven, M., and Walker, R. (2006). Energetic demand of multiple dependents and the evolution of slow human growth. Proceedings of the Royal Society B: Biological Sciences *273*, 835–841.

Gurven, M., Stieglitz, J., Trumble, B., Blackwell, A.D., Beheim, B., Davis, H., Hooper, P., and Kaplan, H. (2017). The Tsimane Health and Life History Project: Integrating anthropology and biomedicine. Evol Anthropol *26*, 54–73.

Gurven, M.D., Trumble, B.C., Stieglitz, J., Yetish, G., Cummings, D., Blackwell, A.D., Beheim, B., Kaplan, H.S., and Pontzer, H. (2016). High resting metabolic rate among Amazonian forager-horticulturalists experiencing high pathogen burden. American Journal of Physical Anthropology *161*, 414–425.

Hagen, E.H., Barrett, H.C., and Price, M.E. (2006). Do human parents face a quantity-quality tradeoff?: Evidence from a Shuar community. American Journal of Physical Anthropology *130*, 405–418.

Hermanussen, M. (2016). Stunted Growth. *European Journal of Clinical Nutrition 70*, 647-649.

Hill, K. (2005). Life history theory and evolutionary anthropology. Evolutionary Anthropology: Issues, News, and Reviews *2*, 78–88.

Hill, K., & Hurtado, M. (1996). Ache Life History: The Ecology and Demography of a Foraging People. New York: Aldine de Gruyter.

Hill, K., and Kaplan, H. (1999). Life History Traits in Humans: Theory and Empirical Studies. Annual Review of Anthropology *28*, 397–430.

Hruschka, D.J. (2020). One size does not fit all. How universal standards for normal height can hide deprivation and create false paradoxes. American Journal of Human Biology

Jaeggi, A.V., Blackwell, A.D., Rueden, C. von, Trumble, B.C., Stieglitz, J., Garcia, A.R., Kraft, T.S., Kaplan, H., and Gurven, M. (2020). Relative wealth and inequality associate with health in a small-scale subsistence society (Public and Global Health).

James, G.D., Gerber, L.M. (2018) Measuring arterial blood pressure in humans: Auscultatory and automatic measurement techniques for human biological field studies. Am J Hum Biol. 30(1). doi: 10.1002/ajhb.23063.

Janson, C.H. & Van Schaik, C.P. (1993). *Ecological risk aversion in juvenile primates: slow and steady wins the race*. in Perieira, M.E., and Fairbanks, L.A. (eds.): Juvenile Primates: Life History, Development, and Behavior. New York: Oxford University Press. 57–74.

Kaplan, H., Hill, K., Lancaster, J., and Hurtado, A.M. (2000). A theory of human life history evolution: Diet, intelligence, and longevity. Evolutionary Anthropology: Issues, News, and Reviews *9*, 156–185.

Katz, S.H., Hediger, M.L., Zemel, B.S., and Parks, J.S. (1985). Adrenal androgens, body fat and advanced skeletal age in puberty: new evidence for the relations of adrenarche and gonadarche in males. *Human Biology, 57*, 401-413.

Kenya National Bureau of Statistics (KNBS). (2019). 2019 Kenya Population and Housing Census: Volume IV.

Klonoff, D.C., Ahn, D., and Drincic, A. (2017). Continuous glucose monitoring: A review of the technology and clinical use. Diabetes Research and Clinical Practice *133*, 178–192.

Lane, P.J. (2013). The archaeology of pastoralism and stock-keeping in East Africa. The Oxford Handbook of African Archaeology. 585-601.

Larrea, C. & Kawachi, K. (2005). Does economic inequality affect child malnutrition? The case of Ecuador. Social Science and Medicine *60*. 165–178.

Lawson, D.W., Alvergne, A., and Gibson, M.A. (2012). The life-history trade-off between fertility and child survival. Proc Biol Sci *279*, 4755–4764.

Lea, A.J., Martins, D., Kamau, J., Gurven, M., and Ayroles, J.F. (2020). Urbanization and market integration have strong, nonlinear effects on cardiometabolic health in the Turkana. Sci. Adv. *6*, eabb1430.

Leslie, P.W., Campbell, K.L., and Little, M.A. (1993). Pregnancy Loss in Nomadic and Settled Women in Turkana, Kenya: A Prospective Study. Human Biology *65*, 237–254.

Liebert, M.A., Snodgrass, J.J., Madimenos, F.C., Cepon, T.J., Blackwell, A.D., and Sugiyama, L.S. (2013). Implications of market integration for cardiovascular and metabolic health among an indigenous Amazonian Ecuadorian population. Annals of Human Biology *40*, 228–242.

Liebmann, B., Hoerling, M.P., Funk, C., Bladé, I., Dole, R.M., Allured, D., Quan, X., Pegion, P., and Eischeid, J.K. (2014). Understanding Recent Eastern Horn of Africa Rainfall Variability and Change. Journal of Climate *27*, 8630–8645.

Little, M.A. (1989). Human biology of African pastoralists. American Journal of Physical Anthropology *32*, 215–247.

Little, M.A. (2015). Pastoralism. In: M.P. Muehlenbein, ed., *Basics in Human Evolution*, 1st ed. London: Elsevier, 337-348.

Little, M.A., and Gray, S.J. (1990). Growth of Young Nomadic and Settled Turkana Children. Medical Anthropology Quarterly *4*, 296–314.

Little, M.A., and Leslie, P.W. (1999). Turkana herders of the dry savanna: ecology and biobehavioral response of nomads to an uncertain environment. Oxford; New York. Oxford University Press.

Little, M.A., Galvin, K., and Mugambi, M. (1983). Cross-Sectional Growth of Nomadic Turkana Pastoralists. Human Biology *55*, 811–830.

Little, M.A., Gray, S.J., and Leslie, P.W. (1993). Growth of nomadic and settled Turkana infants of northwest Kenya. American Journal of Physical Anthropology *92*, 273–289.

Little, P., Mahmoud, H., and Coppock, D. (2001). When deserts flood: risk management and climatic processes among East African pastoralists. Climate Research *19*, 149–159.

Lukaski, H.C., Bolonchuk, W.W., Hall, C.B., and Siders, W.A. (1986). Validation of tetrapolar bioelectrical impedance method to assess human body composition. Journal of Applied Physiology *60*, 1327–1332.

Mace, R. (2000). Evolutionary ecology of human life history. Animal Behaviour *59*, 1–10.

Maggi, S., Irwin, L.J, Siddiqi, A., & Hertzman, C. (2010). The social determinants of early childhood development: An overview. Journal of Paediatrics and Child Health *46*, 627-635.

Manus, M.B. (2018). Evolutionary mismatch. Evol Med Public Health *2018*, 190–191.

Martin, M., Blackwell, A., Kaplan, H., and Gurven, M. (2019). Differences in Tsimane children's growth outcomes and associated determinants as estimated by WHO standards vs. within-population references. PLoS ONE *14*, e0214965.

McDade, T.W., Leonard, W.R., Burhop, J., Reyes-García, V., Vadez, V., Huanca, T., and Godoy, R.A. (2005). Predictors of C-reactive protein in Tsimane' 2 to 15-year-olds in lowland Bolivia. American Journal of Physical Anthropology *128*, 906–913.

McDade, T.W., Williams, S.A. (Sharon A.A., and Snodgrass, J.J. (2007). What a Drop Can Do: Dried Blood Spots as a Minimally Invasive Method for Integrating Biomarkers into Population-Based Research. Demography *44*, 899–925.

MoALF. (2017). Climate Risk Profile for Marsabit County. Kenya County Climate Risk Profile Series. The Ministry of Agriculture, Livestock and Fisheries (MoALF), Nairobi, Kenya.

Müller, B., Linstädter, A., Frank, K., Bollig, M., and Wissel, C. (2007). Learning from Local Knowledge: Modeling the Pastoral-Nomadic Range Management of the Himba, Namibia. Ecological Applications *17*, 1857–1875.

Mwamidi, D.M., Renom, J.G., Fernández-Llamazares, Á., Burgas, D., Domínguez, D., Cabeza, M. (2018). Contemporary Pastoral Commons in East Africa as OECMS: A Case Study From the Daasanach Community. PARKS *24*, 79-88.

Opiyo F., Nyangito, M., Wasonga, O.V., Omondi, P. (2014). Trend Analysis of Rainfall and Temperature Variability in Arid Environment of Turkana, Kenya. *Environmental Research Journal. 8(2)*, 30-43.

Page, A.E., Minter, T., Viguier, S., and Migliano, A.B. (2018). Hunter-gatherer health and development policy: How the promotion of sedentism worsens the Agta's health outcomes. Social Science & Medicine *197*, 39–48.

Page, A.E., Viguier, S., Dyble, M., Smith, D., Chaudhary, N., Salali, G.D., Thompson, J., Vinicius, L., Mace, R., and Migliano, A.B. (2016). Reproductive trade-offs in extant hunter-gatherers suggest adaptive mechanism for the Neolithic expansion. Proceedings of the National Academy of Sciences *113*, 4694–4699.

Pedersen, J., and Benjaminsen, T.A. (2008). One Leg or Two? Food Security and Pastoralism in the Northern Sahel. Human Ecology *36*, 43–57.

Pike, I.L. (1999). Age, reproductive history, seasonality, and maternal body composition during pregnancy for nomadic Turkana of Kenya. American Journal of Human Biology *11*, 658–672.

Pike, I.L. (2000). Pregnancy outcome for nomadic Turkana pastoralists of Kenya. American Journal of Physical Anthropology *113*, 31–45.

Pike, I.L., and Williams, S.R. (2006). Incorporating psychosocial health into biocultural models: Preliminary findings from Turkana women of Kenya. American Journal of Human Biology *18*, 729–740.

Pontzer, H. (2015). Energy Expenditure in Humans and Other Primates: A New Synthesis. Annual Review of Anthropology *44*, 169–187.

Pontzer, H., Brown, M.H., Raichlen, D.A., Dunsworth, H., Hare, B., Walker, K., Luke, A., Dugas, L.R., Durazo-Arvizu, R., Schoeller, D., et al. (2016a). Metabolic acceleration and the evolution of human brain size and life history. Nature *533*, 390.

Pontzer, H., Raichlen, D.A., Gordon, A.D., Schroepfer-Walker, K.K., Hare, B., O'Neill, M.C., Muldoon, K.M., Dunsworth, H.M., Wood, B.M., Isler, K., et al. (2014). Primate energy expenditure and life history. Proceedings of the National Academy of Sciences *111*, 1433–1437.

Raichlen, D.A., Pontzer, H., Harris, J.A., Mabulla, A.Z.P., Marlowe, F.W., Snodgrass, J.J., Eick, G., Berbesque, J.C., Sancilio, A., and Wood, B.M. (2017). Physical activity patterns and biomarkers of cardiovascular disease risk in hunter-gatherers. American Journal of Human Biology *29*, e22919.

Read, A.F., and Harvey, P.H. (1989). Life history differences among the eutherian radiations. Journal of Zoology *219*, 329–353.

Rehman, A.M., Gladstone, B.P., Verghese, V.P., Muliyil, J., Jaffar, S., and Kang, G. (2009). Chronic growth faltering amongst a birth cohort of Indian children begins prior to weaning and is highly prevalent at three years of age. Nutr J *8*, 44.

Roberts, D.F. (1953). Body weight, race and climate. American Journal of Physical Anthropology *11*, 533–558.

Rosinger, A.Y. (2021). Drinking water salinity is associated with hypertension and hyperdilute urine among Daasanach pastoralists in Northern Kenya. Science of the Total Environment 14.

Roth, E.A., Nathan, M.A., and Fratkin, E. (2005). *The effects of pastoral sedentarization on children's growth and nutrition among Ariaal and Rendille in Northern Kenya*, in Fratkin, E., and Roth, E.A. As Pastoralists Settle. Kluwer Academic / Plenum Publishers, 173-208.

Rufino, M.C., Thornton, P.K., Ng'ang'a, S.K., Mutie, I., Jones, P.G., van Wijk, M.T., and Herrero, M. (2013). Transitions in agro-pastoralist systems of East Africa: Impacts on food security and poverty. Agriculture, Ecosystems & Environment *179*, 215–230.

Ruff, C.B. (1991). Climate and body shape in hominid evolution. Journal of Human Evolution *21*, 81–105.

Ruff, C.B. (1994). Morphological adaptation to climate in modern and fossil hominids. American Journal of Physical Anthropology *37*, 65–107.

Saha, K.K., Frongillo, E.A., Alam, D.S., Arifeen, S.E., Persson, L.Å., and Rasmussen, K.M. (2009). Use of the new World Health Organization child growth standards to describe longitudinal growth of breastfed rural Bangladeshi infants and young children. Food Nutr Bull *30*, 137–144.

Santos-Lozano, A., Santín-Medeiros, F., Cardon, G., Torres-Luque, G., Bailón, R., Bergmeir, C., Ruiz, J., Lucia, A., and Garatachea, N. (2013). Actigraph GT3X: Validation and Determination of Physical Activity Intensity Cut Points. International Journal of Sports Medicine *34*, 975–982.

Saunders, J., and Smith, T. (2010). Malnutrition: causes and consequences. Clin Med (Lond) *10*, 624–627.

Schell, L. (1986). Community Health Assessment Through Physical Anthropology: Auxological Epidemiology. Human Organization *45*, 321–327.

Schell-Duncan, B. (1995). Impact of seasonal variation in food availability and disease stress on the health status of nomadic Turkana children: a longitudinal analysis of morbidity, immunity, and nutritional status. American Journal of Human Biology *7*, 339-355.

Schmidt-Nielsen, K. (1984). Scaling: Why is Animal So Important? Cambridge University Press, Cambridge.

Schreider, E. (1950). Geographical Distribution of the Body-Weight/Body-Surface Ratio. Nature *165*, 286–286.

Schreider, E. (1964). Ecological Rules, Body-Heat Regulation, and Human Evolution. Evolution *18*, 1–9.

Sellen, D.W. (1999a). Growth patterns among seminomadic pastoralists (Datoga) of Tanzania. American Journal of Physical Anthropology *109*, 187–209.

Sellen, D.W. (1999b). Polygyny and child growth in a traditional pastoral society: The case of the datoga of Tanzania. Human Nature *10*, 329–371.

Shanahan, L., Copeland, W.E., Worthman, C.M., Erkanli, A., Angold, A., and Costello, E.J. (2013). Sex-Differentiated Changes in C-Reactive Protein from Ages 9 to 21: The Contributions of BMI and Physical/Sexual Maturation. Psychoneuroendocrinology *38*, 2209–2217.

Shinde, S.S., and Kakade, S.V. (2019). The LMS Method and Its Extention for Constructing Smoothed Centile Curves of Weight for Age for 5-10 Years Children. International Journal of Scientific Research in Mathematical and Statistical Sciences *6*, 14.

Shrimpton, R., Victora, C.G., de Onis, M., Lima, R.C., Blossner, M., and Clugston, G. (2001). Worldwide Timing of Growth Faltering: Implications for Nutritional Interventions. PEDIATRICS *107*, e75–e75.

Snodgrass, J.J. (2012). *Human Energetics*, in Stinson, S., Bogin, B., O'Rouke, D. Human Biology (eds.): An Evolutionary and Biocultural Perspective, Second Edition. Wiley, 325-384.

Speakman, J.R. (2005). Body size, energy metabolism and lifespan. Journal of Experimental Biology *208*, 1717–1730.

Spencer, P.R., Sanders, K.A., Amaral, P.C., and Judge, D.S. (2016). Household resources and seasonal patterns of child growth in rural Timor-Leste. American Journal of Human Biology *29*, e22916.

Spencer, P.R., Sanders, K.A., Amaral, P.C., and Judge, D.S. (2017). Household resources and seasonal patterns of child growth in rural Timor-Leste. American Journal of Human Biology *29*, e22916.

Stasinopoulos, D.M., and Rigby, R.A. (2007). Generalized Additive Models for Location Scale and Shape (GAMLSS) in *R*. Journal of Statistical Software *23*.

Stearns, S.C. (1989). Trade-Offs in Life-History Evolution. Functional Ecology *3*, 259.

Stearns, S.C. (1992). The Evolution of Life Histories. Oxford; New York. Oxford University Press.

Stinson, S. (2012). *Growth Variation: Biological and Cultural Factors*, in Stinson, S., Bogin, B., O'Rouke, D. Human Biology (eds.): An Evolutionary and Biocultural Perspective, Second Edition. Wiley, 587-635.

Strassmann, B.I., and Gillespie, B. (2002). Life-history theory, fertility and reproductive success in humans. Proceedings of the Royal Society B: Biological Sciences *269*, 553–562.

Sudfeld, C. R. et al. (2015). Malnutrition and Its Determinants Are Associated with Suboptimal Cognitive, Communication, and Motor Development in Tanzanian Children. J Nutr 2015;145:2705–14.

Ulijaszek, S.J. (2006). The International Growth Standard for Children and Adolescents Project: Environmental Influences on Preadolescent and Adolescent Growth in Weight and Height. Food Nutr Bull *27*, S279–S294.

Ulijaszek, S.J., Johnston, F.E., Preece, M.A. (1998). The Cambridge encyclopedia of human growth and development. Cambridge: Cambridge University Press.

Unger, T., Borghi, C., Charchar, F., Khan, N.A., Poulter, N.R., Pradhakaran, D., Ramirez, A., Schlaich, M., Stergiou, G.S., Tomaszewski, M. (2020). International Society of Hypertension Global Hypertension Practice Guidelines. Hypertension *75(6), 1334-1357.*

Urlacher, S.S., and Kramer, K.L. (2018). Evidence for energetic tradeoffs between physical activity and childhood growth across the nutritional transition. Scientific Reports *8*.

Urlacher, S.S., Blackwell, A.D., Liebert, M.A., Madimenos, F.C., Cepon-Robins, T.J., Gildner, T.E., Snodgrass, J.J., and Sugiyama, L.S. (2016). Physical growth of the shuar: Height, Weight, and BMI references for an indigenous amazonian population: Shuar Physical Growth. American Journal of Human Biology *28*, 16–30.

Urlacher, S.S., Ellison, P.T., Sugiyama, L.S., Pontzer, H., Eick, G., Liebert, M.A., Cepon-Robins, T.J., Gildner, T.E., and Snodgrass, J.J. (2018). Tradeoffs between immune function and childhood growth among Amazonian forager-horticulturalists. Proceedings of the National Academy of Sciences *115*, E3914–E3921.

Urlacher, S.S., Snodgrass, J.J., Dugas, L.R., Madimenos, F.C., Sugiyama, L.S., Liebert, M.A., Joyce, C.J., Terán, E., and Pontzer, H. (2021). Childhood Daily Energy Expenditure Does Not Decrease with Market Integration and Is Not Related to Adiposity in Amazonia. The Journal of Nutrition nxaa361.

Vétérinaires Sans Frontières (VSF-RISPA). (2013) Regional Initiative in Support of Vulnerable pastoralist and Agro-Pastoralist in the Horn of Africa - RISPA (FAO/PFS) Project FAO PFS Project - 0SRO/RAF/RAF/011/EC. Final Report. Reporting Period: July 2011–July 2013.

Victora, C.G., de Onis, M., Hallal, P.C., Blossner, M., and Shrimpton, R. (2010). Worldwide Timing of Growth Faltering: Revisiting Implications for Interventions. PEDIATRICS *125*, e473–e480.

Walker, R., Gurven, M., Hill, K., Migliano, A., Chagnon, N., De Souza, R., Djurovic, G., Hames, R., Hurtado, A.M., Kaplan, H., et al. (2006). Growth rates and life histories in twenty-two small-scale societies. American Journal of Human Biology *18*, 295–311.

Waterlow, J.C. (1994). Introduction. Causes and mechanisms of linear growth retardation (stunting). European Journal of clinical nutrition (0954-3007). 48.

Wells, J.C., Saunders, M.A., Lea, A.S., Cortina-Borja, M., and Shirley, M.K. (2019). Beyond Bergmann's rule: Global variability in human body composition is associated with annual average precipitation and annual temperature volatility. American Journal of Physical Anthropology *170*, 75–87.

Westerterp, K.R., Meijer, G.A.L., Janssen, E.M.E., Saris, W.H.M., and Hoor, F.T. (1992). Long-term effect of physical activity on energy balance and body composition. British Journal of Nutrition *68*, 21.

World Health Organization (2006). Global recommendations on physical activity for health. (Geneva: World Health Organization).

World Health Organization (2010). Global recommendations on physical activity for health. (Geneva: World Health Organization).

Zeng, W., Eisenberg, D.T., Jovel, K.R., Undurraga, E.A., Nyberg, C., Tanner, S., Reyes-Garcıa, V., et al. (2013). Adult obesity: panel study from native Amazonians. Econ Hum Biol 11:227–235

Zhang, Y., Zhou, J., Niu, F., Donowitz, J.R., Haque, R., Petri, W.A., and Ma, J.Z. (2017). Characterizing early child growth patterns of height-for-age in an urban slum cohort of Bangladesh with functional principal component analysis. BMC Pediatr *17*.

Ziegler, E.E., Nelson, S.E. (2012). The WHO growth standards: strengths and limitations. Current Opinion in Clinical Nutrition & Metabolic Care 15(3):298-302.

Zinsstag, J., Schelling, E., Bonfoh, B., Crump, L., and KräTli, S. (2016). The future of pastoralism: an introduction. Revue Scientifique et Technique de l'OIE *35*, 335–355.

Biography

Zane Swanson is a Ph.D. candidate in the Evolutionary Anthropology Department at Duke University. He attended Boston University as an undergraduate, where he received his B.A. in Anthropology with Honors in May of 2014. In 2015, he started his graduate school career as a Ph.D. student in Biological Anthropology at the CUNY Graduate Center as a member of the New York Consortium in Evolutionary Primatology. In August of 2018, he transferred to the Evolutionary Anthropology Department at Duke University as a Ph.D. student and continuing member of the Pontzer Lab, led by Dr. Herman Pontzer.

Zane has been author or co-author on several publications. They include his authorship of, *Water Turnover Among Human Populations: Effects of Environment and Lifestyle*, and co-authorship of, *Drinking water salinity is associated with hypertension and hyperdilute urine among Daasanach pastoralists in Northern Kenya* (Benthancourt et al., 2020); *Hydration in relation to water insecurity, heat index, and lactation status in two small-scale populations in hot-humid and hot-arid environments* (Rosinger et al., 2021); and *Midtarsal break variation in modern humans: Functional causes, skeletal correlates, and paleontological implications* (DeSilva et al., 2015).

Honors, awards, and fellowships received: Phi Beta Kappa, 2014; CUNY Graduate Fellowship, 2015-2018; TriCEM Graduate Award, 2019; Duke Graduate Fellowship, 2018-2020; Duke Grad School Summer Fellowship, 2020; Duke Dissertation Research Travel Award, 2020; and the Duke Sloan Administrative Internship, 2020-2021.