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Material Hardship and Telomere Length in Children

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Analytic Code: Code is available from the first author.

Materials: The materials necessary to attempt to replicate the findings presented here are not publicly accessible.

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Abstract

Telomere length is a biomarker of exposure to stressors, including material hardship. Data from the Future of Families and Child Wellbeing Study (1998-2015) was utilized to determine whether prior material hardship is associated with shorter salivary telomere length at years 9 and 15. 49% of the year 9 study population were female, 49% were Black, and 25% were Hispanic. At year 9 (N = 1990), regression analyses found a significant association between prior material hardship and shorter telomere length (β = -.005, p < .01). Additionally, at year 15 (N = 1,874), material hardship experienced during infancy and toddlerhood was associated with shorter telomere length (β = -.009, p < .01), pointing towards infancy and toddlerhood as a sensitive period.

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Children from poor families experience worse health outcomes compared to their wealthier peers (Ashiabi et al., 2007), and the effect of poverty and low socioeconomic status on adverse child health operates in part through family stress and material deprivation (Chaudry et al., 2016). Until recently, researchers have been unable to identify the ways in which environmental factors "get under the skin" to increase the risk of poor health outcomes (King et al., 2017). Current literature suggests that accelerated biological aging, a phenomenon where "biological aging" (as measured by various biomarkers) outpaces chronological aging, may offer insights into how environmental factors alter biological characteristics and processes (Marini et al., 2018).

Telomeres consist of repetitive DNA sequences, TTAGGG tandem repeats, which form protective caps at the ends of chromosomes (Saretzki et al., 1999). With each round of cell division, telomere length (TL) decreases, limiting the potential number of subsequent divisions (Blackburn et al., 2015). Research demonstrates that once telomeres become critically short, the cell enters a state of replicative senescence and stops dividing (Counter et al., 1992; Wagner et al., 2009). Therefore, TL serves as an indicator of the replicative history of cells in a sample and acts as a mitotic clock that limits the lifespan of a cell (Harley et al., 1990). Human population studies show associations between shorter TL in adulthood and a wide range of diseases and health morbidities, including cancer (Ma et al., 2011), coronary artery disease (Willeit et al., 2010; Farzaneh-Far et al., 2010), type 2 diabetes mellitus (Zhao et al., 2013), dementia (Martin-Ruiz et al., 2006), mood disorders (Simon et al., 2006), and overall mortality (Cawthon et al., 2003; Rode et al., 2015). It is possible that shortening of average TL with chronic stress reflects increased division of cells involved in inflammation and tissue repair. Additionally, research has found associations between shorter TL in adulthood and stress exposure in intrauterine life

(Entringer et al., 2011), early life adversity (Ridout et al., 2018), and low socioeconomic status and poverty (Geronimus et al., 2015; Needham et al., 2013; Robertson et al., 2013).

Prior studies have also established links between shorter TL in childhood and various adversities, such as exposure to interpersonal violence and family disruption (Shalev et al., 2013; Drury et al., 2014), paternal loss or incarceration (Mitchell et al., 2017; Del Toro et al., 2022), neighborhood disorder (Theall et al., 2013), and social or neighborhood disadvantage (Massey et al., 2018; Mitchell et al., 2014). Nonetheless, this study introduces distinctive contributions to the literature on childhood adversity and TL. Existing evidence regarding the relation between material hardship and TL remains limited. Material hardship, defined as the inability to meet basic needs such as food, housing, medical care, and utilities, represents the exact economic stressors placed on families in ways that are not captured by strictly income-based poverty measures (Mayer et al., 1989; Heflin et al., 2009). It is important to note that experiencing extreme poverty, even for a short period, can lead to hardships surpassing those predicted by family income alone (Iceland et al., 2007), and that rates of material hardship do not decline significantly until families' earnings are double the poverty threshold income (Gershoff et al., 2007). Utilizing childhood TL as a marker for chronic stress due to material hardship can potentially provide a time-sensitive and graded predictor of the effect of this stress on long-term health. One prior study has analyzed the relationship between material hardship and TL, but it focused solely on TL in Latina/o children at year 9 (Niño, 2022).

The aforementioned research on the relation between childhood adversity and TL predominantly relies on measures at a single point in time, and very little is subsequently known about how the

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timing of environmental stressors influences TL (Cameron et al., 2002; Dunn et al., 2018). Early life stress, which coincides with sensitive developmental periods, is of particular interest to researchers due to its pervasive long-term impacts on physical and mental health. However, later developmental periods, such as early adolescence, also mark significant changes in emotion, cognition, growth, and relationships (Jones et al., 2019; Ellis et al., 2019). To address these gaps in the literature, this study utilizes recently assayed sTL data from the Future of Families and Child Wellbeing Study (formerly the Fragile Families and Child Wellbeing Study) to examine the association between material hardship across childhood and early adolescence and sTL at years 9 and 15, testing whether the timing of hardship exposure matters in its association with sTL.

Methods

Sample

The FFCWS is a longitudinal, stratified, multistage probability sample of a cohort of 4,898 children born between 1998 and 2000 in twenty large cities in the United States (Reichman et al., 2001). Motivated by the rise of single-parent households in the United States, the study, after approval by the Princeton University Institutional Review Board, oversampled births to unmarried parents by a three-to-one ratio. Consequently, the focal children are disproportionately from low-income, single-parent, racially and ethnically diverse families. As a result of the sampling process, the composition of the sample provides an optimal source of nationwide data to analyze the molecular consequences of material hardship and extend the current research beyond primarily focusing on individuals of European descent.

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Within 48 hours of their child's birth, baseline interviews were conducted with mothers and fathers, and subsequent data were collected when the children were 1, 3, 5, 9, and 15 years of age (Reichman et al., 2001). Salivary DNA samples were taken at years 9 and 15 with the Oragene DNA sample collection kit (DNA Genotek Inc, Ottawa, ON). The following two analytic samples were used for this study: (1) all children for whom we have year 9 sTL data and complete material hardship data from the prior four waves (N = 1,990); and (2) all children for whom we have year 15 sTL data and complete material hardship data from the prior five waves (N = 1,847). Therefore, the study population reflects a select group of FFCWS children whose caregivers remained active in the study through the six waves of data collection and provided saliva samples. 49% of the year 9 study population were female, 49% were Black, and 25% were Hispanic.

Telomere Measurement

The TL measurements were derived from saliva samples provided by the focal children, and the assays of genetic measures were conducted by the Notterman Laboratory at Princeton University. sTL was measured using a modified quantitative real-time polymerase chain reaction assay incorporating an 84-mer oligomer standard with the sequence TTAGGG to construct a standard curve and measure absolute TL in kilobases per chromosome (O'Callaghan et al., 2011). A different standard curve for a single-copy gene incorporated a 79-mer oligomer that represents the reference gene 36B4 and allowed for the calculation of total TL in a diploid genome. To calculate TL per chromosome, TL per genome was divided by 92, the number of telomeres per diploid genome. The samples were measured in triplicate, and the results were averaged. The distribution of samples in the 96-well plates was randomized.

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To monitor batch effects, reference DNA from a cell line with a relatively short TL (3C167b) and a fibroblast cell line after stable integration of the hTert gene (NHFpreT) were included in every plate (Wang et al., 2003; Cheng et al., 2017). Under the conditions used, the mean TL of 3C167b is 3.1 kb and of NHFpreT is 16.8 kb. The reference DNA was harvested, aliquoted, and frozen in a single batch to normalize TL and achieve consistency across different plate measurements. The measurement results from this sample allowed for the computation of an inter-run coefficient of variation, which was <11% across all runs. We estimated a two-way, single-measurement, absolute agreement, random effects model, known as ICC(A,1), and for average measurements ICC(A,k) in McGraw and Wong's terminology (McGraw et al., 1996). In total, there were 242 batches run for Year 9 (2007-2009) and 126 batches run for Year 15 (2013-2015). We calculated the ICC at both Year 9 (ICC (A,1) = .91, 95% CI [.82, 1.0]; ICC(A,k) = .99, 95% CI [.99, 1.0]) and Year 15 (ICC(A,1) = .95, 95% CI [.84, 1.0]; ICC(A,k) = .99, 95% CI [.99, 1.0]). To protect the sample against overly influential outliers, the focal children with sTLs below the 1st percentile or above the 99th percentile of the distribution were removed, and a natural log transformation was utilized.

Material Hardship

At each wave of data collection, each mother or primary caregiver, in the case of the year 15 survey, responded to eight questions regarding their inability to pay for the doctor, rent, or utilities, as well as experience being evicted, homeless, moving in with friends or family, receiving free food, or borrowing money from friends or family. At baseline and Years 1, 3, 5, and 9, the questions referred to the past twelve months. At Year 15, each item pertained to the

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past six years. The eight indicators were coded as binary variables, with 1 indicating that the focal child had experienced the material hardship. For each wave, a material hardship score ranging from 0 to 8 was constructed to represent the number of material hardship indicators experienced. Accumulated material hardship scores for the relevant life course periods of infancy and toddlerhood (0 to 3 years of age), childhood (4 to 9 years of age), and adolescence (9 to 15 years of age) were calculated by summing the constructed total material hardship scores for the relevant waves. Cumulative material hardship scores were also calculated for 0 to 9 years for the year 9 analytic sample and for 0 to 15 years for the year 15 analytic sample. Table 1 presents descriptive statistics for the constructed material hardship scores used in the analyses. Bivariate correlations indicated that the distribution of material hardship scores did not differ significantly ($p > .1$) before and after restricting the dataset to children with sTL data.

Controls

The control variables measured at the baseline interview include mother's self-reported race and ethnicity, child's sex at birth, mother's age at birth, mother's nativity, mother's education level at birth, whether parents were cohabitating at baseline, whether the child was low birth weight, mother's self-report of health at birth, if there was any domestic violence during the pregnancy, maternal smoking during pregnancy, maternal drinking during pregnancy, and maternal drug use during pregnancy. The categories for a mother's self-reported race and ethnicity included: Black (non-Hispanic), Hispanic or Latinx, Multi-racial (non-Hispanic), White (non-Hispanic), and Other (non-Hispanic), which included Alaskan Native, American Indian, Asian, Native Hawaiian, and Pacific Islander.

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Statistical Analysis

Descriptive statistics for the constructed and unconstructed variables were first summarized. To understand the relations between sTL and the control and material hardship variables, Pearson correlation coefficients were calculated (two-sided hypothesis testing). Finally, to investigate the relation between material hardship and sTL, Ordinary Least Squares regression (OLS) models were utilized. The natural log transformation of sTL (to accommodate right skew) was regressed onto our explanatory variables in a series of models that covered different periods of hardship exposure. All statistical analyses were performed using Stata Version 17.0 (Statacorp, College Station, Texas) with a priori level of significance of $\alpha = 0.05$. The analytical approach predominantly reflects a confirmatory effort to validate a predetermined hypothesis. However, due to the complexity of the dataset, the novel nature of the research question, and the investigation of different periods of hardship exposure, the methodology includes elements of exploratory analysis.

Results

Table 1 describes the characteristics of the two analytic samples, while Supplemental Table 1 compares these values with those of the excluded participants. In the year 9 study population, 49% were female, 49% were Black, and 25% were Hispanic. In comparison, in the year 15 population, 50% were female, 47% were Black, and 24% were Hispanic. The average sTL in the year 9 sample (N = 1,990) was 7.77 kb (2.18 - 18.54 kb), whereas the average in the year 15 sample (N = 1,874) was 8.08 kb (4.35 - 21.33 kb). For the year 9 sample, the average material hardship score at infancy and toddlerhood was 1.84 and at childhood was 2.11, while the average cumulative material hardship score was 3.95. Conversely, for the year 15 sample, the average

material hardship score at infancy and toddlerhood was 1.84, at childhood was 2.07, and at adolescence was 1.36, while the average cumulative material hardship score was 5.25.

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Table 1. Descriptive statistics of dependent and independent variables for the analytic samples (Year 9 Sample, *N* = 1,990; Year 15 Sample, *N* = 1,874)

	Year 9 sample				Year 15 sample			
	Mean/%	SD/N	Min.	Max.	Mean/%	SD/N	Min.	Max.
Dependent variables								
sTL at year 9	7.77	1.36	2.18	18.54	---	---	---	---
sTL at year 15	---	---	---	---	8.08	1.32	4.35	21.33
Independent variables								
Material hardship at Infancy and Toddlerhood	1.84	2.16	0	12	1.83	2.13	0	12
Material hardship at Childhood	2.11	2.30	0	13	2.07	2.26	0	11
Material hardship at Adolescence	---	---	---	---	1.36	1.67	0	8
Cumulative material hardship	3.95	3.93	0	23	5.25	4.94	0	27
Control variables (baseline)								
Race								
White	22.86	455	0	1	24.33	456	0	1
Black	49.30	981	0	1	47.33	887	0	1
Hispanic	24.52	488	0	1	24.33	456	0	1
Other	3.12	62	0	1	3.79	71	0	1
Child is female	48.89	973	0	1	50.21	941	0	1
Mother's age at birth	25.03	5..94	15	43	25.41	6.03	15	43
Mother's nativity	12.61	251	0	1	13.29	249	0	1
Mother's education level at birth								
Less than high school	30.15	600	0	1	29.08	545	0	1
High school	33.02	657	0	1	30.74	576	0	1
Some college	25.83	514	0	1	27.05	507	0	1
College graduate	11.01	219	0	1	12.97	243	0	1
Parent cohabitating at birth	60.40	1,202	0	1	61.74	1,157	0	1
Child is low birth weight	9.45	188	0	1	8.64	162	0	1
Mother's report of health at birth	54.57	1,086	0	1	0.53	10	0	1
Mother's report of partner violence	0.80	16	0	1	0.64	12	0	1
Mother smoking during pregnancy	18.69	372	0	1	18.04	338	0	1
Maternal drinking during pregnancy	9.70	193	0	1	10.51	197	0	1

Maternal drug use during pregnancy	4.22	84	0	1	4.00	75	0	1

Tables 2 and 3 summarize the bivariate correlations between the material hardship and sTL variables. A child's sTL at year 9 is negatively correlated with material hardship experienced during infancy and toddlerhood, childhood, and early adolescence. Furthermore, these three hardship measures are significantly correlated with each other. However, a child's sTL at year 15 is only negatively correlated with material hardship experienced during infancy and toddlerhood. Similarly, the hardship measures are significantly correlated with each other.

Table 2. Bivariate correlations of dependent and independent variables for the year 9 analytic sample (N = 1,990)

	sTL at year 9 (ln, trimmed)	Material hardship at Infancy and Toddlerhood	Material hardship at Childhood	Material hardship cumulative
sTL at year 9 (ln, trimmed)	1.0000			
Material hardship at Infancy and Toddlerhood	-0.0476**	1.0000		
Material hardship at Childhood	-0.0502**	0.5596***	1.0000	
Cumulative Material hardship	-0.0554**	0..8751***	0.8908***	1.0000

*** $p < .01$, ** $p < .05$, * $p < .1$

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Table 3. Bivariate correlations of dependent and independent variables for the year 15 analytic sample (N = 1,874)

	sTL at year 15 (ln, trimmed)	Material hardship at Infancy and Toddlerhood	Material hardship at Childhood	Material hardship at Adolescence	Material hardship cumulative
sTL at year 15 (ln, trimmed)	1.0000				
Material hardship at Infancy and Toddlerhood	-0.0557 **	1.0000			
Material hardship at Childhood	-0.0039	0.5508***	1.0000		
Material hardship at Adolescence	-0.0286	0.4063***	0.4918***	1.0000	
Cumulative Material hardship	-0.0355	0.8213***	0..8627***	0.7392***	1.0000

*** $p < .01$, ** $p < .05$, * $p < .1$

Tables 4 and 5 provide estimates for the association between material hardship and natural log-transformed sTL at years 9 and 15. When controlling for the aforementioned covariates, the material hardship experienced during both infancy and toddlerhood (β = -.008, $p < .05$) (Model 1) and childhood (β = -.008, $p < .01$) (Model 2) were negatively associated with sTL at year 9. Additionally, the cumulative measure of material hardship was negatively associated with sTL at year 9 (β = -.005, $p < .01$) (Model 3). Therefore, children who experience a greater number of material hardships before the age of nine have significantly shorter telomeres at year 9 than children who experience fewer hardships; children who experience one more material hardship than their comparable peers have, on average, a sTL that is 1.005 kb shorter.

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Table 4. Regression coefficients for accumulated material hardship scores versus sTL at year 9 (N = 1990)

VARIABLES	(1) Infancy and Toddlerhood	(2) Childhood	(3) Cumulative
Material Hardship Score	-0.00797**	-0.00845***	-0.00542***
	(0.00341)	(0.00322)	(0.00190)
Gender	0.0173	0.0184	0.0180
	(0.0141)	(0.0141)	(0.0141)
Black	0.0292	0.0305	0.0303
	(0.0198)	(0.0198)	(0.0198)
Hispanic	0.0437*	0.0428*	0.0431*
	(0.0238)	(0.0238)	(0.0237)
Other	-0.0217	-0.0200	-0.0192
	(0.0444)	(0.0444)	(0.0444)
Mother Foreign Born	0.0585**	0.0594**	0.0580**
	(0.0249)	(0.0249)	(0.0249)
Mother's Education Level at Birth: High School	-0.0266	-0.0275	-0.0275
	(0.0182)	(0.0182)	(0.0182)
Mother's Education Level at Birth: Some College	-0.0165	-0.0181	-0.0169
	(0.0199)	(0.0199)	(0.0199)
Mother's Education Level at Birth: College Graduate	-0.0852***	-0.0874***	-0.0888***
	(0.0301)	(0.0302)	(0.0302)
Mother's Age at Birth	0.00110	0.000999	0.000963
	(0.00137)	(0.00137)	(0.00137)
Parent's Relationship Status at Birth	0.000953	0.00163	0.00121
	(0.0155)	(0.0155)	(0.0155)
Low Birthweight	-0.0255	-0.0273	-0.0267
	(0.0245)	(0.0245)	(0.0245)
Mother's Self-Reported Health at Birth	-0.145	-0.142	-0.138
	(0.119)	(0.119)	(0.119)
Mother's Report of Partner Violence	0.0106	0.00660	0.0102
	(0.0789)	(0.0788)	(0.0788)
Maternal Smoking During Pregnancy	0.0112	0.0110	0.0130
	(0.0201)	(0.0201)	(0.0201)
Maternal Drinking During Pregnancy	0.0104	0.0106	0.0116
	(0.0248)	(0.0248)	(0.0248)
Maternal Drug Use During Pregnancy	0.00445	0.00740	0.00826
	(0.0367)	(0.0368)	(0.0368)
Constant	2.014***	2.019***	2.023***
	(0.0394)	(0.0396)	(0.0398)
Observations	1,986	1,986	1,986
R-squared	0.020	0.021	0.021

Standard errors in parentheses
*** $p < .01$, ** $p < .05$, * $p < .1$

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In contrast, Table 5 demonstrates that only material hardship experienced during infancy and toddlerhood (β = -.009, p < .01) (Model 1) was significantly associated with sTL in early adolescence (Year 15). Each additional experience of material hardship during this period is associated with an average 1.009 kb shorter sTL. Although not significant, the relations between sTL in early adolescence and material hardship in childhood (β = -.0006) (Model 2) and adolescence (β = -.005) (Model 3) were negative; sTL in early adolescence and cumulative material hardship were weakly negatively associated (β = -.002, p < .1) (Model 4).

Table 5. Regression coefficients for accumulated material hardship scores versus sTL at year 15 (N = 1,874)

VARIABLES	(1) Infancy and Toddlerhood	(2) Childhood	(3) Adolescence	(4) Cumulative
Material Hardship Score	-0.00893***	-0.000579	-0.00482	-0.00244*
	(0.00328)	(0.00308)	(0.00408)	(0.00144)
Gender	0.00307	0.00441	0.00454	0.00426
	(0.0131)	(0.0132)	(0.0132)	(0.0132)
Black	0.00209	0.00187	0.00335	0.00331
	(0.0181)	(0.0181)	(0.0182)	(0.0181)
Hispanic	0.0179	0.0189	0.0187	0.0177
	(0.0218)	(0.0219)	(0.0219)	(0.0219)
Other	-0.0294	-0.0320	-0.0324	-0.0309
	(0.0383)	(0.0384)	(0.0384)	(0.0383)
Mother Foreign Born	0.0299	0.0332	0.0331	0.0317
	(0.0230)	(0.0230)	(0.0230)	(0.0230)
Mother's Education Level at Birth: High School	-0.00302	-0.00248	-0.00212	-0.00290
	(0.0174)	(0.0175)	(0.0175)	(0.0175)
Mother's Education Level at Birth: Some College	0.0204	0.0186	0.0198	0.0199
	(0.0186)	(0.0186)	(0.0186)	(0.0186)
Mother's Education Level at Birth: College Graduate	-0.0217	-0.0142	-0.0152	-0.0189
	(0.0268)	(0.0269)	(0.0267)	(0.0269)
Mother's Age at Birth	0.000679	0.000931	0.000828	0.000731
	(0.00128)	(0.00128)	(0.00128)	(0.00128)
Parent's Relationship Status at Birth	0.00386	0.00525	0.00468	0.00411
	(0.0147)	(0.0148)	(0.0148)	(0.0148)
Low Birthweight	-0.000547	0.00220	0.00185	0.000650
	(0.0238)	(0.0238)	(0.0238)	(0.0238)
Mother's Self-Reported Health at Birth	0.172*	0.154*	0.158*	0.167*
	(0.0909)	(0.0912)	(0.0909)	(0.0912)

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Mother's Report of Partner Violence	0.0734	0.0555	0.0533	0.0591
	(0.0828)	(0.0827)	(0.0827)	(0.0827)
Maternal Smoking During Pregnancy	0.00295	-0.00418	-0.00238	0.000423
	(0.0188)	(0.0188)	(0.0187)	(0.0189)
Maternal Drinking During Pregnancy	0.00889	0.00513	0.00564	0.00708
	(0.0225)	(0.0225)	(0.0225)	(0.0225)
Maternal Drug Use During Pregnancy	0.0523	0.0450	0.0451	0.0490
	(0.0355)	(0.0356)	(0.0355)	(0.0356)
Constant	2.066***	2.044***	2.051***	2.061***
	(0.0368)	(0.0369)	(0.0365)	(0.0373)
Observations	1,867	1,867	1,867	1,867
R-squared	0.012	0.008	0.009	0.010

Standard errors in parentheses
*** $p < .01$, ** $p < .05$, * $p < .1$

Based on prior research, we also conducted sensitivity analyses to examine whether the results varied by the race or sex of the child and whether there was a nonlinear association between material hardship and sTL. Additional analyses included terms that interacted the constructed material hardship values with race or sex to test for differences in the association. We found no evidence that material hardship has different effects on sTL at year 9 or 15 depending on the race or sex of the child. We also evaluated nonlinearity in the association between material hardship and sTL by including a quadratic term for material hardship in our models; however, there was no evidence of nonlinearity.

Discussion

The study utilizes data from a longitudinal birth cohort to analyze the association between material hardship at three different life course stages and sTL in childhood and adolescence. We find that material hardship experienced during infancy and toddlerhood is significantly associated with shorter sTL in both children and adolescents, a conclusion that is consistent with previous literature pointing to material deprivation as a key source of stress for families. These

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findings also point towards infancy and toddlerhood being a sensitive period with regards to telomere attrition and suggest that the timing of hardship matters in relation to sTL. This hypothesis indicates that early life stress may have lasting biological consequences. When looking only at year 9 sTL, hardship experienced during childhood between ages four and nine is also negatively associated with sTL.

On the other hand, we find no association between hardship experienced after infancy and toddlerhood and sTL at year 15. This finding may be attributed to the biological complexities of puberty; during early adolescence, the sensitivity of the period between ages four and nine may decrease, leaving cumulative hardship experienced during infancy and toddlerhood as more significant for the rate of telomere attrition during early adolescence. Additionally, this finding may result from effect modification, which would indicate that the influence of childhood adversity on sTL is modified by a change in exposure to material hardship or by a competing cause for shortened sTL. During adolescence, competing causes may suppress the independent impact of material hardship during childhood.

This study has several limitations that must be acknowledged. TL measurements in individual people vary widely and are affected by measurement error (Aubert et al., 2012), disease- and development-related changes in the proportions of different cell types sampled in the saliva (Geronimus et al., 2021), and by the method of DNA processing (Raschenberger et al., 2016). These sources of variance are reflected in the observation that mean TL was slightly longer at 15 years than 9 years, possibly because the intrinsic variance in the measure exceeded the change in TL over 6 years. However, it is worth noting that this research employed the same laboratory and

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analytic conditions for all samples at both time points, and the ICC was within expected values (Lin et al., 2019).

Furthermore, it is crucial to note that while significant associations were observed between material hardship and sTL, the overall variance explained in these models remains limited. Although material hardship appears to play a role in TL attrition, the primary association between material hardship and TL may reflect unmeasured, collinear variables related to other adverse childhood experiences, including neglect, abuse, or parental separation. Also, while not directly measured in this study, the role of resilience, or the ability to bounce back from adversity, may have acted as a confounding variable, impacting both the experience of material hardship and the maintenance of telomere length.

The study is also limited by the fact that sTL was only measured at two distinct points, despite the material hardship measures being collected prospectively since birth. The data analysis relied on between-person comparisons of sTL rather than capturing changes over time within individuals. This methodology largely precluded us from asserting a causal relation between material hardship and attrition. Although a longitudinal study would better support an assertion of causality, analyses (Supplemental Table 2) were conducted that pointed towards a longitudinal analysis of changes in sTL between years 9 and 15 not being feasible (Gaydosh et al., 2020). Another limitation of the research is that we only utilized data from individuals who both participated in all prior waves of data collection and provided a saliva sample for sTL analysis. Although the attrition rate is relatively low, it is possible that the caregivers who were not interviewed during later waves were those most likely to experience material hardship, such as

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homelessness. Lastly, the FFCWS sample was derived from a largely urban, low-income population, so the findings of these analyses are not necessarily generalizable, especially to rural or suburban populations.

Ultimately, although the effect sizes observed in the study are small, the study points towards telomeres responding to material hardship during the sensitive period of infancy and toddlerhood. Understanding the timing and duration of adversity during childhood and adolescence can inform interventions aimed at mitigating the biological consequences of socioeconomic disadvantage. More basic biological research, such as studies examining the mechanism of apparent TL attrition with chronic stress, is critical before drawing causal relations linking social adversity to cellular aging. Studies should focus on factors that fashion telomere length at birth and telomere attrition dynamics during early life. In addition, a separate longitudinal analysis of percent change in TL between childhood and adolescence would be beneficial. Overall, however, the research contributes to the growing literature on health disparities and provides further support for the hypothesis that telomeres play a role in the biological embedding of childhood hardship.

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Data Availability: The data necessary to reproduce the analyses presented here are not all publicly accessible. Public use data files are free to download from Princeton University's Office of Population Research (OPR) data archive. In order to protect the confidentiality of survey respondents, the genetic biomarkers are not available in the public use data files, but researchers may apply for these data via a restricted use contract (https://ffcws.princeton.edu/restricted). In order to access additional information on the telomere length data, please visit "The Future of Families and Child Wellbeing Study Biomarker Appendage" available at https://ffcws.princeton.edu/data-and-documentation/public-data-documentation.

Analytic Code: Code is available from the first author.

Materials: The materials necessary to attempt to replicate the findings presented here are not publicly accessible.

Preregistration: The analyses presented here were not preregistered.

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