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# Cortisol covariation within parents of young children: Moderation by relationship aggression

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ABSTRACT

Covariation in diurnal cortisol has been observed in several studies of cohabiting couples. In two such studies (Liu et al., 2013; Saxbe and Repetti, 2010), relationship distress was associated with stronger within-couple correlations, suggesting that couples' physiological linkage with each other may indicate problematic dyadic functioning. Although intimate partner aggression has been associated with dysregulation in women's diurnal cortisol, it has not yet been tested as a moderator of within-couple covariation.

This study reports on a diverse sample of 122 parents who sampled salivary cortisol on matched days for two years following the birth of an infant. Partners showed strong positive cortisol covariation. In couples with higher levels of partner-perpetrated aggression reported by women at one year postpartum, both women and men had a flatter diurnal decrease in cortisol and stronger correlations with partners' cortisol sampled at the same timepoints. In other words, relationship aggression was linked both with indices of suboptimal cortisol rhythms in both members of the couples and with stronger within-couple covariation coefficients. These results persisted when relationship satisfaction and demographic covariates were included in the model. During some of the sampling days, some women were pregnant with a subsequent child, but pregnancy did not significantly moderate cortisol levels or within-couple covariation.

The findings suggest that couples experiencing relationship aggression have both suboptimal neuroendocrine profiles and stronger covariation. Cortisol covariation is an understudied phenomenon with potential implications for couples' relationship functioning and physical health.



A growing literature has described the phenomenon of cortisol covariation, also called synchrony, concordance, and coregulation, within families. For example, positive associations between mothers' and children's cortisol levels have been reported in a variety of studies (Granger et al., 1998; Hibel et al., 2009; Papp et al., 2009). Although the literature examining covariation with couples is small, studies have consistently reported positive correlations between partners' cortisol levels, both in the laboratory (e.g., Laws et al., 2015; Saxbe et al., 2014) and in momentary studies conducted over several days (Saxbe and Repetti, 2010; Liu et al., 2013; Papp et al., 2013). The implications of cortisol covariation are complex (Timmons et al., 2015). Within parent-child dyads, covariation might facilitate children's self-regulatory capabilities (Feldman, 2007), and it has been associated with greater physical proximity and behavioral sensitivity (e.g., Hibel et al., 2015; Ruttle et al., 2011). However, the couples' literature has more frequently found stronger covariation among distressed couples (Levenson and Gottman, 1983).

Of the three published studies examining couples' cortisol synchrony in daily life, two (Liu et al., 2013; Saxbe and Repetti, 2010)

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found relationship distress to be associated with stronger within-couple covariation. These results suggest that, while some degree of within-couple physiological linkage may be normative, high covariation may indicate poor relationship functioning. The theory of negative affect reciprocity (Levenson and Gottman, 1983) suggests that couples with more closely linked patterns of cortisol may be more susceptible to each others' distress or arousal levels. These couples may have more aversive interactions and fail to buffer each others' elevations in stress. Although aggressive and/or conflictual couple behavior has never been tested as a moderator of physiological covariation within couples, aggression reflects negative affective reciprocity processes and might be accompanied by heightened covariation. Relatedly, Hibel et al. (2009) found stronger mother-infant covariation in cortisol in families reporting domestic violence, suggesting that physiological linkage may appear in other dyads within households high in aggression and aversive conflict.

Intimate partner violence or aggression includes physical, sexual, or psychological abuse by a current or former partner or spouse (World Health Organization, 2013), and can range from physically aggressive behaviors such as slapping, kicking and punching to coercive control (e.g., restricting a partner's activities), sexual coercion, and emotional abuse. Relationship aggression has serious mental and physical health consequences for victims, including not just bodily injury, but also increased risk of depression, PTSD, and stress-related health problems (Watkins et al., 2014). Relationship aggression during early parenthood may be particularly problematic, given that it has been associated with risks to young children as well as to adults (O'Campo et al., 2010).

The hypothalamic pituitary adrenal axis, which releases the stress hormone cortisol and is associated with metabolic and immune functioning, may be one pathway through which chronic stressors such as relationship aggression contribute to physical health risks. Typically, cortisol levels peak within the first hour after waking and drop across the day before reaching a nadir at night. Flattened diurnal rhythms of cortisol, in which cortisol levels fail to show this typical morning rise or diurnal decline, appear to indicate poor adaptation to chronic stress (Sephton et al., 2000) and have also been linked with relationship distress in women (Adam and Gunnar, 2001; Saxbe et al., 2008). Being a target or victim of partner aggression or violence has been associated with markers of a flattened diurnal HPA axis rhythm in women (Kim et al., 2015; Pico-Alfonso et al., 2004).

Despite findings that women's diurnal cortisol rhythms may be associated with relationship aggression and other forms of relationship dysfunction, less is known about how relationship aggression affects males' health or the covariation of cortisol within couples. Kim et al. (2015) examined intimate partner violence (IPV) within couples, but did not find a significant effect of IPV on males' cortisol. However, males' perpetration was not tested as a predictor of males' cortisol. The current paper will be the first to examine males' perpetration of relationship aggression in conjunction with their HPA axis rhythms. Males at risk for aggressive and antisocial behavior appear to show lower levels of basal cortisol and dampened cortisol reactivity (e.g., Böhnke et al., 2010), but little is known about the relationship between men's aggressive behavior and the diurnal rhythm of cortisol. The current paper will also be the first to examine whether intimate partner aggression affects within-couple HPA axis covariation.

The current study is the first to test cortisol linkage and aggression within couples who sampled cortisol both during and after pregnancy. Although important life stages, pregnancy and early parenthood have been understudied within the couples' neuroendocrine literature. Consistent with the literature on non-pregnant women, studies of psychosocial variables and women's cortisol during pregnancy have found psychological distress and stressful life events to be linked with flatter cortisol slopes (Kivlighan et al., 2008; O'Connor et al., 2014; Obel et al., 2005). Moreover, preliminary studies have reported hormonal covariation within pregnant couples (Edelstein et al., 2015; Storey et al., 2000). However, more research is needed, as pregnancy-related hormonal changes might affect women's HPA axis patterns and couples' covariation during the prenatal and postpartum periods (Sandman et al., 2006).

The current study reports on a diverse sample of 122 couples who provided cortisol samples on 242 matched days during early parenthood. A multilevel model was used to assess within-couple covariation in cortisol and the impact of intimate partner aggression on both covariation and individual diurnal slopes of cortisol. We tested three hypotheses. First, consistent with other studies, we expected diurnal cortisol slopes in couples to be synchronized or to covary, and second, we expected higher aggression reported by women to be associated with stronger within-couple cortisol covariation. Third, consistent with previous work (Kim et al., 2015), we hypothesized that these reports of intimate partner aggression would be associated with a flatter diurnal slope of cortisol. Since all couples were parenting at least one infant and some were pregnant with a subsequent child, we included women's pregnancy and breastfeeding status as covariates in all analyses.

## 2. Methods

### 2.1. Participants

Data from this study came from the Lake County, Illinois site of the Child Community Health Network (CCHN). The data are part of a large community-based participatory research network funded by Eunice Kennedy Shriver National Institute for Child Health and Human Development (NICHD). All study procedures followed Declaration of Helsinki procedures and were carried out with the adequate understanding and written consent of the subjects. Recruitment, eligibility, and demographic characteristics for the larger five-site CCHN study are described in other papers (Ramey et al., 2014; Dunkel Schetter et al., 2013). To summarize, biological mothers were recruited at the birth of their first, second, or third child (referred to as the "index child" for study purposes) and followed at multiple time-points over the first two years postpartum. If mothers became pregnant again at any point during these two years, they were followed through this subsequent pregnancy and at one month postpartum. Eligibility criteria included that mothers were between 18 and 40 years of age, and self-identified as African–American, White, or Latina. Mothers who had delivered preterm infants were oversampled. Fathers were also invited to participate in the study with mothers' consent, but fathers' cortisol was only collected at one of the five CCHN sites (Lake County, IL).

CCHN study visits involving cortisol collection occurred when index children were approximately 6, 12, and 24 months of age. Mothers who became pregnant within a 2–3 year period after birth were interviewed in second and third trimester of their subsequent pregnancies and then 1 month after the birth. At each of these times, they were asked to do a day of saliva sampling within a week of the study interview. As such, there were six possible cortisol sampling days in total, spread out over approximately two to four years, with three of these possible days occurring during pregnancy or the early postpartum period of a subsequent birth.

Although mothers and fathers were not required to sample saliva on the same day, for this study, only matched days were used due the focus on within-couple covariation. In other words, fathers and mothers needed to sample cortisol on the same day in order for that day of data to be included in analyses. Our final model included 242 matched days from 122 couples. Compared to the 237 couples in Lake County who participated in the larger CCHN study and contributed cortisol on sampling days, this sample of 122

was more likely to be cohabiting (95% of included couples vs. 59% of couples; ($x^2(1, N = 2503) = 62.72$, $p = .001$) and married (75% of included couples vs. 31% of all couples; ($x^2(1, N = 2509) = 101.85$, $p = .001$), were older (mean age = 29.31 for included mothers, 25.41 for all mothers ($t(3702) = 7.58$, $p = .001$); 31.75 for included fathers, 28.59 of non-included fathers; $t(1237) = 4.74$, $p = .001$), and were more likely to be Caucasian ($c^2(1, N = 1723) = 62.71$, $p = .001$ for fathers; ($x^2(1, N = 3079) = 61.83$, $p = .001$ for mothers). However, there were no differences in household income, adjusted for cost of living ($M = \$18{,}994$ for included couples, $M = \$15{,}707$ for non-included couples; $t(1431) = 1.33$, $p = .18$), maternal employment ($x^2(1, N = 2497) = 1.97$, $p = .16$), or mothers' intimate partner aggression ratings at one year postpartum ($t(1691) = 0.31$, $p = .76$).

The composition of the 242 matched cortisol sampling days, contributed by 122 couples, is as follows: Almost half of the couples (59 couples, or 48% of the total sample) provided one matched day of saliva sampling, while 28 couples (23%) couples provided two days, 33 couples (27%) provided three days, six couples (5%) provided four days, six couples provided five days, and one couple provided six days. Across all matched visit days, 78 matched days occurred at the six month visit (32% of all days used in analyses), 66 matched days at the 1-year visit (27%), 49 matched days at the 2-year visit (20%), 33 matched days at either the second or third trimester pregnancy visits (14%), and 16 matched days at the one-month-postpartum visit (7%).

## 2.2. Procedures

### 2.2.1. Salivary cortisol

Research staff provided saliva sampling kits along with verbal and written instructions on procedures for collecting saliva at three times over the course of the sampling day (upon waking, 30 mins after waking, and bedtime). Participants were asked to self-collect samples by expelling saliva through straws into sterile 2 ml cryogenic vials, and to record the sampling time on accompanying labels. Completed materials were mailed back to each study office, where they were stored at -80 degrees Celsius. Saliva samples were subsequently shipped to ZRT Laboratories (Beaverton, OR) and assayed for cortisol by a competitive luminescence immunoassay (IBL-America, Minneapolis, MN) with reported detection limits of 0.015 μg/dl. The intra- and inter-assay coefficients of variance were 5.5% and 7.6%, respectively.

As outliers in cortisol data can bias results, we took a conservative two-step approach to handling extreme values. First, all values >3 SD from the sample mean were dropped, a common approach when cortisol values are extremely skewed as was the case in our sample (Dettling et al., 1999). Several outliers remained after truncation, so then we recalculated the sample mean and SD and winsorized any values >3 SD above the mean by transforming them into the mean + 3 SD. Altogether, less than 1% of cortisol values were truncated or winsorized. Finally, because significant skew remained (skewness statistic: 1.72/SE = .07), we natural log-transformed all cortisol values.

### 2.2.2. Daily diaries

Participants completed brief morning and bedtime diaries on the saliva sampling days, reporting on time of waking as well as other daily behaviors (cigarettes smoked, shift work that day).

## 2.3. Measures

### 2.3.1. Intimate partner aggression

At one year postpartum, mothers were given a modified version of the HITS (for Hurt, Insult, Threaten, Screamed at; Sherin et al., 1998). The HITS asks about the frequency of physical hurt, insult, threats, and screaming occurring over the past year on a 5-point scale (never = 1 to frequently = 5). The modified form we used includes one additional item on domination or emotional control that has been included in other studies (e.g., O'Campo et al., 2010): "How often does your partner/spouse restrict your actions? By actions we mean things such as spending money, visiting with family or friends, or going places that you need to go." Any response other than "never" was followed with the question "Was it your partner/spouse, another family member, or someone else in your household?" Only experiences that were attributed to partner/spouse were included in the partner aggression score. Within this sample, 52 mothers (43% of the sample) reported at least some experience of partner aggression and 32 of these mothers (26% of the sample) reported more than one type of aggression exposure. Scores ranged from 5 to 12 (mean = 5.99, SD = 1.57). HITS scores were positively skewed (skewness statistic = 1.95, SE = .22) so we ran analyses with both raw scores and with log-transformed scores. Key results do not differ so we report results using raw HITS scores in this paper.

### 2.3.2. Relationship satisfaction

The Dyadic Adjustment Scale (DAS; Spanier, 1976) is a well-validated measure of relationship functioning. DAS scores were included as covariates because relationship satisfaction has been previously found to be associated with couples' patterns of diurnal slope and covariation (Saxbe et al., 2008; Saxbe and Repetti, 2010). Within this study, a two-item version of this measure was used that included the items "Rate how happy you are in your relationship, ranging from extremely unhappy to perfect" and "Rate your feelings about the future of the relationship, ranging from wanting the relationship to succeed at any cost to feeling that the relationship can never succeed," both rated on a 1–5 scale. Although a full DAS measure was administered at six months postpartum, we used the DAS here as a control variable/covariate for intimate partner aggression. Therefore, we elected to use the two-item version of the measure from the one-year assessment so that it would reflect the same measurement timespan as the partner aggression variable, and also to avoid dropping couples from our final sample with missing data at six months. Mothers' scores ranged from 2 to 4.5 (mean = 2.70, SD = .46) and fathers' scores ranged from 2 to 5 (mean = 2.82, SD = .45). The full scale DAS and two-item DAS were moderately correlated at the six month postpartum assessment: $r(108) = .54$, $p = .001$ (fathers); $r(112) = .53$, $p = .001$ (mothers), suggesting that the short version of the DAS was a reasonable substitute for the full measure.

### 2.3.3. Other covariates

At initial recruitment into the study, mothers and fathers were asked to identify their own ethnic/racial background; for the present analyses, this was coded dichotomously as minority (African American or Latino) or non-minority (Caucasian). Within the current sample, 52% of mothers and 48% of fathers identified as minority group members. For income, we used fathers' and mothers' reports of household income collected at study enrollment and coded these on a three point scale (1 = income < 100% of federal poverty level, 2 = 100–200% of federal poverty level, and 3 => 200% of federal poverty level) to create a categorical "poverty" variable (mothers' mean = 2.32, SD = .77; fathers' mean = 2.41, *SD* = .82). Parity (number of children) was reported by the CCHN study team for mothers at study enrollment and coded dichotomously for the present analyses to reflect whether the index child is the first child or whether the mother has had other children. The number of children the mother had had prior to the index child ranged from zero to two in this sample (mean = .75, SD = .76), and 44% of the mothers in the sample were first-time parents. Ethnicity, income, and parity were included as covariates in the present study because all three

of these variables have been associated with diurnal slope patterns in past investigations (Hajat et al., 2010; Tu et al., 2006).

At each visit, women were asked whether they were breast-feeding and this information was included (no = 0, yes = 1) as a Level 2 (day level) covariate. At the six month visit, 30% of women reported that they were still breast-feeding; at one year, 14% of women were still breast-feeding, and at two years, 11% of women were still breast-feeding. Only 5% of women were breast-feeding at either pregnancy visit, and 61% of women were breast-feeding at the one-month postpartum visit. Other covariates modeled at the day level included father and mother wake time (taken from the daily diaries) and the age of the index child at the time of the visit. Across all visits, the mean age of the index child was 17 months old (range six months to 3.8 years; SD = 7.5 months).

### 2.4. Data analysis

A three level model was tested using Hierarchical Linear Modeling (HLM) 6.0 software (Raudenbush et al., 2004). HLM adjusts for the statistical interdependency found in nested data (e.g., cortisol samples within days and days within couples) and in this case we used a three-level model to account for this nesting, with sample-level variables (e.g., individual cortisol levels and sampling time of day) modeled at Level 1; day-or visit-level variables (e.g., wake time; pregnancy or breastfeeding status) modeled at Level 2; and couple-level variables (e.g., previous-year intimate partner aggression history) modeled at Level 3. HLM is not only well-suited for analyzing nested data but can also handle missing or unevenly sampled data, e.g. adjusting for the fact that not all couples provided the same number of matched sampling days or that some samples were skipped on some days (Hruschka et al., 2005). If a couple is missing data at Level 1 or 2, they can still be included in analyses; only a couple with missing data at Level 3 would be dropped from analyses.

A dual-intercepts model was used to adjust for couple-level interdependency and so that both mothers' and fathers' cortisol patterns could be tested together in the same model (see Laurenceau and Bolger, 2005). Separate models were also tested for each partner, and key results did not differ from the dual-intercepts model reported here. A single ID variable designated each couple, and dummy-coding distinguished mother and father terms (such that fathers' intercept term was coded 1 for fathers and 0 for mothers, while mothers' intercept term was coded 1 for mothers and 0 for fathers; for other Level 1 predictors, e.g. time of day, cortisol awakening response (CAR), and partners' cortisol at the same timepoint, fathers' terms had values for fathers and 0's for mothers and mothers' terms had values for mothers and 0's for fathers). The complete Level 1 equation was:

$$Y_{ij} = \pi 0_i F + \pi 0_i M + \pi 1_i FTime_{ij} + \pi 1_i MTime_{ij} + \pi 2_i FCAR_{ij} + \pi 2_i MCAR_{ij} + \pi 3_i FMcort_{ij} + \pi 3_i MFcort_{ij} + \epsilon_{ij}$$

in which *Y*ij is the individual i's cortisol level at sampling occasion j; F and M designate fathers and mothers; $\pi 0_i$ is the dummy-coded intercept for each partner; Time refers to the sampling time of day (in military time and centered on 5am); CAR is a dummy variable indexing whether the sample is the CAR sample (taken 30 mins after waking; see Adam et al., 2006 for an example of CAR modeled in this way); FMcort represents fathers' cortisol level as associated with mothers' cortisol level (as outcome variable) at the same sampling occasion, and MFcort represents mothers' cortisol level as associated with fathers as outcome; cortisol level at the same sampling occasion; and $\epsilon$ij represents within-couple error. A sample quality variable (whether the lab reported the sample as "clear" or cloudy) was initially included at Level 1, but since it was non-significant and did not affect key results, it was dropped in favor of a more parsimonious model.

At Level 2, day-level variables were group-centered and included pregnancy status; the age of the index child (coded as number of days since birth); and each partner's morning wake time. The age of the index child was used as a covariate rather than whether the cortisol came from the six-month, 1-year, or two-year visit because of variability around these dates. Additional day-level (Level 2) covariates, including shift work schedules, number of cigarettes smoked that day, medications taken that day, and numbers of hours slept the previous night were tested but dropped from the model for the sake of parsimony, because they were non-significant and did not alter key results. On 29% of the sampling days, or 70 days provided by 40 couples, female partners were pregnant with a subsequent child. Twenty of these couples provided one pregnancy sampling day; 11 provided two pregnancy sampling days; and nine provided three pregnancy sampling days. Pregnancy sampling days typically came from the pregnancy visits, but in some cases mothers were pregnant at either the one-year or two-year main study visit and pregnancy status was coded as positive for those mothers as well. Pregnancy days and non-pregnancy days were combined into a single model with pregnancy status added as a covariate for both male and female partners. Since pregnancy status was not significantly associated with Level 1 covariation or slope terms, it was included only as a moderator of the Level 1 intercept terms and not of the other Level 1 terms in the model. Similarly, breast-feeding status was not significantly associated with Level 1 covariation or slope terms and was included only as a moderator of the Level 1 intercept.

Couple-level variables entered at Level 3 were grand mean centered and included mother and father poverty group status; racial or ethnic minority status; mother and father DAS scores; parity; and the mother-reported intimate partner aggression score. Table 1 shows bivariate correlations between all Level 3 variables.

Compared to the null (unconditional) model, the full model described above represented a significant improvement in fit ($x^2 = 866.85$, $df = 51$, $p = .001$) and explained additional variance both at Level 2 (17% additional variance explained for mothers, 17% for fathers) and at Level 3 (21% additional variance explained for mothers, 11% for fathers).

## 3. Results

Final analyses reflected 1390 cortisol samples collected over 242 matched cortisol sampling days (in which both partners sampled saliva on the same day) from 122 couples.

### 3.1. Full model testing Hypotheses 1–3

Consistent with the normal diurnal decline in cortisol, time of day was negatively associated with cortisol values for both partners. Additionally, as can be seen in Table 2, partners' momentary cortisol levels were significantly positively associated with each other in a model that controlled for sampling time and other covariates including pregnancy status, parity, poverty, minority status, and relationship satisfaction (for mothers, $b = .46$, $t = 9.35$, $p = .001$; for fathers, $b = .54$, $t = 12.07$, $p = .001$). Mother-reported partner aggression (measured one year after the birth of the index child) was associated with a lower intercept (waking) cortisol level for fathers and a flatter slope (diurnal decline) for both mothers and fathers. Additionally, couples with more relationship aggression had stronger coefficients linking partners' cortisol; in other words, at the same sampling time points, mother and father cortisol levels were more strongly correlated among couples with higher relationship aggression. None of the other Level 3 covariates in the model (including dyadic adjustment measured at one year after the birth of the index child, poverty group, minority status, and parity)

**Table 1**
Bivariate correlations between level 3 (couple-level) study variables.

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| 1. Mother-reported partner aggression | 1 | | | | | | | |
| 2. Maternal parity (number of children) | .11 | 1 | | | | | | |
| 3. Mother Dyadic Adjustment Scale (DAS) | .12 | −.12 | 1 | | | | | |
| 4. Father DAS | .09 | .12 | −.10 | 1 | | | | |
| 5. Maternal poverty category | −.23* | -.13 | .15 | .25** | 1 | | | |
| 6. Paternal poverty category | −.16 | −.04 | .27** | .19* | .74** | 1 | | |
| 7. Maternal minority status | .05 | .03 | −.10 | −.25** | −.60** | -.48** | 1 | |
| 8. Paternal minority status | .13 | −.02 | −.07 | −.26** | −.63** | −.54** | .86** | 1 |

* $p < .05$.
** $p < .01$.

**Table 2**
Three-level dual intercepts model showing intimate partner aggression as a predictor of Couples' Cortisol, with additional covariates: fixed effects with robust standard errors (model with 122 couples/242 matched days).

| | Mothers' Coefficients | | | Fathers' Coefficients | | |
|---|---|---|---|---|---|---|
| Fixed effects | Estimate | (SE) | t ratio | Estimate | (SE) | t ratio |
| **Cortisol intercept (morning)** | .85 | (.09) | 9.22*** | .59 | (.08) | 7.01*** |
| Level 2 covariates[a] | | | | | | |
| Pregnancy status | .36 | (.15) | 2.46* | −0.25 | (.13) | −2.03* |
| Age of index child | .001 | (.001) | 0.45 | .003 | (.002) | 1.84† |
| Wake time | −.001 | (.003) | −1.26 | .0001 | (.0003) | −0.52 |
| Breastfeeding | −.11 | (.14) | −0.82 | .003 | (.15) | 0.02 |
| 2nd Postpartum | −.12 | (.23) | −0.53 | −0.03 | (.18) | −0.17 |
| Level 3 covariates | | | | | | |
| Poverty level | .02 | (.11) | 0.29 | .10 | (.12) | .79 |
| Minority status | −0.32 | (.18) | −1.72† | -0.06 | (.24) | −.25 |
| Parity | .13 | (.10) | (.10) | .23 | (.12) | 1.92† |
| Dyadic adjustment | .01 | (.20) | .07 | .17 | (.25) | .68 |
| Partner aggression | −.02 | (.04) | −.41 | −.20 | (.06) | −3.45** |
| **Cortisol slope (time)** | −.06 | (.01) | −7.69*** | −0.05 | (.01) | −7.26*** |
| Level 3 covariates | | | | | | |
| Poverty level | .02 | (.01) | 1.45 | −.01 | (.01) | −1.24 |
| Minority status | .02 | (.02) | 1.06 | .01 | (.02) | .37 |
| Parity | −.03 | (.01) | −2.72** | −.01 | (.01) | −.62 |
| Dyadic adjustment | −.02 | (.02) | −1.10 | −.01 | (.02) | −.46 |
| Partner aggression | .01 | (.004) | 1.96* | .01 | (.005) | 3.00** |
| **CAR (post-waking)** | .11 | (.05) | 2.29* | .09 | 006 | 1.54 |
| **Partners' cortisol** | .46 | (.05) | 9.29*** | .54 | (.04) | 12.01*** |
| Level 3 covariates | | | | | | |
| Poverty level | .02 | (.01) | 1.47 | .01 | (.07) | 0.22 |
| Minority status | .20 | (.09) | 2.10* | −.08 | (.12) | −0.67 |
| Parity | −.07 | (.05) | −1.41 | −.08 | (.07) | −1.23 |
| Dyadic adjustment | −.07 | (.11) | −0.64 | −.19 | (.13) | −1.42 |
| Partner aggression | .05 | (.02) | 1.98* | .08 | (.03) | 3.16*** |

† $p < .05$.
* $p < .05$.
** $p < .01$.
*** $p < .001$.
[a] Level 2 and Level 3 covariates refer to effects tested on each of the bolded Level 1 indices.

were significantly associated with couples' cortisol patterns or concordance, with the exception that parity (whether the mother had an additional child or children before the birth of the index child) was linked with steeper slopes for the mother (but not father) and mothers' minority status was associated with stronger covariation for mothers. At Level 2 (the day or visit level), pregnancy status was associated with higher waking cortisol for mothers and with lower waking cortisol for fathers.

### 3.2. Time point-specific correlations

In order to test whether particular sampling occasions were driving the covariation between partners, we created three new Level 1 files, one of which included only waking samples, one which included only waking + 30 min samples, and one which included only evening samples. We then ran three two-level dual-intercept models that included an intercept and covariation (partner cortisol at the same timepoint) term for each partner. These separate models yielded similar results to the full model, with mother cortisol strongly associated with father cortisol and father cortisol strongly associated with mother cortisol at waking (mothers' covariation $b = .56$, $t = 8.24$, $p < .001$; fathers' covariation $b = .63$, $t = 7.03$, $p < .001$); at the waking + 30 timepoint (mothers' covariation $b = .60$, $t = 9.68$, $p = .001$; fathers' covariation $b = .73$, $t = 10.04$, $p < .001$) and at bedtime (fathers' covariation $b = .49$, $t = 6.50$, $p < .001$; mothers' covariation $b = .49$, $t = 7.68$, $p < .001$). We then used deviance statistics extracted from each model to compare the three separate models. All results (waking compared to waking +30, waking +30 compared to bedtime, and bedtime compared to waking) were non-significant ($p > .50$), suggesting that these three models all fit the cortisol data equally well. Therefore, significant within-couple covariation appeared across the whole day and our results were not explained by effects at a particular timepoint.

### 3.3. Results with randomly-paired couples

In an additional check on the results, we randomly re-ordered the couple- and person-level IDs in our Level 1 files so that different partners were paired with each other but the structure of sampling occasions and visit days was preserved. For example, wake, wake +30, and bedtime cortisol taken at the six-month visit by the father in couple A might be matched with the same samples taken by the mother in couple B. We then re-ran our full HLM model with all Level 1, Level 2, and Level 3 covariates. Within-couple covariation no longer emerged as significant (mothers' covariation $b = -.07$, $t = -1.83$, $p = .07$; fathers' covariation $b = -.02$, $t = -.46$, $p = .65$), and none of the other covariates, including intimate partner aggression, significantly moderated covariation.

## 4. Discussion

Using data from a diverse, low-income community sample of parents, we found strong positive within-couple covariation in momentary cortisol levels sampled over matched days. As hypothesized, the strength of within-couple covariation was moderated by intimate partner aggression, such that covariation was higher in couples in which mothers reported that their partners were more physically and emotionally aggressive towards them during the first year of their child's life. Also consistent with hypotheses, relationship aggression was linked with flatter diurnal slopes for both mothers and fathers. In other words, relationship aggression was associated not only with stronger within-couple linkage, but also with less adaptive HPA axis functioning overall.

Our finding that relationship aggression was associated with less optimal cortisol patterns and with stronger cortisol covariation is consistent with past research, but this is the first test of relationship aggression as a moderator of covariation. Although relationship aggression has been studied chiefly with respect to health consequences for women, our results suggest an important new implication for these couples, namely that fathers who perpetrate aggression also show dysregulated neuroendocrine profiles. Men who commit more relationship aggression may experience higher levels of chronic stress coupled with poorer coping resources and perhaps also a limited repertoire of relationship communication behaviors. As our results illustrate, these men may experience compromised physiological as well as psychological functioning.

Consistent with our findings, Hibel et al. (2009) found that mothers and infants with histories of IPV showed stronger covariation in cortisol, suggesting that physiological linkage may be a marker of dysfunctional and particularly of aggressive relationship processes within the family. Negative affect reciprocity theory suggests that distressed couples are more reactive to each others' negative moods and stress states. It is likely that this reactivity has both physiological and behavioral components. In terms of physiology, HPA axis covariation may be one potential substrate of affect reciprocity, while negative affect reciprocity may be a behavioral component that poses risk for intimate partner aggression. However, negative affect reciprocity is unlikely to be the sole process by which cortisol covariation becomes exaggerated in dysfunctional relationships. Another theoretical framework, social baseline theory (Beckes and Coan, 2011), suggests that emotions are most efficiently regulated within a social, rather than in an individual, context. Specifically, the presence of others can reduce threat and helps to regulate stress-response systems (Coan et al., 2006). According to this theory, particularly strong covariation might indicate that couples are unable to jointly return to "baseline" by modulating each others' arousal under conditions of chronic stress or threat. A third possibility is that more distressed couples experience more stress-related sleep disturbances that affect both partners' diurnal rhythms of cortisol. Restricted or misaligned sleep has been associated with alterations in diurnal cortisol (Wright et al., 2015), and early parenthood can be a time of significant sleep disruption. In addition, couples vulnerable to relationship aggression may experience more common daily hassles and have less adaptive dyadic coping. Future research can continue to identify correlates and moderators of within-couple correlation in order to better establish the potential mechanisms of these effects.

An additional unanswered question is whether within-couple covariation is associated with more or less adaptive diurnal overall cortisol profiles. In other words, is couples' covariation linked with flatter or steeper slopes of cortisol? While the current study lacked sufficient days of contiguous data to test this question, future research can explore the association between couples' covariation in diurnal profiles of cortisol and their overall health, including chronic stress, allostatic load, and risk for disease. A related issue concerns the direction of effects: is increased within-couple covariation a consequence, an epiphenomenon, or a predictor of relationship aggression and relationship distress? Longitudinal studies that tease out causal relationships over time (e.g., Laws et al., 2015) can help to clarify these complex questions.

This study replicates prior work on within-couple cortisol covariation with the largest and most ethnically and socioeconomically diverse sample to date. Past studies have reported on affluent, stably married, predominantly Caucasian samples. Our sample included low-income, ethnic minority couples with younger children, placing the phenomena of within couple cortisol covariation in a broader and more generalizable context.

While prior studies dropped participants who were pregnant (e.g., Liu et al., 2013), we included these participants and added pregnancy status as a covariate. We found that pregnancy did not appear to moderate the strength of within-couple correlations, but pregnancy status moderated the intercept (starting/baseline value) of cortisol with higher levels for pregnant women, and lower levels for men with pregnant partners. Pregnancy has been associated with increased cortisol levels in women (Sandman et al., 2006), so these results for mothers are consistent with past research. However, the lower level for fathers is unexpected and may warrant further study. This study did not replicate an effect of pregnancy on the diurnal slope of cortisol. This may be because we sampled women at different times in pregnancy when cortisol levels only increase substantially towards the end of pregnancy (Sandman et al., 2006). Further studies might use narrower windows for cortisol sampling to explore couples' cortisol covariation during pregnancy and its potential impact on relationship and parenting outcomes.

This study is limited by the fact that couples took only three saliva samples over one day at each visit. Published guidelines for ambulatory cortisol research typically recommend a minimum of 2 contiguous days with at least 3–6 samples per day in order to calculate diurnal slope (Saxbe, 2008) but the "minimal protocol" used in this study has been used in other published work (see Adam and Kumari, 2009) and has been found to correlate moderately with more intensive protocols (Hoyt, et al., under review). In this study, a slight majority of couples in the sample provided more than one matched day of cortisol sampling, with a third of the sample providing three or more days of matched saliva sampling. However, these were non-contiguous days that could be spaced apart by six months or more. An additional limitation is that saliva collection times, wake times, and other covariates (such as smoking and medication use) were self-reported by participants and therefore could be vulnerable to bias or error. The CCHN cortisol protocol sought to balance data collection needs with cost considerations, the need to minimize the burden on participants, and to maximize participant adherence, a significant issue in self-sampling of biomarkers (Kudielka et al., 2003). The limitations of the salivary collection pro-

tocol are counterbalanced by our use of a larger and more diverse sample than previous neuroendocrine studies focused on couples.

Psychosocial measures were designed for the larger CCHN study, and not with this study in mind. Based on input from community partners, the intimate partner aggression measure was administered only once because it was potentially a sensitive topic to bring up repeatedly. Therefore, in some cases the cortisol sampling precedes the intimate partner aggression measurement. The focus on men's participation in CCHN emphasized father involvement and other positive aspects of parenting but not intimate aggression. As such, we did not measure men's reports of their aggressive behavior or women's perpetration of aggression in this study. Also, because intimate partner aggression was measured at one year only, in some cases our cortisol sampling precedes the administration of this questionnaire; relatedly, other covariates, such as poverty status, were measured at enrollment and therefore may not map on to the aggression and relationship satisfaction measurements in terms of timing. CCHN did not collect data on the couples' relationship duration or time spent together, which might be important covariates of couple covariation. The use of a two-item measure of relationship satisfaction also represents a limitation, as does our dichotomous treatment of race/ethnicity and of breast-feeding. We also did not measure other potentially mediating variables, such as individual trauma histories, communication skills, or emotion regulation abilities, that might be important for extending these results and can be assessed in future investigations. Finally, because this study focused on a community sample, we treated intimate partner aggression as a continuous measure rather than using clinical cut-off points that can differentiate couples with histories of severe aggression.

Despite these limitations, this study makes an important contribution to the literature on dyadic cortisol covariation within couples and the moderating variables that may affect it. Not only is our sample by far the largest and most economically and racially diverse in the diurnal cortisol covariation literature, this study focuses on parents of young children, some of whom were pregnant with a subsequent child. Intimate partner aggression was associated both with markers of less healthy overall cortisol functioning, and with stronger within-couple covariation. This result suggests that public health efforts to prevent relationship aggression may have an impact not only on couples' mental health and relationship quality, but on their risk of stress-related physical health problems — including the physiological functioning of males who have perpetrated aggression. Moreover, HPA axis covariation may be a meaningful but under-investigated phenomenon with implications for both relationship quality and for couples' physical health. Further investigations can continue to explore the antecedents and sequelae of neuroendocrine covariation within couples and the long-term effects of relationship aggression on the health of men and women.

## Conflict of interest

We have no conflicts of interest to disclose.

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Data used in the present study was gathered at the Lake County, IL site of the Child Community Health Network (CCHN) which is a community-based participatory research network supported through cooperative agreements with the Eunice Kennedy Shriver National Institute of Child Health and Human Development (U HD44207, U HD44219, U HD44226, U HD44245, U HD44253, U HD54791, U HD54019, U HD44226-05S1, U HD44245-06S1, R03 HD59584) and the National Institute for Nursing Research (U NR008929 NICHD was involved in the design of the study and in the decision to submit the work for publication. The funding source did not play a role in the analysis and interpretation of data or in the writing of this report.

## Contributors

All of the authors listed in the by line contributed to this manuscript and have agreed to submission of the manuscript in this form. Dr. Darby Saxbe conceptualized the current paper and analyzed the data, and wrote the first draft of the current manuscript. All other authors contributed to the development of the hypotheses, consulted on analyses, and had input in the writing of the manuscript. In addition, all authors contributed to manuscript preparation and the decision to submit the article for publication in this format.

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