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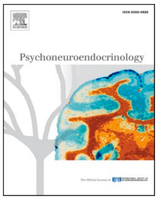

Everyday perceptions of safety and racial disparities in hair cortisol concentration

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ABSTRACT

Objective: Black-White disparities in physiological stress during adolescence are increasingly evident but remain incompletely understood. We examine the role of real-time perceptions of safety in the context of everyday routines to gain insight into the sources of observed adolescent racial differences in chronic stress as measured by hair cortisol concentration (HCC).

Method: We combined social survey, ecological momentary assessment (EMA), and hair cortisol data on 690 Black and White youth ages 11–17 from wave 1 of the Adolescent Health and Development in Context (AHDC) study to investigate racial differences in physiological stress. Individual-level, reliability-adjusted measures of perceived unsafety outside the home were drawn from a week-long smartphone-based EMA and tested for association with hair cortisol concentration.

Results: We observed a statistically significant interaction ($p < .05$) between race and perceptions of unsafety. For Black youth, perceived unsafety was associated with higher HCC ($p < .05$). We observed no evidence of an association between perceptions of safety and expected HCC for White youth. For youth who perceive their out-of-home activity locations to be consistently safe, the racial difference in expected HCC was not statistically significant. At the high end of perceived unsafety, however, Black-White differences in HCC were pronounced (0.75 standard deviations at the 95th percentile on perceived unsafety; $p < .001$).

Discussion: These findings call attention to the role of everyday perceptions of safety across non-home routine activity contexts in explaining race differences in chronic stress as assessed by hair cortisol concentrations. Future research may benefit from data on in situ experiences to capture disparities in psychological and physiological stress.

1. Introduction

Racial disparities in adult physical health, including a number of chronic diseases, are well-documented (Brown et al., 2012; Mitchell et al., 2019; Williams and Mohammed, 2009; Yang et al., 2021). Life course and stress theories posit that these racial disparities in health are often rooted in the disproportionate exposure to adversity, both concurrently and cumulatively across the life span, for racial minorities compared to their White counterparts (Bailey et al., 2017; Ford et al., 2021; Goosby et al., 2018; Shonkoff et al., 2021). Moreover, exposure to adversity occurring during critical or sensitive periods of development, such as early childhood and adolescence, may have independent and direct negative effects on health outcomes or possibly exacerbate deleterious health trajectories (Adam et al., 2015; Bailey et al., 2017; Ford et al., 2021; Goosby et al., 2018; Shonkoff et al., 2021).

Adolescence is a particularly unique period in development, both socially and biologically, that may heighten vulnerability for poor outcomes (Eiland and Romeo, 2013; Ford et al., 2021; IOM (Institute of Medicine) and NRC (National Research Council), 2011; Romeo, 2010). For example, the greater autonomy and time spent with peers and

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romantic partners as opposed to caregivers may increase the likelihood of adolescents' exposure to adverse social and physical environments. These increasing exposures to adversity are occurring alongside rapid structural and functional changes to areas of the brain (e.g. hippocampus, amygdala, prefrontal cortex) that are responsible for emotion regulation and stress responsivity, and highly sensitive to the stress hormone, cortisol. However, for Black adolescents, structural racism leads to greater exposure to adverse social and physical environments compared to their White counterparts (Yusuf et al., 2022), and research on race and health during adolescence reveals evidence of Black-White disparities, indicating that social determinants of health manifest in racial disparities early on in the life course.

The magnitude and breadth of racial health disparities during adolescence (Lau et al., 2012) has drawn research attention to biological processes that are both responsive to social factors and capable of exerting long-term systemic effects on the body. Research on activity of the stress-sensitive hypothalamic-pituitary-adrenocortical (HPA) system demonstrates that irregular cortisol responses to stress may be linked with subsequent health outcomes. For example, chronically elevated cortisol as captured by hair cortisol concentration (HCC) is associated with incidence of, and risk factors for, cardiovascular disease (Iob and Steptoe, 2019), highlighting the need for research on the origins of, and potential disparities in, this outcome among youth.

Empirical research on racial disparities in HPA axis activity has increased substantially in recent years and evidence points to significant Black-White differences across the life span. Black Americans relative to their White counterparts show irregularities in salivary cortisol diurnal rhythm among pre-adolescents (Martin et al., 2012) and adolescents (Deer et al., 2018; DeSantis et al., 2015, 2007); higher salivary cortisol rise and delayed recovery in response to a laboratory stressor in children (Tackett et al., 2017); and higher hair cortisol levels in adolescents (Ford et al., 2021) and adults (Lehrer et al., 2020; Wosu et al., 2015). The source of these racial disparities is not well understood. Tackett et al. (2017) found that socioeconomic status (SES) partially accounted for racial differences in cortisol reactivity to the Trier Social Stress Test, but no evidence of SES mediation was observed for cortisol recovery. Ford et al. (2021) found that racial disparities in a measure of hair cortisol concentration and bedtime salivary cortisol were robust to the inclusion of multiple measures of current and prior SES. The observation that racial disparities in cortisol levels are incompletely explained by group differences in household-level economic adversity underscores the importance of considering alternative sources of this persistent racial gap.

We ask whether exposure to environments perceived to be *unsafe* contributes to elevated HCC among youth and if perceived unsafety accounts for racial disparities in this outcome. We draw on theoretical approaches that acknowledge the safety consequences of social environmental contexts for Black youth. Fundamental cause theory, for instance, points to racial inequalities in a range of flexible resources that promote health in understanding the origins of enduring racial disparities in health (Phelan and Link, 2015). These include factors beyond household-level SES such as segregation-related neighborhood structural disadvantage and associated violence rates. Phelan and Link (2015) also highlight the role of potential discrimination and the threat of harm in the context of routine activities as a unique source of health-relevant adversity for Black Americans. We argue that racial differences in the experience of everyday routine activity-related threat are likely to lead both to elevated levels of perceived unsafety and, potentially, amplified impact of unsafety experiences on HCC among Black compared to White youth. A focus on perceptions of unsafety in situ is consistent with theoretical models of racial health disparities that emphasize the direct physiological consequences of exposure to environmentally-induced stressors rather than more distal mental health outcomes (e.g., depression and anxiety) (Sternthal et al., 2011).

Appraisal of the environment as threatening, i.e. lacking safety, is a cornerstone of Lazarus and Folkman's (1984) transactional model of stress. They delineate exposure to potentially stressful stimuli combined with an individual's assessment of the personal relevance of the situation (primary appraisal) and ability to cope with the stressor (secondary appraisal) as key factors shaping stress responses. In support of this psychological theory, when the environment is appraised as having the potential for harm or loss, this threat is an activator of cortisol release (Denson et al., 2009). Similarly, according to an important evolutionary theory (Adaptive Calibration Model), the threat of violence is a potent signal of an unsafe environment that can lead to a particular cortisol pattern (i.e. vigilant) that is characterized by greater cortisol output, which would be reflected in higher HCC (Del Giudice et al., 2011).

Black youth in urban areas face a number of everyday situations that may be appraised as unsafe of particular relevance is greater exposure to violent crime in the neighborhood for Black youth relative to White youth (Friedson and Sharkey, 2015; Krieger et al., 2017; Peterson and Krivo, 2010). Actual and potential exposure to violence has significant implications for the experience of daily life, with potential health consequences for exposed youth in the form of elevated perceived stress (Heinze et al., 2017). Exposures to neighborhood violence and perceptions of neighborhood unsafety have been associated with HCC, but most samples have consisted of predominantly non-Black youth so it is unclear the degree to which perceptions of neighborhood unsafety contribute to racial disparities in HCC. For example, in a sample of White youth in Quebec (mean age: 17) greater perceived neighborhood dangerousness as rated by the mother at 8 times between age 5 months and 15 years was associated with higher levels of HCC relative to those who grew up in neighborhoods with moderate levels of dangerousness (Ouellet-Morin et al., 2021). Similarly, reduced perceptions of neighborhood safety were associated with higher HCC in a sample of predominantly Hispanic/Latino youth (mean age: 11) (Hollenbach et al., 2019). In studies of young children, similar associations have been found. Low levels of caregiver assessed neighborhood safety were associated with higher HCC among one year old children (Tarullo et al., 2020), two-year old children (Bryson et al., 2019), and three-year old children (Gunnar et al., 2022). Of note, this result for three-year old children was found only among the Black children. Although the mechanism explaining elevated HCC in young children may be different than that for adolescents who spend more time directly exposed to neighborhood risk factors than children do, these findings underscore the impact of perceptions of neighborhood safety on HCC. Thus, perceptions of neighborhood unsafety rooted in exposure to community violence could be a potential contributor to disparities in HCC between Black and White youth.

An exclusive focus on exposure to neighborhood violence and its consequences for perceptions of safety among Black youth, however, obscures the more complex span of urban exposures these youth experience. First, a significant proportion of Black youth do not reside in segregated, concentrated poverty areas. In addition, recent research indicates that Black youth spend a substantial amount of time beyond their home neighborhood environments (Browning et al., 2021a) in areas characterized by considerable sociodemographic heterogeneity. Browning et al. (2022) found that Black youth who reside in Black segregated neighborhoods spend over two hours a day, on average, in areas in which a high proportion of residents are White. Exposure to "white spaces" (as captured by residential or ambient White presence) may result in experienced or anticipated unsafety due to surveillance and targeting by police or other authorities, discrimination, and negative social evaluation (Anderson, 2022).

Extant evidence thus points to the likely greater burden of diminished safety perceptions experienced by Black vs. White youth – even for Black youth residing outside segregated urban areas. Thus, a preliminary hypothesis expects that Black youth will exhibit higher average levels of reported real-time unsafety in non-home spaces than White youth (H1). We then consider the extent to which Black-White differences in real-time perceived unsafety mediate any observed race difference in physiological stress as measured via HCC (H2). Beyond the overall frequency of compromised safety, however, the conditions under which safety is perceived to be reduced are also likely to vary by race in stress-consequential ways. In particular, according to the transactional model of stress, secondary appraisals of the ability to cope also influence the stress response. If violence is concentrated near routine activity locations such as home, school, or other regular and unavoidable destinations, youth may feel they lack the ability to manage exposure to these unsafe conditions elevating their cortisol levels. Moreover, racially-motivated surveillance, scrutiny, and the potential for discriminatory targeting of Black youth may be perceived to be particularly uncontrollable and unpredictable (Smith Lee and Robinson, 2019) – two key drivers of cortisol reactivity (Dickerson and Kemeny, 2004). Indeed, recent research has highlighted the consequences of police killings of Black victims for short-term cortisol levels among Black youth, underscoring the possible perceived safety and stress consequences of anticipated racism-related threats for Black adolescents in the course of their everyday routines (Browning et al., 2021c). Consistent with theoretical orientations that emphasize the interaction between race and social-environmental context in understanding health disparities (Mezuk et al., 2013), we expect that the unique conditions of diminished safety perceptions among Black youth are likely to amplify their stress consequences compared with White youth. Accordingly, we test the hypothesis that race moderates the association between perceived unsafety and physiological stress (H3).

We investigated the physiological stress consequences of everyday unsafety perceptions using data from wave 1 of the Columbus, Ohio-based Adolescent Health and Development in Context (AHDC) study – a large-scale (N = 1405) sample of youth ages 11–17 (2014–2016). The AHDC data combine ecological momentary assessments (EMA) of perceived unsafety over the course of a typical week with extensive social survey data and a measure of cortisol from hair capturing HPA axis activity over a modal period of three months. These data offer a unique opportunity to investigate racial differences in real-time perceptions of unsafety and their physiological stress consequences.

2. Methods

2.1. Study design

The study draws on data from two linked data collection efforts: 1) *The Adolescent Health and Development in Context (AHDC)* study – a representative cohort study that investigates the role of social and spatial environments in shaping the behavioral and health outcomes of youth aged 11–17 years in Franklin County, Ohio (collected during 2014–2016) and 2) *The Linking Biological and Social Pathways to Adolescent Health and Wellbeing* (Bio-Social Linkages) study, a supplementary study focused on the physiological stress consequences of everyday exposures that collected hair samples for a subsample of 1102 of the 1405 Wave 1 (2014–2015) AHDC youth (Ford et al., 2021, 2019). The study design and procedures were reviewed and approved by the Social and Behavioral Sciences Institutional Review Board at Ohio State University before fieldwork began. Written parental permission and youth assent to participate in the study were obtained by trained interviewers prior to the initial in-home interview.

The AHDC study design included an initial entrance survey (face-to-face interviews and computer-assisted personal interviewing with a youth and his/her caregiver) during which demographic, socioeconomic, and self-reported health and behavioral data were collected. The entrance survey was followed by a seven-day smartphone-based geographically explicit ecological momentary assessment (Kirchner and Shiffman, 2016) period for the youth. Youth were provided phones by the project and were instructed to carry the phones with them and ensure the battery was charged to maximize momentary EMA survey response opportunities. The EMA was intended to collect real-time information on youth locations, behaviors, and perceptions of the immediate environment across the study week. Youth were prompted to answer the EMA five times a day randomly within time blocks. The EMA averaged approximately 4.5 min in length. At the in-home Entrance Survey interview, youth were provided instructions on responding to an EMA prompt, including acknowledging a prompt, completing questions, and advancing through the survey. In the field, youth were given 20 min to acknowledge the prompt and an additional 20 min to complete the questionnaire once began. Youth were asked to report on their experiences at the time of the prompt rather than when the survey response occurred. This approach helped avoid scenarios where the youth finds a more comfortable place to fill out the survey and reports on that location rather than the original – potentially less safe – location of the prompt.

Youth participants received a monetary incentive at the completion of 50 % and 75 % of the EMAs administered over the course of the week. Youth also received a certificate of community service reflecting their level of participation in the study. Given restrictions on use of smartphones in many urban school districts, we did not administer EMA prompts during school hours. The overall EMA response rate was 53.8 %. We investigated patterns of missingness in EMAs, finding that a dominant factor was day of the study week, indicating that youth inclination to respond to EMAs declines over the course of a 7-day study period. Notably, we found no evidence of Black-White differences in the tendency to respond to EMAs. We also observed no association between the average safety rating of the routine locations youth typically spend time at (survey-based responses to questions regarding levels of safety experienced at e.g., school, work, etc.) and the tendency to respond to an EMA prompt received while there.

At the end of the EMA week, interviewers conducted an Exit Survey with respondents, during which the youth completed a recall-aided interactive space-time budget (Boettner et al., 2019; Hoeben et al., 2014). The space-time budget interview walks youth through 5 of the 7 days of the smartphone week to confirm the location and duration of all places the youth spent time at. Youth participating in the Bio-Social Linkages study also provided a hair sample during the Exit Survey visit.

2.2. Study location and sample

The study was conducted largely within Franklin County, OH which contains the city of Columbus – Ohio's largest city and the 14th largest city in the U.S. (estimated 2018 population of 892,533). The study area is bounded by Interstate 270, the 55-mile beltway loop freeway containing the most urbanized area within the county. The study area was deliberately designed to include both the City of Columbus and wealthier suburban municipalities that border, or are contained within, the boundaries of Columbus. The Columbus, OH area is roughly average on key indicators of racial composition and segregation when compared with large metropolitan areas in the US. In a recent analysis of 51 major US metropolitan areas, the Columbus metro area was found to have a dissimilarity index score (62.2) and Black population prevalence (14.9 %) comparable to the large metro area means (59.0 and 15.0 %, respectively; Frey, 2018). For more information on the AHDC sampling design and study area, see Boettner et al. (2019) and Browning et al. (2021a).

2.3. Dependent variable – hair cortisol concentration

Interviewers were instructed to obtain a hair sample if youth had at least 1 cm of hair (or enough hair to cut with thinning shears). We included all samples that exceeded 0.5 cm in the analysis as those with shorter hair lengths were disproportionately Black. As recommended, longer hair samples were cut in the laboratory to 3 cm from the root end as prior research has found cortisol is leached out of hair at longer lengths (Meyer et al., 2014). Eighty percent of the sample had 3 cm of assayed hair, capturing the accumulation of cortisol for a roughly three-month period prior to measurement. Consequently, on average, the temporal window over which cortisol was measured included a period prior to that assessed for safety perceptions on the EMA (based on exposures in the week prior to collection of the hair sample). Although this temporal misalignment is unavoidable, we note that youth and their families were encouraged to choose a "typical" week for participation in the EMA/smartphone component of the study to ensure a high correlation between locations experienced during the measured week and routine exposures reported on the entrance survey. Youth were asked to provide the locations of typical routine activities based on a set of structured categories on the survey (e.g., school, work, place of religious services, friend and family residences, etc.). On average, youth spent a majority of their total non-home time (roughly 60 %) during the study week at these listed routine locations.

The hair samples were prepared using an adapted protocol (D'Anna-Hernandez et al., 2011; Meyer et al., 2014) that has been described in previous research (Ford et al., 2021, 2019). The assays were completed at the Ohio State University College of Nursing Stress Science Lab. The hair sample was washed with high-performance liquid chromatography (HPLC) grade isopropanol and then dried over the course of 1–3 days prior to the assay. After mincing the hair sample in a microcentrifuge tube, a Retsch® 400 Mill was used for approximately 5 min to grind the sample into a powder. The ground sample was combined with 1.1 ml of HPLC grade methanol and was then incubated for 18–24 h at room temperature and with constant agitation. The powdered hair was pelleted by centrifuging the tubes at 5000 *g* for 5 min at room temperature. All the supernatant was moved into a clean microcentrifuge tube and a stream of air was used to remove the methanol (6–8 h at room temperature). 100 μl of Salimetrics® immunoassay cortisol analysis diluent buffer was used to immediately reconstitute the cortisol extract. We used the Salimetrics® high sensitivity enzyme immunoassay cortisol kit to assay the hair samples (in duplicate). Inter- and intra-assay coefficients of variation were 16.2 % and 10 %, respectively. We follow Salimetrics® protocol and use the My Assay® analytic software program to calculate cortisol concentrations in μg/dL. We use the formula provided by Meyer et al. (2014) to convert the hair cortisol concentration to pg/mg. Hair cortisol concentrations were positively skewed and subject to natural log transformation prior to analysis.

2.4. Independent variables

2.4.1. Perceived unsafety

On each EMA, youth were asked if they felt the location they currently were at is a safe place to be (1 = strongly agree, 2 = agree, 3 = neither agree nor disagree, 4 = disagree, 5 = strongly disagree; thus higher values capture *lower* perceived safety or "unsafety"). The measure used as a predictor in the analyses of HCC is the estimated youth-level random effect from a multilevel ordinal logit model of unsafety reports outside the home (nesting EMAs within youth), preserving the five response categories. The variable values can be interpreted as the youth-specific deviation from the average cumulative log odds of responding to the safety question at any given category or above vs. below. Predicted values incorporate an empirical Bayes (EB) adjustment "shrinking" values toward the overall mean as a function of their level of unreliability (see Appendix Section 1 for additional detail on the approach).

2.4.2. Controls

We controlled for a number of possible confounders of unsafety perceptions including measures of hair condition; demographic and socioeconomic characteristics; life course and health status; family processes; and mobility and study design factors. We controlled for whether the youth *chemically treated* their hair (yes = 1), and *daily hair washing* (yes = 1). We included several measures of youth sociodemographics and caregiver socioeconomic characteristics. Youth *race/ethnicity* is reported by caregivers and includes two categories (restricted to youth who reported only one race): *non-Hispanic Black* (reference category) and *non-Hispanic White* (youth reporting more than one race were not included in the analysis). Youth *gender* is a dichotomous measure: female (reference) and male. Youth *age* was centered at age 14 and left as a continuous measure. We also included a measure of *age squared* to capture the potential for nonlinearity in the association of age with cortisol during adolescence given the impact of biological, cognitive, and social changes during this development phase (Kamin and Kertes, 2017). *Household income* is a three-category measure ($30,000 or less (reference); $30,001–$60,000, $60,001 or higher). *Caregiver marital status* includes four categories: married (reference), cohabitating, single, and other. *Caregiver education* measured five categories of educational attainment, less than a high school degree (reference category), high school degree, some college, college degree, or a graduate/professional degree. *Years in the residential neighborhood* is a continuous measure of the number of years the caregiver has lived in their current neighborhood of residence to capture potentially stress-relevant confounding due to residential mobility.

Life course and health factors include a measure of *pubertal development.* Youth self-reported sex-specific scales adapted from Ford and Stowe (2017) and Peterson et al. (1988) in which youth were asked about their perceptions of pubertal development (both sexes were asked about growth spurt in height, growth of pubic hair, and skin changes; males were asked about voice change and facial hair and females were asked about breast growth and menstruation onset). Response options for each item ranged from 1 (*no development*) to 4 (*development complete*). To create the composite, the item scores were summed and averaged for those who had data on at least one item. Reliability and validity of the pubertal development scale have been confirmed in prior research (Brooks-Gunn et al., 1987; Koopman-Verhoeff et al., 2020). The Cronbach's alphas for male and female scales are .82 and .83, respectively. Height and weight were measured in-home during the Entrance Survey. Height and weight were each measured twice, and a third time if there was any discrepancy, the average of the measures was calculated. Body mass index (BMI) scores were calculated as weight (kg)/height (m)2 using the Centers for Disease Control and Prevention's recommendations and statistical program (Cole et al., 2000; Kuczmarski et al., 2002). We also included a continuous measure of *financial difficulty* when the youth was aged 0–5. Measures of early life financial difficulty have been linked with internalizing behavior and may influence adolescent HPA axis functioning (Koss and Gunnar, 2018; Wang et al., 2022). The measure is based on a confirmatory factor analysis applied to six indicators of caregiver-reported financial challenges including experiencing (1) eviction/foreclosure (6.1 %); (2) bankruptcy (4.2 %); (3) if the family had difficulty paying bills (24.6 %); (4) if the family received government support (29.9 %); (5) if the mother or father lost their job (20.4 %); and (6) if the child stayed in a hotel/shelter (2.3 %). Considering these indicators are binary measures, we used weighted least-squares estimation when conducting the factor analysis. The financial difficulty scale score used as a covariate in the analyses was derived from the confirmatory factor analysis as a linear combination of factor regression coefficients multiplied with standardized observed indicators (the reliability coefficient H for the scale is .92).

We include several mobility and study participation controls to account for possible bias associated with group differences in these potentially outcome-relevant factors. First, we included a measure that captures the proportion of all waking time during the space-time budget days that was spent at home (the space time budget was administered for 5 of the 7 days of the EMA week, including Friday, Saturday, Sunday, and the two most recent weekdays). This measure captures differences in the baseline amount of time youth had during the study week to provide information on outside-home safety. Second, we included a measure of the *average proportion of EMAs answered outside the home* to capture the tendency to provide outside home EMA responses (conditional on an estimate of the tendency to spend time at home). Third, we included a binary measure of whether the youth reported having their own phone (yes = 1) as phone ownership was found to affect EMA compliance. Fourth, we included a three-category *school status* measure (enrolled/school in session (reference); enrolled/school not in session, and no school Information). A small proportion (3 %) of students

Table 1
Descriptive statistics of analytic sample (N = 690).

Variable	Mean or proportion	Standard deviation	Min	Max
Hair Cortisol (Natural Log)	1.296	1.090	-1.844	4.659
Unsafety Perceptions	-0.827	1.702	-3.256	4.419
Male Youth	0.446			
Age of Youth	0.338	1.859	-3.000	3.000
Youth Race/Ethnicity				
Non-Hispanic Black Youth	0.384			
Non-Hispanic White Youth	0.616			
Hair Chemically Treated	0.155			
Wash Hair Daily	0.351			
Household Income				
$30,000 or less	0.313			
$30,001–$60,000	0.231			
$60,001 or higher	0.456			
Caregiver Education				
Less than High School	0.042			
High School Degree or GED	0.136			
Some College	0.327			
Bachelor's Degree	0.285			
Graduate Degree	0.210			
Years In Neighborhood	12.540	9.976	0.000	62.000
Caregiver Marital Status				
Married	0.580			
Cohabiting	0.088			
Single	0.181			
Other Marital Status	0.152			
Proportion of EMAs Answered Outside Home	0.314	0.192	0.034	1.000
Proportion of Waking Time at Home	0.592	0.204	0.000	1.000
Puberty Score	3.044	0.701	1.000	4.000
BMI	23.690	6.392	9.200	62.852
Age 0–5 Financial Difficulty Score	0.087	0.552	-0.435	1.978
School Status				
Enrolled/in session	0.839			
Enrolled/not in session	0.136			
No School Information	0.025			
Has Own Phone	0.769			
Caregiver Tactics Physical Aggression	0.179	0.473	0.000	3.500
Caregiver Tactics Psychological Aggression	1.396	1.235	0.000	6.000

Table 2
Summary of OLS regression results from hair cortisol concentration (HCC) regressed on race and unsafety perceptions.

	(1) HCC b	(2) HCC b
White Youth	-0.608***	-0.605***
Youth Age (Years)	-0.052*	-0.054*
Youth Age*Youth Age	0.035**	0.036**
Male Youth	0.107	0.105
Hair Chemically Treated	-0.154	-0.159
Wash Hair Daily	-0.039	-0.031
Unsafety Perceptions		0.022
Constant	1.552***	1.565***
Observations	690	690

Notes: P-values based on two-tailed tests. + $p < .10$; * $p < .05$; **$p < .01$; ***$p < .001$.
Source: AHDC and Bio-Social Linkages Adolescents Ages 11–17 years.

provided no school information. Although these youth were mostly interviewed during the summer months, we included them in a separate category given uncertainty about their enrollment status.

We included two measures of family processes adapted from Straus et al. (1998); see Cotter et al. (2018) for more details on the validity of these subscales. These measures capture possible sources of perceived unsafety inside the home that may influence physiological stress levels and with which outdoor unsafety perceptions may be confounded. *Physical aggression* is a continuous measure that assesses the frequency in the past year that the caregiver has shaken the child, hit them on the bottom with an object, spanked with bare hand, and slapped hand/arm/leg; the Cronbach's alpha for the items is 0.77. *Psychological aggression* is a continuous measure that assess the frequency in the past year the caregiver has shouted, yelled, or screamed at the child, sworn or cursed at the child, threatened to (but did not actually) spank the child, or called him/her dumb or lazy or some other name; the Cronbach's alpha for the items is 0.83.

2.5. *Analytic strategy*

We first assessed the baseline bivariate association between race and average EMA unsafety perceptions to determine whether the data offer any evidence that unsafety perceptions are elevated for Black youth (H1). We then estimated models of race differences in HCC using OLS regression with robust standard errors both with and without the measure of unsafety perceptions. We employed Sobel-Goodman tests of formal mediation using the *sgmediation2* package in Stata (Mize, 2021). Moderation is assessed through interactions between race and unsafety (we also consider models of the unsafety effect on HCC in race stratified models in the supplementary material – see Section Table A.1). Table 1 shows descriptive statistics for variables in the analysis. Table 2 reports models estimating baseline race differences in HCC and the potential mediating effect of unsafety perceptions. Table 3 considers the moderating effect of race on unsafety perceptions including clusters of potential confounders (SES and family structure, life course and health factors, family dynamics, and mobility and study participation features).

2.6. *Analytic sample*

Our analyses are limited to the sample of Black and White youth in the AHDC given that sample sizes for other race/ethnic groups (76 Hispanic, 21 Asian/Pacific Islander, 118 multiracial, 2 Native American, and 6 other race youth) were insufficient to permit reliable estimation of perceived unsafety effects on cortisol. After excluding youth with hair length less than 0.5 cm or who reported being on a steroid (given the potential impact of steroids on cortisol production), 87 % of White youth and 72 % of Black youth were eligible to participate. Among those eligible, consent to participate was higher among White youth and their caregivers (98 %), relative to Black youth and their caregivers (88 %). Given the lower eligibility and consent rates, Black youth were less likely to participate in the hair collection than White youth. However, among those from whom a hair sample was collected, a higher percentage of hair samples from Black youth (93 %) compared to White youth (88 %) were useable (i.e., had a non-missing valid cortisol assay value). The final sample size of youth with analyzable hair cortisol values is 789 (485 White and 304 Black youth).

The analytic sample also excludes youth who did not report an EMA outside the home and thus provided no information on levels of safety experienced when not at home (N = 99). Youth who provided no outside home EMA include both those who spent very little time outside the home as well as those who were disinclined to respond to an EMA prompt when not at home. Accordingly, we control for estimates of the proportion of waking time the youth spent at home and the daily proportion of EMAs that were responded to outdoors as potential confounders (we provide estimates for comparable models including youth who did not report an outside-home EMA – imputing unsafety perceptions – in the Supplementary material; see Section 2 of the Appendix). We observe some evidence that Black youth who did not contribute an analyzable hair sample perceived, on average, greater unsafety in their everyday contexts ($p < .10$). Although we cannot rule out the possibility

Table 3

Summary of OLS regression results from hair cortisol concentration (HCC) regressed on unsafety perceptions, demographic/hair characteristics, health and lifecourse factors, family processes, and study design characteristics.

	(1) HCC b	(2) HCC b	(3) HCC b	(4) HCC b	(5) HCC b
Unsafety Perceptions	0.081*	0.079*	0.079*	0.082*	0.084*
White Youth	-0.686***	-0.631***	-0.626***	-0.610***	-0.624***
Unsafety Perceptions * White Youth	-0.104*	-0.103*	-0.104*	-0.109*	-0.116*
Youth Age (Years)	-0.056*	-0.054*	-0.050	-0.046	-0.047
Youth Age*Youth Age	0.036**	0.034**	0.033*	0.032*	0.032*
Male Youth	0.097	0.086	0.072	0.078	0.090
Hair Chemically Treated	-0.146	-0.156	-0.161	-0.150	-0.156
Wash Hair Daily	-0.028	-0.033	-0.036	-0.043	-0.039
HS/GED Degree (CG)		-0.096	-0.105	-0.112	-0.115
Some College Degree (CG)		-0.054	-0.065	-0.072	-0.073
Bachelor’s degree (CG)		-0.000	-0.003	-0.001	0.001
Graduate/Professional Degree (CG)		-0.013	-0.017	-0.013	0.001
$30–60k Household Income		-0.186	-0.188	-0.184	-0.184
$60k or higher Household Income		-0.229	-0.226	-0.223	-0.245^{+}
Cohabitating Caregiver		0.074	0.071	0.078	0.060
Single Caregiver		0.004	-0.000	-0.015	-0.048
Other Marital Status Caregiver		0.106	0.104	0.094	0.055
Years In Neighborhood		0.004	0.004	0.005	0.005
Puberty Score			-0.030	-0.023	-0.027
BMI (Z-score)			0.006	0.007	0.008
Age 0–5 Financial Difficulty Score			-0.009	0.004	0.012
Conflict Tactics Parent Child - Physical Aggression				0.167	0.163
Conflict Tactics Parent Child - Physiological Aggression				-0.028	-0.024
Proportion of EMAs answered outside home					0.180
Proportion of Waking Time at Home					-0.110
Youth Owns Phone					-0.023
Enrolled/not in session					0.230^{+}
No School Information					0.173
Intercept	1.605***	1.689***	1.650***	1.604***	1.600***
Observations	690	690	690	690	690

Notes: P-values based on two-tailed tests. + $p < .10$, * $p < .05$; ** $p < .01$; *** $p < .001$.
CG = Caregiver.
Source: AHDC and Bio-Social Linkages Adolescents Ages 11–17 years.

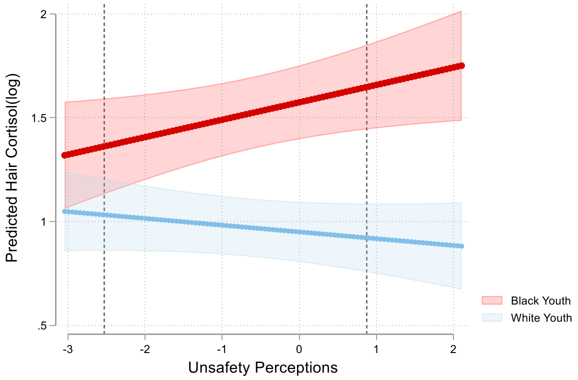

Fig. 1. Plotted predicted hair cortisol concentration (HCC) for black youth and white youth across different levels of unsafety perceptions. Unsafety perceptions values are plotted from the 5th to the 95th percentile. Vertical dotted lines placed at − 1 SD and + 1 SD values of the unsafety perceptions distribution.

that the observed association between safety and hair cortisol is biased due to the select nature of the analysis sample of Black youth, missingness among Black youth who perceive greater unsafety would, plausibly, be expected to attenuate the impact of unsafety on stress for this group (leading to more conservative estimates). Our final analytic sample was 690 youth (425 White youth and 265 Black youth). We employ multiple imputation by chained equations in Stata to address missing data on covariates.

3. Results

3.1. Aggregated EMA unsafety responses; H1 – Black youth experience higher levels of perceived unsafety

Overall, Black and White youth answered 19,126 EMA prompts. These youth strongly agreed that their current location was safe on 70.9 % of EMAs provided. Youth disagreed or strongly disagreed that their current location was safe on 1.6 % of EMAs. However, reports of out-of-home safety (in the aggregated measure, which is the focus of the current analyses) indicated lower levels of perceived safety. On average, youth reported strongly agreeing that their current location was safe on 61.3 % of answered EMAs outside the home – a roughly 10% decline compared to average levels. Youth disagreed or strongly disagreed that their current location was safe on 3.7 % of out-of-home EMAs – over twice the overall rate. Consistent with hypothesis 1, we observe race differences in average safety responses outside the home: Average aggregated responses based on random effects from multilevel ordinal logit models indicate that, consistent with hypothesis 1, Black youth report higher levels of perceived unsafety (− 0.67) than White youth (− 0.93) when outside the home (t-test, $p < .05$).

3.2. Multivariable models of hair cortisol concentration (HCC); H2 – perceived unsafety mediates the racial difference in HCC

Table 2 report the results of OLS regressions of HCC examining baseline models with and without inclusion of the unsafety perceptions measure. Models 1 and 2 of Table 2 include race, age and age squared, gender, and variables for chemically treated hair and frequency of hair washing. The Black vs. White youth comparison in model 1 indicates

Table A.1
Sensitivity analyses of OLS regression results from hair cortisol (natural log) regressed on imputed unsafety perceptions.

	(1) Hair Cortisol (Natural Log)	(2) Hair Cortisol (Natural Log)	(3) (4) Hair Cortisol (Natural Log)	Hair Cortisol (Natural Log)	(5) Hair Cortisol (Natural Log)
	b	b	b	b	b
Imputing Unsafety Perceptions					
Unsafety Perceptions	0.077*	0.075*	0.075*	0.080*	0.079*
White Youth	-0.625***	-0.544***	-0.541***	-0.520***	-0.532***
Unsafety Perceptions* White Youth	-0.095*	-0.095*	-0.096*	-0.103*	-0.109*
Black Youth					
Unsafety Perceptions	0.092*	0.089*	0.088*	0.094*	0.111**
White Youth					
Unsafety Perceptions	-0.033	-0.033	-0.033	-0.033	-0.042

Notes: P-values based on two-tailed tests. + $p < .10$; * $p < .05$; ** $p < .01$; *** $p < .001$. Models 1–5 replicate controls presented in Table 3.
CG = Caregiver.
Source: AHDC and Bio-Social Linkages Adolescents Ages 11–17 years.

that race differences in HCC are substantial in magnitude. The coefficient for the effect of being White (Black youth are the reference category) is −0.608, which is equivalent to over 50 % of the size of the sample standard deviation in HCC (SD = 1.090). Of additional covariates, the quadratic effect of age is significant and indicates that on average HCC declines to mid-adolescence and then increases during later adolescence (the linear effect is negative although not significant at the conventional level). Gender shows no significant association with HCC.

Model 2 includes the measure of average unsafety perceptions. These models offer no evidence of an association between perceived unsafety and HCC. Moreover, the magnitude of the race difference is close to unchanged with the incorporation of the unsafety effect (changing from − 0.608 in model 1 to − 0.605 following the inclusion of the unsafety effect in model 2). Tests of statistical mediation estimated using the sgmediation2 package in Stata (Mize, 2021) provide no evidence of mediation. We observed a trivial and insignificant (b = − 0.0031, p = .50) indirect effect of unsafety on HCC and no evidence of mediation based on the Sobel test, the Aroian test, or the Goodman test, with results suggesting that the inclusion of the unsafety measure mediates approximately .051 % of the Black vs. White difference in HCC. Thus hypothesis 2 (unsafety perceptions mediate the racial disparity in HCC) is not supported.

3.3. *Multivariable models of hair cortisol concentration (HCC); H3 – perceived unsafety moderates the racial difference in HCC*

Model 1 of Table 3 includes an interaction term to assess whether race moderates the association between perceived unsafety and HCC (adjusting for age and age squared, gender, an indicator of chemically treated hair, and frequency of hair washing). The coefficient for the main effect of perceived unsafety (the effect for Black youth – the omitted category of the race variable) is positive and statistically significant, indicating that increased perceived unsafety among Black youth is associated with higher levels of HCC ($p < .05$). The interaction term between race and perceived unsafety is negative and significant ($p < .05$) and indicates that the association between perceived unsafety and HCC among White youth is not significant ($p > .05$). Models 2–5 of Table 3 assess how the inclusion of potential confounders related to SES/family structure (model 2), life course factors (model 3), family dynamics (model 4), and mobility and study participation (model 5) affect the observed moderating effect of race on the association between perceived unsafety and HCC. The main effects associated with race and perceived unsafety, as well as the interaction effect between race and perceived unsafety, remain stable across all models. The inclusion of controls across models resulted in minimal change in the magnitude of the coefficients associated with the main and interactive effects of race and perceived unsafety. Coefficients from model 5 indicate that a one standard deviation increase in perceived unsafety is associated with a 15.37 % increase in HCC.

To better describe the relationship between race, perceived unsafety, and HCC, we plotted the predicted values of HCC by race and representative levels of perceived unsafety in Fig. 1 (roughly corresponding to the 5–95th percentiles of the perceived unsafety distribution), where the solid lines denoted the predictive mean and the bands represent 95 % pointwise prediction intervals. These predictions are based on the results of model 5 in Table 3 and are estimated by holding other covariates at their mean values. The figure reveals the substantial change in the racial disparity in HCC across the range of perceived unsafety. At the lowest levels of perceived unsafety, there is no statistically significant difference in HCC between Black and White youth. For example, at the 5th percentile of unsafety perceptions, the predicted HCC for Black youth is 1.32 compared with 1.05 for White youth, a difference of.27 (p = .09). The resulting race difference in predicted values of HCC becomes substantial at the high end of the distribution of perceived unsafety. For example, at the 95th percentile of unsafety perceptions, the predicted HCC for Black youth is 1.70 compared with 0.88 for White youth, a difference of.82 ($p < .001$), equivalent to 75 % of the size of the sample SD of HCC (0.82/1.090). Thus Table 3 offers support for hypothesis 3 – perceived unsafety moderates the racial difference in HCC.

4. Discussion and conclusion

Racial disparities in physical health have been observed across a wide variety of outcomes and across stages of the life course. Research on racial health disparities during adolescence has received increasing attention given the importance of this life stage for understanding the subsequent emergence of chronic disease during adulthood (Romeo, 2010). Increasing interest in the role of physiological stress in shaping chronic disease risk and evidence of substantial racial disparities in a number of stress biomeasures during adolescence highlight the need to unpack the origins of these stress disparities. We examined the role of variation in everyday perceptions of unsafety during adolescence as captured by ecological momentary assessments in explaining racial disparities in HCC, reflecting cumulative exposure to circulating cortisol over a prolonged period of time (Short et al., 2016).

We considered both mediation- and moderation-based explanations of racial disparities in HCC. Our baseline analyses replicated the substantial racial disparity in HCC found in prior research (Ford et al., 2021). Consistent with our first hypothesis, our analyses demonstrated expected racial differences in average levels of perceived unsafety in out-of-home contexts. However, we found no evidence that average safety perceptions mediate the racial difference in HCC (H2). Addressing the potential that unsafety perceptions exert greater impact on the physiological stress outcomes of Black youth (due to the uniquely uncertain and uncontrollable nature of stressors Black youth face) we considered the hypothesis that race moderates the impact of unsafety perceptions on HCC (H3). We observed a statistically significant interaction between race and perceived unsafety that is robust to the inclusion of a host of potential confounders. For Black youth, higher levels of perceived unsafety were positively associated with HCC. For White youth, perceived unsafety was not significantly associated with HCC. Notably, at the low end of unsafety – i.e., when Black and White youth both consistently report that they strongly agree they are in a safe place – the racial difference in HCC was no longer significant at the conventional level.

The observed racially distinct effect of unsafety perceptions on HCC is consistent with our orienting theoretical framework rooted in the transactional model of stress (Lazarus and Folkman, 1984). At the psychological level, perceived unsafety is a measure of primary appraisal according to the theory. Although we did not find evidence that higher levels of appraised unsafety accounted for racial differences in HCC, the transactional model also points to secondary appraisals – focused on the capacity of the youth to cope with the perceived threat – as important additional determinants of stress outcomes. In this view, comparable levels of perceived unsafety may nevertheless result in elevated cortisol levels for Black youth due to the accompanying unpredictability and uncontrollability of potential threats such as violence concentrated at the sites of key routine activities and race-based targeting, discrimination, and social evaluation. Such secondary appraisals may also lead to differences in rumination about perceptions of unsafety. Race-related stressors can be a potent trigger of perseverative cognition (Williams et al., 2019), which is associated with elevations in cortisol (Ottaviani et al., 2016). A conventional mediation approach – assuming a racially invariant effect of unsafety perceptions on HCC – biases the effect of unsafety downward for Black youth, yielding no evidence of its role in explaining race differences in HCC.

Although we found associations consistent with our orienting moderation hypothesis, a number of alternative interpretations are possible. First, at the physiological level, the potentiated cortisol response to unsafety among Black youth may also be a reflection of prior experiences of distress, such as discrimination. Consistent with this hypothesis, adverse experiences in early life have been demonstrated to sensitize an individual to respond more robustly to current stress, as reflected in a flatter diurnal cortisol slope in adulthood (Young et al., 2019), which would be expected to lead to higher cortisol deposition in head hair. In so far as Black and White youth are appraising the situation similarly, these similar appraisals may lead to different physiological responses due to prior experiences. Accordingly, past experiences of racial discrimination have been associated with greater momentary cortisol levels, for the same level of negative affect (Doane and Zeiders, 2014), akin to what was seen in the present study for unsafety perceptions.

A second possible alternative interpretation is that Black and White youth may be basing their judgments of perceived unsafety on different factors. Because White youth in this sample are exposed to lower levels of violent crime there may be a more restricted range in their safety ratings than the Black youth. Thus, the same level of subjective safety for Black and White youth may correspond with different levels of objective safety. In so far as cortisol production is to prepare the organism to respond to threats this could explain higher levels of cortisol output in the Black youth. Or, alternatively White youths' safety assessments may reflect greater emphasis on emotional safety rather than physical safety, which might have differential effects on cortisol output.

These questions highlight the need for future research to investigate the spatial and social circumstances in which perceived safety is compromised for Black youth. Prior research on contextual associations with stress outcomes has largely focused on circumstances in neighborhoods of residence, underscoring the link between racial segregation, concentrated poverty, and exposure to violence. Yet, recent research has highlighted the complexity of everyday mobility for Black youth – potentially involving exposure to compositionally heterogeneous neighborhoods with respect to race/ethnicity and socioeconomic status. As noted, sources of potential stress may extend beyond those rooted in the everyday experience of concentrated poverty neighborhoods to the challenges associated with navigating compositionally whiter areas characterized by the threat of surveillance, potential targeting by police and other authorities, and social evaluation. Moreover, understanding the social-environmental circumstances that actively *promote* a sense of security for Black youth may reveal important potential intervention targets, given the finding that statistically significant disparities in HCC are not observed when Black and White youth feel consistently safe. Finally, future research will also benefit from incorporation of intensive, real-time methodologies for the assessment of health-relevant exposures. Rich, ecological momentary assessment data provide an opportunity to more comprehensively and reliably capture everyday experiences that may contribute to physiological stress, reducing the threat of recall and, potentially, social desirability bias.

This study is not without limitations. First, we lack longitudinal, appropriately temporally ordered data to make causal claims. Although participants were encouraged to choose a "typical" week for study participation (and data indicate that a high percentage of time was spent at routine locations), the measure of unsafety perceptions may nevertheless be capturing exposures that are not well aligned temporally with those that generated the cumulative cortisol measured in hair samples. We also cannot rule out that stressors experienced prior to the interview period (contributing to cumulative HCC) influenced exposure processes during the EMA week (although both concerns would tend to weaken the association between perceptions and physiological stress). Relatedly, whereas we employed best practices in hair cortisol collection and assay, methodologies are likely to continue to evolve and be refined (Moody et al., 2022), fine-tuning our understanding of racial differences in safety and HCC. Second, although the AHDC study includes comparatively large samples of Black and White youth with hair samples, other race/ethnic groups were insufficiently represented for separate analysis. Third, differences in the participation rates of Black and White youth and the potentially increased likelihood of non-participating Black youth to indicate unsafety in their EMA reports points to the possibility of bias in the estimates of racial difference in unsafety associations with HCC. Although the potential bias is equally (or, arguably, more) likely to result in *reduced* Black-White differences in the impact of unsafety on HCC, we nevertheless cannot rule out the possibility that differential participation by race resulted in an amplified impact of unsafety for Black youth.

Fourth, our measure of unsafety is based on a single item. Smartphone-based EMA surveys are time-constrained leading researchers to employ single-item approaches to social context assessments, including safety (Mennis et al., 2016; Schwerdtfeger et al., 2022). Nevertheless, additional research establishing the validity and reliability of EMA-based safety perception measures and unpacking the components of safety – both physical and psychological – is warranted. Fifth, the study site is a single metropolitan area. Future research based on data from multiple urban settings with adequate representation across race/ethnic groups will be required to fully understand the role of safety perceptions in explaining disparities in physiological stress. Finally, our analysis does not address the potential for some youth to experience reduced cortisol production due to exposure to high levels of adversity, particularly early in life (Bernard et al., 2015; Chen and Paterson, 2006). Although our findings offer evidence of elevated mean levels of HCC for Black youth, more attention to the complex process by which cortisol dysregulation results in blunted cortisol production is needed.

Although research on physiological stress processes during adolescence has increased significantly in recent years, investigations combining rich survey, real-time, and biomeasure information remain scarce. Ongoing improvements in technologies for mobile survey assessment and measurement of biological processes hold the potential to illuminate the origins of substantial and enduring social disparities in health.

Declaration of Interest

None.

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Appendix

1. *Construction of perceived unsafety measure*

To construct the EMA unsafety measure used as a predictor in the model, we employed a modeling approach that could accommodate both the ordinal nature of the response scale and differences in the proportion of EMAs answered across respondents. The multilevel ordinal logit model (preserving the five categories of the EMA unsafety measure) provides estimates of the empirical Bayes residuals or the youth-specific deviation from the average cumulative log odds of responding to a given level of agreement regarding current unsafety or above vs. below. This deviation constitutes the scale score used as a predictor in the models of HCC reported. These residuals are "shrunk" toward the grand mean of the scale as a function of the unreliability with which they are estimated. Individuals who provide fewer EMA responses are effectively down-weighted in this approach. We view this adjustment as important in order to ensure that individuals who provide a small number of EMAs don't exert undue influence on the unsafety-HCC association. For instance, a respondent might strongly agree that they are at a safe place on all EMAs responded to but only provide information on 2 EMAs. Using the EB approach, this individual's estimate would place more weight on the overall grand mean given the lack of information provided by specific EMA responses.

2. *Sensitivity analyses*

We conducted several sensitivity analyses. Our first concern was the robustness of our analysis to the inclusion of youth who were missing EMA reports on their perceptions of safety outside the home. In the analyses presented in the main text, we removed 99 youth who were missing an EMA report outside the home. To assess how our results might change with the inclusion of these youth, we refit the main models presented in Table 3 after imputing an unsafety perception score for those youth. We present these results in the first row of Appendix Table A1. We show only the coefficients for the main effects and the interaction effects, although these models follow the control strategy presented in Table 3. We note that our results are robust to the inclusion of those youth missing on the EMA reports. The coefficients for the main effects and interaction effects, as well as associated test statistics are equivalent to those presented in Table 3.

We also considered the robustness of the unsafety perceptions effect for Black youth by running stratified models by race. These models freely estimate coefficients for control variables across Black and White youth and could be considered a more conservative approach to estimating the unsafety effect. The second row of Appendix Table A1 reports the effect of unsafety perceptions for Black youth only. Across models, we observe a statistically significant ($p < .05$) positive coefficient for the effects of unsafety perceptions on hair cortisol concentration. These results enhance confidence in the robustness of the unsafety effect for Black youth. We also report the results of stratified models for White youth in the third row. Consistent with the pooled results, we observe a negative but statistically insignificant ($p > .05$) effect of unsafety perceptions for White youth.

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