FAMILY PROCESS

Spouses' Cortisol Associations and Moderators: Testing Physiological Synchrony and Connectedness in Everyday Life

LAUREN M. PAPP*
PATRICIA PENDRY†
CLARISSA D. SIMON‡
EMMA K. ADAM§

In this study, associations were examined between cortisol levels of wives and husbands in 47 heterosexual married couples. Both partners' salivary cortisol levels were measured at the same moments seven times a day on 2 typical weekdays. After accounting for the effects of the diurnal rhythm of cortisol and relevant control variables, dyadic hierarchical linear modeling indicated significant positive linkages between partners' cortisol levels, consistent with the hypothesized within-couple physiological synchrony. Variables reflecting more (spousal presence) or less connectedness (loneliness, being alone) were also collected at the time of each cortisol sample. Results indicated that husbands' cortisol levels were higher at moments they reported feeling lonelier and lower at moments they were in the presence of their spouse. Wives' cortisol levels were higher at moments they were alone. In addition, wife–husband cortisol synchrony was stronger for husbands who spent relatively more time with their spouse across the study period—even after accounting for time spent with others in general. These findings suggest that marital partners evidence positive within-couple cortisol associations, and that connectedness (particularly physical closeness) may underpin spouses' physiological synchrony.

Keywords: Cortisol; Marriage; Hierarchical Linear Modeling

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*Department of Human Development and Family Studies, University of Wisconsin-Madison, Madison, WI.

†Department of Human Development, Washington State University, Pullman, WA.

‡Program on Human Development and Social Policy, School of Education and Social Policy, Northwestern University, Evanston, IL.

§Program on Human Development and Social Policy, School of Education and Social Policy, and the Cells to Society Center, Institute for Policy Research, Northwestern University, Evanston, IL.

Correspondence concerning this article should be addressed to Lauren M. Papp, Department of Human Development and Family Studies, University of Wisconsin-Madison, 1300 Linden Drive, 4136 Nancy Nicholas Hall, Madison, WI 53706. E-mail: papp@wisc.edu and Emma K. Adam, Northwestern University, 2120 Campus Drive, Evanston, IL 60208. E-mail: ek-adam@northwestern.edu.

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As biopsychosocial models have broadened (Booth, Carver, & Granger, 2000), individual and family functioning have come to be understood as the product of reciprocal influences among environmental (primarily social), behavioral, and biological processes (see Booth, McHale, & Landale, 2011; Maggi, Irwin, Siddiqi, & Hertzman, 2010). As a result of methodological advances enabling noninvasive measurement of physiology in naturalistic settings, family researchers have begun to examine the way in which family processes induce behavioral adaptation to stress, which in turn affects biological processes, and vice versa. It is this dynamic interplay that is thought to lead to differential adaptation over time, including development of psychopathology (Cummings, Davies, & Campbell, 2002) and physical health outcomes (e.g., compromised immune function, shortened longevity; Sapolsky, Romero, & Munck, 2000). One biological marker that has received particular attention by family scientists is cortisol, a key product of the hypothalamic-pituitary-adrenal (HPA) axis. In fact, altered cortisol diurnal patterns (Pendry & Adam, 2007) and reactivity (Davies, Sturge-Apple, Cicchetti, & Cummings, 2007) have been found in children exposed to marital discord, as well as in adults experiencing marital conflict (Barnett, Steptoe, & Gareis, 2005; Saxbe, Repetti, & Nishina, 2008).

Scholars have long recognized interdependence among family members (Cox & Paley, 1997), and have shown emerging interest in reaching a fuller understanding of how physiological indicators covary within the family (Papp, Pendry, & Adam, 2009; Schreiber et al., 2006). To date, naturalistic and laboratory studies suggest that positive and reliable dyadic "coregulation" of cortisol levels exists between parents and children and between intimate relationship partners. What is less clear is whether everyday experiences within the family (particularly social interactions) play a role in within-dyad physiological functioning and synchrony. A recent review by Repetti, Wang, and Saxbe (2011) suggests that marital partners' activity of the HPA axis—and coregulation thereof—should be examined while considering momentary experiences and day-to-day social and emotional connections between the partners. Guided by the theoretical framework that emerges from that literature, our investigation thus uses the experience sampling method (ESM) to examine within-couple associations of cortisol levels in the naturalistic setting of the home and test whether these associations are moderated by physical and emotional connectedness between partners.

Our investigation considers several relevant processes by which interactional synchrony of cortisol production may be influenced (Repetti et al., 2011). First, daily spillover of stress from work and parenting hassles has been shown to influence individuals' mood and cortisol diurnal activity (e.g., Saxbe et al., 2008). Day-to-day coregulation of married couples' cortisol secretion is thought to be influenced through spouse effects, which encompass short-term impacts that spousal affect, behavior, or daily experiences may have on partner physiological or emotional states. Similarly, positive characteristics of relationship functioning (e.g., perceptions of emotional closeness) are thought to buffer spouses from each other's negative moods and stress states. Known as the "negative affect reciprocity" hypothesis, laboratory findings suggest that couples with lower marital satisfaction tend to less effectively modulate each other's arousal during marital conflict (Levenson & Gottman, 1983). Coregulation of cortisol secretion appears also to be affected by communication behaviors (e.g., expression of emotional and instrumental support, demanding or disapproving behavior) and the broader context in which these behaviors occur (e.g., physical proximity of spouse, presence of children) (Repetti et al., 2011).

Marital Partners and Cortisol

Prior research provides consistent evidence that marriage serves as a significant predictor of partners' health and well-being (Burman & Margolin, 1992) and that HPA-axis functioning might contribute to these associations (Robles & Kiecolt-Glaser, 2003). Although an earlier study based on a single-night assessment showed that being married limits variability in women's overnight cortisol levels (Englert et al., 2008), process-oriented approaches suggest that it is the quality of marital relationships that underlies these associations. In a multilevel analysis of 51 married couples, Ditzen, Hoppman, and Klumb (2008) analyzed salivary cortisol samples over the course of a week, and found that partners displayed lower cortisol levels on days consisting of longer intimacy expressions, underscoring potential health benefits of happy partnerships. In another multilevel analysis of salivary cortisol levels collected across 2 days from 70 mothers with 2-year-old children, Adam and Gunnar (2001) showed that positive relationship functioning predicted higher morning cortisol levels and steeper declines in cortisol levels across the day. In a study that modeled diurnal cortisol rhythm for one partner from each of 20 dyads, Floyd and Riforgiate (2008) reported that participants' waking cortisol levels were positively associated with their ratings of spousal verbal, nonverbal, and supportive affection. Increased affection also predicted greater declines in cortisol levels across the day, a healthy indicator of cortisol variation (Adam & Kumari, 2009).

In contrast, less optimal relationship quality may be linked with patterns of cortisol production that indicate partners' and couples' decreased adaptive functioning. For example, Barnett et al. (2005) found that men and women (not partnered to each other) who expressed having more marital concerns showed an attenuated cortisol increase after waking, and flatter patterns of diurnal cortisol production across the day. A recent study examined the effects of a relationship intervention on cortisol responses and found that cortisol responses during a conflict discussion were significantly reduced compared with preintervention levels, and that cortisol decreases during conflict were partially mediated by increases in self-reported relationship quality (Ditzen, Hahlweg, Fehm-Wolfsdorf, & Baucom, 2011). Clearly, marital relationships have emerged as a key context in which to investigate interplay between cortisol levels of intimate partners.

Physiological Synchrony Among Family Members

In a previous investigation, Papp et al. (2009) used the same dataset employed in the current study to examine covariation between mothers' and adolescents' salivary cortisol levels gathered seven times across the day for 2 days. Results revealed a significant positive association between mothers' and adolescents' cortisol levels (i.e., physiological synchrony), even after accounting for the impact of time of day, health-related variables, and pubertal development. Family characteristics moderated the association such that synchrony was stronger in families which reported spending more time together, engaging in more shared activities, and having higher levels of parental monitoring and supervision of adolescents. Stronger parent–child cortisol synchrony was found at moments of higher levels of both mother and adolescent negative affect (Papp et al., 2009).

The study of physiological synchrony within married partners in family contexts is of particular interest, given that wives and husbands share important environmental contexts, including the home, while not sharing the same genetic overlap found in biologically related parent–child dyads. Initial tests support this within-couple synchrony, finding late afternoon cortisol levels of husband and wives to be positively correlated (Schreiber et al., 2006). In addition, using a sample of 30 marital couples, Saxbe and Repetti (2010) documented coregulation of partners' HPA-axis activity in everyday life. They used dyadic hierarchical linear modeling to show that cortisol levels of husbands and wives were significantly and positively associated, after taking into account sampling time and potential error. Together, these studies provide the foundation for further investigation of within-couple cortisol associations in naturalistic contexts and potential moderators. The next step in the field is to examine how momentary changes in cortisol secretion (and dyadic association therein) across multiple days relate to stable family characteristics and momentary influences of social interactions on emotions, cognition, and behaviors of family members.

Emotional Connections and Physical Closeness as Underpinnings of Spouses' Physiological Synchrony

As highlighted by Repetti et al. (2011), the extent to which the home environment functions as a haven or refuge for stress recovery from daily demands is an important variable in explaining couples' physiological synchrony. This may occur through expressions of emotional and instrumental support. Another important variable appears to be the extent to which family members use social withdrawal as a strategy for short-term coping with daily job stress. While social withdrawal may be effectively used for recovery of stress, withdrawal may also lead to feelings of loneliness in the other spouse.

Loneliness, or global feelings of isolation or dissatisfaction with desired social connections, is linked to poor health outcomes; HPA-axis activity is posited to help account for these robust connections (Cacioppo et al., 2002). Past research has found that increased loneliness is associated with multiple parameters of cortisol dysregulation in adolescents, including flatter diurnal cortisol slopes and higher momentary cortisol levels (Adam, 2006; Doane & Adam, 2010; Matias, Nicolson, & Freire, 2011). Research based on adult men and women (not partnered) also revealed a positive association between loneliness and the cortisol awakening response (CAR) (Steptoe, Owen, Kunz-Ebrecht, & Brydon, 2004). Finally, Saxbe and Repetti's (2010) study of married couples suggests that shared environment (as an indicator of spousal presence) matters, as cortisol coregulation was not found for times when spouses were suspected to be apart. These findings indicate that loneliness is associated with spouses' cortisol and synchrony; however, there is ongoing debate over whether feelings of connectedness or, rather, actual presence of others accounts for links between loneliness and partner physiology (Hawkley, Preacher, & Cacioppo, 2011).

The Current Study

Saxbe and Repetti (2010) documented initial empirical evidence of positive covariation in spouses' momentary cortisol levels in everyday life, with Repetti et al. (2011) extending these findings conceptually by underscoring the need to explicate the naturalistic and family contexts of this covariation. While findings based on studies of individuals encourage the continued consideration of loneliness as an influence on the stress response (Matias et al., 2011; Steptoe et al., 2004), scant work has specifically tested whether emotional versus physical connection (or lack of connection) accounts for these findings. Accordingly, the current study seeks to first replicate couples' cortisol associations in naturalistic settings, and to then extend research based on individuals by exploring whether loneliness and social connections play a role in couples' cortisol function and synchrony. Together, these tests have the potential to clarify linkages between couples' stress-response systems in daily life and reveal how being together or feeling close (or, conversely, how being apart or feeling lonely) may be important to understanding physiological synchrony among couples. This physiological synchrony in intimate partners' stress-response has implications for both concurrent and longitudinal dyadic relationship quality and health outcomes.

The present investigation employed a dyadic hierarchical linear modeling approach to first examine whether wives' and husbands' cortisol levels sampled across a 2-day period in naturalistic contexts demonstrated reliable covariation (i.e., physiological synchrony). We conducted a methodologically rigorous test of synchrony by statistically accounting for interdependent data, sampling course (i.e., diurnal rhythm of cortisol samples nested within days), and health covariates. We hypothesized that wives' and husbands' cortisol levels would be positively related across the sampling moments and days. To explore the momentary, naturalistic contexts of spouses' correlated stress-response systems, we next investigated the role of connectedness in couples' cortisol levels and physiological synchrony. We expected moments of feeling lonely and being alone to relate to higher cortisol levels. We hypothesized that closeness (e.g., spouses spending more time together) would strengthen within-couple cortisol associations. We further expected that spouses' cortisol levels would be robustly associated, and thus would remain significant even when momentary connectedness variables were included in models.

METHOD

Participants

Participants were 47 heterosexual married couples with adolescent children. Data for this study were collected as a follow-up to the Sloan Family Study at the University of Chicago to examine how the stresses of work and family life affected physical stress and health (see Adam, 2005). The couples included at least one employed worker, and most included two: All but two husbands were employed (one was unemployed and looking for work, one was retired), whereas 40 of the wives were currently working and seven were unemployed and not looking for work. Participating wives had a mean age of 43 years (SD = 6 years) and husbands had a mean age of 45 years (SD = 7 years). The couples had lived together for an average of 15 years (SD = 7 years), and were generally very happy: On a scale of 1 (*strongly disagree*) to 5 (*strongly agree*), wives' and husbands' responses to the question, "Overall, I am satisfied with my relationship with my spouse" averaged 4.34 (SD = 1.09) and 4.44 (SD = 0.85), respectively.

Procedures

Participants completed a set of diary entries paired with the collection of salivary cortisol samples. Couples were asked to complete seven diary-sample pairs across the day from morning to evening for 2 days during the course of their everyday lives. Diary-sample pairs were requested in the morning immediately after waking and 30 minutes after waking, in the evening immediately before bedtime, and four times during the day when signaled by a programmed watch. These times were chosen semirandomly and were the same for everyone (Day 1: 10:54 a.m., 1:55 p.m., 3:56 p.m., and 7:56 p.m.; Day 2: 10:22 a.m., 2:00 p.m., 5:11 p.m., and 7:10 p.m.). Including a sample collected 30 minutes after waking allowed us to model the CAR, a documented rise in cortisol levels after morning awakening (Welhelm, Born, Kudielda, Scholtz, & Wüst, 2007). Using the experience sampling method (ESM; Csikszentmihalyi & Larson, 1987), participants answered questions about the current situation at the requested times (for the waking, CAR, and evening samples) or at the time the watch beeped, including who they were with and their current feelings. A second beep occurred 20 minutes after each diary entry to prompt collection of a related cortisol sample; this protocol captured cortisol responses to momentary stressors, as it takes 20–30 minutes poststressor for cortisol levels to reach their salivary peak (Kirschbaum & Hellhammer, 1989).

Cortisol Sampling

Each family received a kit that included the saliva sampling materials along with written/pictorial instructions. We also conducted reminder calls to facilitate compliance. Participants expelled saliva into sterile vials, recorded sampling times, and refrigerated the vials as soon as possible. Samples were returned by mail to our laboratory, where they were stored at −20°C until all study data have been collected. Samples were then sent on dry ice to Salimetrics LLC® (State College, PA), where they were assayed. Additional sampling details are provided in Papp et al. (2009). A normalizing transformation was performed on the positively skewed cortisol data before analyses.

During completion of the ESM diary-cortisol sample pairs, spouses reported on a variety of health/medical issues that might affect cortisol levels. In preliminary analyses, we tested associations between spouses' average awakening cortisol levels, CARs, and slopes and health characteristics (amount of caffeine, amount of nicotine, wives' use of oral contraceptives, regular physical exercise, asthma diagnosis, Body Mass Index [BMI], and wives' menstrual timing). Amount of caffeine (in number of caffeinated drinks) consumed each day by husbands was positively linked to their average awakening cortisol levels ($\gamma = 0.147$, $t = 3.10$, $p = .004$) and was retained as an intercept covariate; wives' BMI (a measure of body fat based on height and weight calculated at www.nhlbisupport.com/bmi) was linked to their CARs ($\gamma = -0.066$, $t = -2.15$, $p = .038$) and was retained as a cortisol intercept and CAR covariate. Other health variables were not associated with spouses' cortisol parameters (all p-values > .05), and were excluded from subsequent analyses.

Measures

Loneliness

As noted above, the ESM diaries contained ratings of participants' current affective states (e.g., happy, sad) at the time of the beep, rated on a scale ranging from 0 (*not at all*) to 3 (*very much).* We focus on loneliness here, consistent with the existing literature (reviewed above) on loneliness and adults' health and well-being. Average loneliness scores were 0.11 ($SD = .38$) for wives and 0.25 ($SD = 0.59$) for husbands. Prior to analysis, loneliness scores were subjected to a log transformation to improve distributional normality.

Being alone

Spouses indicated on the ESM diary whether they were alone (0 = *no*, 1 = *yes*) at the time of the sampling beep. Wives endorsed being alone 36.5% of the time and with others 57.6% of the time. Husbands reported being alone 38.8% of the time and with others 50.6% of the time. (Note that missing ESM data account for response totals not summing to 100%.) These momentary data were also used to calculate proportions over the study period by summing the number of instances that the respondent was alone and then dividing this number by the number of diary entries obtained. Average proportions were 0.38 ($SD = 0.24$) for wives and 0.41 ($SD = 0.23$) for husbands across the two study days.

Spousal presence

If participants indicated not being alone at the time of the sampling beep, they were asked to indicate who they were with, including their spouse (0 = *not in presence of spouse*, 1 = *in presence of spouse*). Across the two reporting days, wives indicated being with their spouse 23.1% of the time, and husbands were with their spouse 22.4% of the time (see Table 1 for spousal presence at each specific sampling point). Average proportions across the study were 0.24 ($SD = 0.22$) for wives and 0.24 ($SD = 0.21$) for husbands.

RESULTS

Dyadic Data Structure and Cortisol Descriptive Statistics

To accommodate the dyadic nature of cortisol data collected from couples, each cortisol sample was entered on two lines of data, dummy-coded for wives and husbands

Table 1
Wives' and Husbands' Cortisol Values at Specific Sampling Points Across Two Days: Descriptive Statistics (untransformed, μg/dl), Spousal Presence, and Intercorrelations

		Wives			**Husbands**			**Wife–Husband correlation**
Sample	**% Samples complete data**	***M***	***SD***	**% With spouse**	***M***	***SD***	**% With spouse**	***r***
1 (wakeup)	78.7	0.52	0.29	37.0	0.55	0.34	42.6	$-.27^{\dagger}$
2 (CAR)	68.1	0.61	0.29	31.5	0.69	0.35	24.1	.02
3	70.2	0.22	0.17	4.9	0.24	0.16	6.1	.00
4	53.2	0.18	0.11	4.1	0.22	0.24	4.1	$.19^{\dagger}$
5	46.8	0.12	0.05	8.1	0.16	0.19	8.3	−.10
6	42.6	0.08	0.07	40.3	0.11	0.10	38.1	$.33^{**}$
7 (bedtime)	25.5	0.06	0.04	50.8	0.13	0.29	47.5	−.07

Note. Results are based on 47 wife–husband dyads. CAR = Cortisol Awakening Response.
$^{\dagger}p \leq .10$. $^{**}p \leq .01$.

(Laurenceau & Bolger, 2005). Models designated intercepts and predictors for wives and husbands, permitting simultaneous estimation of wives' cortisol predicted by husbands' cortisol and husbands' cortisol predicted by wives' cortisol. Analyses were restricted to occasions sampled by both spouses.

Over the course of the 2-day reporting period with a total of 14 possible cortisol samples, spouses provided an average of 9.38 (*SD* = 3.20) matched samples. Examining wives' and husbands' response patterns over the course of the study revealed multiple sources of missing data. For example, wives in the broader study were more likely than husbands to return diary-cortisol pairs and to return a greater number of response pairs. Husbands were more likely than wives to provide cortisol samples that lacked the corresponding ESM report. Wives did not differ in their day 1 versus day 2 responding; however, husbands completed more samples on day 1 than day 2. Bedtime samples have the lowest completion rate of the seven daily samples for both wives and husbands. The current study's dyadic sample reflected these broader patterns, with retained couples providing more matched samples on day 1 than day 2, and providing the least amount of matched data at bedtime (see Table 1).

Table 1 presents the descriptive statistics of untransformed cortisol levels collected by spouses by sampling occasion averaged across the two reporting days. Examining mean levels suggests that our sampling procedures captured the previously documented diurnal rhythm of cortisol (Kirschbaum & Hellhammer, 1989). Table 1 shows correlations between wife and husband cortisol samples, which were most strongly related to each other at the sampling point collected, on average, at 7:45 p.m. (sample 6); this was also one of the most common times for spouses to be together.

Dyadic Hierarchical Linear Modeling of Spouses' Physiological Synchrony

We tested our hypotheses using dyadic hierarchical level modeling (HLM; Raudenbush, Brennan, & Barnett, 1995). Modeling repeated assessments of cortisol using HLM offers advantages that include capturing increased statistical power due to the repeated-measures design, while adjusting for within-person and within-day nesting of cortisol data and the associated correlated error (Hruschka, Kohrt, & Worthman, 2005). Spouses are included in analyses even if they do not provide all seven cortisol samples in 1 day, although, importantly, greater statistical weight is given to those who provide more reliable estimates. HLM also allows simultaneous modeling of the effects of both time-varying (e.g., spousal cortisol) and non-time-varying (e.g., health controls) covariates on cortisol parameters. The dyadic HLM approach further offers the advantage of accommodating interdependent data collected from couples and providing simultaneous estimates and effects for wives and husbands.

At Level 1, cortisol values for wives and husbands were predicted by an indicator for CAR (0 = *not a CAR sample*, 1 = *CAR sample*), time of day (indicated by number of hours since awakening), and time of day squared (to model nonlinear time effects). Remaining variance in cortisol across the day, after controlling for diurnal changes and the CAR, was predicted by spousal cortisol (matched by sample number 1–7), such that the resulting Level 1 model was:

$$\begin{aligned} \mathrm{Y_{tij}} = {} & \pi_{1ij}(\text{Wife}) + \pi_{2ij}(\text{Wife CAR})_{tij} + \pi_{3ij}(\text{Wife Time})_{tij} + \pi_{4ij}(\text{Wife Time}^2)_{tij} \\ & + \pi_{5ij}(\text{Husband})_{tij} + \pi_{6ij}(\text{Husband CAR}) + \pi_{7ij}(\text{Husband Time})_{tij} \\ & + \pi_{8ij}(\text{Husband Time}^2)_{tij} + \pi_{9ij}(\text{Husband Cortisol Predicting Wife Cortisol})_{tij} \\ & + \pi_{10ij}(\text{Wife Cortisol Predicting Husband Cortisol})_{tij} + \mathrm{e_{tij}} \end{aligned}$$

Level 2 modeled within-day dependency (with no day-level covariate):

$$\pi_{1ij} = \beta_{10j} + \mathrm{r}_{1ij}$$

$$\dots$$

$$\pi_{10ij} = \beta_{100j} + \mathrm{r}_{10ij}$$

Level 3 included husbands' reports of daily caffeine amount (centered on the sample mean) as a covariate of the husband cortisol intercept (β_{50}), and wives' BMI scores (centered on the sample mean) as a covariate of the wife cortisol intercept (β_{10}) and wife CAR indicator (β_{20}):

$$\begin{aligned} \beta_{10j} &= \gamma_{100} + \gamma_{101}(\text{Wife BMI})_j + \mathrm{U}_{10} \\ \beta_{20j} &= \gamma_{200} + \gamma_{201}(\text{Wife BMI})_j + \mathrm{U}_{20} \\ \beta_{30j} &= \gamma_{300} + \mathrm{U}_{30} \\ \beta_{40j} &= \gamma_{400} + \mathrm{U}_{40} \\ \beta_{50j} &= \gamma_{500} + \gamma_{501}(\text{Husband Caffeine})_j + \mathrm{U}_{50} \\ \beta_{60j} &= \gamma_{600} + \mathrm{U}_{60} \\ \beta_{70j} &= \gamma_{700} + \mathrm{U}_{70} \\ \beta_{80j} &= \gamma_{800} + \mathrm{U}_{80} \\ \beta_{90j} &= \gamma_{900} + \mathrm{U}_{90} \\ \beta_{100j} &= \gamma_{1000} + \mathrm{U}_{100} \end{aligned}$$

This model yields simultaneous estimates of wife cortisol predicted by husband cortisol (γ_{900}) and husband cortisol predicted by wife cortisol (γ_{1000}), while accounting for effects of the diurnal rhythm of cortisol (Level 1), correlated residuals due to cortisol samples being nested in days (Level 2), and health covariates (Level 3). As the synchrony parameters in Table 2 indicate, levels of wife cortisol and husband cortisol were positively associated with spousal cortisol, beyond any shared association between them due to timing of the sample, diurnal rhythm of cortisol, within-day correlated error, or health covariates. The strength of these synchrony associations did not differ, $\chi^2(df = 1) = 1.50$, $p > .05$.

TABLE 2

Dyadic Hierarchical Linear Model of the Associations Between Wife Cortisol and Husband Cortisol: Physiological Synchrony Accounting for Cortisol's Diurnal Rhythm and Health Control Variables

	Wives (W)			Husbands (H)		
Fixed effect	**Coefficient**	***t***	**Interpretation**	**Coefficient**	***t***	**Interpretation**
Cortisol intercept (at wakeup)						
Intercept	−0.844	-8.43^{**}	$\hat{y}_{\text{wakeup}} = 0.43\ \mu g/dl$[a]	−0.607	-5.55^{**}	$\hat{y}_{\text{wakeup}} = 0.54\ \mu g/dl$[a]
H caffeine	–	–		0.089	3.46^{**}	+9%/h per caffeinated drink/day[b]
W BMI	0.005	0.54	*n.s.*	–	–	
Cortisol awakening response (CAR)						
Intercept	0.447	4.79^{**}	+56% if CAR[b]	0.283	2.59^{*}	+33% if CAR[b]
W BMI	−0.037	$-1.93^{\dagger}$	*n.s.*	–	–	
Time since waking						
Intercept	−0.128	-5.20^{**}	−12%/h at waking[b]	−0.119	-5.25^{**}	−11%/h at waking[b]
Time since waking^2						
Intercept	0.001	1.08	*n.s.*	0.002	$1.79^{\dagger}$	*n.s.*
Spousal cortisol						
Synchrony intercept	0.158	2.37^{*}	+17% in wife cortisol for every 1 *SD* increase in husband cortisol[b]	0.236	3.56^{**}	+27% in husband cortisol for every 1 *SD* increase in wife cortisol[b]

Note. Results are based on 47 wife–husband dyads.

[a]Due to the logarithmically transformed outcome variable (i.e., natural log of cortisol values), the inverse function of that transformation (i.e., exponential function) was applied to return this intercept to its value on the original scale of measurement.

[b]Special properties of a logarithmic outcome variable allow coefficients predicting that outcome to be interpreted as % change in the outcome per unit change in the independent variable, after the following transformation has been applied to the B coefficient: $B_{\%\ \text{change}} = [\exp(B_{\text{raw}})] - 1$.

$^{\dagger}p \leq .10$. $^{*}p \leq .05$. $^{**}p \leq .01$.

Emotional and Physical Connectedness as Underpinnings of Wife–Husband Physiological Synchrony: Feeling Lonely, Being Alone, Spousal Presence, and Time Spent Together

To examine whether naturalistic, momentary experiences at the time of each diary report accounted for the documented wife–husband physiological synchrony associations, we added simultaneously wife and husband reports of feeling lonely, being alone, and spousal presence to Level 1 of the synchrony model detailed above:

$$\begin{aligned}
Y_{tij} = {} & \pi_{1ij}(\text{Wife}) + \pi_{2ij}(\text{Wife CAR})_{tij} + \pi_{3ij}(\text{Wife Time})_{tij} + \pi_{4ij}(\text{Wife Time}^2)_{tij} \\
& + \pi_{5ij}(\text{Husband})_{tij} + \pi_{6ij}(\text{Husband CAR}) + \pi_{7ij}(\text{Husband Time}) \\
& + \pi_{8ij}(\text{Husband Time}^2)_{tij} + \pi_{9ij}(\text{Husband Cortisol Predicting Wife Cortisol})_{tij} \\
& + \pi_{10-12ij}(\text{Wife Momentary Connectedness Variables})_{tij} \\
& + \pi_{13ij}(\text{Wife Cortisol Predicting Husband Cortisol})_{tij} \\
& + \pi_{14-16ij}(\text{Husband Momentary Connectedness Variables}) + e_{tij}
\end{aligned}$$

Results from this dyadic HLM are shown in Table 3. Husbands' ratings of *feeling lonely* uniquely predicted their higher cortisol levels, whereas *presence of their spouse* was associated with their lower cortisol levels. Wives' reports of *being alone* uniquely predicted their higher cortisol levels. Results further indicated that the within-couple

TABLE 3

Associations between Wife Cortisol and Husband Cortisol (Physiological Synchrony): Direct and Moderating Effects of Momentary Characteristics of Loneliness, Being Alone, and Spousal Presence

	Wives		Husbands	
	Coefficient	***t***	**Coefficient**	***t***
Fixed effects: Main effects				
Spousal cortisol[a]	0.155	2.47*	0.236	3.45**
Loneliness[a]	−0.104	−0.45	0.584	2.80**
Being alone[a]	0.108	2.58*	−0.071	−1.25
Spousal presence[a]	0.047	0.66	−0.148	−2.07*
Fixed effects: Interactions with spousal cortisol				
Loneliness[b]	0.497	1.62	0.141	0.75
Being alone[b]	−0.004	−0.05	−0.062	−0.74
Spousal presence[b]	0.115	1.25	0.119	1.33

Note. Results are based on 47 wife–husband dyads. Models retain Level 1 predictors and Level 3 health control variables included in the model in Table 2. Predictors with the same superscripts were entered simultaneously.

*$p \leq .05$. **$p \leq .01$.

cortisol associations (i.e., wife cortisol predicting husband cortisol, husband cortisol predicting wife cortisol) remained positive and significant when these momentary experiences were included in the synchrony model (see Table 3). We next tested whether ESM connectedness variables moderated spousal cortisol synchrony by adding centered variables of loneliness ratings and indicators of being alone and spousal presence; centered wife and husband cortisol values; and their respective interaction terms (i.e., one spouse's momentary ratings interacting with the other spouse's cortisol) simultaneously to Level 1 of the synchrony model (results shown in Table 3). Dyadic HLM indicated that momentary connectedness variables did not significantly modify (at $p < .05$) the synchrony linkages. Thus, spouses' momentary ratings of feeling lonely, being alone, and being with their spouse neither accounted for nor modified within-couple physiological synchrony. To potentially clarify whether *feeling emotionally disconnected from the spouse* was associated with physiological synchrony, we tested three-way interactions of a spouse's feeling lonely, presence of their spouse, and the partner's cortisol; however, these interaction terms did not significantly predict cortisol levels of either wives or husbands.

To address our final hypotheses concerning overall proportion of time spouses spent alone or together as moderators of the documented wife–husband physiological synchrony, we conducted a variant of the dyadic HLM described above with the potential moderators entered as Level 3 predictors of wife and husband cortisol intercepts and wife–husband cortisol associations. Proportion of time spouses spent alone across the study period was not a reliable moderator of within-couple physiological synchrony (see Table 4). Proportion of time together did modify synchrony, with the wife–husband cortisol linkage stronger among husbands who reported spending more time with their wives over the course of the study (Table 4). A final model examined whether time spent with others (excluding the spouse) also similarly strengthened synchrony; results indicated that the time with the spouse remained a significant moderator and, moreover, that it was unique. That is, the wife–husband cortisol synchrony linkage was stronger for husbands who spent more time *specifically with their spouses*, even after accounting for the amount of time husbands spent in the presence of other people (e.g., children, coworkers).

TABLE 4

Spouses' Time Alone and Time Together as Moderators of the Associations between Wife Cortisol and Husband Cortisol (Physiological Synchrony) Accounting for Cortisol's Diurnal Rhythm and Health Control Variables

	Wives		Husbands		
Fixed effect	**Coefficient**	***t***	**Coefficient**	***t***	**Model comparison test**[a]
Model 1					
Spousal cortisol	0.166	2.51*	0.245	3.72**	$\chi^2(df = 4) = 0.65$
Proportion of time alone	−0.136	−0.90	−0.009	−0.06	
Model 2					
Spousal cortisol	0.160	2.37*	0.258	4.06**	$\chi^2(df = 4) = 8.52^{\dagger}$
Proportion of time with spouse	0.035	0.22	0.496	3.46**	
Model 3					
Spousal cortisol	0.171	2.53*	0.268	4.27**	$\chi^2(df = 8) = 10.19$
Proportion of time with spouse	0.084	0.50	0.395	2.36*	
Proportion of time with others (excluding spouse)	0.229	1.19	−0.154	−1.19	

Note. Results are based on 47 wife–husband dyads. Models retain Level 1 predictors and Level 3 health control variables included in the synchrony model shown in Table 3. Synchrony intercept reflects the association between wife cortisol and husband cortisol levels over the 2 days of testing. Models were tested independently.

[a]Improvement in model specification when moderators added to cortisol intercept (not shown) and synchrony intercept parameters in the model in Table 2.

$^{\dagger}p \leq .10$. $^{*}p \leq .05$. $^{**}p \leq .01$.

DISCUSSION

Findings from this study provide additional evidence of physiological linkage in stress hormone rhythms between marital partners in naturalistic settings (Saxbe & Repetti, 2010), while clarifying the nature of associations between HPA-axis activity and both emotional and physical connectedness in dyadic couples. Cortisol synchrony was a relatively consistent and methodologically robust linkage from wives to husbands and from husbands to wives, and was not accounted for by cortisol diurnal rhythms, shared sampling times, or emotional or physical levels of closeness between partners. Responding to calls to contextualize research on synchrony between spouses' stress-response functioning (Repetti et al., 2011), momentary connectedness variables of feeling lonely, being alone, and immediate spousal presence were examined, but did not significantly moderate within-couple synchrony, further suggesting that these particular momentary factors did not account for couples' synchrony. Extending research based on individuals' stress responding and health (e.g., Matias et al., 2011; Steptoe et al., 2004), we found that husband cortisol levels were positively associated with momentary ratings of feeling lonely, whereas wife cortisol levels were positively linked with being alone. Furthermore, husbands' cortisol levels were lower in the presence of their spouse. These findings add to the emerging literature on the physiological implications of contexts of closeness (e.g., Adam, 2006) and reveal potentially disparate social underpinnings of physiological functioning for men and women. The differential momentary correlates for wives' versus husbands' cortisol levels were not anticipated, but may be due to the increased occurrence of husbands being consistently employed outside of the home. Comparatively, wives may have had more opportunity for "repeated hits" to their regulatory systems (Repetti et al., 2011), having potentially experienced more daily stressors in the home with children; thus, wives may gain more recovery from time spent alone. Although Repetti et al. (2011) also reviewed findings showing husbands to recover more when family members demonstrate *lower* emotional engagement, the current study demonstrated that husbands show evidence of *higher* physiological stress when they report feeling lonelier and being apart from their spouse. Although speculative, it is possible that younger average ages of children in the CELF families might account for this difference, reflecting potential changes in these processes over the course of family development. Alternatively, the relatively high levels of marital quality in our sample may help to account for husband's physiological "enjoyment" of togetherness with their wives. Together, the extant data suggest that husbands and wives may respond to family and marital dynamics in different ways and encourage additional research into such questions.

Turning to the moderation results, the current study documented that cortisol synchrony was moderated by husbands spending more time with their spouse, on average, across the two study days. Interestingly, our results indicated that spousal presence plays a unique role, as the within-partner cortisol linkage was not explained by or associated with greater time spent with people besides the spouse. The finding that greater shared time *together* as a couple is associated with greater synchrony is perhaps intuitive, and replicates the Papp et al. (2009) within-family result indicating that mothers and adolescents who spent more time together also evidenced a relatively stronger cortisol association. Continuing the discussion of employment patterns above, husbands' cortisol fluctuations here may have been more uniquely sensitive to the presence of their partner, given that over time these wives more likely were in the presence of others (especially children) in the home. Also, given high levels of marital satisfaction, wives' presence may also assist their husbands in physiologically recovering from a long day at work. Together, these results suggest that within-family physiological correlations result from more than genetic connections alone, and likely draw on shared environmental cues, shared schedules, and/or shared activities (Adam & Gunnar, 2001; Zeiders, Doane, & Adam, 2011). Findings here also provide a unique message for clinical treatment that spousal availability (for husbands, in particular) may play a potent role in couples' biological stress and related functioning.

Considered together with prior studies showing mother–adolescent (Papp et al., 2009) and husband–wife (Saxbe & Repetti, 2010) cortisol coregulation, the current study encourages future research to investigate the implications of cortisol synchrony within family members. To date, the growing literature seems to be mixed: For example, husband–wife cortisol synchrony was stronger for dissatisfied wives in Saxbe and Repetti (2010), but synchrony was stronger in Papp et al. (2009) between parents and adolescents who spent more time together and were more engaged in each other's lives. Here, too, we demonstrated that spousal synchrony was stronger when husbands reported spending more time with their spouses. Still, the question remains: Is this synchrony beneficial or not? We expect that the implications, in the long run, depend on whether this synchrony occurs in relatively adaptive versus maladaptive contexts. For example, considering intimate couples, we expect that expressions of relationship conflict and intimacy would be important modifiers of the effects of synchrony. Also, contexts of work strain and spillover into everyday life clearly deserve continued attention (see Repetti et al., 2011). We documented lower cortisol levels for husbands who spent more time with their spouses, which seems to imply a more adaptive synchrony for the husbands. The couples in this sample, mostly happily partnered, may be more likely to actively buffer each other from stresses of the day; in a more distressed sample, unhappy couples may simply be reactive to each other, rather than reciprocally offering support. Documenting longer term outcomes linked with family members' cortisol associations will be critical for treatment implications, given the host of problems associated with dysfunctional physiological patterns, including poor health outcomes (Gunnar & Vazquez, 2001; Repetti et al., 2011). In sum, our study extends current knowledge of cortisol synchrony between married couples, with careful analytic and theoretical considerations of both emotional and physical connectedness variables.

Although the current study provides important information on the physiological relationship between marital partners, it should be considered within the context of its methodological constraints. To start, others have recognized that collecting naturalistic cortisol assessments is burdensome (Repetti et al., 2011), and our study was missing data from some of the couples at each sampling point. For potential future intervention possibilities, our sample is not ideal. The wives and husbands who participated in this study do not represent an externally generalizable or random selection; furthermore, they were relatively established and happy couples. Additional research in clinical settings may shed more light on how extreme variations in relationship quality and momentary connectedness are associated with within-couple physiological synchrony, including whether Levenson and Gottman's "negative affect reciprocity" theory is evident for less harmonious couples. Our sample was also low in ethnic and racial diversity, which meant that we could not explore potential ethnic/racial differences in partner cortisol synchrony (DeSantis et al., 2007). Furthermore, socioeconomic variability in cortisol rhythms has been well established (Ranjit, Young, & Kaplan, 2005), so further study is needed into the interplay between demographic characteristics, naturalistic experiences, and physiological synchrony.

As noted above, we recommend longitudinal examination into whether the directional arrow of synchronous causality leads from connectedness to physiological responsiveness, or vice versa. Additional specificity regarding "loneliness" is encouraged: The loneliness ratings captured here were not a perfect proxy for feeling disconnected from one's spouse; although we tested the loneliness x spousal presence interaction, we may have had limited statistical power to uncover such an effect. Our data are cross-sectional and represent only 2 days of data collection; more days of assessment would be desirable, given that there is substantial day-to-day variation in cortisol rhythms, in part due to dynamic and transactional associations between cortisol and daily psychosocial/emotional experiences (Adam, Hawkley, Kudielka, & Cacioppo, 2006). Similarly, lagged statistical approaches may provide better insights regarding the directional arrows of social and/or physiological contagion. Future studies should attempt to further explicate the types of family contexts (e.g., a place of physiological recovery or of workplace spillover), as well as the variety of daily family experiences (both momentary and stable), that explain the notable biological synchrony that is evident among many marital pairs.

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