Research Article

Psychological Science
2015, Vol. 26(7) 972–982

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DOI: 10.1177/0956797615575022
pss.sagepub.com

Perceived Partner Responsiveness Predicts Diurnal Cortisol Profiles 10 Years Later

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Abstract
Several decades of research have demonstrated that marital relationships have a powerful influence on physical health. However, surprisingly little is known about *how* marriage affects health—both in terms of psychological processes and biological ones. Over a 10-year period, we investigated the associations between perceived partner responsiveness—the extent to which people feel understood, cared for, and appreciated by their romantic partners—and diurnal cortisol in a large sample of married and cohabitating couples in the United States. Partner responsiveness predicted higher cortisol values at awakening and steeper (i.e., healthier) cortisol slopes at the 10-year follow-up. These associations remained strong after we controlled for demographic factors, depressive symptoms, agreeableness, and other positive and negative relationship factors. Furthermore, declines in negative affect over the 10-year period mediated the prospective association between responsiveness and cortisol slope. These findings suggest that diurnal cortisol may be a key biological pathway through which social relationships affect long-term health.

Keywords
perceived partner responsiveness, social relationships, cortisol, health, marriage, MIDUS, open data, open materials

Received 5/28/14; Revision accepted 2/6/15

Twenty-five years ago, House, Landis, and Umberson (1988) demonstrated that stronger social ties are associated with lower levels of mortality. Since then, there has been a groundswell of research on the links between social relationships and health. Most recently, a meta-analysis of 148 studies showed a 50% increased likelihood of survival for people with better social relationships (Holt-Lunstad, Smith, & Layton, 2010). Yet a critical question remains: How do social relationships get "under the skin" to affect health and longevity, from both a psychological perspective and a biological one?

A recent meta-analysis of the links between marital quality and health showed robust associations between people's marital happiness and their physical health (Robles, Slatcher, Trombello, & McGinn, 2014). However, that meta-analysis also revealed how little is known about the specific aspects of marriage that matter most for physical health—positive aspects (e.g., warmth, understanding), negative aspects (e.g., conflict, hostility), or both. It has been argued that one of the keys to satisfying and lasting romantic relationships is the extent to which people believe that their partners understand, validate, and care for them—termed *perceived partner responsiveness* (Reis, 2012). Partner responsiveness is a strong predictor of satisfaction and intimacy in relationships, including when couples are coping with breast cancer (Manne et al., 2004), discussing personal goals (Feeney, 2004), and sharing positive events with each other (Gable, Gonzaga, & Strachman, 2006). It has been argued that partner responsiveness is an organizing principle in the study of relationships because it shares common elements with many important relationship constructs, provides core validation of the self, and leads to feelings of warmth, acceptance, belonging, and trust (Reis, 2012).

Partner responsiveness also appears to have relevance for health. For instance, among patients undergoing knee surgery, partner responsiveness during recovery

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predicted fewer knee limitations 3 months later (Khan et al., 2009). Perceived partner responsiveness has been shown to interact with social support to predict longevity in a large sample of married and cohabitating couples from the National Survey of Midlife Development in the United States (MIDUS) study (Selcuk & Ong, 2013). We propose that a critical pathway through which perceived partner responsiveness positively affects health and longevity is its effect on the hypothalamic-pituitary-adrenal (HPA) axis and the hormonal product of the HPA axis, cortisol.

The HPA axis has attracted substantial attention from researchers interested in the links between social relationships and health because of its sensitivity to psychological factors and its potent effects on multiple biological systems (Miller, Chen, & Zhou, 2007). The biological reach of cortisol is extensive: Glucocorticoid receptors are present in virtually every cell of the human body. Cortisol plays an important role in facilitating learning, memory, and emotion in the central nervous system; regulates gluconeogenesis in the metabolic system, particularly in times of threat (e.g., the fight-or-flight response); and helps regulate the immune system.

Cortisol production has a diurnal rhythm; levels typically rise in the first 30 min after a person wakes, then decrease over the day to a low point shortly before bedtime. A growing body of evidence suggests that a flatter diurnal cortisol slope is a predictor of poorer physical health, including Type II diabetes status (Hackett, Steptoe, & Kumari, 2014), preclinical atherosclerosis (Hajat et al., 2013), and mortality (Kumari, Shipley, Stafford, & Kivimaki, 2011). In both childhood and adulthood, negative aspects of social relationships (e.g., interpersonal conflict) are linked to flatter diurnal cortisol slopes, whereas relationship satisfaction is linked to steeper slopes (Saxbe, Repetti, & Nishina, 2008; Slatcher & Robles, 2012). It has been theorized that the nature of the early social environment, particularly the degree to which it is nurturing or aversive, can lead to HPA enhancement or dysregulation, respectively, in young adulthood and beyond (Miller, Chen, & Parker, 2011). But the extent to which long-term HPA function is shaped by social relationships formed in adulthood remains unknown.

There are virtually no long-term longitudinal investigations of the potential psychological pathways through which romantic relationships affect health and health-related biological processes (e.g., cortisol). However, psychological processes—particularly affective ones—figure prominently in theoretical models that link marital quality and health (Robles et al., 2014; Slatcher, 2010); negative affect is inversely associated with relationship quality (Gottman, 1998) and physical health (Krantz & McCeney, 2002), and positive affect is positively associated with relationship quality (Lyubomirsky, King, & Diener, 2005) and physical health (Pressman & Cohen, 2005). In line with these models, a recent study demonstrated that perceived partner responsiveness prospectively predicted positive and negative affect, along with other indicators of psychological well-being, in married individuals (Selcuk, Gunaydin, Ong, & Almeida, 2014). Prior research also has shown that negative affect is associated with less healthy (i.e., flatter) diurnal cortisol profiles (Polk, Cohen, Doyle, Skoner, & Kirschbaum, 2005), whereas positive affect is associated with healthier (i.e., steeper) diurnal cortisol profiles (Ong, Fuller-Rowell, Bonanno, & Almeida, 2011). On the basis of these findings, we hypothesized that greater perceived partner responsiveness would prospectively predict steeper cortisol slopes, and would do so, at least in part, through lower negative affect and higher positive affect assessed at follow-up.

We investigated the prospective associations between perceived partner responsiveness and diurnal cortisol over a 10-year period in a large sample of married and cohabitating couples in the United States. We controlled for partner responsiveness at the 10 year follow-up, as well as age, gender, race, education, and wake time—factors known to be associated with diurnal cortisol rhythms (Adam & Kumari, 2009)—as well as other positive and negative aspects of the marital relationship (e.g., provision of emotional support and conflict, respectively), agreeableness,[1] and depressive symptoms. To assess whether responsiveness predicted future cortisol levels for all participants or only for those who remained with the same partner, we tested moderation by relationship status (same or different partner) at Wave 2. Finally, we tested whether changes in positive and negative affect over the 10-year period mediated the associations between partner responsiveness at baseline and diurnal cortisol at follow-up.

Method

The data for this study were drawn from the Midlife in the United States (MIDUS) project, a two-wave panel survey of adults between the ages of 25 and 74. This study included collection of salivary cortisol for a subsample of participants as part of the National Study of Daily Experiences (NSDE). Phone interviews and self-administered questionnaires were collected in 1995–1996 (Wave 1) and again in 2004–2006 (Wave 2). A subset of participants from Wave 2 (n = 2,022) was assessed in the second wave of the NSDE (2004–2009), which was the source of cortisol data for the present analysis. Respondents participated in Wave 2 of NSDE after completing the Wave 2 MIDUS questionnaires.

Sample

In the current study, we included only those individuals who provided partner responsiveness questionnaire data at Waves 1 and 2 and cortisol data at Wave 2. The sample consisted of 1,078 adults (51.9% female, 95.1% White). All participants in the sample were married or cohabitating at Wave 1. Of those, 970 had remained with their partners, and 43 were confirmed to be separated from their partners (because of divorce, separation, or death of the partner) or with new spouses or new cohabitating partners (after divorce, separation, or death of the initial partners). For 65 participants, it was unknown whether they were still with the same partners or separated.

Measures

Covariates. Demographic covariates included age, gender (male = 1, female = 2), education (0 = high school or less, 1 = some college or more), and race (0 = White, 1 = non-White). We also controlled for average wake time across the days of salivary cortisol sampling. These covariates are standard in diurnal cortisol studies (Adam & Kumari, 2009).

Perceived partner responsiveness. Perceived partner responsiveness was assessed at Wave 1 and Wave 2 using three items from the MIDUS self-administered questionnaire. These items, used to assess partner responsiveness in a prior study of the links between responsiveness and mortality from the MIDUS project (Selcuk & Ong, 2013), asked participants to indicate how much their spouse or cohabitating partner cares about them, understands the way they feel about things, and appreciates them. These items match the three core components of responsiveness (i.e., understanding, validating, and caring) identified in the literature (Reis, 2012). Participants responded to the items on a 4-point scale ranging from 1 (*a lot*) to 4 (*not at all*); average α was .83 across Waves 1 and 2. Responses were reverse-scored so that higher scores reflected greater partner responsiveness.

Marital risk. A measure of marital risk (α = .72; Rossi, 2001) at Wave 1 was included to test whether partner responsiveness prospectively predicted diurnal cortisol patterns above and beyond the effects of negative aspects of the marital relationship. The scale is composed of five items assessing how often participants thought their relationship was in trouble over the preceding year (1 = *never*, 5 = *all the time*); the chances that the participant and his or her partner would eventually separate (1 = *very likely*, 4 = *not at all likely*; reverse-scored); and how much the participant and his or her partner disagreed about money, household tasks, and leisure time activities (1 = *a lot*, 4 = *not at all*; reverse-scored).

Perceived provision of emotional support. A measure of perceived provision of emotional support (Rossi, 2001) at Wave 1 was included as a potential confound of the effects of perceived partner responsiveness on diurnal cortisol. Participants were asked, "On average, about how many hours per month do you spend giving informal emotional support (such as comforting, listening to problems, or giving advice) to your spouse or partner?" On average, participants reported providing 29.51 hours of support per month (*SD* = 55.80). Because of the free-response nature of this question, there were a handful of implausibly large values (e.g., 720 hours per month or 24 hours per day). Accordingly, outliers on this variable were Winsorized to 2.5 *SD* above or below the mean (Wilcox, 1998).

Trait agreeableness. Agreeableness at Wave 1 was included as a covariate to rule out any effects of responsiveness on cortisol as a result of personality characteristics (e.g., highly agreeable people reporting high levels of partner responsiveness). Using a scale constructed to assess agreeableness in the MIDUS study (Rossi, 2001), participants reported the extent to which each of five trait adjectives (*helpful, warm, caring, softhearted, sympathetic*) described them on a 4-point scale (1 = *a lot*, 4 = *not at all*; reverse-scored); α = .79.

Depressive symptoms. A measure of depressive symptoms at Wave 1 (Kenney, Holahan, North, & Holahan, 2006) was included to test whether initial depressive symptom levels might explain the prospective association between partner responsiveness and diurnal cortisol patterns. The measure of depressive symptoms was the total number of "yes" responses to 13 items regarding symptoms experienced over the previous 12 months: seven symptoms experienced for 2 weeks or longer during which the participant "felt sad, blue, or depressed" (depressive affect subscale), and six symptoms experienced for 2 weeks or longer during which the participant "had the most complete loss of interest in things" (anhedonia subscale). Examples of items in the subscales included "lose your appetite," "have more trouble falling asleep than usual," and "think a lot about death."

Positive and negative affect. Positive and negative affect (Watson, Clark, & Tellegen, 1988) were assessed at Waves 1 and 2. At Wave 1, participants used a 5-point scale (1 = *all of the time*, 5 = *none of the time*; reverse-scored) to respond to prompts ("During the past 30 days, how much of the time did you feel . . .") for six positive-affect adjectives (e.g., *cheerful, in good spirits; M* = 3.49, *SD* = 0.66; α = .89) and six negative-affect adjectives (e.g., *nervous, restless or fidgety; M* = 1.45, *SD* = 0.52; α = .84). At Wave 2, participants responded to prompts for the adjectives from Wave 1 plus four additional positive-affect adjectives (e.g., *enthusiastic, attentive*) and five additional negative-affect items (e.g., *afraid, jittery*—positive affect: $M = 3.58$, $SD = 0.66$; $\alpha = .93$; negative affect: $M = 1.48$, $SD = 0.47$; $\alpha = .89$).

Salivary cortisol. Salivary cortisol was assessed at Wave 2 using Salivettes (Sarstedt, Rommelsdorft, Germany). Saliva collection occurred an average of 20 months (range = 3–53 months) after the Wave 2 phone assessment. On Days 2 to 5 of the 8-day NSDE study period, participants self-collected saliva samples at four time points each day: immediately on waking, 30 min later (to assess cortisol awakening response, or CAR), before lunch, and at bedtime. Cortisol concentrations were quantified with a commercially available luminescence immunoassay (IBL, Hamburg, Germany) with intra-assay and interassay coefficients of less than 5% (Polk et al., 2005). Saliva collection compliance was assessed using both nightly telephone interviews and paper-and-pencil logs that were included in the collection kits. Cortisol values were Winsorized to 2.5 *SD* above and below the mean to account for outliers in the cortisol distribution (Adam & Kumari, 2009).

Data analysis

Because of the strong diurnal rhythm of cortisol, hierarchical linear modeling (HLM) was used for data analyses. HLM allows for simultaneous estimation of multiple cortisol parameters (e.g., cortisol at awakening, CAR, and cortisol slope) and prediction of individual differences in diurnal cortisol parameters. Following the method of prior diurnal cortisol research (Adam & Kumari, 2009), time since waking, time-since-waking^2 (i.e., the square of time since waking), and CAR (dummy coded 1 for the second cortisol sample of the day and 0 for all other samples) were modeled at Level 1 to provide estimates of each participant's diurnal cortisol rhythm; the coefficient for the CAR variable (π_1) reflects a latent estimate of the size of each person's CAR (additional explanation of this standard approach can be found in Adam, 2006). Second, Level 2 (person level) effects of partner responsiveness at Wave 1 and Wave 2 were entered as predictors. Third, we controlled for potential confounds, including age, gender, race, education, and wake time at Level 2. We also included four Wave 1 psychological factors—marital risk, agreeableness, provision of emotional support, and depressive symptoms—as potential confounds of the links between Wave 1 partner responsiveness and Wave 2 cortisol.

Next, we tested whether the associations between Wave 1 partner responsiveness and cortisol were moderated by whether participants were in the same relationship at Waves 1 and 2. Finally, we tested whether changes in positive and negative affect over the 10-year period mediated the associations between Wave 1 responsiveness and Wave 2 cortisol parameters. Following prior recommendations (Adam & Kumari, 2009), we allowed cortisol intercept, slope (effect of time), and CAR to vary randomly at Level 2 (e.g., treated as random effects), whereas time-since-waking^2 was treated as a fixed effect with no Level 2 predictors. Except for gender, race, and education, all person-level variables were grand-mean-centered. To compare the magnitude of effects on cortisol across predictors, we *z*-scored all variables before analyses. Because the variables time since waking and time-since-waking^2 have meaningful true zeros, we divided these two variables by their standard deviations but did not subtract their means (i.e., we did not center these two variables). This was done so that the cortisol intercept represented the standardized effect of predictors at awakening; otherwise, the cortisol intercept in HLM analyses would reflect the effect of predictors on cortisol in the middle of the day. All HLM analyses used robust standard errors.

In addition to investigating parameters of diurnal cortisol rhythm (waking level, CAR, and slope), we also investigated the associations between partner responsiveness and total cortisol output (area under the curve with respect to ground, or AUC_g) across the 4 days of saliva sampling. We used the standard formula for computing AUC_g described by Pruessner, Kirschbaum, Meinlschmid, and Hellhammer (2003). We then used linear regression to regress AUC_g on perceived partner responsiveness, along with the covariates described previously. Significance tests in all analyses were two-tailed.

Results

Table 1 provides the intercorrelations among study variables. Results for Model 1 (see Table 2) indicated that participants' cortisol values showed the expected diurnal pattern across the day, with high values at awakening, $\beta_{00} = 0.219$, 95% confidence interval (CI) = [0.180, 0.258], an increase in levels in the first 30 min after waking (i.e., CAR), $\beta_{10} = 0.518$, 95% CI = [0.485, 0.551], and a decline in cortisol levels across the day, $\beta_{20} = -0.675$, 95% CI = [−0.720, −0.630].

Wave 1 responsiveness was associated with higher cortisol levels at awakening, $\beta_{01} = 0.041$, 95% CI = [0.008, 0.074], across the 4 days of saliva sampling in Wave 2 (Table 2, Model 1). Furthermore, Wave 1 responsiveness was associated with a steeper cortisol slope, $\beta_{21} = -0.015$, 95% CI = [−0.027, −0.003], in Wave 2. The associations between Wave 1 partner responsiveness and Wave 2 diurnal cortisol are depicted in Figure 1.

Wave 1 responsiveness explained 2.27% of the variance in cortisol slope (pseudo $R = .15$) and 0.5% of the

Table 1. Correlations Among the Predictor Variables

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1. Wave 1 partner responsiveness	—																
2. Wave 2 partner responsiveness	.52**	—															
3. Age	.09**	.15**	—														
4. Gender (female)	−.15**	−.17**	−.12**	—													
5. Race (non-White)	−.06	−.10**	−.00	−.03	—												
6. Education	.02	−.03	−.06*	−.05	−.00	—											
7. Average wake time	−.01	−.02	.03	.10**	.00	.06	—										
8. Trait agreeableness	.11**	.10**	.05	.25**	−.06	−.01	.07*	—									
9. Wave 1 provision of emotional support	.10**	.04	−.04	.08**	.06	−.07*	−.00	.08*	—								
10. Wave 2 provision of emotional support	.04	.09**	.07*	.08**	.02	−.05	−.02	.08**	.39**	—							
11. Wave 1 depressive symptoms	−.09**	−.07*	−.13**	.11**	.03	−.06	.11**	.01	.03	.02	—						
12. Wave 2 depressive symptoms	−.11**	−.11**	−.08*	.10**	.01	−.10**	.10**	.05	.05	.06	.29**	—					
13. Wave 1 marital risk	−.61**	−.37**	−.24**	.06*	.04	.01	.02	−.13**	−.02	−.02	.15**	.11**	—				
14. Wave 2 marital risk	−.33**	−.65**	−.23**	.06*	.12**	−.02	−.02	−.05	.00	−.05	.09**	.15**	.47**	—			
15. Wave 1 positive affect	.29**	.20**	.12**	−.04	.00	.02	−.05	.22**	.04	.01	−.31**	−.23**	−.33**	−.23**	—		
16. Wave 2 positive affect	.22**	.28**	.19**	−.05	.00	.04	−.06	.20**	−.00	−.00	−.19**	−.33**	−.21**	−.29**	.51**	—	
17. Wave 1 negative affect	−.25**	−.21**	−.19**	.10**	.01	−.10**	.04	−.08**	.06*	.04	.38**	.32**	.30**	.22**	−.60**	−.38**	—
18. Wave 2 negative affect	−.20**	−.25**	−.18**	.08*	.03	−.07*	.03	−.04	.02	.03	.22**	.43**	.23**	.30**	−.38**	−.61**	.54**

*p < .05 (two-tailed). **p < .01 (two-tailed).

Table 2. Results of the Multilevel Growth-Curve Models of Diurnal Cortisol Parameters

	Model 1		Model 2		Model 3	
Fixed effect (independent variable)	Coefficient	*p*	Coefficient	*p*	Coefficient	*p*
Cortisol level at awakening, π_0						
Average cortisol at awakening (intercept), β_{00}	0.219 (0.020)	< .001	0.219 (0.020)	< .001	0.389 (0.068)	< .001
Wave 1 partner responsiveness, β_{01}	0.041 (0.017)	.016	—	—	0.043 (0.020)	.036
Wave 2 partner responsiveness, β_{02}	—	—	0.011 (0.017)	.54	–0.033 (0.017)	.048
Age, β_{03}	—	—	—	—	0.074 (0.023)	.002
Gender, β_{04}	—	—	—	—	–0.126 (0.036)	< .001
Race, β_{05}	—	—	—	—	–0.033 (0.103)	.75
Education, β_{06}	—	—	—	—	0.038 (0.038)	.31
Average wake time, β_{07}	—	—	—	—	–0.009 (0.019)	.63
Wave 1 trait agreeableness, β_{08}	—	—	—	—	–0.011 (0.018)	.54
Wave 1 provision of emotional support, β_{09}	—	—	—	—	0.028 (0.017)	.12
Wave 1 depressive symptoms, β_{010}	—	—	—	—	–0.032 (0.014)	.024
Wave 1 marital risk, β_{011}	—	—	—	—	0.012 (0.022)	.58
CAR, π_1						
Average CAR, β_{10}	0.518 (0.017)	< .001	0.519 (0.017)	< .001	0.374 (0.069)	< .001
Wave 1 partner responsiveness, β_{11}	–0.019 (0.016)	.24	—	—	–0.025 (0.024)	.29
Wave 2 partner responsiveness, β_{12}	—	—	0.010 (0.017)	.53	0.026 (0.019)	.19
Age, β_{13}	—	—	—	—	0.084 (0.020)	< .001
Gender, β_{14}	—	—	—	—	0.090 (0.038)	.017
Race, β_{15}	—	—	—	—	0.045 (0.081)	.58
Education, β_{16}	—	—	—	—	0.010 (0.039)	.80
Average wake time, β_{17}	—	—	—	—	–0.003 (0.017)	.85
Wave 1 trait agreeableness, β_{18}	—	—	—	—	0.001 (0.019)	.95
Wave 1 provision of emotional support, β_{19}	—	—	—	—	0.016 (0.021)	.43
Wave 1 depressive symptoms, β_{110}	—	—	—	—	–0.017 (0.019)	.37
Wave 1 marital risk, β_{111}	—	—	—	—	0.016 (0.024)	.48
Cortisol slope of time since waking, π_2						
Average linear slope, β_{20}	–0.675 (0.023)	< .001	–0.676 (0.023)	< .001	–0.730 (0.034)	< .001
Wave 1 partner responsiveness, β_{21}	–0.015 (0.006)	.012	—	—	–0.017 (0.008)	.041
Wave 2 partner responsiveness, β_{22}	—	—	–0.001 (0.006)	.87	0.013 (0.007)	.053
Age, β_{23}	—	—	—	—	–0.008 (0.007)	.29
Gender, β_{24}	—	—	—	—	0.040 (0.013)	.003
Race, β_{25}	—	—	—	—	0.030 (0.028)	.27
Education, β_{26}	—	—	—	—	–0.021 (0.013)	.12
Average wake time, β_{27}	—	—	—	—	–0.001 (0.007)	.88
Wave 1 trait agreeableness, β_{28}	—	—	—	—	0.001 (0.007)	.86
Wave 1 provision of emotional support, β_{29}	—	—	—	—	–0.011 (0.006)	.049
Wave 1 depressive symptoms, β_{210}	—	—	—	—	0.009 (0.006)	.13
Wave 1 marital risk, β_{211}	—	—	—	—	–0.002 (0.008)	.77
Time-since-waking^2, π_3						
Average curvature, β_{30}	0.382 (0.020)	< .001	0.383 (0.020)	< .001	0.389 (0.020)	< .001

Note: Standard errors are given in parentheses. At Level 1, change in cortisol levels was modeled separately for each individual, using cortisol as the outcome variable and collection time as the predictor. Average cortisol value at awakening (in *SD* units) was the intercept, or starting value of cortisol. At Levels 2 and 3, cortisol-profile parameters were predicted using Wave 1 partner responsiveness in Model 1, Wave 2 partner responsiveness in Model 2, and partner responsiveness at Waves 1 and 2 plus covariates in Model 3. Average cortisol awakening response (CAR) indicates the change in cortisol during the 30 min after waking; average cortisol slope of time since waking indicates the change in cortisol per 1-*SD* change in time; average effect of time-since-waking^2 indicates the change in cortisol per 1-*SD* change in time^2. CAR was dummy coded as 1 for the second cortisol sample of the day and 0 for all other samples. For gender, male was coded as 1 and female as 2. For race, White was coded as 0 and non-White as 1. For education, high school or less was coded as 0 and some college or more as 1.

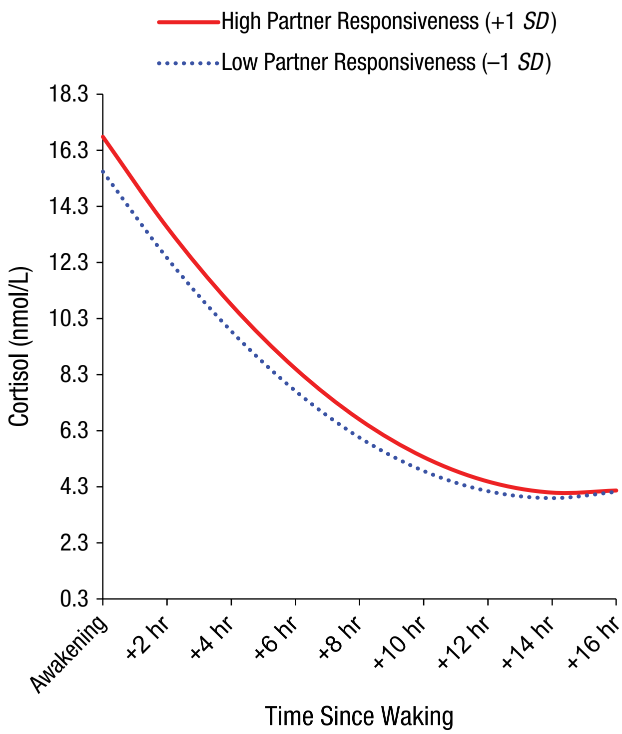

Fig. 1. Associations between Wave 1 perceived partner responsiveness and diurnal cortisol at Wave 2. Cortisol level is graphed as a function of time since waking, separately for participants with low (1 *SD* below the mean) and high (1 *SD* above the mean) partner responsiveness.

variance in cortisol at awakening (pseudo $R = .07$). These effects were similar to those reported in a recent meta-analysis of the associations between marital relationships and physical health (average $r = .07–.21$ across different types of health outcomes; Robles et al., 2014).[2] Wave 2 responsiveness was unrelated to either cortisol levels at awakening or cortisol slope (Table 2, Model 2). Neither Wave 1 nor Wave 2 responsiveness was related to CAR.

We next examined whether the prospective associations between Wave 1 partner responsiveness and Wave 2 diurnal cortisol profiles remained significant when we controlled for demographic characteristics, agreeableness, provision of emotional support, depressive symptoms, and marital risk (Model 3) in Wave 1. As displayed in Table 2, Wave 1 responsiveness remained a significant predictor of both cortisol intercept, $\beta_{01} = 0.043$, 95% CI = [0.004, 0.082], and cortisol slope, $\beta_{21} = -0.017$, 95% CI = [–0.033, –0.001], whereas Wave 2 responsiveness significantly predicted lower cortisol levels at awakening in Model 3, $\beta_{02} = -0.033$, 95% CI = [–0.066, –0.0002], possibly driven by suppression effects. In addition, Wave 1 provision of emotional support significantly predicted a steeper cortisol slope, $\beta_{29} = -0.011$, 95% CI = [–0.023, –0.00003]. Thus, both perceived partner responsiveness and provision of emotional support (which correlated with each other, $r = .10$; see Table 1) uniquely predicted steeper cortisol slopes at Wave 2.[3]

We then conducted AUC_g analyses, regressing AUC_g on perceived partner responsiveness. Initial simple regression showed that neither Wave 1 partner responsiveness ($p = .31$) nor Wave 2 partner responsiveness ($p = .40$) was associated with AUC_g. When we entered both Wave 1 and Wave 2 responsiveness as predictors of AUC_g, neither was a significant predictor of AUC_g ($ps > .50$). Furthermore, neither was a significant predictor of AUC_g when entered together with the covariates ($ps > .60$); the only covariates to significantly predict AUC_g were age, $\beta = .15$, $p < .001$, and average wake time, $\beta = -0.08$, $p = .007$. Thus, perceived partner responsiveness was prospectively associated with cortisol at awakening and cortisol slope, but was unrelated to total cortisol output.

Possible moderation by relationship status at Wave 2

We next explored whether the effect of Wave 1 partner responsiveness on Wave 2 diurnal cortisol parameters (levels at awakening and slope) was moderated by relationship status at Wave 2. In this analysis, Wave 1 responsiveness was grand-mean-centered, and a new variable was created to indicate people no longer with the same spouse or cohabitating partner ($n = 43$; effect coded −1) and people who remained continuously with the same partner between Wave 1 and Wave 2 ($n = 970$; effect coded 1). Wave 1 responsiveness, Wave 2 responsiveness, relationship status, and the Wave 1 Responsiveness × Relationship Status interaction term were entered together at Level 2 to predict cortisol. We found no evidence that the effect of Wave 1 responsiveness on cortisol parameters was moderated by relationship status (ps of all interaction terms > .30). We also found no evidence that whether one was separated or still with the same partner was associated with cortisol parameters (all $ps > .70$). Only Wave 1 responsiveness was associated with cortisol, predicting both cortisol at awakening, $\beta_{01} = 0.058$, $SE = 0.021$, 95% CI = [0.016, 0.100], $p = .006$, and cortisol slope, $\beta_{21} = -0.025$, $SE = 0.007$, 95% CI = [–0.039, –0.011], $p = .001$.

Mediation analyses

Next, we tested whether the association between Wave 1 partner responsiveness and Wave 2 diurnal cortisol profiles could be explained by changes in affect over the 10-year period. The 95% confidence intervals for indirect effects were estimated using an online Monte Carlo calculator (Selig & Preacher, 2008) assessing 2-2-1 multilevel model mediation with 20,000 repetitions.

Positive affect. We first tested positive affect as a mediator. Using simple regression, we determined that Wave 1 responsiveness significantly predicted positive affect at Wave 2, $b = .220$, $SE = 0.030$, 95% CI = [0.161, 0.279], $p < .001$, and this effect remained significant, $b = 0.083$, $SE = 0.028$, 95% CI = [0.028, 0.138], $p = .003$, after we controlled for Wave 1 positive affect. Wave 1 responsiveness and Wave 2 positive affect then were entered together as predictors of diurnal parameters in HLM. In this analysis, the association between responsiveness and cortisol at awakening remained significant, $\beta_{01} = 0.037$, $SE = 0.017$, 95% CI = [0.003, 0.070], $p = .031$, but responsiveness was no longer a significant predictor of cortisol slope, $\beta_{21} = -0.011$, $SE = 0.006$, 95% CI = [−0.023, 0.001], $p = .079$. Positive affect marginally predicted higher CAR, $\beta_{12} = 0.033$, $SE = 0.017$, 95% CI = [−0.0004, 0.067], $p = .053$, but did not significantly predict cortisol at awakening and only marginally predicted cortisol slope, $\beta_{22} = -0.011$, $SE = 0.006$, 95% CI = [−0.023, 0.001], $p = .072$. Furthermore, when we controlled for Wave 1 positive affect, the effect of Wave 2 positive affect on cortisol slope was not significant. These results suggest that neither Wave 2 positive affect nor changes in positive affect from Wave 1 to Wave 2 mediated the effect of Wave 1 responsiveness on Wave 2 cortisol slope.

Negative affect. We took a similar approach for testing mediation with negative affect. Higher partner responsiveness at Wave 1 predicted lower negative affect at Wave 2, $b = -0.196$, $SE = 0.030$, 95% CI = [−0.255, −0.137], $p < .001$, and this association remained significant, $b = -0.066$, $SE = 0.027$, 95% CI = [−0.119, −0.013], $p = .013$, after we controlled for Wave 1 negative affect. When Wave 1 responsiveness and Wave 2 negative affect were entered as predictors of Wave 2 cortisol, the effect of responsiveness on cortisol at awakening was significant, $\beta_{01} = .039$, $SE = 0.017$, 95% CI = [0.005, 0.072], $p = .023$, whereas the effect of negative affect was not ($p = .63$). However, higher levels of negative affect predicted a flatter cortisol slope, $\beta_{22} = 0.018$, $SE = .006$, 95% CI = [0.006, 0.030], $p = .004$, and a lower CAR, $\beta_{12} = -0.035$, $SE = 0.016$, 95% CI = [−0.067, −0.002], $p = .035$. In addition, the effect of responsiveness on cortisol slope was no longer significant, $\beta_{21} = -0.009$, $SE = 0.006$, 95% CI = [−0.022, 0.002], $p = .105$. Furthermore, the effect of Wave 2 negative affect on cortisol slope remained significant, $\beta_{22} = 0.018$, $SE = 0.007$, $p = .007$, 95% CI = [0.005, 0.031], when we controlled for Wave 1 negative affect. This finding indicates that a decrease in negative affect between Wave 1 and Wave 2 was associated with a steeper cortisol slope.

Monte Carlo analysis indicated that partner responsiveness had a significant indirect effect on cortisol slope through changes in negative affect (95% CI = [−0.003, −0.0001]), which suggests that the association between Wave 1 partner responsiveness and Wave 2 cortisol slope was driven by decreases in negative affect between Wave 1 and Wave 2.[4] Because the time lags between the Wave 2 negative-affect measures and cortisol assessments ranged from 3 to 53 months, we checked to see whether the negative-affect mediation results remained significant when we controlled for time lag and whether time lag moderated the association between negative affect and cortisol slope. The association between negative affect and slope remained significant in that analysis ($p = .006$), and the interaction between time lag and negative affect on cortisol slope was not significant ($p = .09$).

Discussion

We found that perceived partner responsiveness predicted diurnal cortisol profiles at a 10-year follow-up in a large sample of married and cohabitating adults in the United States. Specifically, greater responsiveness was prospectively associated with steeper cortisol slopes and higher cortisol levels at awakening (which tend to be negatively correlated with cortisol slope; Adam & Kumari, 2009) but was unrelated to total cortisol output (AUC_g). Note that the associations between responsiveness and diurnal cortisol parameters remained significant after controlling for a number of possible confounds. Furthermore, our findings suggest that the association between partner responsiveness and diurnal cortisol slope was at least partly driven by decreases in negative affect from Wave 1 to Wave 2.

To our knowledge, this is the first study to show long-term longitudinal associations between the quality of one's marital relationship and diurnal cortisol profiles. Prior work has focused on early-life social experiences and how they affect future HPA axis function (for a review, see Gunnar & Quevedo, 2007). However, whether the HPA axis can be fundamentally altered by social relationships in adulthood as it can early in life has been an open question. Our findings demonstrate that positive aspects of marriage—not only partner responsiveness but also provision of emotional support—may help shape the HPA axis in beneficial ways, potentially leading to long-term changes in cortisol production.

A critical question addressed by our findings is whether the associations between partner responsiveness and future HPA-axis function are stronger for people who stay with the same partners or for people who are in new relationships at the 10-year follow-up. We found no evidence that being in a new relationship attenuated the association between partner responsiveness and diurnal cortisol. In other words, the links between partner responsiveness and diurnal cortisol patterns were just as strong for people who were separated or in new relationships as they were for people who had remained with their partners over that entire 10-year time period. This is key preliminary evidence for lasting effects of partner responsiveness on the HPA axis, because it suggests that HPA activity continues to be affected by earlier social experiences, even in the presence of a new partner.

The fact that neither Wave 2 partner responsiveness nor Wave 2 provision of emotional support was concurrently associated with cortisol slope suggests that possible alterations in the HPA axis stemming from positive relationship experiences occur over an extended period of time. It has been argued elsewhere (Robles et al., 2014; Slatcher, 2010) that to better understand the links between marital quality and health, researchers must consider separately the positive and negative aspects of marriage that contribute to one's perception of marital quality. As far as we are aware, the current study is the first to do so with regard to the links between marital quality and diurnal cortisol, showing that positive but not negative aspects of marriage are prospectively associated with HPA function in everyday life.

How big are these effects, and are they practically meaningful? The size of associations between partner responsiveness and cortisol parameters are small but comparable to those reported in a recent meta-analysis of the links between marital quality and physical health (Robles et al., 2014). As noted in that meta-analysis, effect sizes of other well-known associations between behaviors and health also are small, including consumption of fruit and vegetables and coronary heart disease (relative risk = .93; He, Nowson, Lucas, & MacGregor, 2007), exercise interventions for preventing declines in health-related quality of life (r = .05; Gillison, Skevington, Sato, Standage, & Evangelidou, 2009), and increased television viewing and risk for cardiovascular disease (relative risk = 1.15; Grøntved & Hu, 2011). Despite these small effect sizes, increasing fruit and vegetable intake and reducing sedentary activity are considered important targets for improving public health (U.S. Department of Agriculture and U.S. Department of Health and Human Services, 2010). Thus, although the effects of perceived partner responsiveness on diurnal cortisol are small, they are potentially quite meaningful when put in context alongside other well-known health behaviors.

Identifying biological mechanisms underlying the links between marriage and health has been challenging. Of the various cortisol parameters assessed in daily life, cortisol slope in particular is emerging as a key to understanding the long-term impact of marital relationships on longevity because of the links between marital functioning and diurnal cortisol production (Saxbe et al., 2008) and the links between flatter cortisol slopes and poorer health (Hackett et al., 2014; Hajat et al., 2013; Kumari et al., 2011). We propose that diurnal cortisol should be considered a potential mediator of the links between marital quality and longevity. Mortality data from future waves of the MIDUS study will allow researchers to directly test whether diurnal cortisol parameters are associated with longevity and whether perceived partner responsiveness is indirectly associated with longevity via alterations in diurnal cortisol profiles. Furthermore, additional waves of cortisol data will make it possible to test whether partner responsiveness is associated with changes in diurnal cortisol profiles over time.

Perhaps the most noteworthy finding from this study is that decreases in negative affect over the 10-year period mediated the prospective association between responsiveness and cortisol slope. To our knowledge, this is the first study to show that declines in negative affect over time may explain, at least in part, the longitudinal effects of romantic-relationship processes on health-related outcomes. This finding supports theoretical accounts of the links between marital quality and health (Robles et al., 2014; Slatcher, 2010), offering empirical evidence of affective processes mediating the prospective associations between marital quality and HPA function.

Ultimately, only with replication of these findings and additional waves of data will we be able to definitively identify and articulate the mechanisms through which partner responsiveness is associated with diurnal cortisol profiles and long-term physical health. Despite the need for more data, the findings from this study offer a potentially important advance in our understanding of the long-term links between adult social relationships, psychological processes, and health-related biology.

Author Contributions

R. B. Slatcher and E. Selcuk developed the study idea. R. B. Slatcher conducted the data analysis, with assistance from E. Selcuk. R. B. Slatcher drafted the manuscript, and E. Selcuk and A. D. Ong provided critical revisions. All authors approved the final version of the manuscript for submission.

Declaration of Conflicting Interests

The authors declared that they had no conflicts of interest with respect to their authorship or the publication of this article.

Funding

The MIDUS I study (Midlife in the U.S.) was supported by the John D. and Catherine T. MacArthur Foundation Research Network on Successful Midlife Development. The MIDUS II research, a longitudinal follow-up of the MIDUS I investigation, was supported by National Institute on Aging Grant P01-AG020166.

Open Practices

All data and materials have been made publicly available and can be accessed at http://midus.colectica.org. The complete Open Practices Disclosure for this article can be found at http://pss.sagepub.com/content/by/supplemental-data. This article has received badges for Open Data and Open Materials. More information about the Open Practices badges can be found at https://osf.io/tvyxz/wiki/1.%20View%20the%20Badges/ and http://pss.sagepub.com/content/25/1/3.full.

Notes

1. We thank an anonymous reviewer for suggesting that we include agreeableness and perceptions of provision of emotional support as covariates in our analyses. These covariates were included in an attempt to rule out general warmth and relationship positivity that potentially underlie the effects of perceived partner responsiveness on diurnal cortisol patterns.

2. Although there is no direct measure of the variance accounted for in HLM, once variables have been entered into an HLM model, one can estimate a pseudo R^2 statistic (Kreft & De Leeuw, 1998) using the formula $(\sigma^2_{\text{unconditional}} - \sigma^2_{\text{conditional}})/\sigma^2_{\text{unconditional}}$. This formula provides an estimate of the variance explained for any random parameter (e.g., cortisol at awakening, cortisol slope) in an HLM model when adding a predictor variable (e.g., Wave 1 partner responsiveness) to an unconditional growth-curve model (empty model, with no predictors at Level-2).

3. Additional analyses using available Wave 2 MIDUS data showed that the associations between Wave 1 responsiveness and Wave 2 cortisol at awakening, β_{02} = .042, *SE* = 0.015, 95% CI = [0.012, 0.071], p = .005, and between responsiveness and cortisol slope, β_{22} = −0.016, *SE* = 0.006, 95% CI = [−0.028, −0.003], p = .013, also remained significant when using Wave 2 rather than Wave 1 depressive symptoms, marital risk, and provision of emotional support as covariates (but none of these Wave 2 covariates were significant predictors of any cortisol parameters, *p*s > .11).

4. To ensure the robustness of the mediation findings, we also conducted a mediation analysis using negative-affect residualized change scores (unstandardized residual of negative affect at Wave 1 as a predictor of negative affect at Wave 2) to predict cortisol slope, which yielded virtually identical results. In that analysis, residualized increases in negative affect over time significantly predicted a flatter cortisol slope, β_{22} = 0.016, *SE* = .007, 95% CI = [0.003, 0.029], p = .013, after we controlled for Wave 1 partner responsiveness. Monte Carlo analysis indicated a significant indirect association between partner responsiveness and cortisol slope through residualized changes in negative affect (95% CI for the indirect effect = [−0.003, −0.0001]).

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