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Residential Greenness Positively Associated with the Cortisol to DHEA Ratio among Urban-Dwelling African American Women at Risk for HIV

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Abstract As ecosystems that support human health, societies, and civilization change in the era of the Anthropocene, individuals with disproportionate balance of salivary hormones may be at greatest risk of morbidity and mortality. Vulnerable communities, in particular, are overburdened by inequities in features of built environments linked to health disparities. This study examined the cross-sectional association of *greenness* in the built environment with the ratio of cortisol to dehydroepiandrosterone (DHEA) in an urban-dwelling high-risk community sample of African American women ($n = 84$, age 18–44 years). Saliva samples, collected across 2 consecutive days, were assayed for cortisol and DHEA. Controlling for sexual violence, perceived stress, education, and income, as well as crime, traffic density, and vacant properties, we observed a significant positive cross-sectional association between greenness and the cortisol to DHEA ratio, ($\beta = 7{\cdot}5$, 95% CI: 0.89, 14.19). The findings highlight environmental influence on stress response at waking when there is the greatest individual variation. Implications for advancing our understanding of the waking ratio of cortisol to DHEA as a potential marker of physiological resilience are discussed.

Keywords Resilience · Environment and public health · Geographic information systems · Climate change · Salivary hormones · Violence · Greenness

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Introduction

Violence, in vulnerable communities, exacerbates well-established patterns of inequity in minority health and environments, both social and built, especially in regard to access and quality of green space (greenness) resulting in reduced potential for physiological resilience [1]. Globally, 35% of women report physical and/or sexual violence from an intimate partner (IPV) [2]. In the United States of America (USA), reported lifetime prevalence of partner and non-partner rape among African American women (22%) was 3·2% higher than White women (18·8%) and 7·4% higher than Hispanic women (14·6%) [3, 4]. Rates of childhood sexual violence (under age 18) by African American women have been reported as high as 65%, compared with the overall childhood sexual abuse rate of 43% in the US [5]. Additional stressors for African American

women come from social and built environmental inequality (i.e., structural racism, income inequality, crime exposure, noise pollution, neighborhood disorder, lack of greenness) that disproportionately impact health via the stress response [1, 6, 7]. In this era, termed by some theorists as *the Anthropocene*, changes in climate are also predicted to increase violent crime, including sexual assault and IPV, in the USS by 3% (95% CI [1·5, 5·4]) by the end of the century, based on a median carbon dioxide (CO2) emissions trajectory [8]. Increases in violent crime due to climate change will disproportinately impact the health of African American Women.

Biological Sensitivity to Context

Two main components of the psychobiology of the stress response are the Hypothalamic-Pituitary-Adrenal (HPA) axis and the sympathetic branch of the autonomic nervous system. Individual differences in environmental sensitivities of these systems have been linked to a variety of mental and physical health outcomes, particularly when a stressor is experienced on a chronic basis. Prolonged exposure to stress has the potential to alter the structure and function of the limbic system, including the hippocampus, which can be manifest as a dampening of the HPA reaction to the environment [9].

The primary hormonal products of HPA activation are the secretion of cortisol and dehydroepiandrosterone (DHEA) from the adrenal glands into circulation. Individual differences in cortisol levels, the waking response, diurnal pattern of production across the day, and the reactivity and recovery to acute stress have been extensively studied. For instance, negative associations between the chronicity of severe violence and the rise in cortisol levels from waking to 30 min post-waking have been found among women living in a domestic violence shelter and those living with abusive partners [10]. Interestingly, DHEA has a well-established antagonist action with cortisol, and also has neuroprotective and anti-anxiolytic effects. Theorists speculate that individual differences in the ratio of cortisol to DHEA may be an important index differentiating risk versus resilience, the capacity to recover from past stress, resistance to current stress, and rebounding to higher levels of capability [11, 12].

Only one small study to our knowledge has examined the waking ratio of cortisol and DHEA [13]. Izawa et al. (2012) longitudinally examined waking cortisol and DHEA among non-smoking, healthy (no psychiatric or physical disease) college-aged women ($n = 33$, age = 19·5, SD = 3·3) in a teaching practice training at four time points (2 weeks prior, the first and second week, and a few days after training). In an email from S. Izawa (izawa0810@gmail.com) in April 2019, Dr. Izawa reported no significant variation in mean ratios of cortisol to DHEA over the 4 days (mean ratios [8·3, 10·7, 9·5, and 9·3]). In further email communication in August 2020, Dr. Izawa reported for the 4 days mean cortisol levels as 10·5 nmol/l and DHEA as 1·21 nmol/l. One other study by Hucklebridge et al. (2004) studied waking cortisol and DHEA in a sample of healthy college-aged men ($n = 5$) and women ($n = 19$) sampled from an academic community in London. This study of young and middle-aged adults ages 18–46 ($m = 24·3$) reported DHEA levels (mean = 1·37, SD = 0·25) in text; however, they only reported cortisol levels in a graph (approximate mean = 13·5) and did not calculate the ratio [14].

Stress in Vulnerable Communities

Structural barriers related to race, class, and gender reinforce poverty and can exacerbate stress in vulnerable communities [15]. Income inequality disproportionately affects women, particularly African American women in the USA [16]. The mean income for African American females is 45% ($25,234) of the national average, with 27% living below the federal poverty line in the preceding 12 months [16]. Female adolescents ($n = 418$, African American = 12%) living in poverty during infancy (< 1 year of age) had lower waking cortisol than those not living with poverty as infants [17]. African American women are more likely to live with environmental stress including violent crime, noise pollution (e.g., traffic), and vacant properties of all which are associated with alterations in cortisol response [3, 4, 6, 18, 19].

Residential Greenness and Salivary Hormones

Residential greenness is one way of conceptualizing biologically diverse spaces supportive of individual and community health [12]. Urban greenness is the collective natural environment in urban areas, measured from remote satellite through the calculation of normalized difference in vegetation index (NDVI) [20]. Oslo,

Norway, (pop = 643,293) for example is one of the greenest cities in Europe with an NDVI of 0·436 [21]. Greenness (NDVI) measures the amount of healthy vegetation, which has been associated with mental and physical health [22]. African Americans are twice (estimated prevalence ratio = 2.31, (95% CI 2.09, 2·55) as likely to live on streets with no tree canopy and at least 50% impervious surfaces as non-Hispanic whites [23]. Research has also found that among ($n = 52$) women living in deprived urban communities at 3 h post-waking, there were significant ($p < 0·05$) differences in cortisol levels with low green space in their neighborhoods ($\bar{x} = 4·24$ nmol/l, SD = 2·03) compared those living in communities with high green *space* ($\bar{x} = 6·43$ nmol/l, SD = 3·5) [24]. Furthermore, in a cross-sectional urban population based study ($n = 206$) an inter-quartile range increase of greenness was associated with decreased odds (by 54%) of having DHEA levels in the lowest 10th percentile [25]. The knowledge gap in regard to residential greenness and salivary hormones centers on the considerable individual differences cortisol at waking in comparison with the more stable DHEA [26].

Present Study

The way cortisol and DHEA operate together speaks to the multi-dimensional capability of biological processes shielding cells, tissues, and organs from stress and the support healthy functioning [27]. Physiological resilience—this study's theoretical framework—is conceptualized as the capability to recover from conscious, unconscious, and cellular memories of stress, while at the same time enduring current stress and transforming into a stronger more flexible state [12, 28]. Thus, physiological resilience involves a dynamic variation in hormone levels throughout the day and the lifespan [27]. Physiological resilience is operationalized as the ratio of cortisol to DHEA with a higher ratio signifying more resilience at waking. Although there have only been two small studies that have measured the waking ratio of cortisol to DHEA, none examined African American women at high risk of HIV. Therefore, the purpose of this study was to evaluate the relationships between greenness and physiological resilience among African American women at risk for HIV, 41% of whom experienced sexual and other forms of violence, in addition to living in a city with structural environmental and social inequities. Our hypothesis is that women at high risk of HIV living with higher levels of greenness will have higher ratios of cortisol to DHEA.

Method

Study Design and Procedures

This cross-sectional study uses data from a multi-year study of the impact of environmental and physiological factors on the association between women's sexual assault history and HIV risk, called the ESSENCE Project (NICHD #R01HD077891, PI: J.K. Stockman). The ethical review boards of Johns Hopkins University and the University of California San Diego approved of the study and procedures. The ESSENCE Project recruited 310 participants at two Baltimore City Health Department (BCHD) sexually transmitted infection clinics that serve low-income and uninsured individuals in the western and eastern parts of Baltimore, Maryland. Female clients of BCHD were approached systematically with a recruitment flyer describing the study to potential participants. Eligibility criteria included being biologically female, African American or Black, between the ages of 18 and 44 years (mean = 26·67, SD = 6·64), living in Baltimore City, Maryland, and having access to a freezer. Eligibility further required having been in a sexual relationship with a man in the past 6 months and reporting one or more HIV risk factors (i.e., two or more unprotected sex partners, or sex with a high-risk partner defined as a male partner who uses intravenous or non-intravenous drugs, has sex with men, has cheated on them, has a sexually transmitted infection, was in prison for 5+ years, or is HIV-positive).

Upon providing informed consent, participants completed a survey (60–90 min) via Audio Computer–Assisted Self-Interview (ACASI). Then, participants were trained by research to self-collect saliva at home, given supplies and written instructions. Using the passive drool method, participants collected saliva for 3 days upon waking and 30-min post-waking (total of 6 samples) [29].To increase protocol adherence, participants were provided with cell phones programmed to receive reminder text messages. During this time, staff provided support to participants on the saliva collection protocol via phone or in-person. Samples were stored in home freezers until picked up by the study team members. Participants were compensated with $70 for completing the survey and saliva protocol.

Participants in the Present Study

The present study examines 98 participants who were selected because they had usable saliva samples assayed for both DHEA and cortisol. Among them, 85% had locatable addresses and complete survey data. Generally, similar to African American women in Baltimore City in general, the sample was fairly well-educated (high school grad or GED = 33%, started college or vocational school = 25%, completed a 2-year program = 10%, and completed a 4-year degree or graduate school 14%). The sample had an income lower than the median in Baltimore as 60% of participants had an income of less than $10,000 annually.

Measures

Determination of Salivary Analytes

Samples were stored at − 80 °C until being transported to the University of California, Irvine, for assay [10]. On the day of the assay, all samples were thawed and centrifuged to remove mucins. Samples were assayed in duplicate for cortisol (μg/dl) and DHEA (pg/ml) using commercially available immunoassay protocols specifically designed for use with saliva without modification to the manufacturer's recommended protocols (Salimetrics, Carlsbad, CA). For cortisol and DHEA respectively, the test volumes were 25 and 50 μl, lower limit of sensitivity 0·007 μg/dl and 5·0 pg/ml, and range of calibrators 0·007–3·0 μg/dl and 10·2–1000 pg/ml. On average, inter- and intra-assay coefficients of variation were less than 15% and 10%.

Cortisol and DHEA values used in the statistical analyses were averaged across duplicates within the day and then across days [18]. Averages were computed across the two most adherent days—cortisol (mean = 0·48 μg/dl, [2·1, 7·4 μg/dl]) and DHEA (mean = 414·0 pg/ml, [366·1, 461·9 pg/ml]). Cortisol (0·48 μg/dl * 27·59 = 13.2 nmol/l) and DHEA (414 pg/ml * 0·0028 = 1·2 nmol/l) were transformed into nmol/l units to create the ratio of the two values (mean ratio = 11·9, SD = 22·4).

Greenness

Through the use of USGS website Earth Explorer, a Landsat scene with near-infrared (NIR) and visible red (RED) bandwidths was captured on July 16, 2016, including Baltimore City in daytime view, with high vegetation potential and low cloud cover, was obtained [30]. We calculated normalized difference in vegetation index using the formula NDVI = (NIR-RED)/(NIR + RED) in 30 m pixels for the City of Baltimore. We took the average of the NDVI scores within 100 m in a circular polygon (buffer) around participants' addresses.

Participants Characteristics

Covariates included income and education as well as questions about experience of sexual violence, unprotected sex partners, and the perceived level of stress measured by a 10-item scale [31]. We asked the participants regarding their experience of sexual violence both before 18 years (*sexually abused you* (*By sexual abuse, we mean forcing or pressuring for sex or physically hurting the sexual parts of your body, including touching that made you uncomfortable*) and after age 18 years, (*Since you turned 18, has any other male done any of the following: used threats to make you (have sex when you did not want to; or used force (like hitting, holding down, or using a weapon) to make you have sex?*). We treated sexual violence as a categorical variable representing those unexposed to sexual violence (n = 57; 59%), those exposed as adults only (n = 9, 9%), and those both as adults and children (n = 32, 33%). Those who did not report sexual violence, by design of the ESSENCE project, also did not report any other experiences of violence.

Income was a binary variable representing those making above (33%) and below (77%) 200% of the US Federal Poverty Level. Addresses were imported as a comma separated file (CSV) and geographically coded in ArcGiS 10.4.1 [32]. Population-level data were collected from publicly available data sets from the US Geological Survey (USGS), the City of Baltimore, Baltimore Neighborhood Indicators Alliance (BNIA), and the US Environmental Protection Agency (US EPA) [30, 33–35].

Population-Level Covariates

Crime and vacant properties data were collected from the City of Baltimore as in CSV files and geocoded at 100-m buffers [33]. Data on traffic proximity (count of vehicles per day at major roads within 500 m) were gathered from the Environmental Justice Screen at the

US EPA and downloaded as polygon-shaped file at the statistical block group for Baltimore City ($n = 653$) [33]. The Baltimore Neighborhood Indicators Alliance (BNIA) was the source of community statistical area ($n = 55$) data used for cluster analysis [35]. Crime, traffic proximity, and vacant properties were adjusted for population at the block group, which is a statical area representing between 600 and 3000 people.

Statistical Analysis

First, we explored characteristics of the participants using descriptive analysis. Students' t test was used to examine difference between those exposed to sexual violence and those unexposed (see Table 1). We also created a data-embedded spatial map with population-level data to understand the spatial distribution of the covariates, such as greenness, crime, traffic proximity, and vacant property, in Baltimore City.

Next, generalized linear models (GLM) with log link and gamma distribution were implemented to explore the association between greenness and the cortisol to DHEA ratio while controlling for other covariates using a robust variance. Here, log link and gamma distribution are particularly appropriate for our data due to the positive skewness of the salivary hormones and the ratio of cortisol to DHEA [36]. We developed both unadjusted models and adjusted models by including one covariate at a time (Table 2). However, for our final adjusted model, we considered a saturated model, with all the covariate, assuming it will account for all confounding effect.

While including the sexual violence in the model, we created indicator variables for exposure to sexual violence, separating out adult only from adult plus childhood, with unexposed as the reference. In addition, to the participant characteristics (age, income, education, sexual violence, perceived stress, and crime) and greenness, we included several population-level covariates to adjust the contextual effect of the lived environment. These include community-level factors such as vacant properties and traffic proximity. In addition, we accounted for the clustering effect of the data at the community statistical area level ($n = 55$) by Huber–White standard errors. Multicollinearity within the GLM models was assessed using variance inflation factors (VIF). Due to missing data, the full model had a sample of 84.

Results

The mean cortisol in our study was 13·163 nmol/l (95% CI, 5·872, 20·452). The mean DHEA was 1·159 nmol/l (95% CI, 1·025, 1.293). Community Statistical Areas in Baltimore had average greenness measured as NDVI

Table 1 Demographic data

Variable	Exposed ($n = 41$)	Unexposed ($n = 57$)		Total sample ($n = 98$)
Childhood sexual violence	$n = 32$ (78%)	$n = 0$		$n = 32$(32%)
Education: high school or less	$n = 30$(73%)	$n = 37$(65%)		$n = 67$(68%)
Income < $29,999*	$n = 36$(88%)	$n = 39$(68%)		$n = 75$ (77%)
	Mean [95%CI]	Mean [95%CI]	p value	Mean [95% CI]
Cortisol nmol/l	12·47 [2·79, 22.18]	13·66 [2·88, 24.44]	0·8	13·16[5·87, 20·45]
DHEA nmol/l (n =)	1·10 [0·88, 1.33]	1·2 [1·03–1·37]	0.49	1·16[1·03, 1·3]
Cortisol/DHEA	12·22 [6·22, 18·22]	11·63 [5.06, 18·21]	0.9	11·88[7·38, 16·38]
Greenness	0·11 [0·1, 0·12]	0·12 [0·11, 0·13]	0.2	0·12[0·11, 0·12]
Age*	30 [28, 32]	25 [23, 26]	< .0001	27[25, 28]
Unprotected sex partners*	3·98 [2·31, 5·64]	2·45 [2·11, 2·8]	0.04	3·09 [2·37, 3·81]
Perceived Stress (n = 84) *	0·35 [0·05, 0·66]	− 0·03 [− 0·62, − 0·03]	0.002	− ·051 [− 2·04, 1·86]
Traffic proximity adjusted by block group population	1·09 [0·71, 1·46]	1·13 [0·85, 1·42]	0.83	1·12 [0·89, 1·34]
Crime within 100 m adjusted by block group population	0·023 [0·02, 0·03]	0·02 [0·015, 0·02]	0.31	0·02 [0·02, 0·025]
Vacant property adjusted by block group population	0·015 = [0·01, 0·02]	0·01 [0·01, 0·02]	0.35	0·01 [0·01, 0·02]

t test to compare the participants who reported sexual violence (exposed) to those who reported none (unexposed). (* = $p < .05$)

Table 2 Unadjusted and adjusted models

Variable		Unadjusted		Model 1		Model 2		Model 3		Model 4		Model 5		Model 6		Model 7		Model 8		Model 9	
		Coef	*p*value	Coef	*p*value	Coef	*p*value	Coef	*p*value	Coef	*p*value	Coef	*p*value	Coef	*p*value	Coef	*p*value	Coef	*p*value	Coef	*p*value
Greenness		4.72	0.26	4.72	0.33	5.50	0.26	5.73	0.24	6.70	0.14	5.97	0.12	4.95	0.14	6.98	0.04*	7.55	0.03*	7.55	0.03*
Sexual violence (Reference unexposed)	Adult	-0.11	0.88			0.01	0.97	-0.01	0.97	0.01	0.99	-0.06	0.82	-0.17	0.57	-0.21	0.41	-0.28	0.25	-0.27	0.27
	Adult & Child	0.09	0.83			0.24	0.46	0.19	0.60	0.31	0.38	0.25	0.46	0.32	0.34	0.34	0.31	0.37	0.29	0.38	0.29
Unprotected sex partners		0.02	0.69					0.02	0.27	0.03	0.28	0.03	0.32	0.04	0.11	0.04	0.10	0.04	0.10	0.04	0.08*
Perceived Stress		-0.06	0.69							-0.07	0.66	-0.09	0.60	-0.12	0.46	-0.10	0.52	-0.11	0.50	-0.12	0.42
Income		-0.30	0.49									-0.37	0.17	-0.04	0.87	-0.06	0.79	-0.10	0.65	-0.09	0.67
Education		-0.44	0.24											-0.59	0.02*	-0.56	0.02*	-0.57	0.02*	-0.56	0.02*
Population adjusted Crime		-0.24	0.98													8.76	0.16	7.06	0.26	6.11	0.43
Population adjusted vacant property		-0.21	0.98															4.77	0.19	4.55	0.16
Population adjusted traffic proximity		0.00	0.99																	0.03	0.79

Model 9 is the fully adjusted model of the Ratio of cortisol to DHEA (Physiological-Resilience) clustered at the community statical area. Sexual violence is a categorical variable. ($n = 84$) (*$p < .05$)

Model 9 is the fully adjusted model of the ratio of cortisol to DHEA (physiological resilience) clustered at the community statical area. Sexual violence is a categorical variable. ($n = 84$) (*$p < .05$)

that range from 0·041 to 0·217 (see Fig. 1). We found no significant difference ($p = 0·2044$) in greenness between those exposed to sexual violence ($\bar{x} = 0·109$, 95% CI: 0·097, 0·120) and those unexposed ($\bar{x} = 0·119$, 95% CI: 0·108, 0·130) group (see Table 1). There were significant ($p < .05$) differences between the exposed and

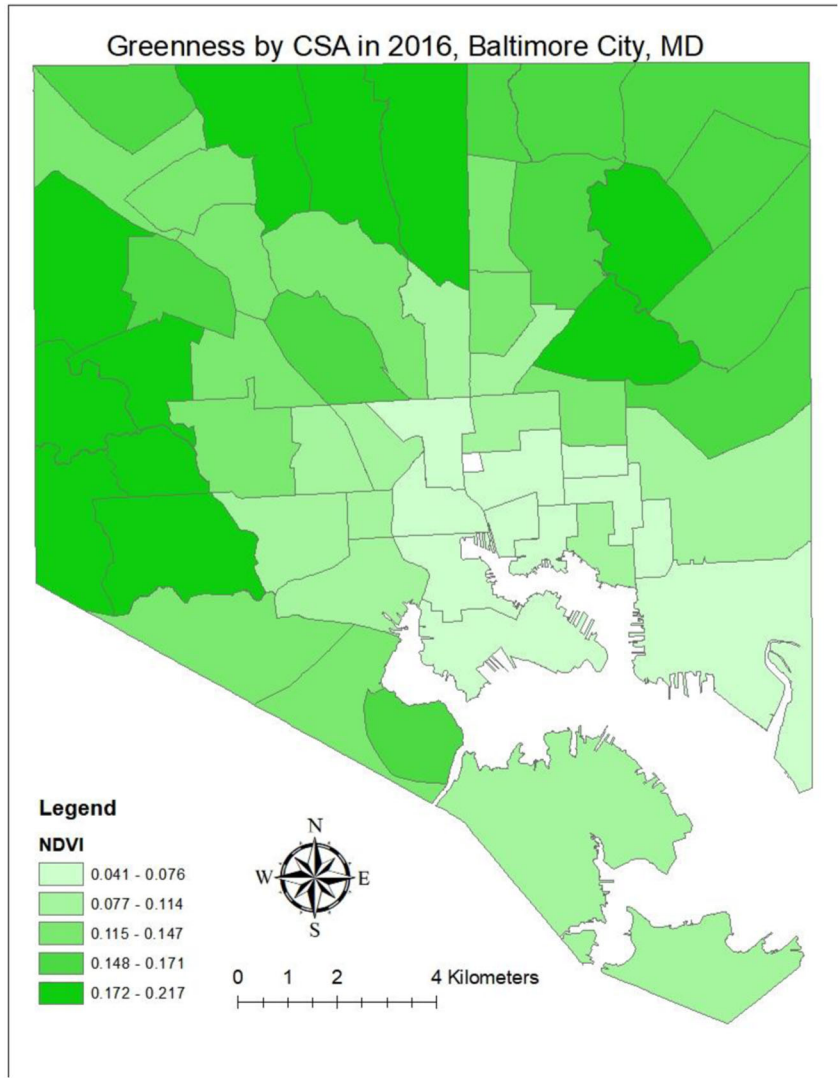

Fig. 1 Choropleth map of Normalized Difference Vegetation Index by Community Statistical Area

unexposed for age, unprotected sex partners, perceived stress, and income. Additional, descriptive statistics of the participants is presented in the Table 1.

When regressing greenness on the ratio of cortisol/DHEA without any covariates, we found non-significant positive associations (β = 4·7, SE = 4·1, p = 0·26, 95% CI; − 3·4, 12·8). After adjusting for all covariates, greenness was significantly associated with the ratio of cortisol and DHEA (β = 7·6, SE = 3·39, p = 0·03, 95% CI: 0·89, 14·2) (see Table 2).

Discussion

This study's purpose was to examine the association between greenness and physiological resilience (operationalized as the ratio of cortisol to DHEA) to stress among African American or Black women at risk for HIV, half of whom (45%) were exposed to sexual violence. Our major finding is that greenness of the neighborhood was positively associated with the ratio of cortisol to DHEA. We found a mean ratio of cortisol to DHEA at waking in our sample of older females higher than that of a younger cohort of female college students participating in a teaching practice training [13]. There are four potential explanations of the higher ratio of cortisol to DHEA: we found that (1) cortisol is elevated and DHEA is normal, (2) cortisol is normal and DHEA is depressed, (3) cortisol is elevated and DHEA is depressed, or (4) both cortisol and DHEA are elevated, with cortisol at a greater magnitude. Our sample mean for cortisol is within the standard error of the mean from a cohort of healthy males and females from an academic community in London [14] and close to those of females in the first week of teaching practice [13]. Given that the perceived stress scores were also elevated during the first week of the teaching practice, our samples similarly elevated cortisol fit given the social and built environmental stress African American women are facing on a daily basis [6]. The more stable hormone DHEA [26] had a mean within the standard error of the mean of healthy males and females from an academic community in London [14] and closer to baseline females before a teaching practice study [13].

In building the model, we found significance in the relationship between greenness and the ratio of cortisol to DHEA in model seven with the addition of crime. Studies that have found that greenness is inversely associated with crime and aggression suggest potential moderation or mediation of the relationships between greenness and the ratio of cortisol to DHEA. Education had a small yet significant negative effect in models six through nine. None of the other studies looking at waking cortisol to DHEA looked at education as a covariate. However, they all were in college. Depending on the implications of the ratio of cortisol to DHEA, education may be protective or a source of stress.

Given the dearth of literature on waking ratio of cortisol to DHEA, especially among a group of African American females at high risk of HIV, the implications of the relationship of the ratio of cortisol to DHEA is still unclear. Our hypothesized positive relationship is based on the explanation that both cortisol and DHEA would be elevated, with cortisol in a greater magnitude. In other words, increased greenness would support healthy waking DHEA and robust cortisol response to anticipated stress.

The covariates used were based on the theoretical framework [12]. The inclusion of population-adjusted traffic proximity and vacant properties in the model made a negligible difference in the direct effect; however, the combination of covariates help explain some of the random error in the relationships between greenness and resilience due to the complex interactions of the population social and built environmental impact on the stress response [6, 37]. Even though some of the covariates are not significant, they help to explain some of the error in the bivariate relationships. The inclusion of the categorical variable of exposure to sexual violence, including adult plus childhood exposure as a covariate resulted in statistical significance of the fully adjusted model. Furthermore, the importance of the impact of the categorical variable regarding sexual violence, including in childhood, is in alignment with the evidence that adverse childhood experiences have long-lasting impacts on the stress response [18].

The intersection of these factors affects the perception of green spaces, safety, and potentially the opportunity to access green spaces for potential benefits [38]. Alternative explanations are that sexual violence, traffic proximity, vacant properties, income, education, and greenness itself are all potential indicators of the ability of individuals and communities to leverage influence over their environment [39]. Nonetheless, these findings are a foundation for a continued investigation into the effect of residential greenness on biological markers that may represent physiological resilience.

The study is limited by the cross-sectional data as we are unable to see changes in salivary hormones before and after waking, as well as changes in greenness over

time. Despite these limitations, to our knowledge, this study is the first to examine at the association of greenness using remote sensing with physiological resilience operationalized as the ratio of cortisol to DHEA at waking among African American women at high risk for HIV. The study gave us a unique opportunity to explore the ratio of cortisol to DHEA when there is the greatest individual variation, and greenness, with the reference data of a unique and vulnerable population. Our finding of a positive association for the relationship of greenness and using the waking ratio of cortisol to DHEA as a potential operationalization of physiological resilience is novel, though requires further investigation.

The question remains whether an increased ratio of cortisol to DHEA is beneficial. Perhaps there may be a curvilinear relationship with parameters of the ratio that are optimal to health. Additional questions persist regarding the moderation and mediation of these complex relationships. Future studies would benefit from the collection of longitudinal data exploring seasonal changes in greenness interacting with the basal diurnal rhythms of the ratio of cortisol to DHEA. This would further our understanding of how long-term stress and changes in greenness impacts our physiological ability to respond to stress. Other covariates to consider include body mass index and, for females, start date of last menstrual period, pregnancy, and use of medication including oral contraceptives.

Conclusion

Increasing the modifiable factor of neighborhood greenness has multiple co-benefits through decreased ground surface temperature, aggression, crime, depression, and potentially promotion of healthy physiological response and recovery to stress. These benefits are life- and cost-saving and central to building the resilience potential of individuals and communities to the increasing impacts of climate change [19, 40, 41]. These findings provide policy makers, health professionals, and health systems and build our understanding of how increasing greenness can be a strategy to promote the health.

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References

1. Mancus GC. *Greenness and resilience to social and built environmental stress [dissertation]*. Baltimore, MD: Johns Hopkins University; 2018. Available from: http://jhir.library.jhu.edu/handle/1774.2/61172. Accessed 23 Aug 2020.
2. World Health *Organization. Global and regional estimates of violence against women: prevalence and health effects of intimate partner violence and non-partner sexual violence*. Geneva, Switzerland: WHO Press; 2013. Available from: https://apps.who.int/iris/handle/10665/85239.
3. Black MC, Basile KC, Breiding MJ, Smith SG, Walters ML, Merrick MT, et al. *The national intimate partner and sexual violence survey (NISVS): 2010 summary report*. Atlanta, GA: National Center for Injury Prevention and Control, Centers for Disease Control and Prevention; 2011. Available from: https://www.cdc.gov/violenceprevention/pdf/nisvs_report2010-a.pdf.
4. Casey JA, Morello-Frosch R, Mennitt DJ, Fristrup K, Ogburn EL, James P. Race/ethnicity, socioeconomic status, residential segregation, and spatial variation in noise exposure in the contiguous United States. *Environ Health Perspect*. 2017;125(7):077017.
5. Bryant-Davis T, Ullman SE, Tsong Y, Tillman S, Smith K. Struggling to survive: sexual assault, poverty, and mental health outcomes of African American women. *Am J Orthopsychiatry*. 2010;80(1):61–70.
6. Dulin-Keita A, Casazza K, Fernandez JR, Goran MI, Gower B. Do neighbourhoods matter? Neighbourhood disorder and long-term trends in serum cortisol levels. *J Epidemiol Community Health*. 2012;66(1):24–9.
7. Grove M, Ogden L, Pickett S, Boone C, Buckley G, Locke DH, et al. The legacy effect: understanding how segregation and environmental injustice unfold over time in Baltimore. *Ann Am Assoc Geographers*. 2018;108(2):524–37.
8. Hsiang S, Kopp R, Jina A, Rising J, Delgado M, Mohan S, et al. Estimating economic damage from climate change in the United States. *Science (New York, NY)*. 2017;356(6345):1362–9.
9. Jin R, Mason S, Mellon S, Epel E, Reus V, Mahan L, et al. Cortisol/DHEA ratio and hippocampal volume: a pilot study in major depression and healthy controls. *Psychoneuroendocrinology*. 2016;72:139–46.

10. Pinto RJ, Correia-Santos P, Costa-Leite J, Levendosky AA, Jongenelen I. Cortisol awakening response among women exposed to intimate partner violence. *Psychoneuroendocrinology*. 2016;74:57–64.
11. Walker FR, Pfingst K, Carnevali L, Sgoifo A, Nalivaiko E. In the search for integrative biomarker of resilience to psychological stress. *Neurosci Biobehav Rev*. 2017;74:310–20.
12. Szanton SL, Gill JM. Facilitating resilience using a society-to-cells framework: a theory of nursing essentials applied to research and practice. *ANS Adv Nurs Sci*. 2010;33(4):329–43.
13. Izawa S, Saito K, Shirotsuki K, Sugaya N, Nomura S. Effects of prolonged stress on salivary cortisol and dehydroepiandrosterone: a study of a two-week teaching practice. *Psychoneuroendocrinology*. 2012;37(6):852–8.
14. Hucklebridge F, Hussain T, Evans P, Clow A. The diurnal patterns of the adrenal steroids cortisol and dehydroepiandrosterone (DHEA) in relation to awakening. *Psychoneuroendocrinology*. 2005;30(1):51–7. https://doi.org/10.1016/j.psyneuen.2004.04.007.
15. Najman JM, Bor W, Ahmadabadi Z, Williams GM, Alati R, Mamun AA, et al. The inter- and intra- generational transmission of family poverty and hardship (adversity): a prospective 30 year study. *PloS One*. 2018;13(1):e0190504.
16. *U. S. Census Bureau. American fact finder. 2016*.
17. McFarland MJ, Hayward MD. Poverty and awakening cortisol in adolescence: the importance of timing in early life. *Soc Mental Health*. 2014;4(1):21–37.
18. Theall KP, Shirtcliff EA, Dismukes AR, Wallace M, Drury SS. Association between neighborhood violence and biological stress in children. *JAMA Pediatr*. 2017;171(1):53–60.
19. Garvin EC, Cannuscio CC, Branas CC. Greening vacant lots to reduce violent crime: a randomised controlled trial. *Inj Prev*. 2013;19(3):198–203.
20. Rhew IC, Vander Stoep A, Kearney A, Smith NL, Dunbar MD. Validation of the normalized difference vegetation index as a measure of neighborhood greenness. *Ann Epidemiol*. 2011;21(12):946–52.
21. Gärtner P. *European capitals line-up according to longitude location*. [Internet]. 2017 [updated 2020; cited 2020 Aug 23]. Available from: https://philippgaertner.github.io/2017/10/european-capital-greenness-evaluation/.
22. James P, Hart JE, Banay RF, Laden F. Exposure to greenness and mortality in a nationwide prospective cohort study of women. *Environ Health Perspect*. 2016;124(9):1344–52.
23. Jesdale BM, Morello-Frosch R, Cushing L. The racial/ethnic distribution of heat risk 2013;related land cover in relation to residential segregation. *Environ Health Perspect*. 2013;121(7):811–7.
24. Roe JJ, Thompson CW, Aspinall PA, Brewer MJ, Duff EI, Miller D, et al. Green space and stress: evidence from cortisol measures in deprived urban communities. *Int J Environ Res Public Health*. 2013;10(9):4086–103.
25. Egorov AI, Griffin SM, Converse RR, Styles JN, Sams EA, Wilson A, et al. Vegetated land cover near residence is associated with reduced allostatic load and improved biomarkers of neuroendocrine, metabolic and immune functions. *Environ Res*. 2017;158:508–21.
26. Granger DA, Marcus KT, editors. *Salivary bioscience: foundations of interdisciplinary saliva research and applications*. Cham, Switzerland: Springer Nature; 2020.
27. Kamin HS, Kertes DA. Cortisol and DHEA in development and psychopathology. *Horm Behav*. 2017;89:69–85.
28. Irvine KN, Warber SL, Devine-Wright P, Gaston KJ. Understanding urban green space as a health resource: a qualitative comparison of visit motivation and derived effects among park users in Sheffield, UK. *Int J Environ Res Public Health*. 2013;10(1):417–42.
29. Granger DA, Cicchetti D, Rogosch FA, Hibel LC, Teisl M, Flores E. Blood contamination in children's saliva: prevalence, stability, and impact on the measurement of salivary cortisol, testosterone, and dehydroepiandrosterone. *Psychoneuroendocrinology*. 2007;32(6):724–33.
30. USGS. Earth explorer. In: Survey UG, editor. 2018.
31. Perera M, Brintz C, Birnbaum-Weitzman O, Penedo F, Gallo L, Gonzalez P, et al. Factor structure of the Perceived Stress Scale-10 (PSS) across English and Spanish language responders in the HCHS/SOL Sociocultural Ancillary Study. *Psychological Assessment*. 2016;29(3):320–8.
32. ESRI. ArcGIS Desktop, 10.4.1 ed. Redlands, CA: *Environmental Systems Research*; 2015.
33. USEPA. EJSCREEN data. *Environmental Justice Screen: United States Environmental Protection Agency*. 2014.
34. City of Baltimore. *Open Baltimore*. Baltimore City, MD: City of Baltimore's open data catalog; 2018.
35. BNIA. *Vital signs*. In: Alliance BNI, editor. Baltimore, MD: BNIA; 2016.
36. Manning WG, Mullahy J. Estimating log models: to transform or not to transform? *J Health Econ*. 2001;20(4):461–94.
37. Watts G. The effects of "greening" urban areas on the perceptions of tranquility. *Urban For Urban Green*. 2017;26:11–7.
38. Mancus GC, Campbell J. Integrative review of the intersection of green space and neighborhood violence. *J Nurs Scholarsh*. 2018;50(2):117–25.
39. Pretty J, Ward H. Social capital and the environment. *World Dev*. 2001;29(2):209–27.
40. Younan D, Li L, Tuvblad C, Wu J, Lurmann F, Franklin M, et al. Long-term ambient temperature and externalizing behaviors in adolescents. *Am J Epidemiol*. 2018;187(9):1931–41.
41. South EC, Hohl BC, Kondo MC, MacDonald JM, Branas CC. Effect of greening vacant land on mental health of community-dwelling adults: a cluster randomized trial. *JAMA Network Open*. 2018;1(3):e180298-e.