Family Socioeconomic Status and Child Telomere Length among the Samburu of Kenya

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ABSTRACT

Previous research in high-income countries suggests that children from families with lower socioeconomic status (SES) tend to have shorter telomere length – a biomarker of stress and cell aging – than children from families with greater social and economic resources. However, little is known about predictors of child telomere length in low-income settings. Data for the current study are from a sample of 214 Samburu children aged 1-9 years. The Samburu are semi-nomadic pastoralists who live in the Rift Valley of north-central Kenya. Samburu livelihood is based primarily on livestock, and polygynous marriage is common. Drawing on prior ethnographic research, we measured 14 culturally relevant indicators of family SES, including mother's education, head of household's education, whether the child is currently attending school, household spending, mother's employment history, head of household's employment history, mother's perceived wealth, whether the child lives in a modern house, livestock holdings (total, cows, sheep/goats, and camels), mother's wife number, and whether the child lives in a polygynous household. Telomere length was measured in salivary DNA by the quantitative polymerase chain reaction (qPCR) method. Using latent class analysis, we identified four groups of children that are similar based on the 14 indicators of family SES: *Lower SES*; *Middle SES, Traditional*; *Middle SES, Modern*; and *Higher SES*. SES classes were not significantly associated with child telomere length. In models examining individual indicators of SES, we found that telomere length was 0.57 standard deviations greater for children who lived in families in the lowest quartile of total livestock holdings compared to those in the highest quartile (b=0.57, p=0.03). While additional research is needed to identify the mechanisms underlying this counterintuitive finding, the current study highlights the importance of cultural context in shaping the social gradient in health.

Keywords: socioeconomic status; telomere length; children; Samburu; Kenya

Family Socioeconomic Status and Child Telomere Length among the Samburu of Northern Kenya

A growing number of studies in Europe and the US have examined whether family socioeconomic status (SES) is associated with child telomere length (for recent reviews, see Coimbra et al., 2017; Rentscher et al., 2020; Willis et al., 2018), a biomarker of stress and cell aging (Aubert & Lansdorp, 2008; Epel, 2009). Despite some null findings (see, for example, Drury et al., 2015; Needham et al., 2017), there is mounting evidence that children from lower SES families, as indicated by parental education, occupation, or income, have shorter telomere length than their more advantaged peers (Bosquet Enlow et al., 2018; Martens et al., 2020a; Mitchell et al., 2014; Needham et al., 2012; Wojcicki et al., 2016). This is consistent with prior research linking greater stress exposure to shorter telomere length (Shalev et al., 2013). Hypothesized mechanisms underlying the association between family SES and child telomere length include differences in material conditions, such as housing and diet quality, as well as differences in psychosocial factors, such as social standing and financial strain. Despite the accumulation of evidence demonstrating an association between family SES and child telomere length in high-income, Western countries, it is unclear whether this finding extends to other cultural contexts where the construct of SES, the magnitude of social inequality, and the relationship between SES and health may differ. In this study, we examine the association between family SES and child telomere length in a sample of Samburu children aged 1-9 years.

The Samburu of Kenya

The Samburu are semi-nomadic pastoralists who live in the Rift Valley of north-central Kenya, an area characterized by frequent droughts. Samburu households typically consist of 2-5 polygynous families living in settlements spread over a wide area, though not all men practice polygyny. In our sample, for example, 47% of households are polygynous. Livelihood is based primarily on livestock, which are distributed among wives within households. While livestock are herded in common, each wife retains use rights (but not exchange rights, which are held by her husband) for animals that were allocated to her upon marriage. Samburu men typically inherit livestock from their mothers, but they may also obtain animals through the livestock trade (usually with earnings from wage labor), charity (generally after a raid), or theft (most often from neighboring pastoralist groups). Although age at marriage has been trending lower for men in recent years, they are not permitted to marry until after the ceremony of the bull, which takes place near the end of their roughly 15-year period as a warrior tasked with care and defense of the community and its livestock herds. Having more than one wife is traditionally a source of prestige for Samburu men, while being a first wife confers prestige and power to Samburu women (Holtzman, 1999; Spencer, 1965; Straight, 1997).

Livestock are the most important source of income and wealth for Samburu, but decreased availability of pasturelands, chronic food and water insecurity, and the emergence of economic opportunities near towns have led some households to engage in alternative income-earning strategies (Lesorogol, 2008; Straight, 1997). By the late 1990s, rural Samburu, particularly those in the lowlands, had begun to refer to Samburu as *mzungui narok* (literally, black Europeans) if they adopted practices Samburu associated with Europeans, such as converting to Christianity, attending school, and working for pay (Straight, 1997). Although the term is still in occasional use, formal education and wage labor have been incorporated as typical, even strategic, features of Samburu identity among those who live near towns, as well as those who live in rural areas. Thus, in addition to livestock holdings, number of wives (for men), and wife number (for women), education and employment have become important markers of socioeconomic status for many contemporary Samburu.

SES and Health

Previous research in high-income countries has consistently shown that higher SES is associated with better health outcomes from infancy through late life (Marmot & Wilkinson, 2006). This is true for a wide variety of health outcomes, ranging from infectious diseases like tuberculosis (Khan et al., 2013) to chronic diseases like major depressive disorder (Muntaner et al., 2004), asthma (Kozyrskyj et al., 2010), and cardiovascular disease (de Mestral & Stringhini, 2017). Though fewer studies have examined the association between SES and health in low- and middle-income countries, much of the extant literature supports the hypothesis that low SES is a risk factor for morbidity and mortality, regardless of a country's level of economic development (Marmot et al., 2008). Notable exceptions include obesity, which shows a reverse social gradient in low-income countries (Dinsa et al., 2012), and diabetes, which shows a reverse social gradient in low- and middle-income countries (Williams et al., 2018).

According to the theory of fundamental causes (Link & Phelan, 1995), SES is a fundamental cause of health because it determines access to flexible social and material resources, such as money, education, prestige, power, and beneficial social connections, which can be used to prevent disease or to minimize the consequences of disease. This theory is based on the observation that low SES is associated with persistent health inequalities despite changes over time in diseases, health risks, and treatments. Though initially developed to explain the social patterning of health in post-industrial countries (Phelan et al., 2010), the theory of fundamental causes has also been used to study health outcomes in developing countries (see, for example, Stratton et al., 2008).

Research on SES and health among the Samburu is limited, but we were able to identify three previous studies that examined nutrition-related outcomes. In the first of these studies, Iannotti and Lesorogol (2014a) found that goat and cattle ownership were associated with more milk consumption among children, while sheep ownership and household income were associated with less milk consumption. In the second study, the same authors found that income, head of household education, and cattle and chicken ownership were positive determinants of household dietary diversity; livestock ownership predicted nutrient adequacy for vitamins A, B12, and zinc; and income predicted vitamin C adequacy (Iannotti & Lesorogol, 2014b). In the third study, which focused on adolescents, Ianotti and colleagues (Under review) found lower copper and zinc levels for children of second or higher order wives compared to first wives; higher zinc levels for children of first wives; higher levels of selenium for children whose families owned sheep and goats; and a negative association of total livestock holdings with magnesium levels. Taken together, the results of these studies suggest that children and adolescents from higher SES families tend to have better nutrition, although results vary somewhat across different indicators of SES.

Telomere Length

Telomeres are the protective caps at the ends of chromosomes that promote chromosomal stability. Due to the end replication problem, telomeres shorten every time a cell divides (Harley et al., 1990). Oxidative damage and DNA replication stress also contribute to telomere shortening (Blackburn et al., 2015; von Zglinicki, 2002). Telomerase can counteract shortening by elongating and protecting telomeres (Blackburn, 1997), but this enzyme is kept downregulated in normal human cells (Blackburn et al., 2015). Once telomeres become critically shortened, cellular senescence is triggered, causing cells to lose the ability to grow and divide (Blackburn, 2000; Blasco, 2005). Telomere shortening is considered a hallmark indicator of biological aging (Kennedy et al., 2014; Lopez-Otin et al., 2013), and recent studies suggest that short telomere length may be a causal determinant of cardiovascular disease and longevity, as well as some types of cancer (Aviv et al., 2015; Codd et al., 2013; Gao et al., 2020; Haycock et al., 2017).

Older people tend to have shorter telomeres than younger people (Muezzinler et al., 2013), but there is substantial inter-individual variation in telomere length, beginning at birth (Factor-Litvak et al., 2016). Heritability estimates range from 30% to 80% (Blackburn et al., 2015), suggesting that telomere length is determined by both genetic and environmental factors. Previous research in the US has shown that SES (Alexeeff et al., 2019; Needham et al., 2013) and factors that are downstream from SES, including perceived stress (Schutte & Malouff, 2016) and food insecurity (Mazidi et al., 2017), are key environmental predictors of telomere length. Given the paucity of research on telomere length in developing countries, it is important to assess replicability of patterns observed in high-income countries in different social contexts. Furthermore, while most prior work has focused on adults, the results of recent longitudinal studies suggest that telomere dynamics are largely determined by telomere length at birth and the rate of attrition during the first two decades of life (Benetos et al., 2013; Benetos et al., 2019; Martens et al., 2020b). For this reason, scholars have called for additional research on the early life determinants of telomere length (Aviv & Shay, 2018).

Hypotheses

We hypothesize that family SES will be positively associated with child telomere length, such that children from higher SES families will have longer telomere length than children from lower SES families. SES is a latent, or unobservable, variable that includes the social and economic factors that shape a person's position in society (Lynch & Kaplan, 2000). Though not directly measureable, we can estimate SES using various observed indicators. Drawing on nearly three decades of ethnographic fieldwork led by members of our multidisciplinary research team, we examine the following culturally-relevant indicators of family SES: mother's education, head of household's education, whether the child is currently in school, household spending, mother's employment history, head of household's employment history, mother's perceived wealth, whether the child lives in a modern house, livestock holdings, mother's wife number, and whether the child lives in a polygynous household. First, we use latent class analysis (LCA) to identify groups of children that are similar based on markers of family SES. While LCA has theoretical and practical advantages over examining individual indicators of SES, one limitation of this approach is that study results are not directly actionable. Thus, in addition to examining latent SES classes, we also examine individual indicators to determine whether specific components of family SES are associated with child telomere length.

METHODS

Data

Between October 2017 and November 2018, members of our research team recruited 105 mothers from rural Samburu communities to participate in a mixed methods study designed to explore the health-related consequences of in utero exposure to an extreme drought in 2008-2009. Women were eligible to participate in the study if they had one child who was exposed to the drought during the first trimester of pregnancy and one or more same-sex children who were born at least two years post-drought. The final sample includes 105 mothers, 105 drought-exposed children, and 109 unexposed siblings. Informed consent was obtained at enrollment and at each study visit. Parents provided consent, and children provided assent. All consent documents and instrumentation were translated and back translated by multilingual Samburu research assistants. The consent and assent processes were performed by a multilingual Samburu research team member working together with a member of the senior research team who is fluent in Kiswahili and conversationally competent in Samburu. Data were collected between January 2018 and July 2019 using various methods, including participant-observation, caregiver interviews, anthropometric measurement, and biospecimen collection. Sociodemographic data were collected from the mother at the first and second visits, and saliva samples were obtained through passive drool collected from the children at the second visit using the OG-500 kit from Oragene (DNA GonoTek, Ottawa, OT, Canada). Nine children who were away from home during the second visit did not provide saliva samples. A detailed description of the study methodology is available in the supplemental materials. Human subjects approval for this study was granted by Western Michigan University, and permission to conduct research was granted by Kenya's National Commission for Science, Technology, and Innovation.

Measures

Dependent variable. The DNA Agencourt DNAdvance kit (cat# A48705, Beckman Coulter Genomics Inc., Brea, CA, USA) was used to extract DNA from saliva samples, and the quantitative polymerase chain reaction (q-PCR) method was used to measure telomere length relative to standard reference DNA (T/S ratio), as described in detail elsewhere (Cawthon, 2002; Lin et al., 2010). Telomere length is typically measured in whole blood or peripheral blood mononuclear cells, but previous studies have shown that the q-PCR method can be used to measure telomere length in saliva, which includes both leukocytes and buccal cells (Lin et al., 2019). While telomere length is correlated across tissues, leukocyte telomere length is hypothesized to be a marker of immune cell aging, whereas buccal cell telomere length may reflect influences on brain development because they share the same ectoderm origin as neural tissues (Lin et al., 2019). DNA extraction and the telomere length assay were performed in the Blackburn Lab at the University of California, San Francisco. All DNA samples were run on 0.8% agarose gels to check DNA integrity. One degraded DNA sample was excluded from the analysis. Each of the remaining 204 samples was assayed at least twice, each in triplicate wells. T/S ratios that fell into the 7% variability range were accepted, and the average of the two was taken as the final value. A third assay was run for samples with greater than 7% variability, and the average of the two closest T/S values was used. The inter-assay coefficient of variation (CV) was 2.2% $\pm$ 1.9%, and the intraclass correlation coefficient (ICC) was 0.97. Additional details about the telomere assay are available in the supplemental materials.

Independent variable. SES indicators include mother's education (no formal education vs. any formal education), head of household's education (no formal education vs. any formal education), whether the child is currently in school (no vs. yes), quartiles of per wife household spending (in Kenya shillings), mother's employment history (never worked for pay vs. ever worked for pay), head of household's employment history (never worked for pay vs. ever worked for pay), mother's perceived wealth (low, medium, or high), whether the child lives in a modern house (no vs. yes), quartiles of per wife total livestock holdings (in tropical livestock units, TLUs[1]), quartiles of per wife number of cows, quartiles of per wife number of sheep and/or goats, per wife number of camels (none vs. any), mother's wife number (other than first vs. first), and whether the household is polygynous (no vs. yes). We used a measure of spending rather than a measure of income because we have observed that reports of spending are more reliable. Samburu wives generally know how much money is spent on family needs but are less

[1] To calculate TLUs, weights are applied to different categories of livestock according to the current exchange values in the community (Ensminger, 1992; Jahnke, 1982). One TLU is equivalent to 0.7 camels, 1 cow, 10 sheep, or 11 goats.

likely to know how much cash their husbands have available. Furthermore, we used per wife measures of spending and livestock holdings, rather than total household measures, because they provide a more accurate estimate of the resources available to children who live in polygynous families. Per wife estimates are considered preferable to per capita measures given the challenges inherent in obtaining an accurate head count for the number of individuals who belong to one semi or fully nomadic polygynous family.

Covariates. Covariates include age (in years), age squared (to account for potential nonlinearity in the association between age and telomere length), sex (female=1; male=0), head of household's age set cohort as a proxy for father's age (dummy variables for Cohorts 1 + 2 and Cohort 3, with Cohorts 4 + 5 as the reference category), and region (1=highlands; 0=lowlands). While it is not feasible to obtain accurate data on father's age, age set cohort is a reasonable proxy. Samburu men are initiated as warriors during their late teens or early twenties. The year in which they are initiated corresponds to an age set, or cohort. Our data set includes men from five age set cohorts: Cohort 1 includes the *Lkishami*, who were initiated beginning in 2006 and are the youngest cohort in our sample; Cohort 2 includes the *Lmooli*, who were initiated beginning in 1990; Cohort 3 includes the *Lkiroro*, who were initiated beginning in 1976; Cohort 4 includes the *Lkishili*, who were initiated beginning in 1961; and Cohort 5 includes the *Lkimaniki*, who were initiated beginning in 1948 and are the oldest cohort in our sample. Region and father's age are hypothesized to be common causes of SES and telomere length and are, therefore, treated as potential confounders. The other covariates are established correlates of telomere length. Controlling for them may improve precision of model estimates (Schisterman et al., 2009). We do not control for in utero exposure to drought for two reasons. First, given the sibling design, there is no correlation between drought exposure and family SES. Thus, drought exposure cannot be a confounder of the association between SES and child telomere length. Next, while controlling for drought exposure may increase precision of model estimates (to the extent that it is a predictor of telomere length), exposure to drought is collinear with age. Given the importance of age as a predictor of telomere length, we believe it is more important to adjust for age than for exposure to drought.

Analysis Plan

First, we used latent class analysis (LCA), a technique for identifying unobservable subgroups within a population, to identify groups of children that are similar based on markers of family SES, including education, employment, spending, wealth, and family structure. LCA is similar to other data reduction techniques, such as cluster analysis, but has the advantage of being model-based. LCA uses maximum-likelihood methods to estimate the probability of class membership, and the technique can accommodate any combination of continuous, categorical, or count variables. Standardization of variables is not required. Model fit statistics, including the AIC and BIC, can be used along with theory or prior knowledge (in this case, our team's decades-long history of ethnographic fieldwork in Samburu communities) to identify the number of classes in the data (Vermunt & Magidson, 2004). We estimated the LCA in Mplus (Version 7) using full information maximum likelihood (Muthen & Muthen, 1998-2012). The analytic sample for this part of the analysis includes all children (n=214).

Next, we used linear multi-level models, which account for the clustering of children within families, to estimate the association between the latent SES classes and telomere length z-score, controlling for age, age squared, sex, head of household's age set cohort, and region. The analytic sample for this part of the analysis includes 198 children with complete data on telomere length, SES latent classes, and the covariates. Next, we regressed telomere length z-score on each of the individual SES indicators. Due to collinearity between measures of livestock holdings, we ran separate models for (1) quartiles of per wife TLUs and (2) quartiles of per wife number of cows, quartiles of per wife number of sheep and/or goats, and per wife number of camels. The analytic sample for this part of the analysis includes 186 children with complete data on telomere length, the individual SES indicators, and the covariates.

In sensitivity analyses, we examined sex, region, and in utero drought exposure as potential moderators of the association between the latent SES classes and telomere length z-score. We examined sex as a potential moderator because some previous studies have found that the association between family SES and child telomere length is stronger among boys than girls (Bosquet Enlow et al., 2018; Martens et al., 2020a). We examined region and in utero drought exposure as potential moderators to determine whether the association between family SES and child telomere length depends on exposure to environmental stressors. On average, temperatures are milder and rainfall is greater in the highlands versus the lowlands, placing residents of the lowlands under greater physiologic stress. Similarly, children who were exposed to the 2008-2009 drought in utero likely experienced greater physiologic stress than their unexposed siblings.

RESULTS

As shown in Table 1, mean age for the final analytic sample is 6.73 years (SD=1.96). Just over 54% of the sample is female; 63% of children were born to fathers in the *Lmooli* age set cohort, who were initiated beginning in 1990; and 59.8% of the sample resides in the highlands. Approximately 20% of mothers have some formal education, compared to nearly 35% of household heads. Despite low levels of formal education among parents, 77.1% of children are currently in school. Per wife monthly spending ranges from 400 to 20,000 Kenya shillings (approximately 4 to 200 US dollars). Just over half of mothers have ever worked for pay, compared to 60.5% of household heads. Most mothers (58.9%) report medium wealth, and just 12% of children live in a modern house. Total per wife livestock holdings range from 0 to 149 TLUs. Per wife number of cows ranges from 0 to 100; per wife number of sheep and/or goats ranges from 0 to 350; and per wife number of camels ranges from 0 to 10, with 81.3% of mothers reporting no camels. Nearly three-quarters of mothers are the first wife, and 46.7% of households are polygynous.

TABLE 1 ABOUT HERE

The results of the latent class analysis are shown in Table 2. We used 14 indicators of family SES to fit models with 1-5 latent classes (see supplementary Table S1 for the model fit statistics for each of the latent class models examined). Based on the model selection consistency of BIC and prior knowledge from our team's ethnographic fieldwork (Straight, 1997, 2007), we concluded that the four-class model with the smallest BIC value provided the best fit and interpretation for the data. Table 2 presents the proportions and conditional probabilities of responses for the four-class model.

TABLE 2 ABOUT HERE

The first row in Table 2 includes the estimated proportion of respondents that are most likely to belong in each SES class: 0.23 in the *Lower SES* class; 0.32 in the *Middle SES, Traditional* class; 0.21 in the *Middle SES, Modern* class; and 0.25 in the *Higher SES* class. The conditional probabilities presented in each of the remaining rows of Table 2 report the probability, within each latent class, of providing a particular response to each of the SES questions. The *Lower SES* class is characterized by low per wife spending per month, high maternal employment, and low per wife livestock holdings. The two middle SES classes are characterized by intermediate per wife livestock holdings but differ considerably with respect to other SES indicators. Household heads of children in the *Middle SES, Traditional* class are least likely to have formal education and are least likely to have worked for pay. Children in the *Middle SES, Traditional* class are least likely to be in school and most likely to live in a polygynous family, while their mothers are most likely to report high perceived wealth and are least likely to be a first wife. In contrast, household heads of children in the *Middle SES, Modern* class are most likely to have worked for pay; their mothers report high levels of per wife spending per month; and they are least likely to live in a polygynous household. Finally, the *Higher SES* class is characterized by high maternal education and high per wife livestock holdings.

As shown in Table 3, the latent SES classes are not significantly associated with child telomere length. Older children have shorter telomere length than younger children (b=-0.65, p=.02), but the age-squared term suggests that the association of age with telomere length is weaker among older children (b=0.04, p=0.05). There are no significant differences in telomere length by sex, head of household's age set cohort, or region. Associations between the latent SES classes and telomere length do not differ by child sex, region of residence, or in utero drought exposure (results not shown).

TABLE 3 ABOUT HERE

Analyses examining individual indicators of SES suggest that total livestock holdings are significantly associated with child telomere length. As shown in Model 1 of Table 4, telomere length is 0.57 standard deviations greater for children in the lowest quartile of per wife TLUs compared to children in the highest quartile (b=0.57, p=0.03). No other individual indicators of SES are significantly associated with child telomere length. Similar to the results for the SES latent classes, age is a significant predictor of child telomere length (b=-0.64, p=0.04 in Model 1; b=-0.64, p=.05 in Model 2), although the age squared term is only marginally significant in models examining individual indicators of SES (b=0.04, p=0.08 in Model 1; b=0.04, p=0.09 in Model 2). There are no significant differences in telomere length by sex, head of household's age set cohort, or region.

TABLE 4 ABOUT HERE

DISCUSSION

Consistent with the theory of fundamental causes, a number of studies in high-income countries have found that children from socioeconomically disadvantaged families have shorter telomere length than children from families with greater social and economic resources (Bosquet Enlow et al., 2018; Martens et al., 2020a; Mitchell et al., 2014; Needham et al., 2012; Wojcicki et al., 2016). This suggests that children from low SES families may be at increased risk for health-related outcomes associated with short telomere length, including cardiovascular disease, some types of cancer, and premature mortality (Aviv et al., 2015; Codd et al., 2013; Gao et al., 2020; Haycock et al., 2017). The purpose of this study was to extend prior research on family SES and child telomere length to a cultural context in which the construct of SES and the magnitude of social inequality differ markedly from the US and other high-income countries. Contrary to expectations, we found no significant association between family SES and child telomere length in models examining latent SES classes. When examining individual indicators of SES, we found that Samburu children from families with the lowest level of total livestock holdings, a key indicator of household wealth, had longer telomere length than children from families with the highest level of total livestock holdings. None of the other 13 individual indicators of SES was significantly associated with child telomere length.

Although research on telomere length in low- and middle-income countries is limited, we were able to identify two previous studies that examined parental education, a marker of family SES, as a predictor of child telomere length. First, a recent study in Pakistan found that maternal education is positively associated with newborn telomere length (Farrukh et al., 2019), which is consistent with findings from high-income countries. In contrast to these results, another study in six Mesoamerican countries found that parental education is inversely associated with child telomere length (Flannagan et al., 2017). The authors point to the nutrition transition as a potential explanation for this finding (Flannagan et al., 2017). In many low- and middle-income countries, economic development has resulted in less famine and increased access to high calorie foods, particularly among those with more resources (Popkin, 2006). While overnutrition may be a plausible explanation for the reverse social gradient in telomere length in Mesoamerican countries, it does not apply to rural Kenya, where extreme drought and diminishing pasture availability contribute to widespread undernutrition, even among youth whose families have the greatest social and economic resources (Iannotti & Lesorogol, 2014a).

Of the 14 SES indicators examined, only per wife TLUs, a measure of total livestock holdings, was significantly associated with child telomere length.[2] In general, previous research has shown that livestock ownership is associated with better nutrition outcomes among Samburu youth (Iannotti & Lesorogol, 2014a, b; Iannotti et al., Under review). However, the health benefits of better nutrition may be offset by the health risks associated with caring for livestock, including exposure to bacteria, viruses, and parasites (Hungerford, 1990). Previous research in humans has shown that infection with various pathogens is associated with shorter telomere length, while animal studies have demonstrated a causal effect of infection on telomere attrition

[2] A follow-up sensitivity analysis revealed similar results for total household TLUs (results not shown).

(Noppert et al., 2020). Research with other populations in Kenya has shown that practices such as consuming unpasteurized milk and raw blood, assisting in animal birth, and handling raw hides are common, particularly among pastoralists (Njenga et al., 2020).

During our own fieldwork, we have observed that Samburu – and we ourselves, as guests – routinely consume unpasteurized milk and raw blood. Samburu also assist in animal birth, slaughter their own animals (with young children present), prepare hides after animal slaughter, sleep on animal hides, and use animal hides as wall coverings. In addition, we have observed that Samburu often mix and apply pesticides to livestock without observing safety precautions. One of our mother respondents reported that her husband forced her to apply pesticides during her pregnancy. Pesticides are typically stored inside houses, where young children may accidentally ingest them. Children in wealthier families who own more livestock may have greater exposure to pesticides, which has been linked to shorter telomere length in previous research (Hou et al., 2013; Zhang et al., 2013). Future studies should explore the role of exposure to livestock-related diseases and pesticides in the socioeconomic patterning of child telomere length among the Samburu.

Overall, the results obtained in this study suggest that child telomere length is not strongly patterned by family SES among the Samburu. The only exception was for total livestock holdings, which, contrary to expectations, was associated with shorter rather than longer telomere length. One potential explanation for this pattern of results is that social inequality is less pronounced among the Samburu compared to other populations. Although power, prestige, and wealth are not equally distributed in Samburu society, the overall level of inequality is relatively low. And unlike the US, where residential segregation by income is commonplace, high and low SES Samburu live in close proximity to one another and interact frequently. An institutionalized form of begging, referred to as *paran*, provides materially for the poor; and despite widespread food insecurity, even among those with the most resources, it is considered socially unacceptable to turn away a hungry child or adult who asks for food (Holtzman, 2009; Straight, 2007). Although there is evidence that wealthy individuals are more likely than those with fewer resources to occasionally violate this norm, it remains intact (Lesorogol, 2007). Moreover, despite land tenure changes, Samburu land owners give grazing access to their friends and neighbors during droughts because this is considered a central aspect of group identity (Bollig & Lesorogol, 2016). Thus, despite extreme poverty in the region, social norms dictate that relatively affluent Samburu provide help to the poorest members of the community, which may help explain why we found limited support for the hypothesis that family SES is associated with child telomere length.

Strengths, Limitations, and Directions for Future Research

The primary strength of this analysis is the unique study population. While research on child telomere length has become increasingly common in the US and Europe, little is known about the predictors of cell aging among children in low- and middle-income countries. To our knowledge, this is the first study to examine child telomere length among the Samburu of Kenya, a group of semi-nomadic pastoralists whose livelihood is based primarily on livestock. Working with the Samburu requires linguistic and cultural competence, familiarity with the remote locations in which people live, and personal relationships built on trust. This multidisciplinary, mixed methods study would not have been possible without our team’s decades-long history of fieldwork in the area. In addition, the ability to measure telomere length in saliva, which can be stored at room temperature for at least 30 months with no significant degradation of DNA (Iwasiow et al., 2011), was essential to the success of this project.

Another strength of this analysis is the measurement of family SES. While social stratification exists in Samburu society, the markers of SES and their relative importance in determining social status differ markedly from other contexts. Drawing on prior ethnographic research (for example, Straight, 1997, 2007), we were able to measure multiple indicators of SES that are relevant to the Samburu, including parent education, child education, per wife monthly expenditures, parents' history of wage labor, mother's perceived wealth, type of house, per wife livestock holdings, mother's wife number, and family structure (polygynous vs. monogamous). In addition to measuring culturally relevant indicators of SES, we used two analytic approaches to examine the association between family SES and child telomere length. First, we used latent class analysis to generate a composite measure of SES based on 14 indicators of social and economic status. This technique allowed us to identify a small number of unobservable subgroups characterized by multiple dimensions of SES. Key advantages of this approach include a strong match between theory and methods, as well as the ability to examine highly correlated SES indicators in the same model. Next, we examined associations of individual SES indicators with child telomere length. An important advantage of this approach is that results are more useful in designing interventions to prevent accelerated cell aging.

Given that nearly half of our study participants live in polygynous families, we decided to use per wife measures of monthly expenditures and livestock holdings, rather than household measures, to more accurately reflect the resources available to each child. However, it should be noted that the use of per wife measures emphasizes the material resources component of SES over the social status component, which may be captured more accurately with household measures. Sensitivity analyses using household measures to identify the latent SES classes produced substantively similar results with respect to the latent class analysis and the regression of child telomere length on family SES (results not shown).

Study limitations include small sample size, failure to account for uncertainty in the latent class assignments, and a lack of data on potential mediators of the association between family SES and child telomere length. Given the challenges of recruitment and data collection, we were only able to obtain data on telomere length for 204 children. The small sample size limits power to detect an association between family SES and child telomere length. While the Southern blot method is preferred over the qPCR method for small samples, the Southern blot method cannot be performed on salivary DNA. Given that collection of blood is not feasible in this setting, larger studies are needed to confirm or refute the findings presented here. A second limitation of this study is that we treated the latent classes as observed variables. This is a common strategy when modeling latent classes as an exposure, but prior research has shown that failure to account for uncertainty in the latent class assignments may result in minor changes in effect estimates and p-values (Elliott et al., 2020). Finally, we do not have data on potential mediators of the association between family SES and child telomere length, including measures of exposure to livestock-related diseases and pesticides. Future studies should consider the role of these factors in explaining why children from families with the lowest total livestock holdings have longer telomere length than children from families with the highest total livestock holdings.

Conclusions

While a growing body of evidence suggests that family SES, as indicated by parental education, occupation, or income, is positively associated with child telomere length, the majority of previous studies have been conducted in high-income, post-industrial countries. In this study, we examined the association between family SES and child telomere length among the Samburu of Kenya, a population of semi-nomadic pastoralists whose livelihood is based primarily on livestock rather than wage labor. Contrary to expectations, we found that children from lower SES families, as indicated by total livestock holdings, had longer telomere length than children from higher SES families. While additional research is needed to identify the mechanisms underlying the association between livestock holdings and child telomere length among the Samburu, this study highlights the importance of cultural context in shaping the social gradient in health.

Table 1. Descriptive statistics for the full sample		
Variable	M, SD or %	n
Age, in years	6.73, 1.96	214
Child sex		
Female	54.2%	116
Male	45.8%	98
Head of household's age set cohort, year of initiation		
Cohort 1: *Lkishami*, 2006	2.9%	6
Cohort 2: *Lmooli*, 1990	63.0%	131
Cohort 3: *Lkiroro*, 1976	25.0%	52
Cohort 4: *Lkishili*, 1961	7.21%	15
Cohort 5: *Lkimaniki*, 1948	1.9%	4
Region		
Highlands	59.8%	128
Lowlands	40.2%	86
Mother's education		
No formal education	79.4%	170
Some formal education	20.6%	44
Head of household's education		
No formal education	65.4%	140
Some formal education	34.6%	74
Child in school		
No	22.9%	48
Yes	77.1%	162
Per wife spending per month, in Kenya shillings		
Quartile 1: 400-1500	27.6%	59
Quartile 2: >1500-3000	34.1%	73
Quartile 3: >3000-5000	19.6%	42
Quartile 4: >5000	18.7%	40
Mother's employment history		
Never worked for pay	48.1%	103
Ever worked for pay	51.9%	111
Head of household's employment history		
Never worked for pay	39.5%	81
Ever worked for pay	60.5%	124
Perceived wealth		
Low	19.2%	41
Medium	58.9%	126
High	22.0%	47
Modern house		
No	88.0%	184
Yes	12.0%	25

Per wife tropical livestock units, TLUs		
Quartile 1: 0-3.2	25.7%	55
Quartile 2: >3.2-6	25.2%	54
Quartile 3: >6-16	24.3%	53
Quartile 4: >16	24.8%	53
Per wife number of cows		
Quartile 1: 0-2	34.6%	74
Quartile 2: >2-5	26.6%	57
Quartile 3: >5-10	16.4%	35
Quartile 4: >10	22.4%	48
Per wife number of sheep and/or goats		
Quartile 1: 0-7	25.2%	54
Quartile 2: >7-19.25	24.8%	53
Quartile 3: >19.25-40	26.6%	57
Quartile 4: >40	23.4%	50
Per wife number of camels		
0	81.3%	174
>0	18.7%	40
Mother’s wife number		
Unmarried, second, third, fourth, or fifth	29.0%	62
First	71.0%	152
Polygynous household		
No	53.3%	114
Yes	46.7%	100
Telomere length, T/S ratio	1.46, 0.25	204

Table 2. Proportions and conditional probabilities of responses for four latent socioeconomic status (SES) classes (n=214)				
	Lower SES	**Middle SES, Traditional**	**Middle SES, Modern**	**Higher SES**
Proportion of sample in class	0.23	0.32	0.21	0.25
Mother's education				
No formal education	**0.79**	**0.83**	**0.82**	**0.74**
Some formal education	0.21	0.17	0.18	0.26
Head of household's education				
No formal education	**0.63**	**0.80**	**0.59**	**0.55**
Some formal education	0.37	0.20	0.41	0.45
Child in school				
No	0.19	0.31	0.22	0.17
Yes	**0.81**	**0.69**	**0.78**	**0.83**
Per wife spending per month, in Kenya shillings				
Quartile 1: 400-1500	**0.45**	**0.42**	0.00	0.15
Quartile 2: >1500-3000	0.43	0.28	0.23	**0.43**
Quartile 3: >3000-5000	0.04	0.18	**0.40**	0.19
Quartile 4: >5000	0.08	0.12	0.37	0.23
Mother's employment history				
Never worked for pay	0.08	**0.52**	**0.69**	**0.62**
Ever worked for pay	**0.92**	0.48	0.31	0.38
Head of household's employment history				
Never worked for pay	0.34	**0.63**	0.13	0.37
Ever worked for pay	**0.66**	0.37	**0.87**	**0.64**
Perceived wealth				
Low	0.37	0.16	0.00	0.23
Medium	**0.55**	**0.46**	**0.82**	**0.60**
High	0.08	0.38	0.18	0.17
Modern house				
No	**0.94**	**0.85**	**0.95**	**0.81**
Yes	0.06	0.15	0.05	0.19
Per wife tropical livestock units, TLUs				
Quartile 1: 0-3.2	**1.00**	0.03	0.09	0.00
Quartile 2: >3.2-6	0.00	**0.52**	0.41	0.00
Quartile 3: >6-16	0.00	0.44	**0.50**	0.00
Quartile 4: >16	0.00	0.00	0.00	**1.00**
Per wife number of cows				
Quartile 1: 0-2	**0.94**	0.21	0.32	0.00
Quartile 2: >2-5	0.06	**0.53**	**0.40**	0.00
Quartile 3: >5-10	0.00	0.23	0.23	0.17

Quartile 4: >10	0.00	0.03	0.05	**0.83**
Per wife number of sheep and/or goats				
Quartile 1: 0-7	**0.80**	0.22	0.00	0.00
Quartile 2: >7-19.25	0.20	**0.55**	0.08	0.04
Quartile 3: >19.25-40	0.00	0.21	**0.64**	0.28
Quartile 4: >40	0.00	0.03	0.28	**0.68**
Per wife number of camels				
0	**1.00**	**0.72**	**0.91**	**0.68**
>0	0.00	0.28	0.09	0.32
Mother's wife number				
Unmarried, second, third, fourth, or fifth	0.24	**0.61**	0.05	0.11
First	**0.76**	0.39	**0.95**	**0.89**
Polygynous household				
No	**0.57**	0.04	**1.00**	**0.76**
Yes	0.43	**0.96**	0.00	0.25
Note: AIC=4385.91; BIC=4705.68. Proportions in bold font are the most frequently reported response to each SES question, within the four latent classes.				

Table 3. Association between latent socioeconomic status (SES) classes and child telomere length (T/S ratio) z-score by linear mixed effects regression (n=198)

	Estimate	Standard Error	p-value
SES (Higher)			
Lower	0.31	0.25	0.21
Middle, traditional	0.14	0.23	0.54
Middle, modern	0.26	0.24	0.28
Age, in years	**-0.65**	**0.28**	**0.02**
Age^2	**0.04**	**0.02**	**0.05**
Female (Male)	0.07	0.17	0.67
Head of household's age set cohort (Cohorts 4 + 5)			
Cohorts 1 + 2	-0.38	0.31	0.21
Cohort 3	-0.27	0.17	0.41
Highlands (Lowlands)	0.02	0.17	0.88
Intercept	**2.31**	**0.88**	**0.01**

Note: Reference category is in parentheses. Model includes a random intercept for mother. Log likelihood=561.7; AIC=565.7; BIC=570.9. Estimates in bold font are significant at the $p \leq .05$ level.

Table 4. Association between socioeconomic status (SES) indicators and child telomere length (T/S ratio) z-score by linear mixed effects regression (n=186)						
	Model 1			Model 2		
	Estimate	Standard Error	P-value	Estimate	Standard Error	P-value
Mother's education						
No formal education (Some formal education)	-0.01	0.25	0.97	-0.01	0.26	0.97
Head of household's education						
No formal education (Some formal education)	-0.19	0.20	0.36	-0.27	0.22	0.23
Child in school						
Yes (No)	-0.16	0.20	0.41	-0.14	0.20	0.47
Per wife spending per month, in Kenya shillings (Quartile 4)						
Quartile 1	-0.23	0.31	0.47	-0.10	0.34	0.77
Quartile 2	0.30	0.26	0.26	0.32	0.29	0.26
Quartile 3	0.09	0.29	0.76	0.14	0.30	0.65
Mother's employment history						
Ever worked for pay (Never worked for pay)	-0.17	0.19	0.38	-0.12	0.20	0.55
Head of household's employment history						
Ever worked for pay (Never worked for pay)	0.12	0.20	0.56	0.20	0.21	0.34
Perceived wealth (High)						
Low	0.14	0.31	0.65	0.22	0.32	0.49
Medium	-0.05	0.24	0.83	0.07	0.26	0.78
Style of house						
Not modern (Modern)	-0.15	0.32	0.64	-0.23	0.34	0.49
Per wife tropical livestock units, TLUs (Quartile 4)						
Quartile 1	**0.57**	**0.26**	**0.03**	---	---	---
Quartile 2	0.07	0.27	0.80	---	---	---

Quartile 3	0.09	0.26	0.73	---	---	---
Per wife number of cows (Quartile 4)						
Quartile 1	---	---	---	0.17	0.33	0.60
Quartile 2	---	---	---	-0.10	0.34	0.77
Quartile 3	---	---	---	0.15	0.33	0.65
Per wife number of sheep and/or goats (Quartile 4)						
Quartile 1	---	---	---	0.38	0.40	0.34
Quartile 2	---	---	---	0.48	0.39	0.22
Quartile 3	---	---	---	0.10	0.33	0.75
Per wife number of camels						
0 (>0)	---	---	---	-0.32	0.33	0.35
Mother's wife number						
Never married, second, third, fourth, or fifth wife (First wife)	-0.07	0.25	0.78	-0.04	0.27	0.88
Polygynous household						
No (Yes)	0.21	0.24	0.38	-0.03	0.38	0.90
Age, in years	**-0.64**	**0.31**	**0.04**	**-0.64**	**0.32**	**0.05**
Age^2	0.04	0.02	0.08	0.04	0.02	0.09
Child sex						
Female (Male)	0.16	0.18	0.37	0.15	0.19	0.43
Head of household's age set cohort (Cohorts 4 + 5)						
Cohorts 1 + 2	-0.32	0.42	0.45	-0.46	0.45	0.31
Cohort 3	-0.15	0.40	0.70	-0.27	0.44	0.54
Region						
Highlands (Lowlands)	0.08	0.20	0.68	0.22	0.25	0.38
Intercept	**2.33**	**1.07**	**0.03**	**2.54**	**1.13**	**0.03**

Note: Reference category is in parentheses. Model includes a random intercept for mother. Model 1 log likelihood=530.0; AIC=534.0; BIC=539.1. Model 2 log likelihood=533.2; AIC=537.2; BIC=542.4. Estimates in bold font are significant at the $p \leq .05$ level.

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