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Positive upshots of cortisol in everyday life

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Abstract

Cortisol, the major physiological end-product of the hypothalamic-pituitary-adrenal (HPA) axis, is usually associated with stress and negative affect. However, a new body of research highlights the complex, adaptive significance of elevated cortisol within individuals in everyday life. Whereas most studies do not have the power to test the dynamic transactions between cortisol and affect within a person throughout the entire waking day, we employed an intensive study protocol analyzing hourly diary reports of affect in relation to hourly salivary cortisol samples among 24 healthy adults from morning to bedtime, across two consecutive weekdays ($n = 862$ total samples). Utilizing multi-leveling modeling and focusing on within-person effects, we examined whether momentary increases in cortisol could be mood protective, or energy enhancing, in everyday life, supporting the cortisol boost hypothesis. Results revealed no significant associations between cortisol and *current* affective state; however, within-person increases in cortisol were significantly associated with *subsequent* rises in activeness, alertness, and relaxation, and trend-level reductions in stress and nervousness. This study adds to growing evidence that cortisol plays a positive role in regulating affect in everyday life.

Keywords

hypothalamic-pituitary-adrenal (HPA) axis; positive affect; negative affect; cortisol boost hypothesis

Cortisol is the major physiological end-product of the hypothalamic-pituitary-adrenal (HPA) axis and has long been considered a biomarker of stress (McEwen, 1998). Over time, cortisol has come to be associated with negative affect and the negative health consequences of stressors, invoking the popular idea that cortisol is aversive or maladaptive. However, numerous paradoxical findings now demonstrate that high cortisol is not necessarily bad and low cortisol is not necessarily good (Lovallo & Thomas, 2000; Shirtcliff, Peres, Dismukes, Lee, & Phan, 2014). For example, cortisol can rise acutely in response to perceived positive,

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exciting, and fun experiences, such as sports competitions among adults (Bateup, Booth, Shirtcliff, & Granger, 2002; Carré, Muir, Belanger, & Putnam, 2006) or Christmas Eve for children (Flinn, 2006). Therefore, an emerging body of research highlights a complex, *adaptive* role of elevated cortisol. In the current study, we examined whether momentary increases in cortisol could be mood protective, or energy enhancing, in everyday life.

The hypothesis of mood protective effects of elevated cortisol has thus far been predominately supported by pharmacological and psychosocial laboratory studies involving acute stress manipulation tasks. For example, one study found that cortisol-treated participants reported significantly less negative affect after stress exposure than that of placebo-treated subjects (Het & Wolf, 2007). Similarly, in studies examining circulating endogenous cortisol levels in relation to measures of affect, higher cortisol reactivity to a lab stressor was associated with lower levels of negative feelings (e.g., upset, angry; Het, Schoofs, Rohleder, & Wolf, 2012; Kazén, Kuenne, Frankenberg, & Quirin, 2012). Overall, these laboratory studies suggest that elevated cortisol during stressful situations might be mood protective, helping individuals cope with the emotional load of situations by reducing negative emotional responses.

Outside of the laboratory setting, there is some evidence that short-term surges in cortisol levels – such as high waking levels and the sharp rise in cortisol 30–45 minutes after waking, the cortisol awakening response (CAR) – may provide an energetic “boost” to help individuals prepare to face the demands of the coming day (Adam, Hawkley, Kudielka, & Cacioppo, 2006; Doane & Adam, 2010). Elevated cortisol, through its influence on metabolic processes, may contribute directly to increased energy and lower fatigue, which in turn help protect against negative affect and/or help boost positive affect. However, most studies have not had the power to test the dynamic, bidirectional relations between cortisol and affect within a person throughout the entire waking day. It is possible that cortisol surges at other times of day also contribute to boosts of energy and positive affect, but most investigations of cortisol and affect in naturalistic settings have only examined the influence of affect on cortisol as opposed to vice versa.

To investigate the cortisol boost hypothesis in a naturalistic setting, we analyzed hourly diary reports of affect in relation to hourly salivary cortisol samples among 24 healthy adults from morning to bedtime, across two consecutive weekdays ($n = 862$ total samples). Utilizing multilevel growth curve modeling and time-lagged data, we examined our hypothesis that within-person increases in cortisol would predict increases in high arousal positive affective states in the subsequent hour, even after controlling for affect measured concurrent with cortisol measurement.

Methods

Participants

Students and community members from a large Midwestern city were recruited by word-of-mouth and flyers posted on campus. Eligible participants had to be: (a) between the ages of 18 and 49, (b) not currently taking corticosteroid-based medication, and (c) not in the 3rd trimester of pregnancy. The first eligible 25 individuals to respond were selected for the

study and consented in person by a member of the study research team. One person withdrew for medical reasons. The final sample consisted of 24 healthy adults (17 female) between the ages of 21 and 42 years ($M = 27.5$; $SD = 5.2$). None of the participants reported being pregnant. Twenty participants reported their racial/ethnic background as White; four participants self-identified as Asian/Asian American. Participants received a \$30 gift card upon study completion.

Procedures

For each of two typical weekdays, participants were asked to provide samples of saliva in the morning immediately upon awakening, 30, 45, and 60 minutes after waking, in the evening immediately before bedtime, and every hour on the hour during the day between waking and bedtime. Participants provided an average of 36 samples across the two days ($SD = 3.5$, Range = 29 to 40). Participants were instructed not to eat, drink, or brush their teeth in the first hour after waking, if possible. Saliva sampling involved expectorating saliva through a straw into a sterile 2 ml cryogenic vial. Participants wrote the time of collection on a label and attached it to the vial. Participants refrigerated samples as soon as possible, and then returned them to the lab when sampling was complete, where they were stored at -20°C . Salivary cortisol levels are robust to variations in temperature and motion over a period of several days (Clements & Parker, 1998).

Samples were sent on dry ice to the Biochemisches Labor at the University of Trier, Germany and were assayed in duplicate for cortisol using a time-resolved immunoassay with fluorometric detection (DELFI). Duplicate cortisol results were averaged and mean values were used in analysis. Intra-assay coefficients of variation (CVs) were between 4.0% and 6.7%, and inter-assay CVs ranged from 7.1% to 9.0%. Consistent with prior cortisol studies (Doane et al., 2013; Nicolson, 2008), raw cortisol values were winsorized at 1.8 $\mu\text{g}/\text{dl}$ ($n=2$) to reduce the effects of outliers on the analysis.

Participants also completed a questionnaire reporting about health and lifestyle factors, such as medication use, consumption of caffeine and alcohol, use of nicotine, timing of menstrual cycle, presence of chronic illness, and their height and weight. Additionally, along with each saliva sample, participants completed diary reports of their moods, activities, and health behaviors over the past hour. All procedures were approved by the Institutional Review Board at Northwestern University.

Measures

Cortisol—Estimates suggest that 60-70% of the variation in levels of cortisol across the waking day is explained by time of day (Adam, 2006; Adam & Gunnar, 2001). Therefore, the current analyses relied on time-based residual values, or “detrended” values (Curran & Bauer, 2011), which represented the cortisol level above or below the expected cortisol level for each person on each day. Detrended cortisol values were estimated using multiple regression techniques with all available cortisol data samples, with detrending conducted separately for each participant in order to adjust for person-specific diurnal cortisol rhythms. Specifically, raw cortisol levels were regressed on cortisol sampling times separately for

each person on each day, with the person-specific beta coefficient or the effect of time of day on cortisol representing the cortisol slope: b_1 in equation (1), below.

$$CORT = b_0 + b_1 * Time + b_2 * Time^2 + b_3 CAR_{30} + b_4 CAR_{45} + b_5 CAR_{60} + e \quad (1)$$

A squared time parameter was included to model the curvilinear shape of the rhythm (b_2) and three dummy variables (b_3 - b_5) indicating which samples are CAR samples (0 = non-CAR sample, 1 = CAR sample) were included to remove the impact of the CAR on the cortisol slope (Adam & Gunnar, 2001). The residual values were stored and used in the next step of the analysis.

Affect—Participants were asked to indicate, in their hourly diary reports, how much they felt each of the following affective states: alert, active, cheerful, relaxed, stressed, nervous, sad, and worried. Responses were rated on a scale of 0 (not at all) to 3 (very much) and within-person centered before analysis by subtracting the mean daily affect score for each person. We examined both current affect ($Affect_t$) and future affect ($Affect_{t+1}$) in the following hour. Descriptive statistics for affect variables are shown in Table 1.

Covariates—Diary-based measures of exercise, sleep, alcohol, nicotine, and caffeine consumption in the last hour (0 = no, 1 = yes) were examined as covariates.

Data Analysis

We utilized growth models in the multi-leveling modeling framework due to the nested structure of the data. Specifically, a three-level model was specified with momentary data at Level 1, day-level data at Level 2, and individual-level data at Level 3. Given our interest in understanding how cortisol levels related to changes in individuals' *subsequent* mood, we examined lagged analyses; *future* affect variables (i.e., alert, active, cheerful, relaxed, stressed, nervous, sad, worried) were regressed upon *prior* detrended cortisol levels. In each analysis (separate analyses for each affect variable), we accounted for current levels of affect, and whether or not individuals had exercised, eaten, or consumed caffeine in the past hour. Additional covariates were examined (medication use, consumption of alcohol, use of nicotine, timing of menstrual cycle, presence of chronic illness, and height/weight), but due to limited variability and/or non-significance, these variables were excluded from the final analyses. We also accounted for diurnal fluctuations in affect across each day by including a time trend predictor (centered at waking) for each affect variable; initial growth models identified whether affect remained stable or changed across the day (e.g., linear, quadratic, or cubic pattern). We then examined whether significant time trends in affect should be random or fixed. After establishing the time trends in the dependent variables (i.e., affect variables), we examined the effect of detrended cortisol on subsequent affect, including aforementioned time trends and covariates. In order to remove the effect of the CAR, the analyses excluded data points (affect and cortisol) that occurred during the first two hours after waking.

Results

Positive affect (PA)

Initial growth models revealed a cubic pattern of change across the days for alert and relaxed, and a quadratic pattern of change across the days for active and cheerful. Therefore, each proceeding model incorporated the appropriate (linear, quadratic, cubic) time terms.

The inclusion of cortisol and covariates in the next set of models revealed that cortisol predicted subsequent increases in feelings of alert, active, and feeling relaxed (Table 2). Specifically, an increase in individuals' cortisol levels predicted increases in feelings of alertness in the next hour ($b = .58, p = .03$; 95% Confidence Interval (CI) = .07, 1.10), accounting for individuals' average daily fluctuations in alertness, current level of alertness, and health variables. Similarly, an increase in individuals' cortisol levels predicted increases in feelings of activeness ($b = .92, p < .001$; 95% CI = .31, 1.52) and feeling relaxed ($b = 1.19, p < .001$; 95% CI = .59, 1.79), with the full set of covariates. Cortisol did not significantly predict subsequent cheerfulness ($b = .45, p = .12$; 95% CI = -.11, 1.02).

Negative affect (NA)

Initial growth models revealed a pattern of linear decline across the days for stressed and nervousness, and no time trends across the day for sadness and worry. As seen in Table 2b, cortisol was marginally related to subsequent feelings of stress ($b = -.44, p = .09$; 95% CI = -.94, .06), suggesting that an increase in individuals' cortisol predicted a *decrease* in stress the next hour. Cortisol emerged as a marginally significant predictor of nervousness ($b = -.30, p = .07$; 95% CI = -.62, .03), suggesting that an increase in individuals' cortisol predicted a decrease in feelings of nervousness the next hour. Cortisol was a non-significant predictor in both models of sadness and worry.

Follow-up analyses

To further uncover the relationship between cortisol and affect, we ran two additional sets of analyses: (1) to explore associations between cortisol and *current* PA and NA, and (2) to test if PA and/or NA variables predicted subsequent changes in cortisol. In the cross-sectional models (Supplemental Table 1), none of the affect variables was related to concurrent cortisol levels. However, two of the health covariates were associated with concurrent affect: exercise was related to higher reports of alert and active, and lower reports of stress; caffeine consumption was positively correlated with nervousness. In the second set of follow-up analyses (i.e., affect predicting subsequent cortisol), sadness emerged as a marginally significant predictor of cortisol one hour later ($b = .03, p = .06$; 95% CI = .00, .06); all other affect variables did not predict cortisol (Supplemental Table 2).

Discussion

The association between cortisol and affect is bidirectional and complex. In order to understand this dynamic relation, it is vital to study within-person processes, which can only be accomplished through the study of intra-individual differences in repeated-measures data (Curran & Bauer, 2011). This study adds to growing evidence that cortisol plays an adaptive

role in everyday life, by examining dynamic, hour-to-hour associations between cortisol and affect in a naturalistic setting. Importantly, all of these time-lagged models controlled for current levels of affect, which allowed us to predict increases or decreases in affect from cortisol changes within-persons, over time. Although there were no significant associations between cortisol and *current* affective state, within-person increases in cortisol were significantly associated with a *subsequent* rise in activeness, alertness, and relaxation, and a trend-level reduction in stress and nervousness.

The associations between cortisol and feelings of active and alert support the hypothesis of a cortisol “boost,” such that elevated cortisol may contribute to increased feelings of activeness and alertness, perhaps due to direct effects via metabolic processes like increasing blood glucose levels. Importantly, these associations were independent of health-related behaviors tied to metabolic changes in energy (e.g., food, exercise, sleep). Furthermore, follow-up analyses confirmed that cortisol predicted these energy-boosting changes, but increases in activity or alertness did not predict changes in cortisol.

One unexpected finding was that increases in cortisol were associated with feeling more relaxed one hour later. On the surface, if cortisol boosts lead to feeling more active and alert, one may assume a *negative* correlation between cortisol and feeling relaxed. However, since cortisol helps mobilize the body to deal with the task at hand, the added physiological resources provided by cortisol may lead to feelings of relaxation or calmness over time, a protective response to daily interactions in the environment. This response may help explain the trend-level associations between cortisol increases and reduced feelings of stress and nervousness: As suggested in previous research, the amount of cortisol released may reduce or buffer the magnitude and/or the duration of NA (Het et al., 2012). Cortisol feedback to the central nervous system may not only reduce HPA activity, but may also help to reduce NA and reestablish emotional well-being (e.g., facilitate positive reappraisal processes or other effective strategies for emotion regulation). However, these findings should be interpreted with caution, given the relatively small sample size ($N = 24$); this effect should be replicated in larger samples. Furthermore, studies of more diverse samples (e.g., patient populations, children, or older adults) may reveal different types or directions of cortisol-affect interrelations.

Although there was a trend for sadness to predict increased cortisol an hour later, surprisingly, most of the NA variables were not associated with concurrent cortisol, nor did NA predict subsequent cortisol. The latter null results are contrary to previous research examining momentary emotions and cortisol (Adam, 2005; Hanson, Maas, Meijman, & Godaert, 2000; Smyth et al., 1998; van Eck, Berkhof, Nicolson, & Sulon, 1996). These null findings may be related to the small sample size or another limitation of our study. For example, the assessment period between samples was one hour, whereas the projected time difference between cortisol reactivity and point of maximum cortisol concentration in saliva is significantly shorter (i.e., 20 minutes). Thus, we may have missed some short-term increases in cortisol in response to NA. Additionally, there are theorized gender differences in physiological responses to stressors (Taylor et al., 2000) that were not captured in our small, mostly female sample. Finally, given that overall mean levels of negative affect in the

current sample are relatively low, limited variability in NA in our sample may obscure potential associations between NA and cortisol.

Despite these limitations, the current study contributes to our understanding of the role of cortisol in everyday life and introduces novel analytic approaches to studying cortisol-affect relations in everyday life that can be replicated and extended in future research. Our findings suggest that cortisol may play a role in promoting positive affect.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Table 1

Descriptive statistics for affect variables.

	Between-Person		Average Affect ^d		Within-Person Variability in Affect ^b		
	Min	Max	Mean	(SD)	Min	Max	Mean (SD)
<i>Positive Affect</i>							
Alert	.91	2.83	2.00	(.48)	.37	1.18	.77 (.22)
Active	.45	1.94	1.05	(.39)	.44	1.11	.82 (.16)
Cheerful	.63	2.92	1.82	(.58)	.37	1.15	.72 (.18)
Relaxed	.53	2.86	1.66	(.51)	.35	1.07	.73 (.17)
<i>Negative Affect</i>							
Stressed	.03	1.17	.51	(.32)	.17	.87	.60 (.16)
Nervous	.00	.60	.16	(.15)	.00	.62	.35 (.18)
Sad	.00	.33	.08	(.10)	.00	.55	.21 (.21)
Worried	.00	1.06	.21	(.22)	.00	.76	.39 (.21)

Note. Table compiled using affect ratings (range 0-3) from all sampling points available for each person (M=35.92 sampling points per person, SD=3.45, range = 29-40).

^aCreated using mean affect scores for each person.

^bCreated using within-person standard deviation scores.

Table 2
Multi-level regression analyses for Cortisol predicting subsequent positive and negative affect.

	Positive Affect											
	Alert _(t+1)		Active _(t+1)		Cheerful _(t+1)		Relaxed _(t+1)					
	<i>b</i>	<i>SE</i>	<i>p</i> value	<i>b</i>	<i>SE</i>	<i>p</i> value	<i>b</i>	<i>SE</i>	<i>p</i> value	<i>b</i>	<i>SE</i>	<i>p</i> value
Intercept	2.53	0.23	0.00	1.21	0.17	0.00	1.75	0.19	0.00	1.37	0.26	0.00
Time	-0.16	0.09	0.07	0.04	0.03	0.21	0.06	0.03	0.06	0.02	0.10	0.82
Time ²	0.03	0.01	0.02	-0.01	0.00	0.00	0.00	0.00	0.02	0.00	0.01	0.74
Time ³	0.00	0.00	0.00	--	--	--	--	--	--	0.00	0.00	0.65
Mood _(t)	0.19	0.04	0.00	-0.19	0.14	0.18	0.08	0.04	0.06	0.10	0.04	0.03
Exercise	-0.08	0.12	0.51	-0.08	0.07	0.20	-0.23	0.13	0.07	-0.08	0.13	0.53
Eating	-0.05	0.06	0.36	0.04	0.11	0.73	0.00	0.06	0.96	-0.04	0.06	0.49
Caffeine	0.02	0.09	0.82	0.14	0.04	0.00	0.03	0.10	0.76	0.06	0.11	0.55
<i>Corr</i> _(t)	0.58	0.26	0.03	0.92	0.31	0.00	0.45	0.29	0.12	1.19	0.31	0.00

	Negative Affect											
	Stressed _(t+1)		Nervous _(t+1)		Sad _(t+1)		Worried _(t+1)					
	<i>b</i>	<i>SE</i>	<i>p</i> value	<i>b</i>	<i>SE</i>	<i>p</i> value	<i>b</i>	<i>SE</i>	<i>p</i> value	<i>b</i>	<i>SE</i>	<i>p</i> value
Intercept	0.62	0.09	0.00	0.23	0.05	0.00	0.09	0.03	0.00	0.23	0.05	0.00
Time	-0.01	0.01	0.04	-0.01	0.00	0.06	--	--	--	--	--	--
Mood _(t)	0.11	0.04	0.01	0.13	0.04	0.00	0.07	0.04	0.10	0.05	0.04	0.23
Exercise	-0.03	0.11	0.79	0.07	0.07	0.31	-0.03	0.05	0.54	0.07	0.08	0.35
Eating	-0.02	0.05	0.78	-0.05	0.03	0.19	-0.04	0.03	0.16	-0.05	0.04	0.21
Caffeine	-0.07	0.09	0.44	-0.05	0.06	0.39	0.06	0.04	0.15	-0.03	0.06	0.58
<i>Corr</i> _(t)	-0.44	0.26	0.09	-0.30	0.17	0.07	-0.06	0.13	0.62	-0.02	0.19	0.90

Note. Time is centered at waking. Exercise, eating, and caffeine are coded (0 = No, 1 = Yes).