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State and trait affect as predictors of salivary cortisol in healthy adults

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Summary We measured affect in 334 healthy adults on each of 7 days over a 3-week period. On the last day, salivary cortisol was assessed 14 times yielding scores for total concentration, morning rise amplitude, and slope of the time function. Trait negative affect (NA) was associated with higher total cortisol concentrations and greater morning rise in men. Cortisol levels for men low in trait positive affect (PA) did not decrease in the afternoon, resulting in a relatively high, flat rhythm. In contrast, women high in trait PA had low morning cortisol resulting in a low flat rhythm. State (person-centered) NA was not associated with same-day cortisol measures. State PA was associated with decreased total cortisol concentration in women. These are the first results showing associations between cortisol and trait PA. Differences in rhythmicity found here are noteworthy given the possible role of cortisol dysregulation in disease incidence, morbidity, mortality, and severity.

1. Introduction

Negative affect (NA) refers to subjective distress and subsumes such aversive moods as anxiety, hostility, and depression. Positive affect (PA), on the other hand, refers to appetitive moods such as vigor, well-being, and calm. Affect is believed to be the 'proximal' psychological pathway through which psychosocial factors influence health (Cohen et al., 1997). This is because strong emotions trigger emotion-appropriate behavior (e.g. fight or flight in the face of fear) and activate physiological systems that both support this behavior and regulate the host response to disease. One physiological system that supports emotion-appropriate behavior by releasing a number of hormones is the hypothalamic–pituitary–adrenal (HPA) system. Of the HPA hormones, cortisol is of particular interest because it both supports emotion-appropriate behavior by regulating metabolic processes and is involved in regulating immune function

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(Sheridan et al., 1994). Although there is evidence that circulating cortisol is higher with greater NA (Rose et al., 1982; Schaeffer and Baum, 1984; Hubert and de Jong-Meyer, 1992; van Eck et al., 1996; Smyth et al., 1998; Hanson et al., 2000), the degree to which this association is due to stable individual differences in affect (i.e. traits) or transient fluctuations in mood (i.e. states) remains unclear. Moreover, the possible association of cortisol level with PA is relatively unexplored. The primary purpose of the present study was to determine if cortisol level is related to the trait and state components of both NA and PA.

1.1. Cortisol

Cortisol has a characteristic daily rhythm, peaking shortly after an individual wakens and then falling throughout the day. This rhythm can be disrupted by psychological and environmental influences such as low socio-economic status (Steptoe et al., 2003), stressful work or home environments (Adam and Gunnar, 2001), or chronic stress (McEwen, 1998). Cortisol levels that are either higher or lower than normal for any given time of day may set the stage for pathogenic processes that predispose an individual to illness (McEwen, 1998). Cortisol dysregulation has also been proposed as a possible contributor to morbidity, mortality, and severity of disease (McEwen, 1998). An initial study provides evidence of a role for cortisol dysregulation in the progression of breast cancer (Sephaton et al., 2000).

To characterize cortisol rhythm in humans, several features of the diurnal cortisol pattern are commonly extracted, including the overall level of circulating cortisol over the waking day, the amplitude of the increase on wakening, and the linear slope of the decrease over the course of the day. In one study, total daily cortisol level and morning rise area under the curve (AUC) were found to be negatively correlated (Schmidt-Reinwald et al., 1999), but, in general, the independence or redundancy of the information contained in the different rhythm parameters is not established. Additionally, in several studies sex differences in these parameters have been reported (Van Cauter et al., 1996; Wust et al., 2000).

1.2. Affect

State affect represents transient fluctuations in mood, and trait affect represents stable individual predispositions to certain states. Trait affect is measured either as the respondent's report of how he or she 'typically' feels or as an average of multiple measures of state affect (Diener and Emmons, 1984). State affect is measured either as the respondent's report of how he or she feels over a short period of time, such as a day or moment, or as the deviation of the short-term measure from the respondent's trait (mean) affect (Diener and Emmons, 1984). Affective responses can also be categorized as having either a negative or positive valence. Whether NA and PA are bipolar opposites or are independent is a source of controversy (Feldman et al., 1999). Measures based on the bipolar approach place negative and positive valence on opposite ends of the same scale of emotion. Measures assuming independence assess the degree to which each particular valence is experienced. Finally, that affect differs in men and women may not be completely implausible. One recent review argued that men and women handle stressful situations differently (Taylor et al., 2000) and have evolved differently to support these different behaviors.

1.3. Associations between affect and cortisol

Most research on cortisol and affect has focused on trait NA. In one community sample, depression and anxiety levels measured by the Symptom Checklist-90 were associated with greater 15-h urinary cortisol levels (Schaeffer and Baum, 1984). Other studies of community samples measured salivary cortisol multiple times a day for several days (van Eck et al., 1996; Hanson et al., 2000; Vedhara et al., 2003). Higher cortisol (sampled over 5 days) was associated with greater depression measured by the Zung and with greater trait anxiety measured by the Spielberger State–Trait Anxiety Scale (van Eck et al., 1996). However, higher depression measured by the Hospital Anxiety and Depression scale was associated with a greater quadratic decrease over the course of the day in women (Vedhara et al., 2003). Finally, anger measured by the Spielberger Trait Anger Scale and trait NA measured by seven depression and anxiety items from the Well-Being Questionnaire were not associated with salivary cortisol (van Eck et al., 1996; Hanson et al., 2000). Thus the evidence for a main effect of trait NA on cortisol is somewhat mixed. The evidence for sex differences in this association is limited. In the one study that examined interactions with sex, the elevation in cortisol seen with higher trait NA was limited primarily to men (Schaeffer and Baum, 1984). To our knowledge, there are no studies of trait PA and cortisol. Studies of surgency—high activity level, impulsivity, pleasure, and low

shyness—generally find that children low in surgency or both high in surgency and low in effortful control experience higher cortisol levels in response to new social situations (Gunnar et al., 2003). However, the conceptual relationship between trait PA and surgency remains unclear.

With respect to state NA and PA, the association between the depression, fatigue, and vigor scales of the POMS assessed at the start of each of 5 days and plasma cortisol drawn using an in-dwelling catheter throughout those same days was examined in a group of air traffic controllers. Within subjects, there was a positive relationship between depression and increased cortisol levels (Rose et al., 1982). A similar relationship with cortisol was observed for fatigue, and there was a tendency for cortisol to be higher with greater vigor, but these associations were marginally significant. In other studies, multi-item scales were used to sample state NA and PA multiple times a day over several days. The results of those studies documented a positive association between extant state NA and salivary cortisol level at that time (van Eck et al., 1996; Hanson et al., 2000) or 20 min later (Smyth et al., 1998). For state PA, study results are less homogeneous, with one study reporting no association with cortisol (van Eck et al., 1996) and a second reporting an inverse relationship between state PA and cortisol level (Smyth et al., 1998). However, the methodologies of these studies vary in terms of the degree to which they adequately distinguish between state and trait affect. To our knowledge, no study examined sex differences in these associations.

A few studies manipulated state affect and examined the effect on cortisol. In one, salivary cortisol level was lower after participants viewed a film clip that elicited relaxation and joy when compared with a film clip that elicited sadness and fear (Hubert and de Jong-Meyer, 1992). Because that study did not include a neutral control condition, it is unclear whether the observed effect is attributable to the impact of PA, NA, or both. In contrast, other studies that manipulated affect found no effect on cortisol (e.g. Buchanan et al., 1999). Overall, the literature suggests that higher state NA is associated with higher cortisol and provides weak evidence that higher state PA is associated with lower cortisol, though some of these associations may partly or wholly be explained by confounding with trait influences.

Although most research on psychosocial variables and cortisol focuses on discrete cortisol levels, a few studies focus on characteristics of the daily cortisol rhythm. Greater median morning rise amplitudes were associated with higher levels of depression as measured by the self-report Hamilton Depression Inventory in healthy young men (Pruessner et al., 2003a) and with measures of both chronic (Schulz et al., 1998) and perceived stress (Pruessner et al., 1999; which are correlated with NA). Morning rise was highest among chronically stressed women (Schulz et al., 1998). In one study (Smyth et al., 1997), the linear cortisol slope over the waking day was not associated with either state PA or NA. Although preliminary, these studies suggest that affect may be associated with morning rise, but not linear slope. However, whether cortisol level and morning rise have independent associations with affect is unclear.

1.4. The present study

In the current study, we attempt to clarify the associations between affect and cortisol level. We differentiate and compare the associations with cortisol of affect varying in valence and tonic-phasic dimensions. We define trait affect as the mean affect level over multiple days of assessment and state as the deviation from that mean on any specific day. For cortisol, we use characteristics of the daily rhythm and distinguish between total cortisol concentrations during the waking day, cortisol response to waking, and the linear slope of the cortisol decline over the day. In general, we expect that cortisol will be higher with greater trait and state NA and lower with greater state and trait PA. We examine the following questions. First, what is the relationship between affect and the cortisol responses? Second, do cortisol concentration over the waking day and response to awakening provide separate components of explanatory power in affect? Third, does affect of one valence moderate the association between affect of the other valence and cortisol? Finally, we examine sex differences in these associations.

2. Method

2.1. Participants

The participants were 159 men and 175 women, aged 18–54 years (mean = 28.8, SD = 10.4), who responded to newspaper advertisements for volunteers to participate in a study of psychological factors and respiratory infections. Forty-two percent were smokers. All enrolled participants were judged to be in good health and were paid $800 for participation in the complete study that involved exposure to a virus that causes the common cold

(Cohen et al., 2003). All data reported in this article were part of the baseline data collection (before viral exposure) of the larger study. Institutional Review Board approval was obtained from both the University of Pittsburgh and Carnegie Mellon University. All participants provided written informed consent.

2.2. Procedure

Participants underwent medical screenings and were excluded if they had a history of psychiatric illness, nasal or otologic surgery, asthma, or cardiovascular disease; if they had abnormal clinical profiles on urinalysis, CBC, or blood enzymes; if they were pregnant, lactating, or seropositive for HIV; or if they were on a regular medical regimen other than oral contraceptives or hormone replacement therapy. Demographic variables were obtained during the medical screening. Measures of state affect were obtained during six telephone interviews on evenings during a 6-week baseline period. All interviewers were women. A final state affect measure and samples of cortisol were collected during a 24-h baseline (before viral exposure) period at a hotel, where the participants were quarantined as a part of the larger study.

2.3. Measures

2.3.1. Affect measures

Over 2 weeks during the 6 week baseline period, participants were phone interviewed on three evenings (two weekdays and one weekend day) per week. In the evening 24 h after entering the hotel, they completed a questionnaire with the same adjectives. Each evening they were asked how accurately (0 = not at all accurate to 4 = extremely accurate) each of nine positive and nine negative mood adjectives described how they felt in the previous 24 h (Usala and Hertzog, 1989; Benyamini, et al., 2000; Cohen et al., 2003). The positive adjectives were representative of three subcategories of positive emotion: vigor (i.e. lively, full-of-pep, energetic), well-being (i.e. happy, pleased, cheerful), and calm (i.e. at ease, calm, relaxed). The nine negative adjectives were representative of three subcategories of negative emotion: depression (i.e. sad, depressed, unhappy), anxiety (i.e. on edge, nervous, tense), and hostility (i.e. hostile, resentful, angry). Daily positive mood scores were calculated by summing the ratings of the nine positive adjectives; and daily negative mood scores were calculated by summing the ratings of the nine negative adjectives. The internal reliabilities (coefficient α) for the seven interviews ranged from 0.89 to 0.93 for the positive mood scale and 0.87 to 0.92 for the negative mood scale.

These daily interview scores were utilized to construct both trait and state measures of affect. For trait affect measures, daily scores were averaged across the 7 days (i.e. six telephone interviews before entering the hotel and the paper and pencil questionnaire from the 24-h baseline period at the hotel) separately for positive and negative scores. The coefficient α for the trait measure of PA was 0.90 and for the trait measure of NA was 0.79. Preliminary analyses revealed that the raw state scores from the day cortisol was assessed (i.e. 24 h in the hotel overlapping with cortisol sample collection) were strongly correlated with the trait measures of affect (see Table 1). To form unconfounded measures of state affect, each person's 7 day positive and negative averages (i.e. trait scores) were subtracted from their positive and negative scores from the hotel day (i.e. hotel day scores were centered around person means). This approach resulted in unconfounded measures of trait and state.

2.3.2. Cortisol

Samples for measurement of salivary cortisol were collected from participants at the hotel over the same 24-h period covered by the last assessment of affect. Participants provided 14 cortisol samples under supervision of the study staff: at 18:30, 22:30 h, on being awoken the following day at 05:45, 06:15, 06:45 h, and hourly between 08:00 and 16:00 h. To provide a sample, participants placed a roll of cotton in their mouths, chewed on it until it became saturated, and placed it in a tube called a salivette (Sarstedt, Rommelsdorft, Germany). Cortisol level was determined by time-resolved immunoassay with fluorometric end point detection (Dressendorfer et al., 1992). Intra- and inter-assay variabilities were each less than 12%.

2.3.3. Control variables

During the medical screening, demographic variables including age, sex, race, and month of trial were obtained. On 2 days during the 6-week baseline period, participants also indicated the time they awoke. These two times were averaged to calculate their average waking time.

2.4. Data analysis

Following standard practices (e.g. Smyth et al., 1997; Schulz et al., 1998; Dekkers et al., 2000), we examined the AUC for the total waking day,

the amplitude of the morning rise, and the linear slope of the decrease over the waking day. To calculate AUC for the waking day, we first removed the observations at 06:15 h (i.e. 30 min after waking) and 14:00 h (i.e. peak lunch rise 1 h after lunch) and treated the 18:30 and 22:30 h observations from day 1 as if they had been collected on day 2; then we applied the trapezoid rule with the base of the trapezoid being zero (Pruessner et al., 2003a). Because the resulting values were positively skewed, a base 10 logarithmic transformation was used to approximate a normal distribution. Morning rise was calculated as the difference in the cortisol level at the time of being awoken (i.e. 05:45 h) and the higher of the values at 06:15 or 06:45 h. Linear slope was calculated from log transformed observations between 08:00 and 16:00 h after dropping the observation at 14:00 h (i.e. lunch rise).

Because scores on the measure of trait NA were positively skewed, to provide the best approximation of a normal distribution, a base 10 logarithmic transformation was applied. *T*-tests were used to assess significance for differences between men and women in the major study variables. Omnibus multiple linear regression was used separately regressing each of the cortisol variables on all four affect variables simultaneously except when the cortisol slope was the dependent variable. There, multilevel modeling was used with time of day as a fixed effect and intercept as a random effect. Analyses examining the association of each cortisol variable with each affect variable separately resulted in essentially the same pattern of findings. In all analyses with cortisol as the dependent variable, we included the following control variables: age, sex, month of trial, and whether the participant was Caucasian, which were coded as dummy variables, and average morning wakeup time, which was coded as a continuous variable. Interactions with sex were always tested but are presented only when significant.

Values in the figures are estimated values generated from the regression equations at 1 standard deviation above and below the mean.

3. Results

3.1. Descriptive analyses

Table 1 presents the correlations among the measures of trait and state affect. Traits PA and NA shared approximately 22% of their variance. States PA and NA shared approximately 2% of their variance. Table 2 presents demographic information about the participants. Home- and workload have been shown to be associated with flattened cortisol rhythms in women (Adam and Gunnar, 2001). There were no differences by sex in either employment status or number of children. Table 3 presents the means and standard errors for the major variables in this study. State NA was higher in men than in women. Cortisol morning rise was higher in women than in men. Slope was steeper in women than in men. We also

Table 1 Correlations between measures of trait and state affect.

Measure	1	2	3	4	5	6	7	8
Trait PA								
1 **Interview**	1.00							
2 Questionnaire	0.75	1.00						
State PA								
3 **Centered**	−0.09	0.31	1.00					
4 Raw	0.77	0.82	0.55	1.00				
Trait NA[a]								
5 **Interview**	−0.47	−0.32	0.08	−0.35	1.00			
6 Questionnaire	−0.43	−0.42	0.02	−0.34	0.65	1.00		
State NA								
7 **Centered**	0.20	0.11	−0.14	0.08	−0.45	0.73	1.00	
8 Raw	−0.30	−0.23	−0.03	−0.27	0.64	0.32	0.41	1.00

Note: Interview trait scores are averages of raw state affect scores across 7 days. Questionnaire trait scores are averages of scores on two administrations of a self-report questionnaire using the same adjectives as the raw state affect measures with a response set focused on how one 'typically feels.' To calculate centered state scores, person means of raw state affect scores were subtracted from raw state affect scores. $N = 329$–334 due to missing values. All correlations greater than 0.14 are significant at $p < 0.01$. PA, positive affect; NA, negative affect. Variables in bold were used in the present study.

[a] Log transformation.

Table 2 Demographic information by sex.

Variable	Women		Men		t/χ^2(df)
	Mean (Frequency)	SE (%)	Mean (Frequency)	SE (%)	
Age	28.32	0.79	29.43	0.82	0.98
Race					2.38 (1)
Caucasian	125	37.4	101	30.2	
Non-Caucasian	50	15.0	58	17.4	
Education					3.03 (3)
Did not finish high school	12	3.6	18	5.4	
High school graduate	40	12.0	29	8.7	
Completed high school and some additional education	94	28.1	82	24.6	
Earned at least a bachelor's degree	29	8.7	30	9.0	
Marital status (%)					0.07 (1)
Married or living in a marital-like relationship	44	13.2	38	11.4	
Never married, never lived in a marital-like relationship, separated, divorced, widowed	131	39.2	121	36.2	
Premenopausal (% yes; women only)	165	94.3			
Employment					0.73 (2)
No	78	23.4	65	19.5	
Yes, by self	11	3.3	13	3.9	
Yes, by other	86	27.8	81	24.2	
Number of children					4.43 (3)
0	105	31.4	103	30.8	
1	19	5.7	23	6.9	
2-3	39	11.7	22	6.6	
4-7	12	3.6	11	3.3	

examined correlations among the different measures of cortisol. Morning rise and waking day cortisol concentration were moderately correlated, $r=0.31$, $p<0.01$; but slope was not correlated with either waking day cortisol concentration, $r=0.05$; or morning rise, $r=-0.12$. Table 4 presents the correlations between the affect and cortisol measures.

Because the cortisol measures were obtained when the participants were in the hotel, the associated change from a normal routine could have disrupted health behaviors known to influence

Table 3 Means and standard errors for variables in the study.

Variable	Women			Men			t
	n	Mean	SE	n	Mean	SE	
Trait PA	175	2.27	0.06	159	2.35	0.06	0.94
Trait NA	175	0.43	0.03	155	0.39	0.03	−0.73
State PA	174	−0.15	0.04	159	−0.09	0.04	0.99
State NA	174	−0.24	0.02	159	−0.14	0.03	2.80**
Waking day AUC	169	7436	302	153	8455	553	1.62
Morning rise	171	10.33	0.85	154	6.49	0.62	−3.65**
Slope[a]	174	−0.11	0.00	155	−0.09	0.00	2.03*

Note: Ratings for the trait affect variables were made on a five-point scale (0=not at all accurate, 4=extremely accurate). Although the trait NA scale was transformed for analyses, the mean and standard error of the untransformed scale are presented here for ease of comparison. To calculate state scores, person means were subtracted from raw state scores. Cortisol is in nmol/l. PA, positive affect; NA, negative affect; AUC, area under the curve; *$p<0.05$; **$p<0.01$.

[a] Log transformation.

Table 4 Correlations between affect and cortisol measures.

Affect variable	Waking day cortisol concentration	Morning rise	Slope
PA			
Trait	−0.12	−0.08	−0.04
State	−0.05	−0.02	0.10
NA			
Trait[a]	0.18	0.05	0.01
State	0.04	−0.04	−0.03

Note: Ratings for the trait affect variables were made on a five-point scale (0=not at all accurate, 4=extremely accurate). To calculate state scores, person means were subtracted from raw state scores. All correlations greater than 0.14 are significant at $p<0.01$. PA, positive affect; NA, negative affect.

[a] Log transformation.

cortisol. Sleep quality was somewhat affected, with 35% of the participants reporting decreased quality, 52% reporting the same quality, and 13% reporting improved quality compared with sleep at home. However, the relationships between cortisol and affect are not attributable to average sleep quality, hotel sleep quality, or change in sleep quality influencing both cortisol and affect. Smoking behavior during quarantine was essentially unchanged from the baseline period, with a coefficient κ of 0.91.

In analyses with only the five covariates in the models, sex was associated with both waking day cortisol concentration, $B=0.04$ (SE=0.02, 95% CI=0.00, 0.08), $t(305)=2.03$, $p<0.04$, and morning rise, $B=-3.52$ (SE=1.12, 95% CI=−5.72, −1.32), $t(305)=-3.15$, $p<0.01$. Compared with men, women had lower waking day cortisol concentration but higher morning rise. Month was associated with waking day cortisol concentration but not morning rise. Compared with December, cortisol levels were higher in May, $B=0.08$ (SE=0.03, 95% CI=0.02, 0.14), $t(305)=2.78$, $p<0.01$. Race was associated with waking day cortisol concentration, such that Caucasians had higher levels than non-Caucasians, $B=-0.06$ (SE=0.02, 95% CI=−0.11, −0.02), $t(305)=-2.96$, $p<0.01$. Neither age nor average morning wake up time was associated with any variable.

3.2. Are trait and state affect associated with cortisol?

3.2.1. PA

There was a state PA by sex interaction for waking day cortisol concentration, $B=0.09$ (SE=0.04, 95% CI=0.02, 0.16), $F(1,296)=6.86$, $p<0.01$. Simple

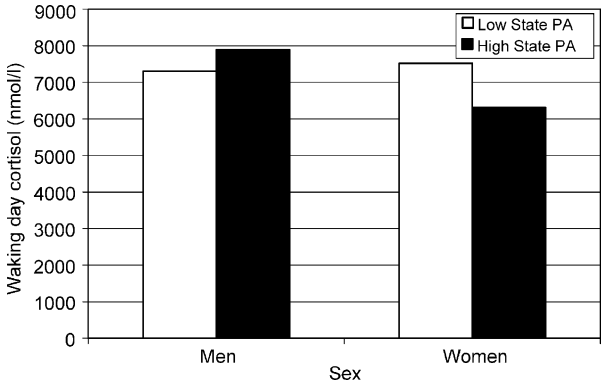

Figure 1 Waking day cortisol concentration as a function of state PA and sex.

effects analyses revealed that higher state PA was associated with lower waking day cortisol concentration in women only, $B=-0.07$ (SE=0.02, 95% CI=−0.11, −0.02), $t(153)=-2.95$, $p<0.01$ (see Fig. 1).

In the multilevel model used to analyze cortisol slope, there was an interaction of trait PA by sex by time, B=−0.02 (SE=0.01, 95% CI=−0.04, −0.01), $F(1,2127)=6.62$, $p<0.01$. Cortisol levels for men low in trait PA did not decrease in the afternoon, resulting in a relatively high, flat rhythm. In contrast, women high in trait PA had low morning cortisol resulting in a low flat rhythm (see Fig. 2). In pairwise comparisons comparing men and women high in trait PA, the women were significantly lower than the men at every time point until 16:00 h, $B=0.18$-0.16, (SE=0.08-0.07, 95% CI=0.04-0.31, 0.01-0.31), $t(2141)=2.09$-2.53, $p<0.04$, <0.01. In pairwise comparisons comparing men and women low in trait PA, the men were significantly higher than the women at every time point after 12:00 h, $B=0.16$-0.31 (SE=0.07-0.08, 95% CI=0.03-0.29, 0.15-0.48), $t(2141)=2.34$-3.77, $p<0.02$-<0.01. There was an interaction of state PA by time, $B=2.51$ (SE=0.01, 95% CI=0.00,

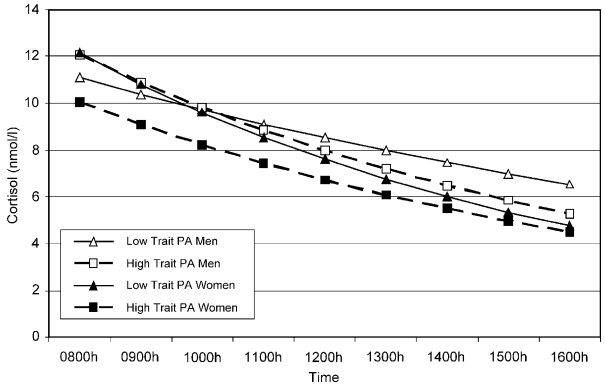

Figure 2 Cortisol as a function of trait PA, sex, and time.

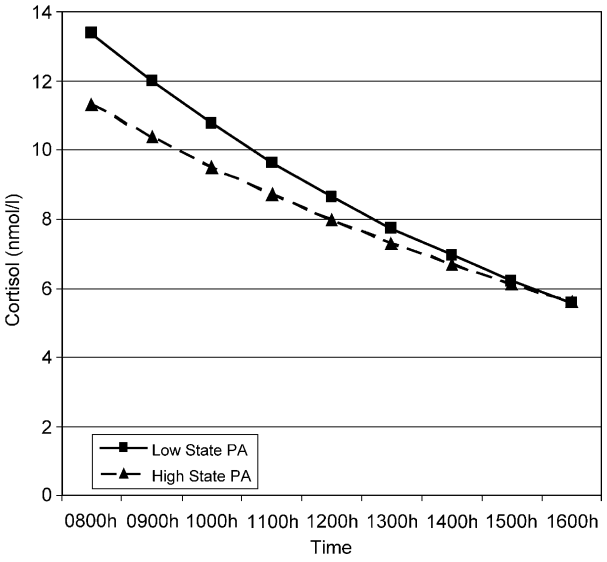

Figure 3 Cortisol as a function of state PA and time.

0.03), $F(1,2132)=6.29$, $p<0.01$, such that higher state PA was associated with a flatter slope through lower morning values (see Fig. 3).

Neither trait nor state PA was associated with morning rise.

3.2.2. NA

Higher trait NA was associated with higher waking day cortisol concentration, $B=0.04$ (SE=0.01; 95% CI=0.01, 0.06), $F(1,300)=9.01$, $p<0.01$.

In morning rise, there was an interaction of trait NA by sex, $B=3.44$ (SE=1.37, 95% CI=0.75, 6.13) $F(1,299)=6.36$, $p<0.01$. Lower trait NA was associated with lower morning rise among men, $B=2.01$ (SE=0.62, 95% CI=0.79, 3.23), $t(142)=3.26$, $p<0.01$, (see Fig. 4). This association remained when controlling for the cortisol level at awakening (i.e. 5:45 a.m.).

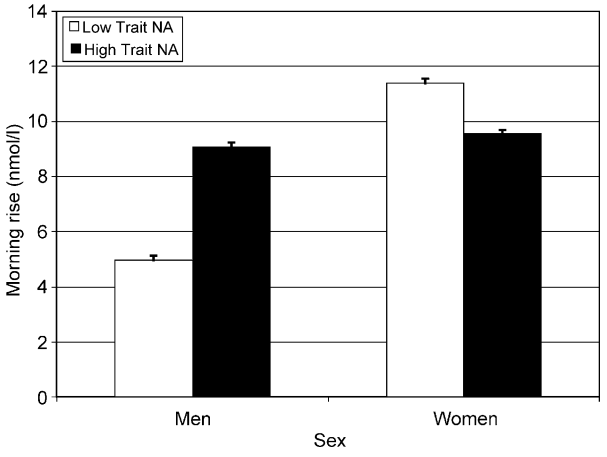

Figure 4 Morning rise amplitude as a function of trait NA and sex.

State NA was not associated with any measure of cortisol.

3.3. Do different measures of cortisol provide separate components of explanatory power in affect?

The degree to which different measures of cortisol provide separate components of explanatory power in affect can be examined for trait NA, with which both waking day cortisol concentration and morning rise were associated. To address this question, we regressed trait NA on each cortisol variable controlling for the other cortisol variable and the standard covariates. Regardless of the order of entry, each cortisol measure and its interaction with sex were significantly associated with higher trait NA. In either model, the estimates were quite similar. Trait NA was associated with waking day cortisol concentration, $B=1.01$ (SE=0.47, 95% CI=0.09, 1.92), $t(300)=2.15$, $p<0.03$; waking day cortisol concentration by sex, $B=-0.11$ (SE=0.68, 95% CI=−1.46, 1.23), $t(300)=-0.17$, $p>0.05$; morning rise, $B=0.02$ (SE=0.01, 95% CI=0.00, 0.05), $t(300)=2.08$, $p<0.04$; morning rise by sex, $B=-0.04$ (SE=0.01, 95% CI=−0.06, −0.01), $t(300)=-2.63$, $p<0.01$.

3.4. Are there cross-valence affect interactions?

We examined cross-valence affect interactions for their effects on the cortisol responses. There was no evidence for cortisol moderation by trait-trait, state-state, or trait-state cross-valence interactions.

4. Discussion

4.1. Are trait and state affect associated with cortisol response?

4.1.1. Waking day cortisol concentration

In general, PA was associated with lower concentrations of cortisol and NA with higher concentrations. However, one association was moderated by sex. Waking day cortisol concentration was associated with state PA only in women. It is not clear why PA's biggest association was in women. Because men and women did not differ in mean levels or variances of state PA, neither the magnitude nor variation in the affective responses can account for the sex differences. It may be that men and women have different biological responses to PA

that in turn mediate the cortisol response. For example, oxytocin is thought to increase (especially in females) in response to positive affiliative behaviors (Taylor et al., 2000). Because oxytocin inhibits glucocorticoids (Uvnas-Moberg, 1997) and is potentiated by estrogen (McCarthy, 1995), women with PA may inhibit the basal release of cortisol more efficiently than men with PA.

Our results replicated earlier work reporting that trait NA is associated with elevated waking day cortisol concentrations. However, we failed to replicate the past finding that state NA is associated with elevated cortisol concentration. Typically in previous research, the measure of state NA was based on responses to diary prompts throughout a day (van Eck et al., 1996; Smyth et al., 1998; Hanson et al., 2000). In several of these studies, however, the influence of trait NA may not have been adequately removed (i.e. by person centering or controlling for mean NA). It is possible, therefore, that some of the associations reported in earlier studies were actually attributable to *trait* NA. Alternatively, our operationalization of state NA differs in several respects of those of previous studies. For example, our state affect encompassed affective responding over the course of the entire day, whereas previous studies examined momentary affect. It is possible that momentary NA does result in a time-limited cortisol increase that is of too short a nature to affect our cortisol measures. Finally, because the studies showing an association between state NA and cortisol included repeated measures of both state NA and cortisol, which was not done in our study, those analyses may have been more sensitive to detecting such effects.

4.1.2. Morning rise

Earlier work reported that depression and stress are associated with a greater morning rise (cf. Schulz et al., 1998; Pruessner et al., 1999, 2003a,b). Similarly, we found that higher trait NA is associated with a greater morning rise even after controlling for waking level; however, this association is limited to men. This is similar to the Pruessner, et al., (2003a,b) study where the association between depression and morning rise was also found in men and in contrast to the Schulz et al. (1998) study where the association between chronic stress and morning rise level was limited to women. Conceptual differences in the psychosocial variables may account for this difference.

4.1.3. Cortisol rhythm

The association between cortisol rhythm and trait affect differed by sex, and the pattern of discriminations was complicated. Among participants high in trait PA, cortisol in women was lower than it was in men until 16:00 h. Among participants low in trait PA, however, cortisol in the men was significantly higher than it was in the women at every time point after 12:00 h, which is expressed as a relatively high, flat rhythm. Thus, just as in the waking day cortisol concentration and morning rise results, we see sex differences in cortisol rhythm as well.

The greater elevation of cortisol in low trait PA men is similar to the rhythm dysregulation observed in depression (e.g. Deuschle et al., 1997; Weber et al., 2000). Although dysregulation of the diurnal cortisol rhythm has been associated with clinical depression and posttraumatic stress disorder (Yehuda et al., 1996), the pattern of findings in healthy participants is at best mixed with respect to psychosocial influences (Ockenfels et al., 1995; Smyth et al., 1997; Adam and Gunnar, 2001; Grossi et al., 2001). Rhythm differences were related to employment status or workload (Ockenfels et al., 1995; Adam and Gunnar, 2001; Grossi et al., 2001) but not to demographic or personality factors (Ockenfels et al., 1995; Smyth et al., 1997). Inconsistencies among the results of these studies may be explicable by whether the analyses considered sex as a moderator. Of note, studies that failed to find associations between psychosocial factors and rhythm did not use sex as a moderating variable (Ockenfels et al., 1995; Smyth et al., 1997) while the one study that stratified the analyses by sex reported that financial strain caused by unemployment was associated with higher evening cortisol levels in women but not men (Grossi et al., 2001) and the one that reported that greater number of hours of work and greater number of children was associated with flatter slopes was conducted in women only (Adam and Gunnar, 2001). In our study, affect associations with cortisol rhythm were sex-specific, and because of the relatively large sample size and our treatment of slope as a continuous variable we may have had more power to detect associations. Overall, these results suggest that trait affect is associated with altered rhythms in healthy adults and that there may be sex differences in these effects. These findings highlight the importance of examining the regulation of HPA activity separately in men and women.

It should be noted that in every association we obtained, the effect sizes appear to be small. It remains to be seen whether associations of these magnitudes act through cortisol to have any effects on health outcomes. The possibility of accumulated effects over time should be considered. Additionally, by its nature there is error in the measurements we obtained. Thus, it is likely that the effect

sizes we obtained are smaller than the true magnitude of the associations.

4.2. Do different measures of cortisol provide separate components of explanatory power in affect?

In analyses predicting trait NA, waking day cortisol concentration and morning rise each contributed separate components of explanatory power, which suggests that these relationships are attributable to different mechanisms.

4.3. Are there cross-valence affect interactions?

There was no evidence for cortisol moderation by trait–trait, state–state, or trait–state cross-valence interactions. Recently it has been proposed that PA might have the ability to 'undo' the effects of NA on physiological responses (Fredrickson, 2001). Our failure to document such an interaction is inconsistent with that hypothesis.

4.4. Which is more closely associated with cortisol, state or trait affect?

Most of the associations were obtained with trait affect measures and not state affect measures. This suggests that deviations may be less important than overall level. On the other hand, the associations obtained with trait affect were not also obtained with state affect and vice versa. We conclude from this that although trait affect may be more closely associated with cortisol in general, when state affect is associated with cortisol, it accounts for a unique portion of the variance. Additionally, we note that the deviations we obtained were small. If data were collected under conditions resulting in larger deviations, it is possible that state affect would be associated with changes in cortisol.

4.5. Replications of analyses using alternative operationalizations of the affect variables[1]

In analyses not reported here, we examined the association of the cortisol measures with measures of trait affect in which the same adjectives used in the present study were administered in a self-report questionnaire format with a response set focused on how one 'typically feels.' This form of assessment is a more traditional approach to trait affect measurement. We administered the questionnaire twice during the 6-week baseline period and averaged the responses. Trait PA was strongly correlated with the traditional measure of trait PA ($r=0.75$), and trait NA was strongly correlated with the traditional measure of trait NA ($r=0.65$; see Table 1). Associations between these traditional measures and cortisol outcomes were similar to those reported in this paper. We prefer the approach that aggregates state affect over multiple days because it reduces the bias that occurs when retrospectively reporting mood over periods longer than 24 h (Stone, 1997). However, the traditional approach appears to be equivalent. In those studies in which measurement across multiple days is not an option and the traditional approach is adopted, we suggest administering the questionnaire multiple times to improve reliability.

We also conducted a reanalysis of our data using a measure of state affect similar to that employed in many previous studies; that is one based on the raw, uncentered interview scores. As expected, because the traditional measures of state affect were seriously confounded with trait affect (see Table 1), the pattern of associations with the cortisol measures was similar to those we report for trait NA and different from those we report for state NA. To obtain unconfounded measures of state and trait affect we suggest using approaches such as the centered measure reported here, which removes absolute level and focuses on deviation from mean affect.

Finally, we examined whether using standardized, as opposed to centered, state affect scores affected the pattern of results. To standardize, we transformed the raw scores to have a mean of zero and a standard deviation of one. We obtained the same state PA by sex interaction on waking day cortisol concentration but did not obtain an interaction with time in the slope analyses. It remains unclear whether how the deviations are scaled is important. However, the use of centered scores is not confounded with individuals' variance in responses over days as is the standardized measure.

4.6. Limitations and conclusions

There are several limitations to the interpretation of the results of our study. First, the documented associations are correlational, and, as such, it is possible that cortisol influenced affect or that a third, unmeasured, factor influenced both affect and cortisol. Second, the state affect analyses were

[1] The results of the analyses are available by request from the first author.

based on measures from only 1 day; thus the reliability of the results for state affect may be less than that of results in studies that employed multiple assessments of state affect and cortisol. This could have lessened our power to detect significant associations in these analyses. Third, although we examined the association of cortisol with affect varying in tonic-phasic and valence distinctions, there are additional affective distinctions such as activation that we did not examine.

Finally, the generalizability of the findings must be considered. For example, the participants in the present study were carefully screened for good health; hence extrapolation of our findings may be limited to healthy people. Additionally, generalizability may be limited because some of the data were collected when participants were under quarantine. With respect to affect, however, when the state affect scores are standardized (i.e. in standard deviation units), each of the state affect scores is well within one standard deviation of each person's mean (i.e. zero), suggesting that the quarantine did not markedly disrupt affect. As reported above, smoking was similarly unaffected, and sleep was only moderately affected. Because we assessed cortisol only on the day of quarantine, we have no non-quarantine day with which to compare it.

In conclusion, although most research to date has conceptualized cortisol as a physiological measure of stress and NA, our results suggest that it may reflect PA as well. Additionally, we observed associations between affect and disruptions in rhythms. Evidence from an increasing number of studies points to the importance of dysregulation of cortisol rhythms as a potential pathway in disease incidence, morbidity, mortality, and severity (e.g. McEwen, 1998; Sephaton et al., 2000). With affect, thought to be the proximal pathway through which many psychosocial factors influence health, being associated with cortisol dysregulation, we strengthen a link in a putative pathway through which psychosocial processes 'get inside' the body to affect physical health. The importance of PA, as well as the sex differences and possibility of multiple mechanisms, clearly warrants future study.

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