Short title: TRAIT RUMINATION AND CORTISOL RECOVERY

Extending the recovery window: Effects of trait rumination on subsequent evening cortisol following a
laboratory performance stressor

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Abstract

Mental rehearsal of past stressors through rumination may extend the physiological stress response and exposure to stress-related physiological mediators, such as cortisol. If repeated over time, this prolonged activation may contribute to a number of chronic health conditions. Findings from the emerging literature on the tendency to ruminate and its association with cortisol have been somewhat mixed. In the present study, we tested whether trait rumination predicted elevated cortisol concentrations in response to a performance stressor, and whether this association varied by the social-evaluative context of the stressor and gender. We also examined whether associations persisted into the evening of the stressor. Participants (50% female; mean age = 19.83, $SD = 1.62$) were randomly assigned to complete a laboratory speech stressor either in a social-evaluative (SET; $n = 86$) or non-evaluative context (non-SET; $n = 58$). Salivary cortisol concentrations were measured throughout the laboratory visit and later that evening. There was a main effect of trait rumination on greater total cortisol exposure into the evening of the stressor. In addition, trait rumination interacted with stressor context to predict cortisol declines: On the night of the SET stressor, high trait ruminators did not exhibit typical declines in cortisol. Different cortisol patterns emerged for men and women with tendencies to ruminate: Women with higher rumination scores had flatter cortisol slopes with greater evening cortisol, whereas men with higher trait rumination scores had greater initial cortisol reactivity to the stressor. Together, these findings suggest that the relationship between the tendency to ruminate and cortisol concentrations is qualified by individual differences (gender) and stressor characteristics (social-evaluative threat).

Keywords: cortisol; gender; rumination; recovery; social evaluative threat; stress

1. Introduction

Persistent or excessive exposure to stressors and consequent physiological changes have a range of negative health implications (for review, see Juster et al., 2010). One route to persistent activation of the stress response is through the mental rehearsal of stressful experiences, or rumination. In other words, cognitive representations of past stressful events may perpetuate stress-related physiological changes or reactivate stress responses. This conceptual model is outlined by the Perseverative Cognition Hypothesis, and there is growing empirical support for the premise that cognitive processes such as rumination can amplify, maintain, or reactivate physiological stress responses and predict greater somatic symptoms and physical health complaints (Brosschot et al., 2006). Thus far, the majority of the evidence for the association between rumination and extended related physiological activation has come from the cardiovascular domain. A smaller, but increasing body of work has begun to test this model within the context of the hypothalamic-pituitary-adrenal (HPA) axis (for review, see Zoccola and Dickerson, 2012). However, findings from the emerging literature on rumination and cortisol have been somewhat mixed. These discrepancies may stem in part from situational factors and individual differences, such as gender and the social-evaluative nature of the stressor.

Rumination has been defined in multiple ways across contexts, but there is general consensus that rumination can be described as repetitive, past-oriented thoughts about negatively-valenced content (Segerstrom et al., 2003; Smith and Alloy, 2009). Rumination is a relatively stable emotion regulation strategy and certain individuals are more prone to perseverate than others. For example, individuals who display a ruminative cognitive style of responding to sad or depressive mood consistently report this tendency over a range of time intervals (e.g., Just and Alloy, 1997; Nolen-Hoeksema and Davis, 1999). In addition, gender differences are frequently noted, with women tending to report more rumination than men (Zlomke and Hahn, 2010). Thus, to better understand whether and how rumination prolongs cortisol elevations, it may be useful to examine individual differences in the tendency for rumination and test for gender differences.

Conditions in which central goals are threatened or blocked are also important for shaping

cortisol responses and ruminative thought. This is well illustrated with social self-preservation theory (Dickerson et al., 2004). According to this model, social-evaluative threat (SET) occurs when a key component of one's self-identity is actually or potentially judged in a negative way by others (e.g., rejection). In response to SET, one may engage in negative *self* evaluation and consequently, may experience shame and other self-conscious emotions, which in turn coordinate a specific set of physiological and behavioral responses, including HPA axis activation (Dickerson et al., 2004). Meta-analytic and empirical studies indicate that SET preferentially elicits the HPA axis and subsequent increases in salivary cortisol (Dickerson et al., 2008; Dickerson and Kemeny, 2004). In contrast, mood inductions or difficult distressing tasks that lack a social-evaluative component have been less reliable methods for eliciting increases in cortisol (Dickerson and Kemeny, 2004). Therefore, individuals who tend to ruminate on stressors may be more likely to experience prolonged cortisol exposure in responses to cortisol-eliciting stressors, or SET contexts, compared to non-SET situations.

Rumination may also be more likely in response to a SET context. In evaluative and potentially rejecting situations, the fundamental needs of an individual are threatened (e.g., need for social belonging). Such a failure in goal attainment is expected to elicit rumination (Martin and Tesser, 1996). Consistent with this premise, recent work provides support for the notion that SET can lead to both shame and rumination (Zoccola et al., 2012, 2008). Specifically, participants assigned to perform a SET stressor reported greater post-task ruminative thoughts than those who performed identical tasks without the evaluative component (Zoccola et al., 2008). A follow-up study confirmed these results, and demonstrated that SET effects on state rumination can persist at least 3-5 days post-stressor (Zoccola et al., 2012). Together these results suggest that stressors characterized by SET may be particularly likely to induce ruminative thought and prolong stress-related cortisol activation.

Past studies that have utilized SET stressors in the laboratory to test the relationship between rumination and cortisol have generally showed that rumination predicts greater cortisol reactivity or delayed recovery (e.g., Puterman et al., 2011; Zoccola et al., 2010, 2014), although there have also been null (Young and Nolen-Hoeksema, 2001) and mixed findings depending on the rumination measure

(Gianferante et al., 2014; Zoccola et al., 2008). Results from studies testing the link between rumination and cortisol following *non-evaluative* stressor tasks (e.g., anger-provocation; challenging model construction) indicate that cortisol concentrations may sometimes be greater in ruminative conditions relative to comparison tasks, such as distraction (Denson et al., 2009; Rudolph et al., 2011). However, these studies have not demonstrated net increases in cortisol relative to pre-stressor resting values. Furthermore, the SET studies that demonstrated rumination-related elevations in cortisol during the recovery period had somewhat limited post-stressor follow-up periods (up to 75 minutes post-stressor). Although cortisol concentrations typically return to resting levels within the first hour following a social-evaluative psychosocial stressor (Dickerson and Kemeny, 2004), for individuals with a tendency to ruminate, cortisol recovery may take longer (Puterman et al., 2011; Zoccola et al., 2010). Deviations from the normative diurnal decline in cortisol (flatter slopes) have been linked to a variety of adverse conditions, including cardiovascular disease and cancer morbidity and mortality (Kumari et al., 2011; Matthews et al., 2006; Sephton et al., 2000). Given the significant health correlates of flattened cortisol slopes, it is important to examine an extended recovery period to test the associations between trait rumination and diurnal cortisol declines.

Another likely moderator of the rumination-cortisol association is gender. An abundance of evidence that men and women have different salivary cortisol patterns in response to acute performance-based stressors. Compared to women, men typically demonstrate greater increases, or reactivity, in cortisol concentrations (for review, see Kudielka and Kirschbaum, 2005). In some cases, men exhibit elevated cortisol in anticipation of an impending stressor (Ennis et al., 2001; Kirschbaum et al., 1992). Biological differences between men and women (e.g., sex hormones) as well as psychosocial differences in gender identity (e.g., masculinity/femininity) may moderate cortisol responses to SET stressors and influence associations between rumination and cortisol concentrations. Dedovic and colleagues provide an excellent review of the evidence for synergistic biological and gender effects on neuroendocrine stress reactivity (Dedovic et al., 2009). In particular, their review indicates that differences in cortisol stress responses between men and women may be accounted for by gender socialization in early life, which in

turn influence stressors appraisals, brain morphology, and HPA axis activation. Although it is beyond the scope of this project to distinguish between the unique or synergistic biological and gender effects, we examined the extent to which rumination-cortisol associations were similar or different for men and women. In doing so, we use the term gender to represent the broad social categories that encompass biological factors and psychosocial processes.

In the present study, we took a novel approach by extending the post-stressor recovery window beyond the immediate laboratory stressor period into the subsequent evening. We predicted that trait rumination would be associated with elevated cortisol on the night of the stressor. We also tested whether the association between trait rumination and cortisol responses to the stressor was impacted by the social-evaluative context of the stressor (SET v. non-SET). We hypothesized that trait rumination would be associated with greater cortisol concentrations under conditions of SET (compared to non-SET), based on theoretical and empirical work (Martin and Tesser, 1996; Zoccola and Dickerson, 2012). Finally, given the frequently reported gender differences in rumination (Zlomke and Hahn, 2010) and cortisol stress reactivity (Kudielka and Kirschbaum, 2005), we also explored the extent to which the rumination-cortisol associations were moderated by gender.

2. Methods

2.1 Participants

Healthy undergraduate students from the University of California, Irvine, were recruited to participate in a broader investigation on “health responses to everyday events.” Due to their influence on cortisol concentrations, exclusion criteria included chronic or serious health conditions (e.g., diabetes), tobacco smoking, and medication use. In addition, individuals were eligible if they indicated a typical wake time by 1000h on weekdays and were at least 18 years of age. One hundred forty-nine participants were recruited, and five participants were excluded for the following reasons: four reported infectious illnesses and/or use of cold medication and one individual reported a recent diagnosis of anxiety and/or depression. The 144 eligible participants (50% female) had a mean age of 19.83 years ($SD = 1.62$) and had culturally diverse backgrounds: 67% Asian, 1% Black or African American, 1% Native Hawaiian or

Other Pacific Islander, 24% White (18% of whom were Hispanic or Latino), and 7% More than one race.

2.2 Procedures

All procedures were approved by the university's Institutional Review Board. Laboratory visits took place in the afternoon to control for diurnal variations in cortisol. Upon arrival to the laboratory, participants provided informed consent and then completed baseline measures (e.g., trait rumination). Afterward, they underwent the laboratory speech stressor in one of two randomly assigned contexts: social-evaluative threat (SET; $n = 87$) or non-SET ($n = 57$).¹ All participants were instructed to deliver a speech on why they would be ideal job candidates, and then had five minutes to mentally prepare. In the SET condition, participants performed their speeches in front of a video camera and two trained research assistants (one male, one female), who wore lab coats and held clipboards. The confederates provided negative, non-verbal feedback by maintaining stoic expressions and eye contact. In the non-SET condition, participants completed the speech alone in front of a video camera. To ensure task engagement, if anyone stopped talking for more than 20 seconds during the five-minute task, s/he was prompted to continue talking. In the SET condition, one of the confederates prompted the participant. In the non-SET condition, participants were monitored remotely; they were told that a sound detection device would allow the experimenter to know whether the participant is talking, but not what s/he is saying. If the participant stopped talking for more than 20 seconds during the five-minute task, the experimenter signaled him/her with a buzzer to continue. These procedures have been used effectively in other studies that have manipulated social-evaluative threat (e.g., Gruenewald et al., 2004).

After the end of the speech task, participants completed additional questionnaires (e.g., post-stressor appraisals, health items) and relaxed with a neutral magazine once questionnaires were

¹ An unbalanced randomization ratio (1.5:1; SET: non-SET) was selected to create a slightly larger experimental SET group relative to the non-SET control. Given that it is well-established that non-SET stressors do not reliably activate HPA axis (Dickerson & Kemeny, 2004), we opted for greater power in the SET group to test for differences in cortisol profiles.

completed. After the final saliva sample was collected, the participant was debriefed about the visit. During the debriefing, the experimenter explained the need for using the speech task, stating that it was designed to be challenging for everyone, regardless of ability. In addition, the experimenter told those in the SET condition that the panelists were trained to withhold positive feedback during the speech task. Finally, the participant was thanked, compensated with \$25 and given instructions for the at-home data collection. On the night of the stressor, participants were instructed to provide one saliva sample at 2000h and one at their bedtime.

2.3 Measures

2.3.1 Salivary cortisol

Saliva samples were collected with Salivette sampling devices (Sarstedt, Inc., Newton, N. C.) five times throughout the laboratory visit: end of baseline (10 minutes pre-stressor) as well as 0, 10, 25, and 40 minutes post-stressor termination. In addition, participants were instructed to provide two additional saliva samples on the night of the laboratory visit: at 2000h and at bedtime. Participants were instructed to saturate the cotton roll at each sampling period and then replace it in the tube. For the daily life component, participants stored their samples in home freezers until they returned them to the laboratory (one week after the initial laboratory visit). At this point, all samples were stored at -20°C until the end of the study. All but eight participants (94.4%) provided both of the evening samples. At study completion, samples were shipped on dry ice to a laboratory for cortisol assessment. Cortisol levels for each sample were determined using an enzyme-linked immunosorbent assay (IBL-International, Hamburg, Germany). The assay had a lower limit of sensitivity of 0.005 µg/dl, with average inter- and intra-assay coefficients of covariance of less than 10%. The distribution of cortisol concentration at each time point was significantly positively skewed, so the values were transformed (natural log) prior to analysis. Cortisol outliers greater than 3 *SD* from the mean were excluded from cortisol analyses ($n = 17$, 1.7%).

2.3.2 Manipulation check

Following the speech, participants rated how much they perceived that their performances had been evaluated during the task (1 = *Not at all*, 7 = *Very much*).

2.3.3 Trait rumination

Trait rumination was assessed during the baseline period of the laboratory visit with the Rehearsal subscale of the Revised Emotion Control Questionnaire (Roger and Najarian, 1989). Scale items reflect the tendency to ruminate on stressful or distressing events. The full scale was developed in the context of determining vulnerability to stress-related illness, and it predicts greater stress-related increases in urinary and salivary cortisol in past studies (e.g., Roger and Najarian, 1998; Zoccola et al., 2010). Participants indicated whether each statement was generally “true” or “false” of them (e.g., “I get ‘worked up’ just thinking about things that have upset me in the past”). Higher scores indicate greater ruminative tendencies.

2.3.4 Covariates and sensitivity analyses

Several variables were considered for inclusion as covariates in analyses predicting cortisol responses, including body mass index (BMI) and time of day (e.g., wake time, session start time, bedtime). In addition, given the potential shared variance between trait rumination and constructs such as depressed mood, anxiety, neuroticism, and perceived stress, these variables were examined in post-hoc sensitivity analyses (Roelofs et al., 2008; Segerstrom et al., 2003). Using self-reported height and weight, body mass index (BMI) was calculated for all participants with the following formula: $BMI = (\text{weight in pounds}) \times 703 / (\text{height in inches})^2$. Depressed mood over the past week was assessed with the Center for Epidemiologic Studies Depression Scale (Radloff, 1977). Trait anxiety was measured with the Spielberger State-Trait Anxiety Inventory (Spielberger et al., 1979). Neuroticism was measured with the 8-item subscale of the Big Five Inventory (John and Srivastava, 1999). Perceived stress over the past month was assessed with 10-item Perceived Stress Scale (Cohen and Williamson, 1988). All scales were completed during the laboratory visit. Internal reliabilities of scales and means by experimental condition are presented in Table 1.

2.4 Analytic Strategy

Analyses predicting cortisol trajectories were performed with multilevel modeling using the SAS 9.3 PROC MIXED procedure with the maximum likelihood method (SAS Institute, Cary, N.C.). This

technique incorporates both within-subject and between-subject differences in overall cortisol response patterns, is robust to missing data, and allows for comparisons between models containing different fixed effects (Singer and Willett, 2003). Two-level models were fit to predict cortisol, with level one representing intra-individual differences in cortisol as a function of time as a continuous measure (in hours). Level two represents inter-individual differences in cortisol intercepts and slopes (e.g., trait rumination). Cortisol trajectories were examined for the laboratory visit (first five time points) and into the evening (all seven time points). Trait rumination, gender (male = 1, female = 0), experimental condition (SET = 1, non-SET = 0), and covariates (as specified) were included in models as level two predictors of cortisol (intercepts, linear slopes over time, quadratic slopes over time [time^2]). A random coefficients model with unstructured covariance matrices was used in all analyses and intercepts were allowed to vary randomly as these specifications resulted in the best fit (Littell et al., 2000). All continuous level two variables were mean centered to reduce risk of collinearity and to facilitate a more meaningful interpretation of the results. Analyses containing interactions included the corresponding lower-order terms, and lower-order terms that include the level two predictor variable(s) of interest (e.g., experimental condition, trait rumination, gender) are presented alongside the higher-order interaction term in the results. To facilitate interpretation of interactions containing the continuous variable of trait rumination, we used Preacher and colleagues' method of probing interactions in multilevel modeling to estimate simple slopes for linear change in cortisol at ± 1 SD trait rumination scores (Preacher et al., 2006; for online calculator, see <http://www.quantpsy.org/interact>). We performed follow-up contrasts to estimate quadratic cortisol trajectories by group (experimental condition, gender).

Coefficients for linear time variables reflect linear changes in cortisol concentration (log nmol/L) per hour, except when in the presence of higher-order time variables, such as quadratic time (time^2). In the presence of time^2 , a first-order time coefficient reflects the instantaneous rate of change at the time point at which the model is centered (e.g., baseline, bedtime), and a time^2 coefficient reflects the degree of curvature, or peak, of the overall cortisol trajectory across the time points (Singer and Willett, 2003). Intercept coefficients reflect predicted cortisol concentrations at the centered time points (in log nmol/L

units), and centered time points are specified in the results. Because the outcome variable cortisol is log transformed, coefficients can be interpreted as percent change in cortisol per unit change in the predictor variable after the following transformation is performed on the regression coefficient (b): $(e^b - 1) \times 100$ (Gordon, 2012).

In addition to calculating cortisol response trajectories, area under the curve (AUC) with respect to ground values were calculated to assess total cortisol exposure as a function of trait rumination and social-evaluative threat (Pruessner et al., 2003). We used raw cortisol values for the five cortisol samples collected in the laboratory to measure cortisol exposure during the laboratory component (AUC-lab) and all seven cortisol samples to assess cortisol exposure during the lab and rest of the day (AUC-day). All statistical tests were two-tailed with the significance level set at $p \leq .05$ and the level of borderline significance set at $p \leq .10$.

3. Results

3.1 Descriptive Statistics and Manipulation Check Results

Descriptive statistics stratified by experimental condition and bivariate correlations for the entire sample are presented in Table 1. As shown, there were no differences between SET and non-SET groups on basic demographics or key variables such as trait rumination BMI, depressed mood, anxiety, or baseline cortisol, indicating successful random assignment, $t_s < 1.40$, $p_s > .16$. Demonstrating that the manipulation was successful, the SET group reported feeling more evaluated during the speech than the non-SET group (SET: $M = 5.35$, $SD = 1.65$; non-SET: $M = 2.64$, $SD = 2.01$), $t(105.74) = 8.50$, $p < .001$, $d = 1.47$. There were no gender differences in trait rumination (men: $M = 5.69$, $SD = 3.52$; women: $M = 6.17$, $SD = 3.01$).

3.2 Overall Cortisol Response Patterns by Social Context of Stressor

As expected, cortisol responses to the speech stressor differed by experimental group across the laboratory visit (see Figure 1). Compared to the non-SET condition, the curvature of the cortisol trajectory was more peaked in the SET condition, condition $\times$ time²: $b = -1.078$, $SE = 0.314$, $t(551) = 3.43$, $p < .001$, and the ascending rise in cortisol in anticipation of the stressor was more positive,

condition X time: $b = 1.201$, $SE = 0.275$, $t(552) = 4.37$, $p < .001$. Cortisol intercepts did not differ at baseline by condition, $t(201) = 0.31$, $p = .76$. Follow-up contrasts further revealed that those in the SET condition demonstrated the expected peaked cortisol response to the stressor during the laboratory visit, time²: $b = -1.306$, $SE = 0.201$, $t(553) = 6.49$, $p < .0001$. In contrast, participants in the non-SET condition did not demonstrate a peak in cortisol levels across the visit, time²: $t(551) = 0.94$, $p = .35$. Instead, cortisol levels declined in a linear fashion throughout the visit, time: $b = -0.479$, $SE = 0.061$, $t(551) = 7.91$, $p < .0001$. A t -test comparing AUC-lab values also confirmed greater total cortisol exposure in the SET group ($M = 497.66$, $SD = 270.78$) compared to the non-SET group ($M = 401.12$, $SD = 211.81$), $t(130.27) = 2.31$, $p = .02$, $d = .40$. By 2000h on the evening of the laboratory stressor, cortisol concentrations no longer differed between the SET and non-SET groups, $t(137) = 0.90$, $p = .37$, and there were no longer significant differences between the two experimental groups in total cortisol exposure when including the evening measures (AUC-day), $t(119) = 1.24$, $p = .22$.

3.3 Cortisol Response Patterns by Trait Rumination, Social Context, and Gender

Consistent with the central hypothesis that trait rumination would predict elevated cortisol, analyses revealed a significant effect of trait rumination on the linear slope of cortisol, trait rumination X time: $b = 0.003$, $SE = 0.001$, $t(835) = 2.16$, $p = .03$, and a positive association between trait rumination and cortisol intercepts at bedtime, trait rumination: $b = 0.04$, $t(419) = 2.52$, $p = .01$. These results indicate that higher rumination scores were associated with flatter cortisol declines across the afternoon and evening of the laboratory stressor, independent of experimental condition. To probe the trait rumination X time interaction, we used Preacher's calculators to estimate the simple slopes for the effect of trait rumination on linear cortisol declines at ± 1 SD trait rumination scores. At -1 SD trait rumination, the slope estimate was -0.09 ($SE = 0.02$, $p < .001$) and at $+1$ SD , it was -0.05 ($SE = 0.02$, $p = .01$). Thus, cortisol levels declined through the evening for both low and high trait ruminators across experimental conditions, but the decline in cortisol was not as steep for high ruminators. A Pearson correlation between trait rumination and AUC-day also revealed a significant association ($r = .21$, $p = .02$), which indicates that higher trait rumination scores predicted greater cortisol exposure across the afternoon and evening of

the stressor. Of note, the trait rumination X time interaction effect was only marginally significant when only examining the cortisol values determined from the laboratory samples (i.e., first five time points), $b = 0.019$, $SE = 0.011$, $t(553) = 1.66$, $p = .097$.

We next tested the hypothesis that trait rumination would predict greater cortisol in response to SET compared to non-SET stressors. Our analysis revealed a significant interaction of trait rumination and condition to predict linear change in cortisol responses across the afternoon and evening, trait rumination X condition X time: $b = 0.007$, $SE = 0.003$, $t(834) = 2.16$, $p = .03$, (see Figure 2a). To probe the trait rumination X condition X time interaction, simple slopes were calculated to estimate effects of trait rumination on linear cortisol declines in the SET and non-SET conditions at ± 1 SD trait rumination. For participants in the SET condition, the slope estimate of cortisol at -1 SD trait rumination was -0.17 ($SE = 0.09$, $p = .05$), and at $+1$ SD trait rumination it was -0.02 ($SE = 0.09$, $p = .83$). In other words, cortisol levels declined for low ruminators, but not high ruminators, through the evening of the SET stressor. Regions of significance tests revealed that cortisol levels declined only for participants with trait rumination scores of less than 8. For participants in the non-SET condition, the slope estimate at -1 SD trait rumination was -0.12 ($SE = 0.01$, $p < .001$), and at $+1$ SD trait rumination it was -0.05 ($SE = 0.01$, $p < .001$). Thus, cortisol levels declined through the evening for both low and high trait ruminators on the night of the non-SET stressor, but the decline in cortisol was less steep for high ruminators. Lower-order rumination terms indicated that trait rumination continued to predict flatter cortisol declines in the presence of the higher-order interaction term, trait rumination X time: $b = 0.006$, $SE = 0.002$, $t(839) = 3.05$, $p = .002$, and trait rumination was associated with greater cortisol intercepts at bedtime, $b = 0.06$, $t(461) = 2.81$, $p = .005$.

We next explored whether the association between trait rumination and cortisol differed for men and women. Our analysis revealed a significant interaction of trait rumination and gender to predict linear change in cortisol responses across the afternoon and evening, trait rumination X gender X time $b = -0.006$, $SE = 0.003$, $t(837) = 2.10$, $p = .04$ (see Figure 2b). Follow-up contrasts by gender demonstrated that for women, cortisol slopes became flatter as trait rumination scores increased, trait rumination X

time: $b = 0.01$, $SE = 0.002$, $t(426) = 2.66$, $p < .001$, and trait rumination predicted greater cortisol concentrations at bedtime, $b = 0.075$, $SE = 0.024$, $t(264) = 3.13$, $p = .002$. For men, as trait rumination scores increased, the curvature of the cortisol trajectory became more peaked, time²: $b = -0.001$, $SE = 0.0006$, $t(415) = 2.19$, $p = .03$, and the ascending rise in cortisol in anticipation of the stressor was steeper, time: $b = 0.013$, $SE = 0.006$, $t(412) = 2.19$, $p = .03$. There were, however, no differences in bedtime cortisol as a function of trait rumination for men, $b = 0.016$, $SE = 0.021$, $t(176) = 0.75$, $p = .46$.

Significant lower-order interaction terms indicated that, compared to women, men had greater initial cortisol concentrations that declined more steeply over time, gender: $b = 0.297$, $SE = 0.022$, $t(166) = 3.78$, $p < .001$, gender X time: $b = -0.041$, $SE = 0.01$, $t(837) = 4.18$. In addition, trait rumination continued to predict flatter cortisol declines in the presence of the higher-order interaction term, trait rumination X time: $b = 0.006$, $SE = 0.002$, $t(839) = 3.05$, $p = .002$. Additional higher order interaction terms were tested (e.g., trait rumination X gender X condition), but none were significant predictors of cortisol intercepts or slopes.

3.4 Sensitivity Analyses

Analyses were repeated with the potential covariates included individually and as a group. There were two significant predictors of cortisol, including bedtime in minutes since midnight (later bedtime was associated greater cortisol output, AUC-day, $r = .19$, $p = .04$) and wake time (later wake time predicted greater cortisol exposure during the laboratory visit, AUC-lab, $r = .24$, $p = .004$). When significant covariates were included in analyses predicting cortisol outcomes, all effects remained the same.

4. Discussion

Consistent with the Perseverative Cognition Hypothesis (Brosschot et al., 2006), our central hypothesis was that the tendency to ruminate on stressful events would be associated with greater cortisol output in the present study. Building on theoretical models and empirical findings (Martin and Tesser, 1996; Zoccola and Dickerson, 2012), we also tested the extent to which the social-evaluative context would moderate the association between rumination and cortisol stress responses. Specifically, we

hypothesized that trait rumination would be associated with greater cortisol concentrations under conditions of SET (compared to non-SET). We also extended the post-stressor recovery window into the night of the laboratory stressor and explored whether rumination-cortisol associations differed by gender.

Overall, results supported the central hypothesis that trait rumination is associated with elevated cortisol when the recovery window was extended into the evening of the stressor. Our results also indicate that the association between trait rumination and elevated evening cortisol concentrations may be more pronounced in response to social-evaluative stressors compared to stressors not characterized by social-evaluative threat. Furthermore, different cortisol patterns emerged for men and women with tendencies to ruminate. Specifically, women with higher rumination scores had flatter cortisol slopes with greater evening cortisol. Men with higher trait rumination scores had greater initial cortisol reactivity to the stressor that generally declined throughout the evening.

4.1 Social-Evaluative Threat

In line with the social self-preservation theory (Dickerson et al., 2004), cortisol levels peaked approximately ten minutes after the end of the SET stressor in the present study. In contrast, for those completing the identical stressor task in the absence of social evaluation (non-SET), cortisol declined across the visit. These results add to the growing literature linking SET to heightened cortisol reactivity (Dickerson and Kemeny, 2004). Given the converging theoretical and empirical evidence that SET is a robust elicitor of both the HPA axis and ruminative thought (Dickerson et al., 2008, e.g., 2004; Martin and Tesser, 1996; Zoccola et al., 2012), we were interested in testing whether the rumination-cortisol association was enhanced under conditions of SET. Results from our moderation analyses revealed a significant effect indicating that on the evening of a SET stressor, the rumination-cortisol association is most pronounced. Participants with high ruminative tendencies did not exhibit the typical decline in cortisol on the night of the SET stressor. Thus, our results suggest that ruminating on SET stressors may activate the HPA axis and prevent the normative diurnal cortisol decline. This is particularly noteworthy as we found no overall group differences in cortisol concentration at 2000h (i.e., several hours after the stressor ended). In addition, the debriefing at the end of the laboratory visit may have lessened potential

lingering effects of the stressor for participants – particularly for those in the SET condition. Therefore, our results may underestimate the impact of SET on subsequent cortisol secretion directly or as a function of trait rumination.

It is important to highlight that in the presence of the trait rumination X condition X time interaction, trait rumination continued to predict flatter cortisol declines. In other words, our results suggest that although rumination may be *more strongly* related to cortisol concentrations following a stressful interpersonal event compared to a non-interpersonal stressor, a SET stressor is not *necessary* to observe trait rumination-related increases in cortisol. Other studies similarly demonstrate significant main effects of personality traits and stressor type in the daily experience of stressors, distress, and diurnal cortisol. For instance, Bolger & Schilling (1991) found that trait neuroticism predicted greater exposure to daily stressors and distress over a 6-week observation period. In another project with data from the National Study of Daily Experiences, analyses suggest that stressor type predict day-to-day variations in daily cortisol (Stawski et al., 2013). For instance, total cortisol output was greater on days with arguments. Therefore, our findings taken together with the broader literature on stress and coping in daily life, demonstrate that it is important to examine individual differences, stressor characteristics, and the interactive effects of individual differences and stressor characteristics to more fully understand stress-related HPA axis activation in daily life.

4.2 Recovery Period

A novel feature of the present work is the extension of the post-stressor recovery window beyond the immediate laboratory stressor period, which serves to answer the call by multiple researchers to more fully consider anticipatory and recovery stress processes (Brosschot et al., 2006; Juster et al., 2012; McEwen, 1998). The inclusion of evening assessments in our analyses allowed us to detect rumination-related differences in salivary cortisol that were not present when only examining the immediate (i.e., 40-minute post-stressor) recovery period. This pattern of results may help shed light on the mixed findings of past studies that have tested the relationship between stress-related trait rumination and salivary cortisol recovery (e.g., Gianferante et al., 2014; Zoccola et al., 2010). For instance, it is possible that study

procedures (i.e., questionnaire completion) during the laboratory-based recovery period may have distracted participants from ruminative thought and thus reduced afternoon rumination-cortisol associations. In addition, there is some evidence that rumination may be less likely to occur in the afternoon hours compared to mornings and evenings (Moberly and Watkins, 2008). Thus, by extending the recovery window into evening, we may have minimized study features that prevent rumination. Alternatively, our results may simply indicate that there are delayed effects of trait rumination on stress-related salivary cortisol. Moving forward, it will be valuable for researchers to include longer recovery periods with limited distractions and/or evening assessments in subsequent studies.

4.3 Gender

Men and women reported rumination tendencies in equal degree in the present study. This finding is in line with some past studies that compared ruminative tendencies in men and women using the same measure (e.g., Lok and Bishop, 1999; Zoccola et al., 2010); however, it deviates from other research that detected small to moderate gender differences, with women scoring higher on stress-related ruminative tendencies (e.g., Rydstedt et al., 2009; Thomsen et al., 2005). Our results are also at odds with the relatively consistent gender differences for related forms of repetitive thought (e.g., greater depressive rumination and worry in women; Nolen-Hoeksema and Aldao, 2011; Tamres et al., 2002). One possible explanation for the absence of gender differences in trait rumination in the present study may be sample characteristics. Our participants were culturally diverse, young adults with a majority endorsing Asian ethnicities. Other researchers have identified greater gender differences in related personality traits (e.g., neuroticism) in Western, individualistic cultures (i.e., European and American countries) compared to Asian and other cultures (Costa et al., 2001). Future research should investigate the conditions under which there are gender differences in stress-related rumination and the potential implications for these differences (or lack thereof) for coping and health.

Although men and women reported similar tendencies to ruminate in the present study, the association between rumination and cortisol differed between them. For women, a greater tendency to ruminate predicted higher post-stressor cortisol concentrations into the evening hours. For men, trait

rumination predicted greater anticipatory rises in cortisol and more peaked responses (i.e., higher cortisol concentrations early in the response trajectory). Taken together, these results suggest that high trait rumination scores may signify different things for men and women in the context of psychosocial stressors. For instance, negative stress appraisals (e.g., threat) may not occur at the same magnitude or for the same duration for men as they do for women who report ruminative tendencies. Indeed, our past work demonstrated that women with greater rumination tendencies also reported more negative thoughts about a social-evaluative laboratory stressor during a two-week follow-up period (Zoccola et al., 2010). In contrast, there was no association between ruminative tendencies and two-week post-stressor rumination for men. Future studies that examine the extent to which gender moderates the relationship between rumination tendencies and stressor appraisals over time will be useful in better understanding these associations, and the mechanisms through which they occur. In addition, research by Juster and colleagues has also shown that anticipatory stress responses (i.e., cortisol concentrations in advance of a known stressor) may modulate subsequent recovery (Juster et al., 2012). Thus, it may be beneficial for researchers to explore the potentially unique and/or synergistic effects of anticipatory and recovery processes in their investigations.

4.4 Alternative Explanations

Given that we measured rumination as a dispositional tendency rather than experimentally manipulating it, alternative explanations for the rumination-cortisol associations warrant consideration. For instance, it is possible that other personality traits and individual differences might account for the association between trait rumination and cortisol outcomes, rendering it spurious. Although the trait rumination construct has shared variance with a number of other factors (e.g., neuroticism, depression, anxiety, perceived stress), when we re-evaluated our hypotheses with these variables included as covariates in our analyses, the results remained the same. Additionally, although we have interpreted our findings to suggest that trait rumination may lead to elevated cortisol, it may also be possible that elevated cortisol could contribute to ruminative thought, and thus greater scores on rumination measures. In support of the former interpretation, two experimental studies have established a causal path between

rumination inductions (relative to distraction) and subsequent elevations in cortisol or slower declines in laboratory settings (Denson et al., 2009; Zoccola et al., 2014). Thus, the results of these experiments, in combination with the results of our sensitivity analyses, make it difficult to attribute our findings to spuriousness or reverse causation. However, it will be important for future research to assess emotional and behavioral responses (e.g., stressor appraisals, rumination and coping strategies, emotional states) that might elucidate the underlying mechanisms.

4.5 Strengths, Limitations, and Future Directions

The results obtained in the present study provide important information about the nature of the rumination-cortisol relationship and shed light on factors contributing to individual variability in stress responding, which has implications for stress-related disease processes. In addition, the present study had a number of methodological strengths, including the use of laboratory and evening cortisol data, a relatively large and ethnically diverse sample, the inclusion of measures to rule out alternative explanations, and an experimental manipulation of stressor context. Nonetheless, the current study is not without limitations.

Sample characteristics may serve both as a strength and limitation of this investigation. The relatively large sample allowed us to investigate complex interactions among our key variables, which have often gone unexamined or undetected in past work. In addition, participants in current study were ethnically diverse, with a majority of students endorsing various Asian nationalities as part of their cultural background. Shame-related HPA axis activation may be particularly salient in Asian and other collectivistic cultures such those in Latin America (Hofstede, 1980; Triandis et al., 1988). This is because individuals from collectivistic cultures may be more likely to make shame-related appraisals (Tracy and Robins, 2007), and greater shame-related cognitions and emotions have in turn been linked to greater cortisol (Dickerson et al., 2008; Gruenewald et al., 2004; Lewis and Ramsay, 2002). Thus it is possible that our findings may not generalize to predominantly individualistic or non-Asian populations. It will be useful for future investigations to test whether these effects are replicated in culturally distinct samples or specifically test cultural differences in rumination and cortisol responses in the context of SET.

Although ethnically diverse, the present study relied on healthy, young undergraduate students. Young adults, however, may be particularly likely to experience rumination and its potential consequences. For instance, it has been reported that adolescents become more sensitive to SET as they get closer to young adulthood (Sumter et al., 2010). In addition, self-exploration and rumination may be higher in this age group compared to older adults who typically demonstrate enhanced emotion regulation (Nolen-Hoeksema and Aldao, 2011; Urry and Gross, 2010). That said, it will be important for future research to examine the relationships tested here across the lifespan.

Gender was assessed by self-report to a single item prompt “Gender.” We did not have any information on gender identity or gender role attitudes, and sex hormones were not assessed. Consequently, we are unable to tease apart the biological and psychosocial contributions to the current findings. Biological and social antecedents likely have unique and synergistic effects on the differences found between men and women in terms of exposure to stressors, stressor appraisals, coping strategies, and neuroendocrine responses (Dedovic et al., 2009; Tamres et al., 2002). Moving forward, it would be useful to attempt to disentangle the factors contributing to these differences between men and women. For instance, concentrations of sex hormones (e.g., estradiol, testosterone) could be incorporated into future investigations or researchers could examine the rumination-cortisol association across menstrual cycle for women. In addition, measures of gender identity and/or gender role attitudes could be considered.

Although the focus of the present research was on cortisol, ruminative thought has also been linked to other biological systems. For example, rumination has been related to slower blood pressure recovery (Gerin et al., 2006; Key et al., 2008) and poorer heart rate variability during post-stressor time periods (Key et al., 2008). Recent experimental work has also demonstrated that ruminating on a speech stressor after it has ended leads to greater post-stressor concentrations of cortisol and C-reactive protein (a marker of inflammation) relative to post-stressor distraction (Zoccola et al., 2014). To explicate the full range of physiological processes associated with rumination and to explore potential interactions between biological systems, it will be important to take multisystem approaches in future research.

4.6 Conclusions

The results obtained in the present study provide important information about the nature of the rumination-cortisol relationship and shed light on factors contributing to individual variability in stress responding and diurnal cortisol. Overall, our results suggest that those with a tendency to ruminate on stressors demonstrate heightened cortisol levels and flatter cortisol declines through the evening following a laboratory performance stressor, consistent with the Perseverative Cognition Hypothesis (Brosschot et al., 2006). Given the existing links between flattened diurnal cortisol slopes and cardiovascular disease and cancer morbidity and mortality, our findings have important implications for stress-related disease processes and health (Kumari et al., 2011; Matthews et al., 2006; Sephton et al., 2000).

The current findings also indicate that the relationship between rumination and cortisol concentration is complex and depends on individual differences and situational factors. Thus, one implication of the results of the present study is that ruminators should not be treated as a homogenous group, as trait rumination predicted different cortisol response patterns for men and women. Another implication is that the social-evaluative context or interpersonal nature of stressors should be taken into consideration when designing studies to test rumination-cortisol associations. Our results also illustrate the importance of extending the acute stress reactivity period to more fully examine anticipatory and recovery processes as effects may persist and even become more pronounced hours after a stressor ends. It will be important for future research to replicate and extend these findings by confirming the mechanisms linking rumination to elevated cortisol and by testing for gender differences in subsequent studies.

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Figure Legends

Figure 1. Raw salivary cortisol response patterns by experimental condition. Error bars represent standard errors of group cortisol means at each time point. SET = social-evaluative threat

Figure 2. Raw salivary cortisol response patterns for low (25th percentile) and high (75th percentile) trait rumination scores are shown to facilitate interpretation of (a) the rumination X condition interaction effect, and (b) the rumination X gender interaction effect. Mean cortisol concentrations for those with high trait rumination scores are indicated with the solid line. Mean cortisol concentrations for individuals with low trait rumination scores are indicated with the dashed line. In Figure 2a, black line markers denote the social-evaluative threat (SET) condition and white line markers denote the non-SET condition. In Figure 2b, black line markers denote women and white line markers denote men. Error bars represent unadjusted standard errors of raw cortisol means at each time point. Please note that transformed cortisol concentrations (natural log) and continuous rumination scores were used in analyses to test hypotheses.

Table 1*Descriptive Statistics by Experimental Group and Pearson Correlations for Total Sample*

	SET <i>M (SD)</i> <i>n = 57</i>	Non-SET <i>M (SD)</i> <i>n = 87</i>	Scale α	1	2	3	4	5	6	7	8
1. Trait rumination	6.15 (3.33)	5.60 (3.18)	.78	-----							
2. Depressed mood	15.03 (6.29)	13.88 (6.53)	.80	.48***	-----						
3. Trait anxiety	43.09 (9.78)	41.37 (9.35)	.90	.52***	.75***	-----					
4. Perceived stress	17.84 (5.49)	16.75 (6.21)	.84	.44***	.69***	.74***	-----				
5. Neuroticism	23.00 (5.70)	21.65 (6.36)	.82	.53***	.53***	.54***	.56***	-----			
6. BMI	22.76 (3.77)	22.51 (3.33)	----	-.01	-.01	.00	-.09	-.10	-----		
7. Baseline cortisol	8.07 (4.50)	8.62 (5.17)	----	.04	-.13	-.13	-.12	-.04	-.04	-----	
8. Lab start time	14:05 (1:54)	14:30 (1:51)	----	-.05	-.01	-.06	-.07	.01	.12	-.30***	-----
9. Bed time	0:34 (1:35)	0:46 (1:28)	----	.03	.00	.02	-.04	.04	-.05	.22**	.03

Note. *** $p < .001$; ** $p < .01$; BMI = body mass index; SET = social-evaluative threat

Figure 1

Figure 2