

Article

Greater Diurnal Variation in Human Milk Cortisol Is Associated with Larger Infant Height-for-Age: A Take on Maternal Capital Evolutionary Framework

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Abstract

Maternal capital (e.g., anthropometrics, hormones, bioactives) enables investment in infant somatic growth during lactation. We draw from the maternal capital hypothesis to contextualize the associations between human milk cortisol variation and infant height-for-age z-score (HAZ) and weight-for-height z-score (WHZ). We hypothesize stable conditions (e.g., low perceived stress, high socioeconomic status/SES including income and education attained) will be associated with greater milk cortisol declines (i.e., steeper slopes), signaling increased capital to invest in larger infant anthropometrics, while stressful conditions (e.g., illness within the dyad, low SES, poor maternal sleep quality) may be associated with flatter slopes and subsequent reduced investment. We measured milk cortisol (N = 110) in U.S. mother–infant dyads using enzyme immunoassay. We collected milk 30–45 min after waking and at the last evening infant feeding, and provided questionnaires (e.g., demographics, perceived stress, Pittsburgh sleep quality index) for mothers to complete. We calculated milk cortisol slope (%Δ) (AM-PM/AM) to assess variation between collections. Larger %Δ indicated steeper slopes; smaller %Δ indicated flatter slopes. We employed an information-theoretic approach to estimate associations between maternal stress and %Δ, and %Δ and infant anthropometrics using multivariable linear regressions. The %Δ best-fit model suggested maternal postgraduate education and poor sleep quality was associated with steep %Δ. The HAZ best-fit model suggested the combined effect of steeper %Δ and milk intake was associated with increased HAZ. Additionally, the combined effect of steeper %Δ and infant milk intake was associated with increased HAZ among mothers with postgraduate degrees and who woke up three or more times to night-feed. %Δ was not associated with WHZ. We speculate %Δ exposure calibrates infant development to their shared environment, with implications for lifelong fitness.



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1. Introduction

Infants exhibit significant phenotypic plasticity during the early stages of their development (Hill, 1993; Hochberg, 2011; Kuzawa & Bragg, 2012). This ‘neonatal window of opportunity’ marks a critical period whereby infant physiology is sensitive to environmental cues (Renz et al., 2018; Wells, 2014). Such sensitivity allows infant development to be

programmed, or calibrated, to variation in prevailing conditions (e.g., adversity, resource abundance, hormone regulation or dysregulation), suggesting that it is an adaptation favored by natural selection (Bogin, 1997; Del Giudice et al., 2011; Gluckman et al., 2008; Hill, 1993; Nettle et al., 2013; Wells, 2014, 2025). Moreover, it is likely that any cues signaled to infants would have to be derived from the environmental ‘niche’ shared with their mothers and carers more broadly (Wells, 2010, 2019). The impact of early exposure to the maternal niche (e.g., during gestation or lactation) would theoretically reflect maternal biological/physiological traits (i.e., maternal capital) and environmental settings that foster investment in infant outcomes (Dib et al., 2023; Kaplan et al., 2003; Wells, 2010, 2025; Wells et al., 2019). Maternal capital can be affected by stressors (e.g., psychosocial conditions, infections); thus, its variation can have long-term implications for infant growth, development, and overall health (Kuzawa & Bragg, 2012; Kuzawa & Quinn, 2009; Wells, 2019, 2025; Worthman & Kuzara, 2005). Here, we use Wells and colleagues’ seminal research on maternal capital to contextualize variation in the stress response system within milk, and its subsequent impact on infant growth (Dib et al., 2023; Wells, 2010, 2019, 2025; Wells et al., 2019).

1.1. Maternal Capital and Stress

Drawing from the embodied capital model, somatic maternal capital refers to maternal physiological traits, or phenotypes, that shape infant development and optimize fitness (Kaplan et al., 2003; Wells, 2010, 2019). Maternal capital can be categorized as illiquid—i.e., stable traits, such as maternal height, amassed over longer periods of the individual’s life course (Wells, 2010). These traits can then be inherited intergenerationally (e.g., associations between maternal height and infant body sizes).

But maternal capital can also refer to liquid traits (e.g., hormones, macro- and micronutrient reserves, immune factors, homeostatic regulation) that are gained and utilized over shorter periods of time (Wells, 2010). Given its function in homeostatic regulation, cortisol can be considered a form of liquid somatic capital (Dib et al., 2023; Wells, 2010, 2019, 2025). Cortisol is a physiological indicator of hypothalamic–pituitary–adrenal (HPA) axis functioning and is involved in mobilizing energy needed for daily functioning (Thau et al., 2022). Additionally, in non-stressful environments, greater daily variation in cortisol is a marker for healthy HPA axis regulation (Adam et al., 2017; Hucklebridge et al., 2005; Le Moal, 2007; Pollard, 1995). It is characterized by higher concentrations in the morning with steep declines as the day progresses—i.e., diurnal rhythmicity (Adam et al., 2017; Hucklebridge et al., 2005; Pollard, 1995). Among mother–infant dyads, steep interpregnancy and pregnancy diurnal cortisol slopes are associated with greater infant birthweight (Guardino et al., 2016), while steep maternal slopes after childbirth are associated with steep infant slopes (St. John et al., 2017). These studies suggest greater diurnal variability in maternal cortisol enhances infants’ development and promotes their calibration to maternal physiological traits, a central tenet of the maternal capital hypothesis.

Conversely, under challenging circumstances (e.g., low socioeconomic status (SES), adverse life experiences), cortisol is instrumental in triggering fight-or-flight responses to stressors (e.g., increased blood pressure, allocation of resources such as oxygen, fat, and sugar) (Cannon, 1929; Le Moal, 2007; Selye, 1955; Thau et al., 2022). Cortisol maintains homeostasis between these physiological responses as the body adapts to various stimuli, whether or not they are considered stressful (Cannon, 1929; Dib et al., 2023; Thau et al., 2022; Wells, 2010). However, prolonged activation of the HPA axis can become embodied as flatter cortisol patterns—caused by higher evening concentrations, lower morning concentrations, or minimal variation across the day—and subsequent deleterious health (e.g., cardiovascular disease, immune dysfunction) (Adam et al., 2017; McEwen, 1998a, 1998b). The impact of such HPA axis dysregulation can be observed in mother–infant dyads,

with embodied maternal cortisol patterning signaling the quality of the environment and shaping neonatal outcomes accordingly. For instance, maternal physical (e.g., poor sleep quality) and psychological (e.g., anxiety) stressors during pregnancy are associated with higher evening cortisol, potentially leading to shorter neonatal gestational age, and suggests flatter maternal cortisol patterns may reflect reduced capital for investing in infant somatic growth (Bublitz et al., 2018; Wells, 2010, 2019, 2025).

While critics of the model have raised important political and theoretical concerns over explanations for infant outcomes that place too much responsibility on carers (Warin et al., 2016), Wells argues that the intention of the maternal capital hypothesis is not to “blame” mothers’ physiological traits and conditions when considering their impact on infant survival advantages or disadvantages (Wells, 2025). In fact, the framework can elucidate how societal conditions become embodied in maternal phenotypes, such as hormone variation, with lasting effects for both mother and child (Wells, 2025). From this perspective, other research has applied maternal capital to social dimensions of life, such as supportive environments, SES, and stressors (e.g., depression), which show how systemic and structural factors might contribute to larger infant body size, poor infant appetite, or compromised cognitive development (Bégin et al., 1999; Dib et al., 2023; Hanson & Müller, 2017; Kenney & Müller, 2017; Warin et al., 2016; Wells, 2010, 2025).

Regardless of the parameterizations of maternal capital, the effect of maternal investment on infant somatic growth is dictated by early exposure to the maternal niche, the amount and quality of available resources, and how these conditions manifest physiologically (Wells, 2010, 2019, 2025). Indeed, stable conditions with abundant resources (e.g., finances) reflect greater maternal capital and are associated with favoring infant quality over quantity (Charnov & Berrigan, 1993; Hill, 1993; Hill & Kaplan, 1999; Sear, 2020; Stearns et al., 2008). On the other hand, harsh, stressful, and unpredictable ecological settings (e.g., nutrient scarcity, low SES) may favor a greater number of offspring with smaller bodies and reduced maternal investment in each offspring (Hill & Kaplan, 1999; Sear, 2020; Stearns et al., 2008), though links between adversity and fertility appear mixed (Klimek et al., 2023; Sheppard et al., 2016). Taken together, these suggest the variability of maternal capital can greatly impact infant survival in the postnatal environment.

1.2. Milk Cortisol and Maternal Capital

The concept of maternal capital also extends to human milk constituents and lactation more broadly, given their roles in helping infants transition from life in utero to their extrauterine conditions. Lactation represents an important means for providing infants the bioactive factors (e.g., liquid capital such as fatty acids and immune agents) needed to support healthy growth and development (Andreas et al., 2015; Ballard & Morrow, 2013; Savino et al., 2009; Wells, 2010). Within the framework of maternal capital, existing evidence points to the fact that milk cortisol may actually serve as a reflection of somatic maternal capital, shaping infant development and influencing investment strategies for their ultimate fitness (Anyim et al., 2023a, 2023b; Dettmer et al., 2018; Grey et al., 2013; Hamosh, 2001; Hinde et al., 2015; Power et al., 2017; Power & Schulkin, 2013; Sullivan et al., 2011).

Milk cortisol is transferred from maternal circulation into the breast and therefore, exhibits similar stress-induced variation and diurnal rhythmicity (Adam et al., 2017; Pundir et al., 2017; Toorop et al., 2020). However, to our knowledge, associations between its diurnal rhythmicity and infant outcomes have not been observed. Instead, studies utilized other parameterizations of milk cortisol to demonstrate the importance of its variation for programming infant development. For instance, greater milk cortisol variation across two time points (early versus peak lactation) in rhesus macaques is associated with better growth in offspring (Hinde et al., 2015). A study with absolutes of human milk cortisol

(i.e., collections obtained at one point in time) demonstrated that it increases with the focal infants' age and the age at which their immediate older sibling stopped breastfeeding, both of which are proxies for the duration of lactational investment (Anyim et al., 2023a). Similarly, absolute human milk cortisol is positively associated with milk immunity and subsequent responses to pathogenic bacteria (Anyim et al., 2023b). This suggests milk cortisol enhances the protection of the milk immune system and infants' long-term survival when faced with infectious disease threats.

That said, cortisol is multifaceted, as it is also implicated in biochemical signaling via lactation. Indeed, milk cortisol is able to signal embodied maternal stress and other ecological conditions to program infant development (Dettmer et al., 2018; Grey et al., 2013; Hamosh, 2001; Power et al., 2017; Power & Schulkin, 2013; Sullivan et al., 2011). Consider rhesus macaques, for example. After activation of the HPA axis due to separation stress, higher absolute milk cortisol is associated with more confident temperament in infant rhesus monkey sons, which can help them cope with social hierarchies (Sullivan et al., 2011). Similarly, higher milk cortisol concentrations can signal greater maternal stress and program human infant temperaments as fearful, frustrated, and unable to be soothed (Grey et al., 2013). In addition to shaping temperament and social behavior, milk cortisol can stimulate maturation of the intestinal microvilli, which increases nutrient absorption and facilitates colonization of the gastrointestinal tract with beneficial bacteria (Bernt & Walker, 1999; Hahn-Holbrook et al., 2016). As such, milk cortisol is linked with modulating risks for obesity, infectious diseases, and mortality (Bernt & Walker, 1999; Hahn-Holbrook et al., 2016). Despite differences in its collection methods, these findings suggest that variation in milk cortisol signaling could help infants adapt to prevailing conditions in the shared maternal–infant setting (Dettmer et al., 2018; Grey et al., 2013; Hamosh, 2001; Power et al., 2017; Power & Schulkin, 2013; Sullivan et al., 2011). Thus, lactation is a means of maternal investment, as it serves to buffer infants against ecological stressors, thereby optimizing infant fitness.

1.3. Study Scope and Hypotheses

Due to its multiple functions in infant development, we draw from previous work to posit diurnal variation in human milk cortisol as a form of maternal capital. We evaluate potential influences on milk cortisol variation (i.e., perceived stress, maternal sleep quality, symptoms of illness in the mother–infant dyad, parity, SES, maternal anthropometrics, ages, pregnancy duration, race/ethnicity, country of birth, marital status, breastfeeding practices, mode of delivery, infant birthweight, infant sex, milk fat and milk energy density) in order to contextualize patterns of dynamism. We hypothesize that stable conditions (e.g., low perceived stress, high SES) would be associated with greater variation in milk cortisol (i.e., steep declines) and reflect increased maternal capital to invest in infant outcomes, captured here via height-for-age z-score (HAZ) and weight-for-height z-score (WHZ). Such investment could lead to larger infant body sizes. In contrast, we hypothesize that harsh conditions (e.g., high perceived stress, low SES, poor sleep quality, symptoms of illness) would be embodied as minimal variation in milk cortisol, or flatter slopes, and reflect reduced maternal capital, potentially leading to smaller infants.

2. Materials and Methods

Participants: We recruited mother–infant dyads between 2019 and 2023 from upstate New York through local breastfeeding support organizations and hospitals. Mothers who were at least 18 years of age, lactating from at least one breast daily, had given birth to singletons (inclusive of all birthweights and pregnancy durations), and exclusively or partially breastfeeding the focal, or participating, infant were eligible to participate.

Mothers with multiple births (e.g., twins, triplets) were excluded to minimize potential associated confounding variables, such as intrauterine growth restriction (Filipecka-Tyczka et al., 2021). Participants provided written informed consent. All procedures were approved by the Binghamton University Institutional Review Board and were in accordance with the ethical standards established by the 1964 Helsinki Declaration and its later amendments.

Data Collection and Analyses

Primary Outcome Variable: Mothers reported information about their daily waking and sleeping habits, as well as final evening times for their infants' feedings. For instance, during initial enrollment, each mother reported their personal waking and sleeping times, which ranged from 4:00 to 11:00 a.m. and 4:00 to 10:00 p.m., respectively. This information was then used to schedule morning and evening appointments at their homes to capture milk cortisol diurnal rhythmicity. We collected milk samples during appointments before mothers initiated their breastfeeding sessions, which is established in the literature as ensuring a standardized baseline for evaluating milk composition (Miller et al., 2013). We provided mothers with a sanitized and assembled electric breast pump and bottle. Using the assembled apparatus, they expressed approximately 30 milliliters of milk in the morning (30–45 min after waking) and at the last reported infant feeding in the evening, as this was least disruptive to participants' daily routines (Adam et al., 2017; Miller et al., 2013; Pundir et al., 2017; Toorop et al., 2020). Mothers were then encouraged to breastfeed their infants. Samples were frozen at -80°C until assay, which occurred within 2–3 months after collections. Due to the diurnal rhythmicity observed in milk cortisol, we calculated a percent change (% Δ) between the morning and evening concentrations using the following equation: AM-PM/AM (Adam et al., 2017; Pundir et al., 2017; Toorop et al., 2020). Larger % Δ indicated greater magnitudes of decline across the day (i.e., steeper slopes). In contrast, smaller % Δ indicated minimal declines, or flatter slope patterns.

Secondary Outcome Variables: Infant anthropometrics (i.e., weight and height/length) were measured using a digital scale (Taylor Salter 914-WHLKR) and an infant measuring mat (Seca 210). Infant age-specific z-scores (HAZ and WHZ) were calculated using the measurements obtained on the day of data collection (World Health Organization, 2006).

Primary Predictor Variables: Mothers completed the perceived stress scale, which is validated to assess if an individual has felt or thought a certain way (e.g., confident, overwhelmed, unable to control irritations) in the past month (Cohen et al., 1983). Responses rank from 0 to 4, or "Never" to "Very Often", respectively. Items on the perceived stress scale assessing positive aspects of the lived experience (e.g., confidence, control) were reverse scaled and summed with the remaining items on the questionnaire.

Sleep quality was evaluated using the Pittsburgh sleep quality index, which assessed sleep habits within the past month (e.g., sleep duration, wake/sleep times) (Buysse et al., 1989). Items on the survey were summed according to procedure, with higher scores representing worse sleep quality. The survey also contains a written response section asking participants to describe other reasons they may have woken up in the middle of the night for and how many times this occurred (i.e., not during the past month, less than once a week, once or twice a week, three or more times a week) (Buysse et al., 1989). A subset of mothers reported waking three or more times a week to breastfeed their infants. We created a binary variable to compare the associations between milk cortisol diurnal variation among mothers who woke three or more times to breastfeed and those who did not (i.e., mothers who did not wake to night-feed, or who reported waking less than three times). Though the Pittsburgh sleep quality index provides a comprehensive assessment of sleep habits and quality, this variable was created because feeding frequency, as reported in

mothers' written response, can serve as a form of maternal investment with implications for infant growth.

Maternal SES was operationalized as two separate variables: reported total household income (yearly) and highest degree achieved (e.g., bachelor's, postgraduate degrees). Maternal education ranged from 8th grade to postgraduate degrees (e.g., Master's and Doctorate level degrees). The questionnaire did not ask the number of years of education, but rather the type of education attained, if any. Therefore, we created three categories for highest degree achieved (i.e., less than bachelor's, bachelor's, and postgraduate).

As these may be an additional source of stress and therefore a potential influence on milk cortisol concentration, mothers reported any current symptoms of illness (e.g., fever, congestion, conjunctivitis, nausea, aches) in either themselves or their infants. The presence or absence of symptoms (yes/no) was evaluated as a binary variable.

Covariates: We obtained demographic data via questionnaire: parity, pregnancy duration (weeks), marital status (i.e., married, single, divorced, widowed), race/ethnicity, country of birth, mode of delivery (vaginal, cesarean), neonatal intensive care unit admittance (yes/no), infant birthweight and sex, whether the infant was exclusively breastfeeding or receiving complementary foods (e.g., baby food, cow's milk and other dairy, family foods) at the time of participation, and age (months for infants, years for mothers). Since the focal infant was breastfeeding, we used infant age as a proxy for lactation duration, which can influence milk cortisol variation (Anyim et al., 2023a). We evaluated marital status (i.e., married and unmarried), race/ethnicity (i.e., white and minority), country of birth (inside or outside of the United States), mode of delivery (vaginal and cesarean), exclusive breastfeeding (yes/no), symptoms of illness (yes/no), neonatal intensive care unit admittance (yes/no), and infant sex as binary variables. Given the wide range, infant age was categorized as a binary to reflect age 0–6 months and age older than 6 months—i.e., the World Health Organization's delineation for exclusive and complementary feeding (Geneva: World Health Organization, 2009). To account for temporal variation, we created categorical variables for seasons of data collection (winter, spring, summer, fall). Temporal variation due to time of day was evaluated as three continuous variables: morning and evening collection times, and difference in time between the two collections (hours).

We also measured maternal height and weight using a digital scale (Taylor 7595) and portable stadiometer (Seca 213). We calculated maternal body mass index (BMI) using the anthropometric measurements obtained on the day of data collection. These were evaluated as continuous variables.

Relative to milk proteins and carbohydrates, milk fat is a significant driver of human milk calorie content and its variability, and is a primary source of energy for meeting infants' growing demands (e.g., brain size and development) (Belfort et al., 2024; Hill, 1993; Hill & Kaplan, 1999; Kaplan et al., 2003; Lucas et al., 1978; Miller et al., 2013). It is also an area of interest for researchers, from an evolutionary standpoint, because milk is a dynamic means of communication between mothers and infants, with the effects of higher stress (e.g., resource scarcity) influencing the mobilization of fat stores and subsequent physiological investment in offspring. Associations between milk fat (or energy density) and cortisol can serve as a means of signaling environmental stressors and conditions to help the infant cope with their surroundings. For example, when infant rhesus macaques consume milk that is high in cortisol and energy, they can be programmed to prioritize building fat over high-energy behavioral exploration, which could be adaptive for surviving harsh environments (Hinde et al., 2015). Therefore, we used the creatatocrit method to estimate milk fat percentages in the morning and evening samples, in order to determine milk nutritional composition and evaluate its potential associations with milk cortisol (Belfort et al., 2024; Lucas et al., 1978; Miller et al., 2013). From these, we calculated milk energy

density using the following equation for frozen samples: $6.2 \times \text{crematocrit (\%)} + 35.1$ (Wang et al., 1999). The literature is mixed regarding the diurnal rhythmicity of milk fat and energy content. For example, mothers in Australia and the United States respectively exhibited lower milk fat and energy in the morning, while some African populations have been shown to have higher fat in the morning (Italianer et al., 2020; Kent et al., 2006; Miller et al., 2013; A. Prentice et al., 1981). Therefore, we calculated the mean between morning and evening values of milk fat creatatocrit percentages and energy content. We included milk fat creatatocrit percentages and energy content as covariables for both milk cortisol slope and infant anthropometrics.

We used weigh-test-weigh methods (i.e., weighing infants before and after feedings) to assess typical infants' milk intake/milk volume (Miller et al., 2013). We created an interaction term by multiplying total milk volume and milk cortisol % Δ because the effects of milk cortisol depend on not only its concentrations, but also the volume of milk consumed (Miller et al., 2013).

Enzyme Immunoassay: We used Salimetrics (1-3002) enzyme immunoassays validated for use in breastmilk to estimate milk cortisol concentrations (Anyim et al., 2023a; Cook, 2012; Miller et al., 2013; Minkinen, 2004). We assayed aqueous milk specimens at 1:1 dilution. The inter-assay coefficient of variation (CV) was 12.3% and the intra-assay CV was 8.63% across the 26 assays used for analyses.

Statistical Analyses: To test the hypothesis that variation in milk cortisol patterns with stress would reflect maternal capital, we employed multivariable linear regressions to estimate associations between (1) maternal stress/conditions and milk cortisol slope and (2) milk cortisol slope and infant age-specific z-scores. We also assessed the associations between milk cortisol slope of mothers with varying education attained, those who reported waking three or more times to night-feed, and infant age-specific z-scores. In doing so, we sought to provide additional context for the embodiment of maternal stress/conditions within these groups and its effects on infants' body sizes. Associations between maternal stress/conditions and milk cortisol slope were interpreted as being upstream of infant somatic growth. We employed an information-theoretic approach, via Akaike's corrected information criterion (AIC_c), to identify parsimonious models of best-fit (i.e., the models with the lowest AIC_c value) (Burnham & Anderson, 2002; Lindsey, 2014). AIC_c is an appropriate tool to use for selecting the model of best-fit as it corrects for potential bias when the number of parameters (e.g., predictor variables) is greater than the small sample size (Burnham & Anderson, 2002; Lindsey, 2014). Maternal anthropometrics, SES, parity, duration of pregnancy, infant sex and age (0–6 months and older than 6 months), birthweight, binary and continuous age variables, breastfeeding practices, milk nutritional composition, and temporal variation (e.g., time of day, seasonality) were assessed and controlled for confounding as appropriate (Astone et al., 2007; Lesiński, 1962; Moradi et al., 2023; Narumi et al., 2020; Saiklang et al., 2019; Wells et al., 2011; Zhang et al., 2015). As maternal education and seasons of data collection contained three and four categories, respectively, the categories with the lowest numerical value (i.e., below bachelor's degree and winter) were selected as reference points to enable comparisons between groups in regression analyses. All statistical analyses were completed using Stata SE 17 software (StataCorp, 2021).

3. Results

Descriptive Statistics: We recruited 92 white and 29 minority (e.g., Hispanic, African, Caribbean, bi-racial/multiethnic, Asian, Pacific Islander, South American) breastfeeding mother–infant dyads (N = 121) (Table 1). Maternal age ranged from 20 to 41 years, while infant age ranged from 2 weeks to 36 months. Pregnancy duration ranged from 35.4 to 41.4

weeks. Infant HAZ ranged from -2.82 to 3.76 , while maternal height ranged from 1.47 to 1.92 m. The means for milk energy content and milk cortisol slope were 35.5 kcal/dL and 0.75 , respectively. Complete data was available for 110 participants; thus, all statistical analyses were restricted to these individuals.

Table 1. Demographic, anthropometric, Perceived Stress Scale, Pittsburgh Sleep Quality Index, and specimen (i.e., milk cortisol slope (% Δ), milk fat creatinocrit percent (%), milk energy density (kcal/dL)) characteristics across mother infant dyads.

	N	Mean (or %)	Standard Deviation (SD)	Range (min, max)
Maternal characteristics				
Age (yrs.)	121	31.4	4.99	20, 41
Parity	121	2	1.04	1, 5
Pregnancy duration (weeks)	121	39.2	1.43	35.4, 41.4
Height (m)	121	1.65	0.07	1.47, 1.92
Weight (kg)	121	71.6	15.3	49, 113
BMI (kg/m ²)	121	26.4	4.98	18.9, 38.8
Total household income (yearly)	121	96,826	66,702	0, 420,000
Perceived stress scale	121	14.9	6.89	0, 35
Pittsburgh sleep quality index	114	8.30	3.40	2, 16
Waking three or more times to breastfeed (yes)	81	74		
Race/ethnicity				
White	92	76		
Minority	29	24		
Born outside US (yes)	14	12		
Highest degree achieved				
Below bachelor's (reference)	27	23		
Bachelor's	44	39		
Postgraduate	43	38		
Marital status (married)	105	87		
Mode of delivery				
Vaginal	97	80		
Cesarean	24	20		
Exclusive breastfeeding (yes)	44	36		
Current symptoms of illness (yes)	8	7		
Infant characteristics				
Age (mo) *	121	7.3	6.39	0, 36
Birthweight (kg)	120	3.54	0.51	2.18, 4.73
Height/length (cm)	121	67.8	9.24	50.5, 94
Height-for-age z-score	121	0.62	1.26	-2.82 , 3.76
Weight (kg)	121	7.63	2.28	3.13, 15
Weight-for-height z-score	121	-0.21	1.14	-3.71 , 2.19
Current symptoms of illness (yes)	29	24		
Neonatal intensive care unit admittance (yes)	10	8		
Sex (female)	62	51		
Human milk characteristics				
Milk cortisol slope (% Δ)	121	0.75	0.25	-0.31 , 0.97
Average milk fat creatinocrit (%)	121	6.00	4.00	1, 35
Average milk energy density (kcal/dL)	121	35.5	0.26	35.2, 37.3
Total milk volume consumed (oz)	110	2.64	1.28	1.06, 6.17
Time constraints				
Morning collection times (a.m.)	121	8:06	1.13	4:00–11:00
Evening collection times (p.m.)	121	7:02	1.37	4:00–10:00
Time between collections (hours)	121	11.2	2.05	7, 16
Season of collection				
Winter (reference)	21	18		
Spring	62	51		
Summer	29	24		
Fall	9	7		

* Note: Infant age was also stratified. Infants of 0–6 months represented 55% of the sample (N = 67), while infants aged older than 6 months represented 45% of the sample (N = 54).

Regression Analyses (model selection determined by AIC_c): The best-fit model assessing predictors of milk cortisol slope (Table 2; Figure 1) included positive associations with spring (β : 0.126 , p : 0.036), summer (β : 0.163 , p : 0.017), and fall (β : 0.126 , p : 0.146) seasons of collection, hours between collections (β : 0.036 , p : 0.003), attaining bachelor's (β : 0.102 , p : 0.061) and postgraduate (β : 0.141 , p : 0.014) degrees, and the Pittsburgh sleep quality

index (β : 0.017, p : 0.006). This suggests that spring and summer seasons of collection, greater number of hours between morning and evening collections, attaining postgraduate degrees, and worse maternal sleep quality were associated with steeper milk cortisol slopes. Fall season of collection and attaining a bachelor's were not significant predictors of milk cortisol slope ($p > 0.05$). The model's goodness of fit parameters (R^2 : 0.315, adjusted R^2 : 0.268) indicate approximately 32% variability in milk cortisol slope explained by the selected predictors.

Table 2. Linear regression model of best-fit by AIC_c for milk cortisol slope (%Δ) (N = 110).

Predictors	Unstandardized (β)	Standardized (β)	95% CI	p
Season of collection				
Spring	0.126	0.258	0.008, 0.244	0.036
Summer	0.163	0.271	0.030, 0.295	0.017
Fall	0.126	0.142	−0.045, 0.298	0.146
Time between collections (h)	0.036	0.288	0.012, 0.059	0.003
Highest degree achieved				
Bachelor's	0.102	0.203	−0.005, 0.208	0.061
Postgraduate	0.141	0.279	0.030, 0.253	0.014
Pittsburgh Sleep Quality Index	0.017	0.233	0.005, 0.029	0.006

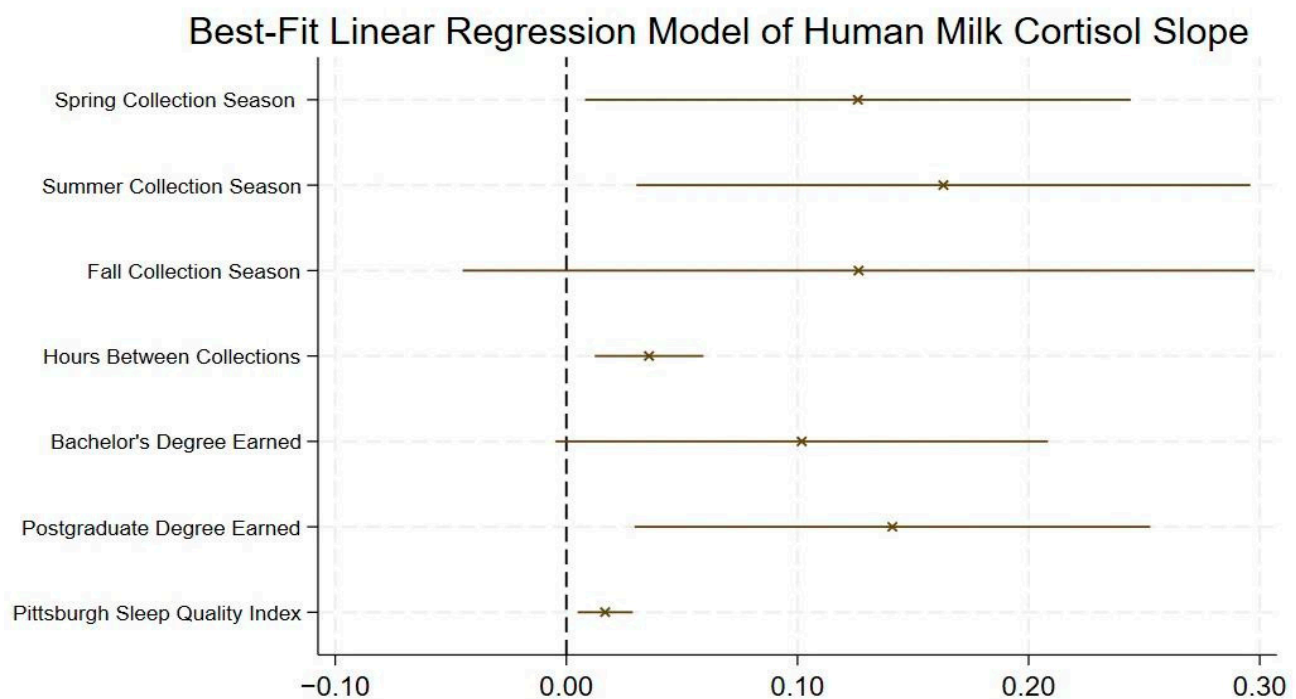


Figure 1. Coefficient plot for each predictor of milk cortisol slope (%Δ) in the best-fit model (for full model details, see Table 2): Each “X” represents beta coefficients and the horizontal bars represent the 95% confidence intervals. 95% confidence intervals that crossed the dotted line at 0 indicated that the variable was not significant.

The best-fit model assessing predictors of infant HAZ (Table 3, Model 1; Figure 2) included positive associations with maternal height (β : 6.825, $p < 0.001$), pregnancy duration (β : 0.245, $p < 0.001$), and the milk cortisol slope $\times$ volume consumed interaction term (β : 0.230, p : 0.007), and negative associations with infant age (β : −0.804, $p < 0.001$). This suggests that taller maternal height, longer durations of pregnancy, and the combined effect of steeper milk cortisol slopes with volume consumed were associated with larger

infant HAZ, while being older than 6 months was associated with smaller infant HAZ. We did not find an association between infant HAZ and milk fat creatinocrit percentage or milk energy density. The model's goodness of fit parameters (R^2 : 0.369, adjusted R^2 : 0.345) indicate approximately 37% variability in infant HAZ explained by the selected predictors.

Table 3. Linear regression models of best-fit by AIC_c for infant height-for-age z-score (HAZ) and infant weight-for-height z-score (WHZ).

Model 1: Best-fit linear regression model of infant HAZ (N = 110)				
Predictors	Unstandardized (β)	Standardized (β)	95% CI	<i>p</i>
Maternal height (m)	6.825	0.345	3.756, 9.895	<0.001
Pregnancy duration (weeks)	0.245	0.283	0.111, 0.378	<0.001
Milk cortisol slope (% Δ) $\times$ total volume consumed (oz)	0.230	0.216	0.064, 0.396	0.007
Infant age (older than 6 months)	−0.804	−0.316	−1.197, −0.411	<0.001
Model 2: Best-fit linear regression model of infant WHZ (N = 110)				
Predictors	Unstandardized (β)	Standardized (β)	95% CI	<i>p</i>
Infant age (older than 6 months)	0.463	0.217	0.070, 0.855	0.021
Infant sex (male)	−0.404	−0.190	−0.794, −0.013	0.043

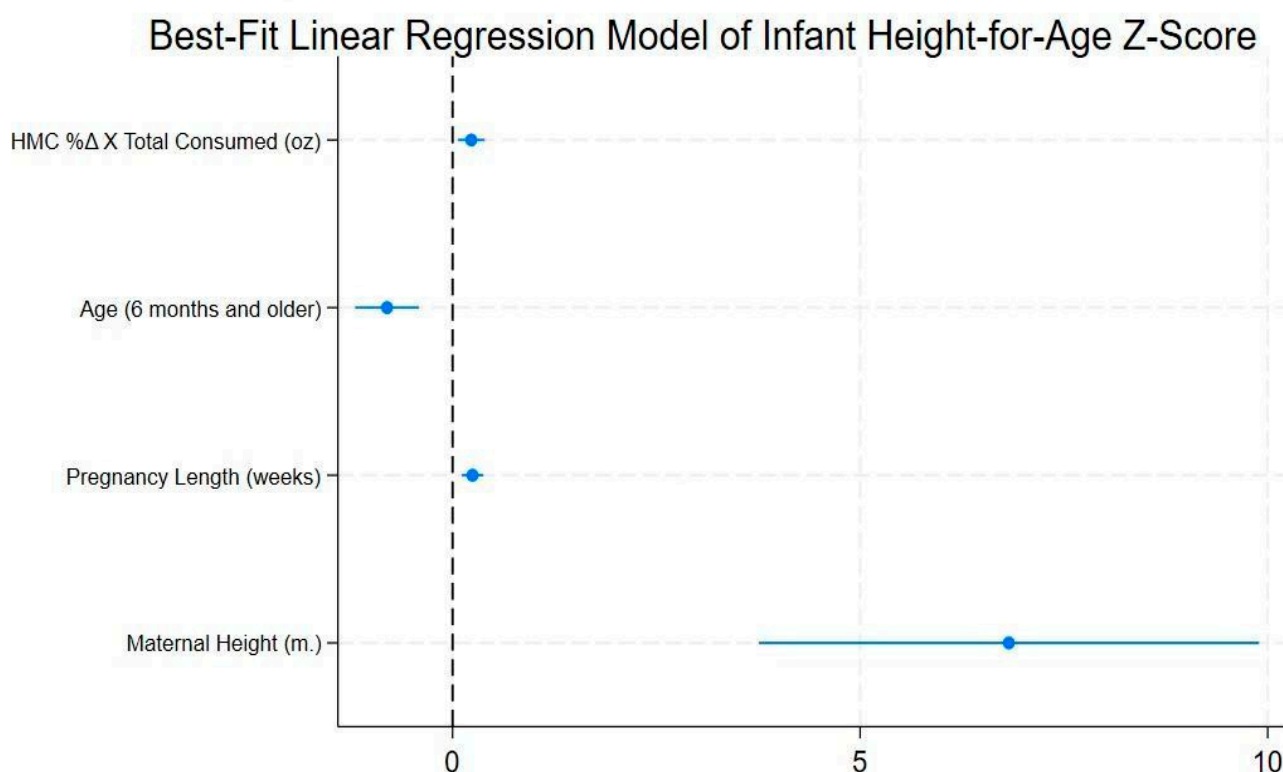


Figure 2. Coefficient plot for each predictor of infant HAZ in the best-fit model (for full model details, see Table 3, Model 1): Each circle represents beta coefficients and the horizontal bars represent the 95% confidence intervals. Note: the abbreviation “HMC” refers to “human milk cortisol”.

The best-fit model for infant WHZ (Table 3, Model 2, Figure 3) did not include milk cortisol slope, milk fat creatinocrit percentage or milk energy density. Instead, being older than 6 months (β : 0.463, p : 0.021) was associated with larger infant WHZ and male infant sex (β : −0.404, p : 0.043) was associated with smaller infant WHZ. The model's goodness of fit parameters (R^2 : 0.092, adjusted R^2 : 0.075) indicate approximately 9.2% variability in WHZ explained by the selected predictors.

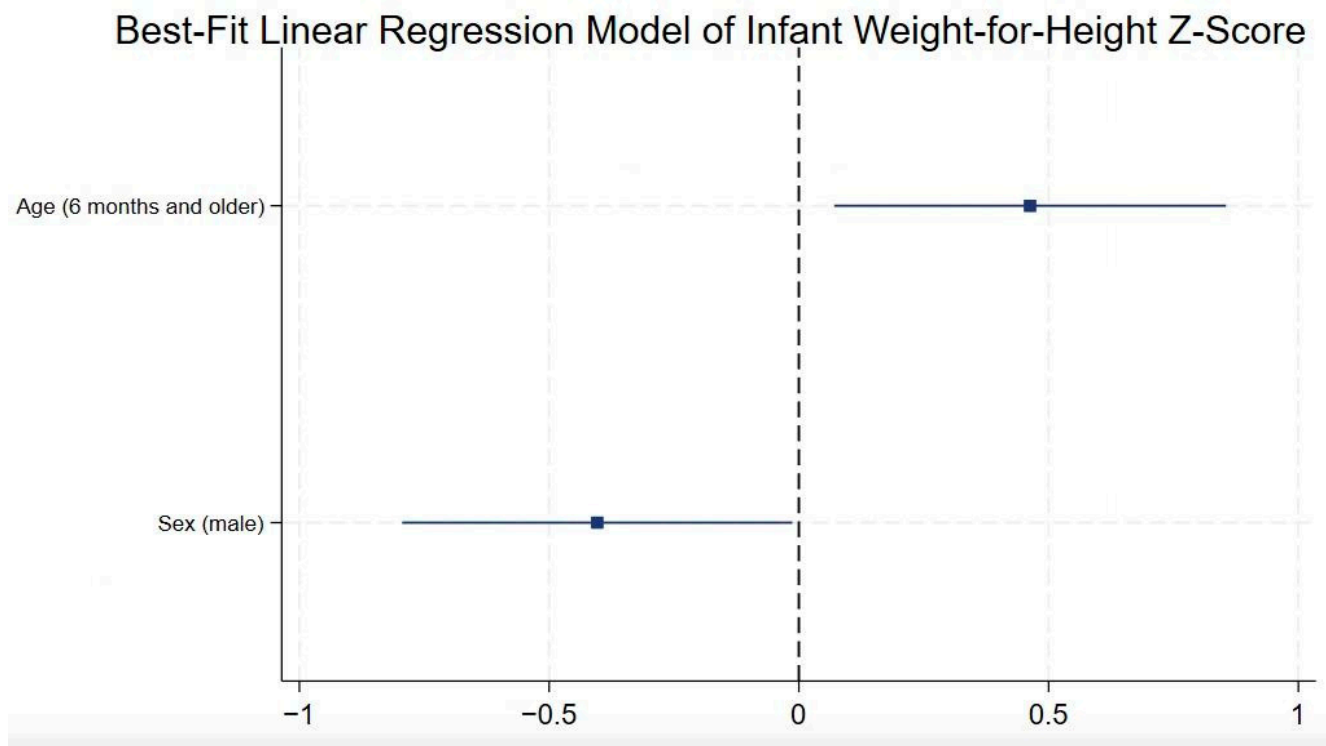


Figure 3. Coefficient plot for each predictor of infant WHZ in the best-fit model (for full model details, see Table 3, Model 2): each square represents beta coefficients and the horizontal bars represent the 95% confidence intervals.

Using the previously identified predictors of infant HAZ, we conducted separate analyses to evaluate the association between milk cortisol slope and infant HAZ among mothers with bachelor's and postgraduate degrees (Table 4). Among mothers with bachelor's degrees (Model 1), the milk cortisol slope $\times$ volume consumed interaction term, maternal height, and pregnancy duration were no longer significant predictors of infant HAZ ($p > 0.05$), while infant age older than 6 months had smaller HAZ. The model's goodness of fit parameters (R^2 : 0.322, adjusted R^2 : 0.247) indicate approximately 32% variability in infant HAZ explained by the selected predictors. However, among mothers with postgraduate degrees (Model 2), maternal height, the milk cortisol slope $\times$ volume consumed interaction term, and infant age older than 6 months were still significant and positively associated with HAZ, while pregnancy duration was no longer significant. The model's goodness of fit parameters (R^2 : 0.523, adjusted R^2 : 0.472) indicate approximately 52% variability in infant HAZ explained by the selected predictors.

Likewise, we conducted separate analyses evaluating the association between milk cortisol slope and infant HAZ among mothers who reported waking three or more times in a week to breastfeed and those who did not (Table 5). Among mothers who reported waking three or more times to breastfeed (Model 1), maternal height, pregnancy duration, and the milk cortisol slope $\times$ volume consumed interaction term were still significant and positively associated with infant HAZ, while being older than 6 months was associated with smaller HAZ. The model's goodness of fit parameters (R^2 : 0.362, adjusted R^2 : 0.328) indicate approximately 36% variability in infant HAZ explained by the selected predictors. Among mothers who did not report waking three or more times to breastfeed (Model 2), only maternal height and being older than 6 months were significantly associated with HAZ. The model's goodness of fit parameters (R^2 : 0.412, adjusted R^2 : 0.305) indicate approximately 41% variability in infant HAZ explained by the selected predictors.

Table 4. Linear regression models of best-fit by AIC_c for infant height-for-age z-score (HAZ) among mothers with Bachelor’s and postgraduate degrees.

Model 1: Best-fit linear regression model of infant HAZ among mothers with bachelor’s degrees (N = 44)				
Predictors	Unstandardized (β)	Standardized (β)	95% CI	p
Maternal height (m)	3.310	0.220	−1.091, 7.710	0.136
Pregnancy duration (weeks)	0.153	0.176	−0.090, 0.395	0.210
Milk cortisol slope (%Δ) × total volume consumed (oz)	0.132	0.137	−0.153, 0.417	0.353
Infant age (older than 6 months)	−0.999	−0.452	−1.654, −0.345	0.004
Model 2: Best-fit linear regression model of infant HAZ among mothers with postgraduate degrees (N = 43)				
Predictors	Unstandardized (β)	Standardized (β)	95% CI	p
Maternal height (m)	10.57	0.461	5.061, 16.08	<0.001
Pregnancy duration (weeks)	0.173	0.193	−0.039, 0.384	0.106
Milk cortisol slope (%Δ) × total volume consumed (oz)	0.328	0.252	0.025, 0.630	0.034
Infant age (older than 6 months)	−1.069	−0.391	−1.700, −0.438	0.001

Table 5. Linear regression models of best-fit by AIC_c for infant height-for-age z-score (HAZ) among mothers who reported waking three or more times in a week to breastfeed and those who did not.

Model 1: Best-fit linear regression model of infant HAZ among mothers waking three or more times to breastfeed (N = 81)				
Predictors	Unstandardized (β)	Standardized (β)	95% CI	p
Maternal height (m)	6.603	0.331	2.860, 10.34	0.001
Pregnancy duration (weeks)	0.283	0.318	0.119, 0.448	0.001
Milk cortisol slope (%Δ) × total volume consumed (oz)	0.274	0.248	0.068, 0.479	0.010
Infant age (older than 6 months)	−0.754	−0.292	−1.227, −0.281	0.002
Model 2: Best-fit linear regression model of infant HAZ among mothers who did not report waking three or more times to breastfeed (N = 27)				
Predictors	Unstandardized (β)	Standardized (β)	95% CI	p
Maternal height (m)	11.87	0.586	3.759, 19.98	0.006
Pregnancy duration (weeks)	0.024	0.033	−0.268, 0.317	0.864
Milk cortisol slope (%Δ) × total volume consumed (oz)	0.178	0.203	−0.160, 0.515	0.287
Infant age (older than 6 months)	−1.063	−0.483	−1.872, −0.255	0.012

4. Discussion

In line with the literature on maternal capital (Dib et al., 2023; Kaplan et al., 2003; Wells, 2010, 2019, 2025; Wells et al., 2019), we expected stable ecological conditions marked by characteristics, such as low stress and resource abundance (e.g., high SES), to be positively associated with steep milk cortisol slopes, which would signal increased maternal capital for investing in large infant body sizes (i.e., HAZ, WHZ). We also expected harsh, more stressful conditions (e.g., increased perceived stress, poor sleep quality, symptoms of illness within the dyad, low SES) to be associated with flat milk cortisol slopes, which would signal decreased maternal capital and subsequent investment in smaller infant body sizes. We found mixed support for our hypotheses. Attaining postgraduate degrees, which represents high SES, and poor sleep quality were associated with steep milk cortisol slopes. The combined effect of steep milk cortisol slopes and milk volume consumed, longer pregnancy durations, and maternal height were associated with larger infant HAZ, while infant age older than 6 months was associated with smaller HAZ. Our analyses suggest varying upstream associations with milk cortisol slopes have downstream associations with infant outcomes. For example, mothers with higher SES have greater maternal capital to invest in infant HAZ via milk cortisol, compared to mothers with bachelor’s level degrees. However, our results are surprising because poor sleep quality was associated

with greater declines in milk cortisol concentrations, which are indicative of healthy HPA axis functioning, and suggests more sleep-deprived mothers may invest more in infant HAZ via milk cortisol. Our results seem to confirm this, as mothers reporting worse sleep quality due to waking three or more times in the past week to breastfeed had infants with larger infant HAZ via greater milk cortisol variation. We did not observe an association between milk cortisol slopes and infant WHZ, nor did we find an association between infant growth and milk fat or energy content. To our surprise, we did not find any associations between milk cortisol slope and symptoms of illness within the dyad, infant age (our proxy for lactation duration), or mode of delivery. This may, in part, be due to lack of variation in questionnaire responses, as only 7% of mothers reported experiencing symptoms of illness on the day of participation. Our findings may also be inconsistent with the literature due to differences in ecological settings (e.g., rural versus urban areas), methods of milk collection and parameterization of cortisol (e.g., absolutes, pooled samples) (Anyim et al., 2023a; Zielinska-Pukos et al., 2022). We also included hours between collections, seasons of collection, maternal height and pregnancy duration as control variables. Though our hypotheses did not explicitly involve these predictors, the patterns we observed were consistent with the literature (Addo et al., 2013; Derraik et al., 2016; Lindberg et al., 2021; Pundir et al., 2017; Toorop et al., 2020; Zhang et al., 2015).

Body size and growth patterns can be used as a reflection of resource availability. For example, larger infant stature is associated with obtaining adequate nutrition, while smaller body sizes are associated with signals of reduced capital (e.g., low SES) (Wells, 2010). This may also apply to intergenerational traits, such as maternal height. Indeed, greater maternal height is associated with increased infant birthweight and height, while shorter maternal stature is associated with adverse infant development such as stunting (Addo et al., 2013; Dib et al., 2023; Floris et al., 2023; Griffiths et al., 2007). We found that greater maternal height was the strongest predictor of increased infant HAZ, which suggests taller mothers have greater capital for investing in infant height. Height as a predictor of infant HAZ can also be driven by genetics and environmental factors in high-income countries, where there may be greater access to resources (e.g., nutrition, hydration) to sustain the energetic demands for steady and healthy growth within dyads (Zhang et al., 2015). Similarly, as lactation is energetically costly, exclusive breastfeeding places additional demands on the body and thus, is a significant investment for mothers (A. M. Prentice & Prentice, 1988). We found that, relative to infants who were exclusively breastfeeding (i.e., 0–6 months of age), older infants who were receiving complementary foods were shorter in height for their age. Our results are consistent with findings that, relative to formula feeding, exclusive breastfeeding is associated with greater infant length (or height), which suggests that it may represent a means of investing in infant somatic growth (Moradi et al., 2023; Wells, 2010). The transition to complementary feeding represents a critical window for optimizing infant survival, as human milk alone is no longer sufficient to meet their developmental demands (Harrison et al., 2023). However, it may be that complementary feeding practices and the quality or quantity of the nutrition received by infants in this sample are inadequate for healthy infant growth, leading to stunting and potentially long-term adversities (e.g., illness, anemia, macro- and micro-nutrient deficiencies) (Harrison et al., 2023).

Human milk constituents, including cortisol, are dynamic and are associated with maternal investment that can shape infant outcomes. Indeed, milk cortisol can readily diffuse through infants' gastrointestinal tracts and brains, suggesting the collaborative network of HPA and gut–brain axes has implications for infant development (e.g., immunity, stimulating growth hormones, regulating adiposity) (Allen-Blevins et al., 2015; Anyim et al., 2023b; Bernt & Walker, 1999; Hahn-Holbrook et al., 2016; Hinde et al., 2015). Our results that steep milk cortisol slopes were associated with greater infant HAZ are similar to other

findings in humans and non-human primates. Among humans, higher concentrations of milk cortisol are associated with faster infant growth in height between ages 3 months and 2 years (Hahn-Holbrook et al., 2016; Pundir et al., 2020). Our results also show that postgraduate education is associated with increased variation in milk cortisol—i.e., a cortisol profile associated with less stress—and that these mothers had taller infants, with milk cortisol playing a significant role in this effect. Our results are consistent with findings that suggest higher maternal education is associated with increased infant HAZ (Bienertová-Vašků et al., 2017; Le & Nguyen, 2020). However, through our analyses, we offer insight into a potential mechanism through which social dimensions of life become embodied via maternal capital. It may be that higher SES, embodied as greater milk cortisol variation, is signaling to infants the stable conditions available for investing in their height and ultimate fitness.

The observed association between steep milk cortisol slopes and postpartum sleep disruptions is unexpected. As previously mentioned, when not considering the effects of maternal anxiety, poor maternal sleep quality is associated with higher evening cortisol (Bublitz et al., 2018), with implications for flattening cortisol slopes. Additionally, there are strong correlations between different sources of cortisol (e.g., saliva, plasma, milk) (Dettmer et al., 2018; Hinde et al., 2015; van der Voorn et al., 2016), so one might expect milk cortisol to likely be sensitive to the same diminished variation caused by worse sleep quality. However, our results suggest that milk cortisol slope may differ in its sensitivity to sleep quality; furthermore, such variation could signal available capital to invest in infant outcomes. Indeed, mothers who reported waking three or more times to feed their infants had infants with larger HAZ via the combined effect of milk cortisol slopes and volume consumed. This could be because relatively stable environments (e.g., high-income United States), where there is less of a threat to the immediate survival of the dyad, which could lead to greater physiological resources to invest in infants' long-term development. Furthermore, maternal sleep quality can be derived from aspects of childrearing, including frequent feedings and nighttime feedings, the latter of which may be an adaptation to diminish ovarian function or to meet the demands of maturational transitions (e.g., complementary feeding) (Haig, 2014). This allows infants to enhance their own fitness by having mothers allocate resources for the focal infant's interests (e.g., frequent nursing promotes colonization of the gut with commensal bacteria) (Haig, 2014; Hinde, 2014).

Calculation of milk cortisol variation using morning and evening concentrations to predict infant HAZ offers a novel contribution to the literature. As previously discussed, cortisol exhibits diurnal rhythmicity, which can be affected by variation in societal constraints (e.g., stressors, resource scarcity or availability) (Dib et al., 2023; Guardino et al., 2016; Pundir et al., 2017; Wells, 2010, 2025). The extent to which stress-induced HPA axis dysregulation can affect milk cortisol diurnal patterns is ambiguous, which likely stems from differences in cortisol parameterizations (e.g., slopes, absolutes) and sampling times (Grey et al., 2013; Hinde et al., 2015). That said, it seems biologically plausible that milk cortisol's dynamism would signal exposure to chronic stress, acute stress, or even non-stressful environments, as these would be environments to which infants are exposed. Additionally, such variation in milk cortisol could reflect somatic maternal capital, with the association between steep milk cortisol slopes and increased infant HAZ denoting adaptive calibration to the maternal niche—i.e., the non-stressed environment. Furthermore, our findings are the associations to be expected in lush conditions, with minimal extrinsic mortality and abundant resources. Such signals of ecological stability via cortisol suggests the HPA axis within milk is critical for allocating resources for infant phenotype, thereby allowing for greater investment in growth and overall fitness.

Limitations: Our study faced some limitations. We purposively recruited our sample of participants, which limits sociodemographic diversity (e.g., race/ethnicity, SES) and generalizability (e.g., experiences of psychosocial stress, illness prevalence, rates and duration of breastfeeding). In doing so, we also could not account for mothers' place of residence, such as rural or urban settings. Urban versus rural environments can potentially affect milk cortisol concentrations, with urban settings generally leading to elevated stress and subsequent higher cortisol levels. Indeed, research demonstrates that mothers residing in densely populated city centers, relative to city outskirts, exhibited higher milk cortisol concentrations, likely due to the fast-paced psychosocial stressors, traffic, and greater noise associated with city life (Dombrowska-Pali et al., 2024). Because cortisol is a lipophilic (i.e., fat-soluble) steroid hormone, it readily passes from the maternal bloodstream into mammary tissue and milk (Linderborg et al., 2020), suggesting that elevated stress due to urban environments can directly translate to higher milk cortisol as well. We did not have data on maternal diet and physical activity/exercise, which can influence human milk cortisol concentrations and overall milk composition (e.g., lipid content, fatty acids), as lifestyle factors that affect systemic cortisol can also alter milk cortisol due to the hormone's lipophilic nature (Calcaterra et al., 2025; Linderborg et al., 2020). For example, mothers who are lactating may exhibit an attenuated stress response due to intense exercise, compared to non-lactating mothers, suggesting an adaptation to buffer infants against bouts of maternal stress during lactation (Calcaterra et al., 2025). Additionally, relative to mothers with high-fat diets, mothers whose diets consist of very low amounts of fat can produce milk with greater medium-chain fatty acids. Conversely, during fasting states or fat-free diets, milk synthesis shifts from acquiring fats from maternal diet and instead mobilizes the mother's existing fat stores (Linderborg et al., 2020). We did not have data on maternal–infant medication and/or supplement use. Because human milk cortisol is positively associated with maternal plasma cortisol, substances capable of altering systemic cortisol concentrations can also affect milk cortisol concentrations (Pundir et al., 2017; van der Voorn et al., 2016). According to the National Institute of Child Health and Human Development (2026), the most notable impact on human milk glucocorticoids levels stem from medications in the glucocorticoid class (e.g., hydrocortisone), which can impact HPA axis functioning and subsequent cortisol production. We employed a cross-sectional study design, which allowed us to estimate associations among mother–infant dyads at one point in time, without the need for follow up. However, a prospective longitudinal study would be more appropriate for inferring causality, particularly regarding the longer-term effects of maternal stress on infant development via milk cortisol. Mothers were asked to express approximately 30 mL of milk, which means that our sample consisted of mostly foremilk. Foremilk is dilute and low in fat content relative to hindmilk, which has implications for the amount of cortisol assessed given its fat solubility (Linderborg et al., 2020; Miller et al., 2013). We collected milk samples twice a day. However, research suggests milk cortisol varies over a 24 h period, with multiple measurements required to accurately assess its adequacy as maternal capital (Pundir et al., 2017). Additionally, we were able to capture diurnal rhythmicity and standardized each morning collection to 30–45 min after mothers' self-reported waking habits (Adam et al., 2017; Pollard, 1995). However, we could only standardize evening collections to the infants' last feedings before their bedtime because this was most convenient for mothers. It is possible that only collecting two samples and variation with time of day influenced the patterns we observed in milk cortisol and introduced inter-individual variation into our results. These may have resulted in spurious associations with infant anthropometrics. Though we were unable to account for diurnal variation across multiple times in the day, we did try to control for confounding by collection times (morning and evening) and hours between collections during model

selection through our creation of the respective continuous variables. However, only the variable “hours between collections” was retained by AIC_c in the final model of best-fit for milk cortisol slope. Human milk fat and energy content vary with suckling frequency and duration, within a feeding, between multiple feedings, and across the day, and both are often associated with infant growth (Aksit et al., 2002; Brockway et al., 2024; Miller et al., 2013). We collected an imperfect proxy for feeding frequency and subsequent maternal investment by parameterizing mothers who reported waking three or more times to feed their infants. Sampling only twice a day without properly assessing feeding frequency may have also limited our ability to evaluate the effects of such variation, as we did not find an association between milk fat, energy content, and infant growth. Our use of infant age as a proxy for lactation duration also faced limitations. Though it is common practice to estimate lactation duration from infant age at the time of participation, doing so requires consideration of additional factors such as immediate initiation of breastfeeding, interruptions to breastfeeding, and breastfeeding practices (e.g., exclusivity). We tried to account for this by creating the binary variable for exclusive versus partial breastfeeding.

5. Conclusions

Maternal capital functions as the niche that infants are exposed to early in life. Such exposure can occur through human milk constituents, such as cortisol. Milk cortisol can influence infant phenotypic traits (e.g., body sizes, growth) to shape adaptations best suited for prevailing conditions, a crucial tenet of phenotypic plasticity. This suggests milk cortisol can be understood as a form of somatic maternal capital, with its variability affecting investment in growth, development, and lifelong fitness. Capital, in this sense, is not solely something that mothers and carers can strategically control or accumulate, like an economic resource. While strategic decision-making is not out of the question, it is worth recognizing that, like other forms of capital including social or economic (Warin et al., 2016), maternal capital would be a result of environmental and social conditions (e.g., stress) beyond anyone’s specific control or possibly even beyond their awareness. Nevertheless, what allows maternal capital, in the form of cortisol exposure, to potentially play an important role in human evolution and in people’s everyday lives is the enormous consequences on infant growth, health, and survival.

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Data Availability Statement: The data that support the findings of this study are available from the corresponding author (R.A.) upon reasonable request.

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Abbreviations

The following abbreviations are used in this manuscript:

HAZ	Height-for-age z-score
WHZ	Weight-for-height z-score
SES	Socioeconomic status
HPA	Hypothalamic–pituitary–adrenal
BMI	Body mass index
CV	Coefficient of variation
AIC _c	Akaike’s corrected information criterion
HMC	Human milk cortisol

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