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Featured Article

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Featured Article: Community Crime Exposure and Risk for Obesity in Preschool Children: Moderation by the Hypothalamic–Pituitary–Adrenal-Axis Response

Maria A. Gartstein,[1] PhD, Erich Seamon,[2] MS, Stephanie F. Thompson,[3] PhD, and Liliana J. Lengua,[3] PhD

[1]Department of Psychology, Washington State University, [2]Department of Forest, Rangeland, and Fire Science, University of Idaho, and [3]Department of Psychology, University of Washington

All correspondence concerning this article should be addressed to Maria A. Gartstein, PhD, Department of Psychology, Washington State University, P.O. Box 644820, Pullman, WA 99164-4820, USA. E-mail: gartstma@wsu.edu

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Abstract

Objective Identification of early risk factors related to obesity is critical to preventative public health efforts. In this study, we investigated links between the Hypothalamic–Pituitary–Adrenal (HPA)-axis activity (diurnal cortisol pattern), geospatially operationalized exposure to neighborhood crime, and body mass index (BMI) for a sample of 5-year-old children. Greater community crime exposure and lower HPA-axis activity were hypothesized to contribute to higher BMI, with child HPA-axis moderating the association between crime exposure and BMI. **Method** Families residing within the boundaries of the City of Seattle ($N = 114$) provided information concerning demographic/psychosocial risk factors, used to calculate a Cumulative Risk Index, indicating the number of contextual adversities present. Child BMI and diurnal cortisol pattern (derived from assays of saliva samples) were examined, along with neighborhood crime indices computed with publically available information, based on participants' locations. **Results** Hierarchical multiple regression analyses, adjusted for covariates (cumulative risk, age, and sex), indicated that crime proximity made a unique contribution to child BMI, in the direction signaling an increase in the risk for obesity. Consistent with our hypothesis, a significant interaction was observed, indicative of moderation by diurnal cortisol pattern. Follow-up simple slope analyses demonstrated that crime exposure was significantly related to higher BMI for children with low-flat (blunted) diurnal cortisol patterns, where community crime and BMI were not significantly associated at higher levels of cortisol. **Conclusion** Community crime exposure contributes to higher BMI as early as the preschool period, and blunted diurnal cortisol patterns may place children experiencing neighborhood adversity at greater risk for obesity.

Key words: childhood BMI; community crime; HPA-axis.

Obesity represents a significant public health concern, and identification of early risk factors is critical to preventative efforts. Ogden and colleagues (2014) reported that 35% of adults and 17% of children (2–19 years of age) were obese. These figures represent a dramatic increase previously referred to as the "obesity epidemic" (McAllister et al., 2009), and make it imperative to understand contributing factors starting in early childhood, given considerable stability of obesity (Park, Sovio, Vinern, Hardy, & Kinra, 2013).

A recent review indicated consistent evidence for links between overweight or obesity status in childhood and premature mortality/physical morbidity in adulthood (Reilly & Kelly, 2011). Increasing attention to precursors of childhood obesity requires an examination of biological and community-level etiological factors working in tandem. Hypothalamic–Pituitary–Adrenal (HPA)-axis activity and exposure to community crime have been linked with body mass index (BMI) in separate investigations (Chu et al., 2017; Hillman, Dorn, Loucks, & Berga, 2012), yet their compound effects have not been considered in prior research, and will be examined in this study.

Diurnal cortisol pattern is an indicator of the regulation of the HPA-axis system. The HPA-axis is responsible for stress reactivity, with physiological and psychological stressors resulting in an increased secretion of the corticotropin-releasing hormone, stimulating the anterior pituitary gland to release adrenocorticotropic hormone, which activates the adrenal gland to release cortisol. In a healthy situation, this system is flexible, wherein negative feedback to the pituitary gland and hypothalamus leads to inhibition of cortisol. Dysregulation of the HPA-axis, evidenced by its end product cortisol, has been linked with psychiatric disorders, most notably depression and posttraumatic stress disorder (PTSD; Stetler & Miller, 2011; Yehuda & Seckl, 2011). Thus, the HPA-axis activates in response to the environmental context, producing a hormonal cascade that ends in the production of cortisol. Cortisol follows a diurnal rhythm, with levels reaching their peak about 30 min after awakening and decreasing throughout the day (Kirschbaum et al., 1990). Well-regulated HPA-axis activity is typically reflected in diurnal cortisol patterns characterized by higher morning levels and a steep declining slope across the day. Stress, particularly severe or chronic adversity, can disrupt diurnal patterns or levels of cortisol (Miller, Chen, & Zhou, 2007). A meta-analysis showed that acute stress was more often associated with elevations in cortisol, whereas chronic stress was related to blunted levels in adults (Miller et al., 2007).

Empirical support for links between HPA-axis activity and obesity has been reported, with notable variability in cortisol effects across studies. There is evidence of a positive association between cortisol levels and obesity (Chu et al., 2017; Reinehr & Andler, 2004), along with findings in the opposite direction, indicating a negative association between cortisol concentrations and overweight status (Hillman et al., 2012), and null results (Larsen, Fahrenkrug, Olsen, & Heitmann, 2016). Larsen et al. (2016) examined hair cortisol concentrations for 2- to 6-year-old children in a cross-sectional investigation that utilized follow-up data for the Healthy Start intervention designed to lower the risk for obesity, and failed to detect a significant link with child BMI. Chu et al. (2017) conducted a cross-sectional study with school-age children and collected a single saliva sample as a source of cortisol concentration data, demonstrating higher concentrations were positively associated with BMI. Reinehr and Andler (2004) reported a decrease in cortisol levels, derived via baseline serum profiles, for obese children following weight loss in the context of a yearlong intervention. Thus, a negative relationship between cortisol concentrations and overweight status emerged in this longitudinal investigation. Hillman et al. (2012) examined baseline serum cortisol levels as well as serial serum cortisol measures in response to venipuncture, demonstrating a negative relationship with BMI for both cortisol indicators with female adolescents of different ages. Although this study was carried out over multiple days, it should still be considered cross-sectional in nature, and the primary strength of this investigation lies in assessing both baseline and reactivity-related cortisol levels. Hillman et al. (2012) described potential mechanisms responsible for this inverse relationship based on an established link between obesity/overweight status and insulin resistance, apparent as early as childhood (Daniels et al., 1999). As cortisol stimulates insulin activity, resulting in increased blood glucose levels, lower cortisol concentrations may reflect an early adaptive mechanism to assist in the maintenance of glucose/metabolic homeostasis in the face of emerging insulin resistance. That is, a blunted cortisol response could provide an effective means of suppressing insulin activity, facilitating glucose management for those at risk of insulin resistance.

The inconsistency in these findings is likely owing to the variety of measures of HPA-axis activity, including serum and saliva concentrations, reactivity to a stimulus, and baseline indicators. Null results emerged for analyses of cortisol obtained from hair samples (Larsen et al., 2016). In the present study, regulation of the HPA-axis was measured as diurnal patterns reflecting higher morning levels that decline through the day, not previously considered in the context of obesity-related research. Although Chu et al. (2017) obtained cortisol measures from saliva samples, these were collected during a single morning time point, not permitting a determination of diurnal patterns. Moreover, cortisol levels can fluctuate from day to day in response to a variety of factors. Therefore, averaging samples across multiple days can provide a more stable indication of an individual's trait-like diurnal levels and patterns (Adam & Kumari, 2009; Stalder et al., 2016). HPA-axis functioning is inherently responsive to environmental circumstances that involve stress, such as adversity resulting from neighborhood crime exposure, linked with obesity and stress reactivity.

Community crime has not been sufficiently investigated as a contributing factor to BMI, especially in childhood, despite considerable odds of crime exposure in the United States, and documented links between crime exposure and obesity (32% increase in risk; Sumner, et al., 2015). Crime was shown to amplify the odds of obesity via increased sedentary behaviors (Brown, Pérez, Mirchandani, Hoelscher, & Kelder, 2008), as apprehension related to crime results in decreased physical activity (Lumeng, Appugliese, Cabral, Bradley, & Zuckerman, 2006). An alternative pathway via HPA-axis activity involves fear of being victimized that translates into physiological readiness. According to Taylor and Repetti (1997), exposure to threatening environments results in dysregulation of physiological systems, the HPA-axis in particular, as capacity for recovery diminishes owing to frequent/chronic exposure to threat. Over time, proximity to neighborhood crime likely results in downregulation of the HPA-axis response, similar to other chronic stress exposures, such as low income (Zalewski et al., 2016) and bullying or victimization at school (Ouellet-Morin et al., 2011). Younger children do not experience community risk factors directly in the same manner as adults. Nonetheless they are likely to witness and be victims of crime when frequent incidents occur in proximity of their family residence. In national samples, approximately 10% of toddlers (2–5-year-olds) were reported to have witnessed violent crime in their community (Finkelhor, Turner, Ormrod, & Hamby, 2009). Young children can also be exposed indirectly by hearing caregivers describe their own victimization. This experience is thought to be associated with considerable stress reactivity, and is now characterized as secondary trauma, sufficient for a diagnosis of PTSD in preschool-age children (American Psychiatric Association, 2013). Thus, although not commonly direct victims of crime, young children are nonetheless affected by proximity of criminal activity in their community because of witnessing incidents, and experiencing the impact of their parents' victimization.

We set out to examine links between diurnal cortisol patterns, exposure to crime, and BMI for a sample of 5-year-old children. This developmental period is critical to obesity, with significant weight gains translating into long-term risk (Mamun, Hayatbakhsh, O'callaghan, Williams, & Najman, 2009). Higher levels of crime exposure were hypothesized to be associated with higher BMI. An inverse relationship was predicted for the diurnal cortisol pattern and BMI, with lower concentrations expected to result in greater body mass, consistent with research indicating lower cortisol levels reflect chronic stress exposure and represent a risk factor for obesity. Importantly, HPA-axis dysregulation reflected in the diurnal pattern was expected to alter the contribution of crime exposure to childhood obesity risk, acting as a moderator—changing the magnitude or direction of the association between crime exposure and BMI. Diurnal cortisol was conceptualized as a moderator insofar as dysregulation of the HPA-axis was expected to increase vulnerability resulting from neighborhood crime exposure with respect to child BMI.

Method

Participants

The present study was based on a portion of a data set collected in the context of a larger, longitudinal investigation including 306 mothers and their 36- to 39-month-old children ($M = 37$, $SD = 0.84$ months), equally distributed with respect to gender, recruited from birth registers, daycares, health clinics, and community organizations serving low-income families (Lengua, Zalewski, Fisher, & Moran, 2013). The larger sample was evenly distributed across income levels, with 29% of the sample at or near poverty ($N = 90 \leq$ 150% 2010 federal poverty threshold: $27,463 for a three-person household), 28% lower income ($N = 84 >$ 150% poverty threshold and < local median income of $58 K), 25% middle- to upper-income ($N = 77 >$ median income to $100 K), and 18% affluent ($N = 54 >$ $100 K). Data collected at 5 years of age (in 2008) were contemporaneous to the publically available crime information for the City of Seattle, and thus included in this study. Because geospatial crime data were available only for the City of Seattle, and not the surrounding areas, the final sample resided within the city boundaries ($N = 120$), with six families excluded due to missing data ($N = 114$). This subsample was somewhat more representative of both disadvantaged and affluent portions of the distribution, with 31% at or near poverty ($N = 90 \leq$ 150% federal poverty threshold), 26% lower income ($N = 84 >$ 150% poverty threshold and < local median income of $58 K), 18% middle to upper income ($N = 77 >$ median income to $100 K), and 26% affluent ($N = 54 >$ $100 K). This flat distribution of income ensures variability for indicators of risk and crime exposure, and provides a robust test of the associated effects examined in this study. Additional demographic inforamtion is provided in Table I.

Measures

Body Mass Index

BMI was calculated from the children's weight and height [BMI = weight (kg)/(height (m)^2] measured by trained research assistants using a standard procedure that included having a scale in a set place on a hard

Table I. *Descriptive Statistics: Caregiver/Family Demographics and Study Variables*

Variable	Percentage
Child gender	
Male	49.3
Female	50.7
Race/ethnicity	
Caucasian	62.9
Minority status	37.1
Marital status	
Never married	13.1
Married	73.9
Divorced/separated	7.2
Living with partner	5.2
Remarried	0.3
Widowed	0.3
Maternal education attainment	
Less than high school	2.0
High school diploma	4.4
Technical/professional school	9.9
Some college	21.1
Bachelor's degree	31.6
Some graduate school	5.5
Graduate/professional degree	25.5
Family income	
$0–$14,570	6.8
$14,571–$18,310	4.1
$18,310–$22,050	1.7
$22,051–$25,790	3.4
$25,791–$29,530	2.4
$29,531–$33,270	4.1
$33,271–$37,010	5.1
$37,011–$39,200	2.7
$39,201–$48,200	6.5
$48,201–$58,400	11.6
$58,401–$75,000	15.7
$75,000–$100,000	14.7
$100,000–$150,000	16.4
Over–$150,000	4.8

Variable	Mean	Range	Standard deviation
Child body mass index	15.06	8.06–27.18	2.09
Cumulative risk	0.80	0.18–3.51	0.61
Crime proximity index	709.49	37.00–10,515	1080.89
Diurnal cortisol concentration	0.04	−1.42–0.81	0.37

floor and a wall-mounted measuring stick. Research staff were instructed to ensure that the child was still on the scale before recording the number and to ensure the child was standing with her back to the measuring stick, with feet together and straight for the height measurement. Height and weight data were checked for unlikely values, and mean, standard deviation, as well as range statistics, all indicated values were within the expected range. Categorical weight status was established using standardized growth charts and the following definition: Underweight <5th%; Overweight >85th% and <95th%; Obese >95th% (CDC, 2000). In the overall sample, the weight status was distributed in the following manner: 20% were considered underweight, 10% overweight, and 5% obese. The subsample with available geospatial indicators produced a simular distribution: 21% underweight; 8% overweight; 5% obese. Although we are not able to provide a conclusive explanation for the number of underweight children, this category was not overrepresented in the lower income bracket, as inidcated by a nonsignficant χ^2 test ($\chi^2 = 13.56$, $p = .14$).

Diurnal Cortisol Pattern

Cortisol was assayed from saliva samples collected from children. Parents were provided detailed instructions for obtaining saliva samples, and collected morning and evening saliva samples on three consecutive days. Samples were sent to the university's Biobehavioral Behavioral and Nursing Systems laboratory for processing, where they were stored at −70°C until extraction. The concentration of cortisol in each sample was extrapolated from a standard curve generated in each test plate and results were averaged, as previously described (Zalewski, Lengua, Kiff, & Fisher, 2012). Mothers completed a daily questionnaire regarding sampling times and their children's health, medication use, eating times, and napping on sampling days, reviewed to ensure compliance. In addition, mothers received a phone call on the first evening of collection to review the procedures and answer questions, and were reminded to avoid sampling when their children were using steroid-based medications or were ill. Only one case was fully discarded because all cortisol values (CV) were suspect (>2.0 lg/dl; Zalewski et al., 2012).

Immunoassay Kit provided by Salimetrics LLC (State College, PA, USA), with sensitivity ranging from 0.005 to 2.5 lg/dl, was utilized. All samples from the same subject for each set of saliva were included in the same assay batch to minimize inter-assay within-subject variability. Intra-assay reliabilities were obtained using high and low cortisol controls provided by Salimetrics: mean cortisol value (MCV) for the high concentration sample = 0.950 lg/dl; MCV for the low concentration sample = 0.083 lg/dl. The intra-assay CV was 6.3%, for the high cortisol concentration, and for low concentration, the intraassay CV was 5.4%; all acceptable values. Assessment of diurnal CVs include both a "state" component, that is variations that are attributable to daily variations in experineces, and a "trait" component, variations in which are accounted for by a stable context or experiences (Kirschbaum et al., 1990). To attain an estimate of stable or trait-like diurnal patterns, it is recommended to average across multiple daily values (Adam & Kumari, 2009; Stalder et al., 2016), which was the approach taken in the present study. Assay results for all three mornings and evenings were averaged (Lengua et al., 2013; Zalewski et al., 2012) to create a summary measure of morning and evening levels. A diurnal slope value was computed by subtracting the average evening from the average morning value. The average morning score was 0.29 ($SD = 0.21$), average evening was 0.13 ($SD = 0.18$), and average diurnal slope was 0.16 ($SD = 0.20$). As is common with cortisol data, values were positively skewed, and log transformations were applied to average morning and the average evening variables before calculating the diurnal pattern. An overall indicator of diurnal pattern was calculated as the mean of the average morning level and average diurnal slope, with higher values indicating higher morning levels and a steeper deline over the day and reflecting a well-regulated HPA-axis.

In prior analyses with these data, potential covariates of diurnal cortisol patterns were examined. These included covariates related to the time of saliva collection (time of day, latency to collect from waking or bed time, amount of time between sample collection) and illness and medication use (when children were sick or using steroidal medication on a temporary basis, and families were asked to postpone collection). There were few modest associations between these control variables and diurnal cortisol indicators averaged across days, yet controlling for these covariates did not alter the patterns of associations with other variables (Lengua et al., 2013; Zalewski et al., 2012). These procedural covariates were excluded from the present investigation because of their negligible contributions, and in light of power considerations and our relatively small sample size.

Crime Proximity Index

Crime data for 2008 were obtained from the city of Seattle's publically available data portal (data.seattle.-gov). For this study, 911 incident calls were used (approximately 183,000), grouped into seven major crime areas, homicide, assault, larceny/stolen property, robbery, burglary, car theft/car prowl, and, lastly, nuisance crimes (disturbance, narcotics), and weighted in order of severity, as previously described (Gartstein, Seamon, & Dishion, 2014). Geospatial analyses began with an examination of spatial autocorrelation effects for crime incident data—the degree to which a set of spatial features and their associated data tend to cluster in space (Rowland et al., 2015), because of potential for such clustering to inflate Type I error (Diniz-Filho, 2003). This evaluation of potential "hot" and "cold" spots, regions of significant (hot) or insignificant (cold) variation, is particularly important in the context of community crime, as occurrences are usually not evenly distributed across a geographic region, but rather cluster in specific neighborhoods (Eck, Chainey, Cameron, Leitner, & Wilson, 2005; Paynich & Hill, 2010). The present approach, sensitive to clustering of cases, represents a methodological advancement relative to earlier efforts (Gartstein et al., 2014).

Local Morans I and Ord Getis Gi indices of local and global autocorrelation (Diniz-Filho, 2003) were computed and deemed significant, indicating that autocorrelation was present. Given the large number of crime incidents (+180,000), we remedied this situation by randomly sampling our crime incidents to ~10% of the original (+18,000), as recommended (Rowland et al., 2015). This resampling resulted in deflated autocorrelation effects, evidenced by considerably fewer "hot" and "cold" spots after the implementation of this procedure (Figure 1).

The crime proximity index (CPI) was defined as follows:

$$\text{CPI} = \frac{1 + N\ (\text{Distance to crime event} \ast \text{Crime severity factor})}{\text{Total number of crime events within } 1{,}000 \text{ feet of participant residence}}$$

Crimes (i.e., homicide, assault, larceny/stolen property, etc.) were weighted in a linear progression—from least severe (car theft) to most severe (homicide), according to a previously reported procedure, summarizing all crimes within 1,000 feet of the residence (Gartstein et al., 2014). The CPI thus represents a weighted distribution of crime that reflects exposure at each participant's location (Figure 2).

This novel approach is objective in nature and does not rely on residents' self-report to ascertain their perceptions of community crime. Thus, the geospatial CPI has the advantage of not being impacted by recall or other perceptual biases likely operating when individuals are asked to provide responses concerning neighborhood safety, and can be expected to provide a more accurate representation of distance from crime events, relative to individuals' judgment/spatial memory. At the same time, this index was correlated ($r = .25$, $p < .01$) with maternal report of neighborhood safety, obtained via the six-item Neighborhood Safety scale (Neighborhood Questionnaire; Conduct Problems Prevention Research Group, 1991).

Cumulative Family Risk

Demographic (mother education, single parent status) and contextual (household density, residential instability) factors contribute to child and family adversity along with psychosocial risk, such as negative life events (changing schools, death of a family member or friend) and maternal depression. Indices that account for the number or accumulation of such risk factors were shown to predict important early childhood developmental outcomes (e.g., behavior problems, academic achievement; Evans, Li, & Sepanski Whipple, 2013). Thus, rather than considering each of these contributing factors in turn, a cumulative score

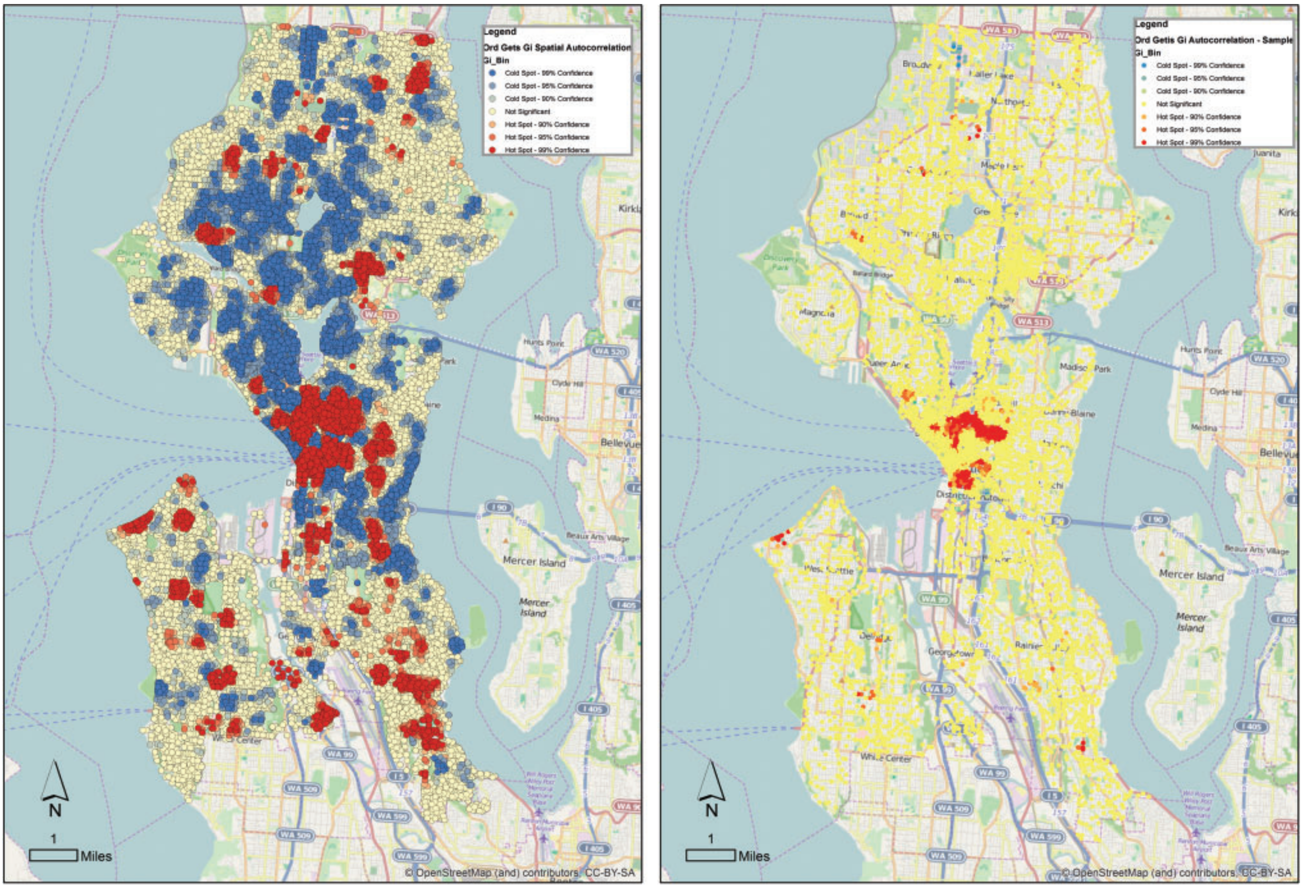

Figure 1. Comparison of spatial autocorrelation before reducing observations through random resampling (left), and after (right). This graphic depiction of "Hot" and "Cold" spot occurrence before/after resampling demonstrates it was greatly diminished as a result of this procedure.

was constructed, as previously described (Lengua et al., 2015; Zalewski et al., 2012), to capture the overall burden of risk experienced by children and families (Vernon-Feagans & Cox, 2013).

The eight considered risk factors included low maternal education, single-parent status, divorce, adolescent parent, maternal depression, negative life events, residential instability, and household density. Mothers reported concerning their education, marital and adolescent parent status, changing households, and number of individuals residing in the home. Maternal responses to the General Life Events Schedule for Children (Sandler, Ramirez, & Reynolds, 1986) addressing negative life events, and the Center for Epidemiological Studies–Depression Scale (Radloff, 1977), were also included in the cumulative risk score. Correlations among these ranged from 0.02 to 0.50, indicating that they were related but not redundant. An average cumulative risk score was the sum of dichotomous risk factors (scored 0 = *not present*, 1 = *present*) and continuous scores, converted into proportions of the total possible score, so that they ranged from 0 to 1, weighted equally with the dichotomous variables without loss of their continuous scale (Mean = 1.01; *SD* = 0.83; range 0–4; Lengua et al., 2015).

Procedures

Families were assessed in research offices on the university campus. Following the guidelines stipulated by the Social and Behavioral Sciences institutional review board, both active parental consent and child assent were secured before data collection. Assessments included physiological and questionnaire measures administered by a team of trained experimenters, and families were compensated $130 for this visit. Mothers were instructed to collect their child's saliva 30 min after the child woke in the morning and 30 min before bedtime, for three consecutive days. Mothers were to place a sorbette (Salimetrics, LLC State College, PA, USA) under the child's tongue for 1 min and then place the sorbettes into a prelabeled swab storage tube, repeating this process with another sorbette to ensure adequate saliva volume. Families were compensated $30 for returning the saliva samples by mail.

Analytic Strategy

Descriptive statistics and simple correlations were computed first. Hierarchical multiple regression was then performed to address unique contributions of

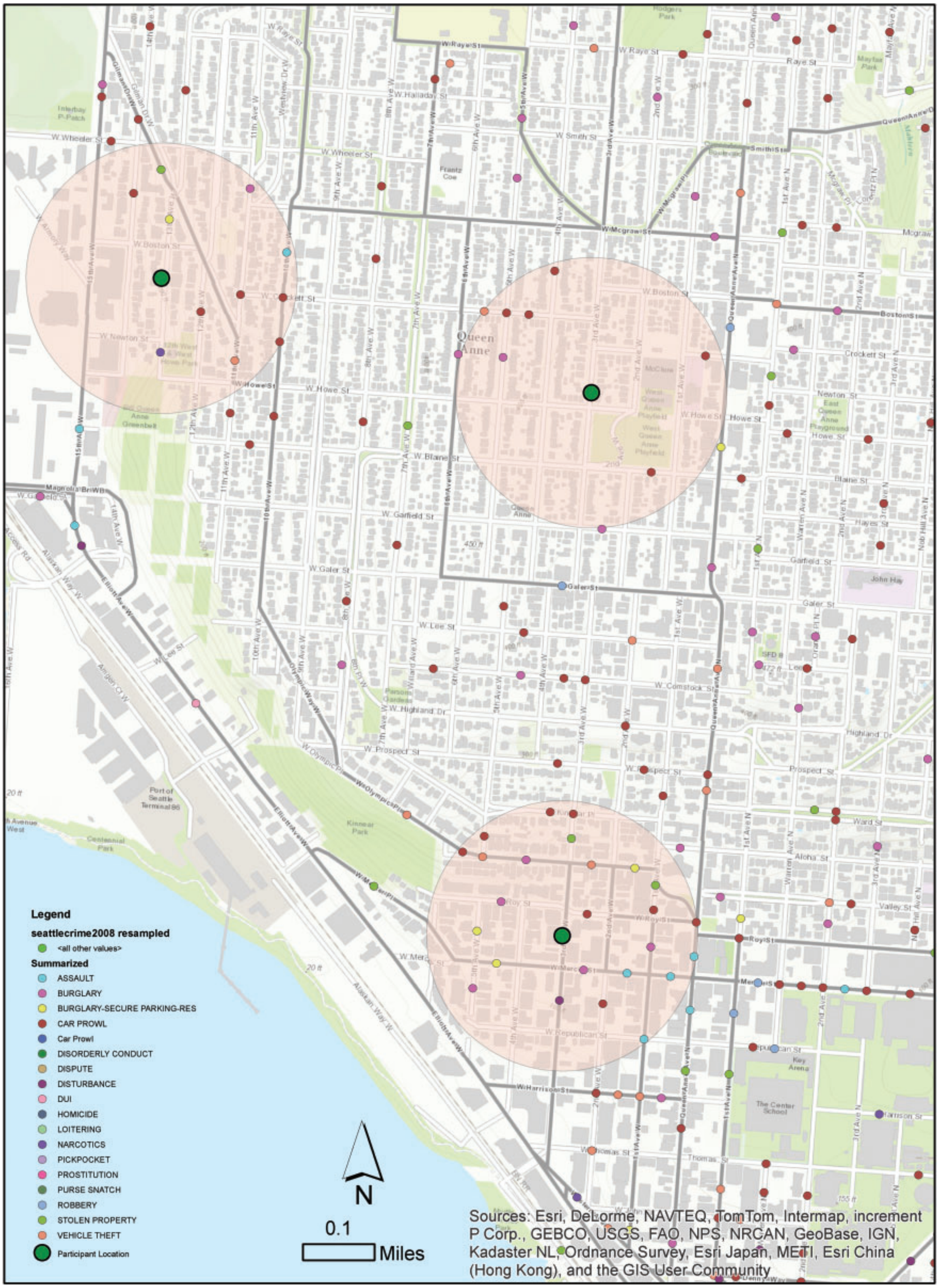

Figure 2. Crime incident locations with a 1,000 ft buffer of participants' households. This graphic illustrates selection of crime incidents that served as the basis for the crime proximity index calculation.

diurnal cortisol pattern and community crime exposure to child BMI, controlling for covariates. The diurnal cortisol pattern was examined as a moderator of the association between proximity to neighborhood crime and BMI consistent with recommendations of Aiken and West (2013), with an interaction term computed as a product of the centered geospatial crime and diurnal cortisol indicators. A statistically significant test of this interaction (i.e., significant F Δ, β coefficient) was considered evidence for a moderation effect, followed by simple-slope analyses and Regions of Significance (RoS) testing (Preacher, Curran, & Bauer, 2006; Roisman et al., 2012) to further inform interpretation of moderation.

Results

Descriptive statistics were computed (Table I), followed by simple correlations (Table II) between all of the considered variables. The Cumulative Risk Index was significantly positively correlated with child BMI, lower diurnal cortisol levels, and higher crime exposure, and therefore included as a covariate.

Hierarchical multiple regression was performed to examine independent contributions of diurnal cortisol pattern and community crime exposure, along with their interaction (Table III). We statistically controlled for child age and sex and the cumulative risk index, which emerged as the only covariate approaching statistical significance in explaining BMI. The CPI, but not diurnal cortisol, independently accounted for BMI above the effects of covariates. However, this main effect was no longer statistically significant once the cortisol-by-crime interaction term was included, indicating the association was conditioned by diurnal cortisol.

Simple slope analyses were subsequently performed to probe the nature of this significant interaction effect (Preacher, Curran, & Bauer, 2006): Simple slope at $Z=1$ SD (i.e., higher cortisol levels): −0.21, $t(115)=0.46$, $p=.648$; Simple slope at $Z=-1$ SD (i.e., lower cortisol levels): 0.51, $t(115)=2.28$, $p=.024$, indicating that the association between crime exposure and BMI was significant at lower, but not higher, levels of cortisol. The interaction effect was also examined for RoS with respect to the independent variable (X)—crime exposure, indicating values for which regression of child BMI on the diurnal pattern was statistically significant. The RoS on X for which diurnal cortisol levels predict BMI was contained within the following CPI regions: (1) lower threshold for RoS with respect to $X=-5.008$; (2) upper threshold for RoS with respect to $X=5.069$. These thresholds represent the upper and lower bounds of values for crime exposure, beyond which the regression of BMI on diurnal cortisol is statistically significant (alpha = .05), and although the lower value of X is not plausible for our sample, the higher value falls within the crime exposure distribution (−0.62 to 9.07). The interaction between geospatial crime and diurnal cortisol indicators was also graphed (Figure 3) to facilitate interpretation.

Discussion

In this study, our goal was to examine the interplay between individual and community factors linked with risk for obesity in predicting child BMI. Greater crime exposure was hypothesized to predict higher BMI, with an inverse relationship expected for the diurnal cortisol level and BMI. We also expected that child diurnal cortisol patterns would moderate the association between crime exposure and BMI, altering the strength and/or direction of this relationship. Analyses provided evidence of several significant simple correlations between the variables examined in this study. Notably, cumulative risk index was significantly positively correlated with child BMI, blunted or lower diurnal cortisol levels, and higher crime exposure. Hierarchical multiple regression analysis indicated that the cumulative risk index was the only covariate that made a marginal contribution to explaining BMI. The CPI explained unique child BMI variance when entered into the regression equation, whereas diurnal cortisol level was not a statistically significant independent predictor. Importantly, a significant interaction effect, indicating a diurnal cortisol pattern moderated the link between crime exposure and BMI, was evident after controlling for cumulative risk, previously associated with HPA-axis dysregulation (Zalewski et al., 2012). Simple slope and RoS analyses that followed indicated this moderation effect was primarily operating at lower diurnal cortisol levels and higher crime exposure. Thus, more frequent occurrences of proximal crime contributed to higher child BMI, and this effect was informed by an interaction with the diurnal cortisol pattern: greater community crime exposure was associated with higher BMI for children exhibiting low-flat diurnal cortisol levels indicating blunted HPA-axis activity. For the low-flat diurnal cortisol group (1 SD < mean), BMI of 19 would be expected, reflective of the obese range, under high crime conditions.

The present study extends prior findings with this sample of families that demonstrated greater cumulative risk was associated with higher BMI and lower cortisol concentrations (Tandon, Thompson, Moran, & Lengua, 2015; Zalewski et al., 2012), examining diurnal cortisol pattern as a moderator of the link

Table II. *Correlation Coefficients: Independent and Dependent Variables Included in the Study*

Study Variables	1	2	3	4	5	6
1. Child age	–					
2. Child gender	.026	–				
3. Cumulative risk index	.008	−.079	–			
4. Body mass index	.168	−.022	.235*	–		
5. Diurnal cortisol	−.091	−.048	−.245*	−.047	–	
6. Crime proximity index	.188*	−.025	.193*	.385**	−.157	–

Note. *$p<.01$; **$p<.001$.

Table III. *Multiple Regression: Predicting Child BMI With Diurnal Cortisol and Crime Exposure*

Regression Indicators	Model 1: Age, sex	Model 2: Cumulative risk	Model 3: Cortisol, crime	Model 4: Interaction[a]
R^2	.01	.04	.21	.26
R^2 change	.01	.03	.17	.05
F change	0.23	3.25***	9.30**	5.92*
β child age	−.07	−.06	−.06	−.05
β child sex	−.03	−.01	.00	.04
β cumulative risk		.19***	.09	.12
β diurnal cortisol			.07	.11
β CPI			.43**	.14
β diurnal cortisol-by-CPI interaction				−.37*

Note. BMI = body mass index; CPI = crime proximity index.
[a]Neighborhood Safety scale was also considered as a covariate, but did not make a significant contribution ($\beta = .06$, $p = .62$) to explaining child BMI, or change any of the other significant effects.
*$p < .05$; **$p < .01$; ***$p < .10$.

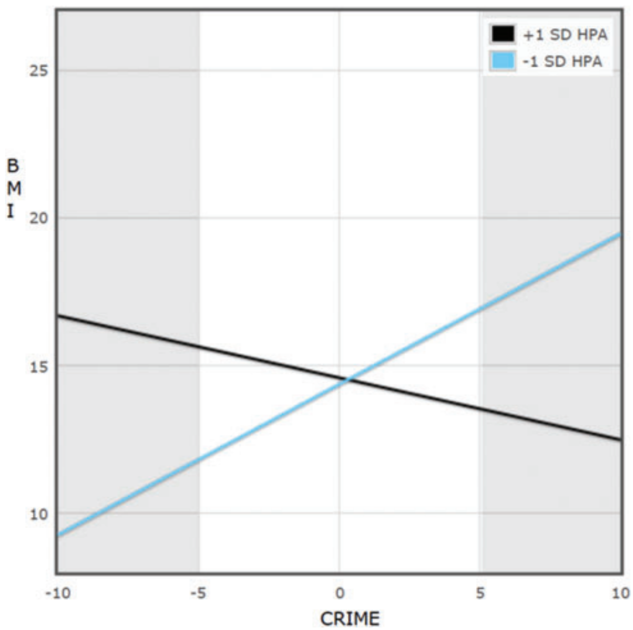

Figure 3. Hypothalamic–Pituitary–Adrenal (HPA)-axis functioning moderates crime exposure: regions of significance on X (crime). The lines represent two levels of HPA-axis activity defined in terms of standard deviations (SDs): 1 SD < mean and 1 SD > the mean, in predicting body mass index (BMI).

between geospatially operationalized neighborhood crime and child BMI. We are not aware of other studies utilizing spatially aggregated community-level crime data in making connections between neighborhood exposure and individual risk for childhood obesity. Our geospatial indicator of crime derived from publically available City of Seattle law enforcement data resulted in a significant independent contribution to child BMI. This main effect of crime exposure on child BMI was consistent with existing research demonstrating that for older youth greater incidence of property crime was related to higher BMI (Carroll-Scott et al., 2013). The significant interaction between crime exposure and HPA system functioning is notable, as it represents joint action of community-level and individual/biological-level processes, resulting in compound effects on child BMI. The interplay across these levels of risk observed in the present study has a number of implications with respect to theory and applied efforts related to prevention of obesity. Conceptually, the interconnectedness and systemic effects across community and biological levels of analysis are notable, and should be considered in future models of obesity-related etiology. With respect to intervention targeting obesity, preventative efforts could be honed to high-crime areas. Specifically, preschool-age children exhibiting blunted HPA-axis activity residing in such neighborhood, shown to be at increased risk based on the results of this study, could be targeted. Interventions could focus on building resilience, developing strategies for overcoming ill effects of neighborhood crime-related risks, such as identifying indoor activities deemed safe and effective in terms of increasing child energy expenditure.

The main effect of cortisol on BMI did not reach statistical significance, yet observed links between lower diurnal cortisol concentrations and greater BMI values under high crime exposure conditions were consistent with research indicating that blunted HPA-axis activity is associated with increased obesity risk, even in preschool-age children (Miller et al., 2013). HPA-axis downregulation after chronic periods of elevated stress has been noted (Gunnar & Vazquez, 2001; Zalewski et al., 2012), and may represent habituation to chronic stress exposure (Dienstbier, 1989). Chronic stress can accumulate in childhood as well as adulthood, as children facing more severe or proximal neighborhood crime are also likely to experience additional adversities (Margolin & Gordis, 2000). Importantly, these youngsters are likely to have caregivers with elevated stress levels that result from their direct experience of community crime. Even if such exposure to parental victimization does not result in manifestations of PTSD, it likely contributes to child physiological dysregulation. Epidemiological research addressing causes of the obesity crisis provides evidence for such effects of parental stress. Swedish children ($N = 7443$) followed from infancy through 5 years of age experienced significantly greater odds (odds ratio = 2.6) of being overweight when their caregivers reported stress in at least two of the four considered domains (Koch, Sepa, & Ludvigsson, 2008). Although cortisol was not evaluated in this investigation, results support a stress-related pathway to obesity.

The HPA-axis moderation of community crime exposure effects on child BMI could be a function of insulin resistance noted earlier (Hillman et al., 2012), insofar as lower cortisol concentrations likely represent an adaptation, aimed at maintaining a glucose/metabolic homeostasis as insulin resistance looms. Maripuu, Wikgren, Karling, Adolfsson, and Norrback (2016) suggested that hypocortisolism could be best described as an adaption to local or global tissue glucocorticoid hypersensitivity, in the context of a paradoxical mechanism wherein cortisol signaling is increased despite low circulating cortisol levels. In addition, hypocortisolism is thought to be associated with low-grade inflammation, and inflammatory interleukins may contribute to links between lowered cortisol levels and BMI. These inflammatory markers result in metabolic effects similar to glucocorticoids, contributing to obesity-related outcomes, such as the metabolic syndrome (Straub, Cutolo, Buttgereit, & Pongratz, 2010). Alternatively, it is possible that a link between lower cortisol levels and obesity is a function of enhanced metabolic clearance of cortisol in those with high BMIs (Praveen et al., 2011). Biological mechanisms implicated by the results of the present study require further research, and should be considered tentative at this time.

Although exact biological pathways responsible for links between hypocortisolism and increased BMI have not yet been elucidated, our findings indicate these become critical in the context of greater community crime exposure. That is, biological vulnerability conferred by lower cortisol concentrations did not result in an increased risk for obesity in the absence of contextual risk, indexed by neighborhood crime. In older children, multiple studies have shown that police-reported crime and perceptions of crime were related to child BMI, with decreased physical and increased sedentary activities in the context of greater crime exposure (Forsyth et al., 2015; Janssen, 2014; Kneeshaw-Price et al., 2015). It may be that the dampening of physical activity noted for older children also operates in the preschool period. Results of this investigation suggest that the impact of increased screen time and other sedentary activities that replace outdoor play in high-crime neighborhood are likely exaggerated by lower child diurnal cortisol levels, and these energy expenditure-related impacts of crime should be examined in the future in the context of variables considered in this study.

Innovative in its multidisciplinary nature, this work is nonetheless associated with several limitations. Perhaps most importantly, the data reported in this study were cross-sectional in nature, admittedly not optimal for examining moderator relationships. Although the parent project from which these data were drawn was longitudinal, we were limited by the timing of data collection for the City of Seattle geospatial law enforcement indicators, and thus constrained to cross-sectional analyses. Future research is important for replication and extension, and should include longitudinal evaluations that ensure all included families have resided in the community long enough to be impacted by crime proximity in a nontrivial manner, and to address fluctuations in crime exposure over time. Furthermore, communities that afford greater exposure to crime likely present with additional BMI-related effects, such as limited access to healthy food outlets. “Food deserts” were not examined in the context of this study, and should be addressed alongside contributions of community crime in future research. High crime areas may be associated with additional unaccounted risk, disproportionally composed of low socioeconomic status households with stressors which may not have been adequately captured by our measurement strategy/design. The assessment of diurnal cortisol patterns could also be improved with additional assessment points within each day to capture the curvilinear pattern of change of cortisol levels across the day. Moreover, it would be useful to consider child diet, physical activity, and maternal BMI, as these factors could also play a role in the context of associations considered in this study. Despite these limitations, our investigation adds to the growing literature addressing obesity risk, making a unique contribution by simultaneously considering neighborhood crime effects and child HPA-axis responsiveness. Mixed-method community-based investigations of this type can be expected to play an important role in public health efforts, providing contextual information concerning challenges and potential solutions afforded by local ecology. Importantly, future research will need to ensure that the statistically significant interaction between child HPA-axis functioning and community crime reported in this study translates into clinically meaningful phenomenon, such as weight status shifts.

Identification of early risk factors related to obesity is critical to preventative public health efforts, and we investigated links between HPA-axis activity (diurnal cortisol levels), geospatially operationalized exposure to neighborhood crime, and BMI with a sample of 5-year-old children. The CPI made a unique contribution to explaining child BMI, and HPA-axis moderation was supported. Thus, our findings indicate obesity-related risk that results from proximity of neighborhood crime was materialized primarily in the presence of blunted or low diurnal cortisol levels, often associated with chronic/pervasive exposure to adversity. Results of this study contribute to the existing literature, suggesting interactions between contextual risk and biological vulnerability in the context of childhood BMI and pathways to long-term risk for obesity. Although this study addressed child BMI, rather than obesity or overweight status, relevance to public health dictates that policy implications be noted. Specifically, our findings suggest that addressing community crime exposure is essential not only from the standpoint of preventing the harm caused by direct victimization, but also with respect to preventing adverse health effects occurring as a result of proximity to criminal activity in the community.

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