Gender Differences Between Diurnal Cortisol and Rumination

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Abstract

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Prior work has demonstrated prolonged hypothalamic-pituitary-adrenal (HPA) axis activation during ruminative episodes. However, research into rumination and diurnal cortisol is limited as it pertains to prolonged HPA activation and particularly with respect to gender differences in this relationship. Diurnal cortisol slope (DCS) is related to many psychosocial phenomena and may be used as a proxy for daily HPA activation, which measures circadian cortisol decline throughout the day. This study extrapolated laboratory evidence of prolonged HPA axis activation—particularly in women higher in trait rumination—in a naturalistic setting among otherwise healthy undergraduate students (n = 116) to examine the relationship between DCS, stressor-related and brooding rumination, and gender; stressor-related rumination reflects the tendency to ruminate over prior and current stressful events, whereas brooding rumination captures the tendency to ruminate over depressive symptoms and emotional reactions to events. Participants were prompted to provide multiple cortisol samples throughout the day over five-days. I hypothesized that higher trait rumination would be related to flatter DCS throughout the day, particularly in women higher in trait rumination. Contrary to my main hypotheses, trait rumination was not related to flatter DCS throughout the day. However, there was a non-significant trend in the expected direction for stressor-related rumination suggesting men and women have different neuroendocrine profiles as it

relates to rumination. Exploratory analyses revealed flatter DCS for women higher in stressor-related rumination compared to men higher in stressor-related rumination and women lower in stressor-related rumination, when controlling for brooding rumination. In conclusion, there was limited support for my hypotheses. Implications, interpretations, and future directions are discussed.

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Introduction

Men and women experience emotions similarly (Barrett et al., 1998) and use similar coping strategies (Nolen-Hoeksema et al., 2012); however, women have higher prevalence rates of almost all psychopathologies including depression and anxiety disorders (Eaton et al., 2012) which have dramatically risen since the COVID-19 pandemic by 129.4 million, afflicting women two-fold (Institute of Health Metrics and Evaluation, 2021). Investigations into the nature of coping and health outcomes between genders is needed to ultimately attenuate this health discrepancy. Looking retrospectively for guidance, ancient Greek wisdom insisted that health was a measure of harmony, a balance of bodily humors that touched even the psyche. Our modern understanding of one such humor, cortisol, is the end product of the hypothalamic-pituitary-adrenal (HPA) axis which is tied intricately with emotion regulation (Rnic et al., 2022) and psychopathology (Burke et al., 2005; Stewart et al., 2013). Further, gender differences in psychopathology can be attributed in part to frequency of use of different coping strategies (Nolen-Hoeksema, 2012). One coping strategy women consistently use more often than men is rumination (Johnson & Whisman, 2013), which is a frequent concomitant in psychopathologies with consistent gender differences such as depression, anxiety, eating disorders, inter alia (Aldao et al., 2010; Nolen-Hoeksema et al., 2007). In this manuscript, the term “gender” refers to self-identified gender. Throughout the literature review, “gender” terminology is employed to be consistent with the language used in past studies. Gender and sex and their implications for rumination and cortisol are discussed in more detail later.

Rumination is generally defined as negative repetitive thought that surrounds some goal frustration of an organism (Martin & Tesser, 1989). Given these gender differences in rumination, the tendency to ruminate may in part explain gender differences in certain psychopathologies. Indeed, rumination mediated the gender difference in depression symptoms in a large community-based sample (Nolen-Hoeksema et al., 1999). Rumination on stressors that activate cortisol release may lead to prolonged cortisol activation (Brosschot et al., 2006; Zoccola et al., 2008), and overexposure to cortisol is a typical feature of major depressive disorder (Burke et al., 2005).

The manner in which cortisol relates to trait rumination appears different for men and women in a laboratory setting (Zoccola & Dickerson, 2015; Shull et al., 2016), with women higher in trait rumination displaying less cortisol recovery in response to an acute social stressor across different forms of rumination. This may lend support to a general tendency for women higher in trait rumination to not recover as efficiently from ruminative processes as men higher in trait rumination. It is less clear whether there are gender differences in rumination-cortisol associations in daily life.

Examining cortisol in a naturalistic context with rumination is necessary. Daily or diurnal cortisol patterns capture global activity of cortisol which shows greater stability and is robustly linked to health outcomes including inflammatory diseases, cancer diagnoses, and mood disorders (Adam et al., 2017), whereas laboratory stress response profiles may be better suited to capture transient factors such as daily events and mood (Adam et al., 2006). Multiple forms of rumination are related to diurnal cortisol (e.g., Rydstedt et al., 2011; Rnic et al., 2022; Hilt et al., 2017), however the pattern is unclear

and underexplored between certain diurnal cortisol measures and different conceptualizations of rumination, which this study seeks to further elucidate. If diurnal cortisol follows the pattern of results from laboratory settings of prolonged recovery in those higher in trait rumination, then these differences may be captured by prolonged diurnal cortisol activation. This will be examined through altered diurnal cortisol slopes (DCS), which reflect the decline in cortisol levels throughout the day. This current study will examine two operationalizations to test whether men and women higher in trait rumination differ in diurnal cortisol in a naturalistic context. This will be examined for both stressor-related and brooding rumination.

The proposed study will investigate whether those higher in trait rumination, both types of rumination, will exhibit flatter DCS over a five-day period than those without such a tendency. Further, there is a sparsity of studies directly examining gender differences between rumination and diurnal cortisol, where nuances may lie. Both forms of rumination reflect adaptational efforts and may prolong physiological stress exposure, leading to flatter cortisol slopes compared to those with a lower propensity to ruminate, particularly in women. Thus, this study will examine whether women higher in trait rumination, both stressor-focused and brooding rumination, will exhibit flatter DCS than men higher in trait rumination.

Common Conceptualizations of Rumination

According to the goal progress theory of rumination (Martin & Tesser, 1989) also known as control theory more broadly (Watkins, 2008), rumination involves repetitive thinking around a central theme brought about by goal frustration of some pursuit of an

individual which can occur in the absence of immediate demands requiring such attention (Martin & Tesser, 1996). To illustrate, a sailor who accidentally scratched the surface of their boat earlier in the day mentally replays this event during dinner with a fellow seaman. The goal which was thwarted was to maintain integrity to the boat's structure while using the rotary buffer, leaving the sailor ruminating around the theme of what to do about it or how bad they feel, even without direct demand from the environment requiring such efforts (not a required task while eating and discussing other topics with a friend). Cognitive systems sort self-relevant information which requires attention for processing. In the absence of immediate environmental demands, internal representation of an unresolved conflict might arise as a function of its importance to the organism and immediate environmental cues to activate these representations (Martin & Tesser, 1996). In our example, this boat had enormous value having been passed on intergenerationally; thoughts privately pervaded in the sailor's head throughout discussion about a basketball game, hardly related to buffering a boat–although the game taking place on an aircraft carrier may have cued some of these thoughts, but they need not have. As hinted earlier these goal frustrations may revolve around stressors, feelings of distress, or causes and consequences of distress. Despite situational factors that likely elicit rumination such as damaging a prized possession, there are individual differences in propensities for ruminative thought, that is trait rumination. In other words, some individuals are more likely to engage in ruminative thinking than others. This propensity shows reasonable stability even in the face of changing depressive symptoms (Bagby et al., 2004).

Further, different operationalizations of trait rumination have been offered, each capturing some goal frustration of importance to that individual (for review, see Watkins, 2008). Although there are different operationalizations of rumination, depressive rumination and stressor-related rumination are commonly examined in psychological research (Watkins, 2008) including in the context of diurnal cortisol (Zoccola & Dickerson, 2012). Both of these operationalizations of rumination have been linked to diurnal cortisol, and the pattern of results between diurnal cortisol and rumination seems dependent on the operationalization or subscale along with the diurnal cortisol measure (e.g., Rydstedt et al., 2011; Rnic et al., 2022). However, the existing literature is scant and without replicated patterns. Given the limited available evidence, there is a need for further investigation between the different types of rumination and diurnal cortisol. Building upon and clarifying prior work, I will examine brooding rumination (and pondering) and stressor-related rumination with DCS, thereby extending prior work in efforts to elucidate diurnal cortisol and rumination relationships. In the subsequent sections, I will discuss the operationalizations of rumination and their associations with cortisol from the lab and daily life.

Depressive Rumination

The Response Style Theory (Nolen-Hoeksema, 1991) conceptualizes rumination as a repetitive and passive focus on feelings of distress as well as on the possible causes and consequences of these feelings. The Response Styles Questionnaire (RSQ) was developed to measure the tendency to internally focus "when feeling sad or blue," which is widely known as depressive rumination. The ruminative responses scale (RRS; Nolen-Hoeksema

& Morrow, 1991) was derived from the RSQ; the RSQ includes other scales such as distraction and problem-solving scales; however are now excluded when examining rumination due to poor internal validity. Examples from the RRS scale include "think about how alone you feel" or "Why do I have problems other people don't have?" Those higher in depressive rumination tend to believe this pattern of thinking is useful for insight into their depression and solving their problems (Lyubomirsky & Nolen-Hoeksema, 1993), consistent with the control theory view mentioned earlier that posits rumination largely functions to resolve goal-based discrepancies. Depressive rumination is related to major depression both concurrently (Aldao et al., 2010) and prospectively. For example, higher scores predicted an increase in depression symptomatology 7 weeks after a natural disaster (Nolen-Hoeksema & Morrow, 1991), characteristic of a maladaptive coping strategy.

Subtypes of Depressive Rumination

The RRS can be further divided into the brooding and pondering subscales (Treynor et al., 2003), which was formulated after removing items that conflate rumination with depression symptoms. Specifically, researchers were concerned that the depression outcomes related to depressive rumination were due to items in the RRS assessing depression symptoms, which is circular reasoning. Brooding and pondering relate differentially to a variety of outcomes (Treynor et al., 2003), such as depression, anxiety, and cortisol (Olatunji et al., 2013; Rnic et al., 2022). Brooding focuses on negative aspects of self-evaluation during rumination as well as obstacles: "Why can't I handle things better?" or "Think about a recent situation, wishing it had gone better" (Nolen-Hoeksema & Morrow, 1991). In contrast, pondering is captured by self-reflection and the capacity to

deal with and attempt to overcome problems and difficulties, such as “Write down what you’re thinking and analyze it” or “I go someplace alone to think about my feelings.” (Nolen-Hoeksema & Morrow, 1991). The former coping strategy is ostensibly self-destructive, whereas the latter is more problem-oriented and less self-critical. Consistent with the goal progress theory of rumination mentioned earlier, Treynor et al. (2003) interpreted brooding as “a passive comparison of one’s current situation with some unachieved standard (p. 256).”

Treynor et al. (2003) found pondering positively associated with depressive symptoms concurrently, yet was associated with less depression over time, whereas brooding was positively associated with depressive symptoms both concurrently and one year later. Similarly, a meta-analysis revealed brooding is more strongly related to depression and anxiety symptoms than pondering (Olatunji et al., 2013). It may not be overly surprising that pondering is related to depressed mood in the short-term, given that negative affect generally is related to a change in desired rate of goal progress (Carver & Scheier, 1990). Depressed mood may be present in certain individuals when persistent frustration of goal progress is not met with relinquishing or altering the goal itself, perhaps evolving into clinical depression in the extreme (Carver & Scheier, 1990). However, Moberly & Watkins (2008) found brooding predicted mean levels of momentary negative affect in a daily context even after controlling for depressive symptoms. In contrast, pondering had no such associations with negative affect.

In sum, although pondering is frequently related to concurrent depressive symptoms (Siegle et al., 2004; Treynor et al., 2003), it may lead to more efficient

processing of emotional information than brooding given its negative association with depressive symptoms over a year (Treynor et al., 2003). In contrast, the overly self-critical nature of brooding may be a uniquely harmful component of rumination. Therefore, in examining depressive rumination a multidimensional rather than a unitary approach is warranted due to the subscales differing relations to outcome variables. In particular, I predict the brooding subscale of the RRS will be related to a maladaptive diurnal cortisol profile, in parallel with its associated negative outcomes. Given pondering is ambiguous in terms of its adaptive value, I will explore whether pondering is related to diurnal cortisol.

Stressor-Related Rumination

In contrast to persistently dwelling on the causes, consequences, and symptoms of depressed affect, another form of rumination involves the tendency to focus on past stressful life events and become upset as a consequence, that is stressor-related rumination. The tendency for stressor-related rumination can be measured by the Rehearsal or Rumination subscale of the Revised Emotion Control Questionnaire (ECQ-R; Roger & Najarian, 1989). The impetus for this scale was to determine vulnerability to stress-related illness. Indeed, higher scores in a young sample on the ECQ-R are related to poorer self-reported physical symptoms in a 1-year follow-up (Thomsen et al., 2004). Examples from this scale include “I get worked up just thinking about things that have upset me in the past” or “I find it hard to get thoughts about things that have upset me out of my mind.” Here, the stressor that initiated the ruminative chain can be seen by examining some personal goal(s) that were thwarted. For instance, if you continually get ‘worked up about’ the sports bet you lost, the goal was to win the bet, which the recurrent thoughts continually

remind in a feedback fashion for modification of future behavior. The ECQ-R is also correlated with depression symptoms measured by the Beck Depression Inventory (BDI; Beck, Steer, and Brown, 1996), $r = .31$ (Siegle et al., 2004). Further, the ECQ-R and RRS share some variance, $r = .36$ (Siegle et al., 2004). The tendency to endorse either or both of these scales reflects maladaptive and perseverative thoughts in relation to some unachieved goal, which may be mirrored in particular patterns of global cortisol activation.

Fundamentals of the HPA Axis

The hypothalamic-pituitary-adrenal (HPA) axis vitally regulates the body in everyday functioning ranging from glucose metabolism to coping with stress. The HPA axis follows a circadian rhythm governed by the suprachiasmatic nucleus in the hypothalamus releasing cortisol throughout the 24-hour day in a pulsatile manner, with approximately nine secretory episodes or 'dumps' (Weitzman et al., 1971), that results in increased cortisol levels throughout the body. The cortisol awakening response (CAR) is the dramatic increase of cortisol upon awakening resulting in an all-day peak about 30-45 minutes post-wake, presumably in efforts to prepare the body for upcoming demands of the day. Cortisol concentrations subsequently decline gradually throughout the rest of the day into the night with a nadir or trough around midnight (Lovallo & Thomas, 2000). This daily rhythm is also known as diurnal cortisol. Further, the HPA axis is sensitive to stressors, particularly in social-evaluative threat (SET) situations (Dickerson & Kemeny, 2004), or situations where there could be social judgment. In response to neuronal threat input from the amygdala (Amaral et al., 1992), the hypothalamus initiates a neuroendocrine cascade that results in cortisol release from the adrenal cortex of the kidney. Once released,

cortisol can enter almost every cell in the body given its lipophilic properties to commence its effects. Cortisol initiates bodily defenses from acute threats such as energy mobilization (Kuo et al., 2013) and anti-inflammatory effects (Segerstrom & Miller, 2004) to prepare for bodily harm. However, persistent activation of the HPA axis from stressors may damage the inhibitory systems that regulate the HPA axis, such as the hippocampus (Sapolsky et al., 1986). This overexposure of cortisol over time may alter the diurnal pattern of cortisol (Epel et al., 2018). One diurnal cortisol parameter which is frequently used to examine altered diurnal cortisol is the DCS (Adam et al., 2017).

Diurnal Cortisol Slope and Gender

Diurnal cortisol slope (DCS) is a diurnal cortisol parameter which is measured by taking the difference from waking to evening or bedtime cortisol levels, while accounting for the time between these values (slope). As mentioned earlier, there is a marked decrease from wake to night as the rhythm naturally progresses throughout the day (Lovallo & Thomas, 2000). Steeper slopes reflect typical or adaptational down-regulation of the HPA axis throughout the day, and flatter slopes reflect an altered rhythm with less down-regulation of cortisol. Lower morning and higher evening values may both contribute to a flatter DCS (Adam & Kumari, 2006). In turn, this resistance to down-regulating cortisol throughout the day may have served an adaptive function of keeping cortisol levels high for survival functions (Miller et al., 2007). However, flatter slopes are related to a myriad of physical and mental health outcomes such as all-cause mortality in civil servants (Kumari et al., 2011), earlier mortality over 7-years in metastatic breast cancer patients (Sephton et al., 2000), and internalizing symptoms such as depression, general distress,

sadness, and loneliness (Adam et al., 2017; Miller et al., 2007; Doane et al., 2013). However, it is unclear whether flatter DCS is a cause or biomarker of pathology from the lack of mechanistic evidence.

There is a dearth of studies examining the relations between rumination, gender, and DCS. Before examining the literature relating these constructs, it is important to note that gender and sex are intertwined yet separable (Hyde et al., 2019). Gender typically refers to norms and expectations of males and females set by sociocultural influences (Hyde et al., 2019) whereas sex typically refers to varying biological differences (e.g., hormones, phenotype, genotype). Gender differences in coping are subject to many socialization factors such as women using more strategies because of the expectation that they are more emotional (Barrett & Bliss-Moreau, 2009). Thus, any differences in the relation between DCS and rumination between genders could reflect environmental factors. On the other hand, any differences in the relation between DCS and rumination between sexes rather than gender could reflect biological differences captured by sex.

However, these constructs are not simple and are yet to be fully dissociated in this literature, and one is usually captured at the expense of the other. Gender is typically asked in a binary way suggesting sex or not having enough options for non-traditional identities. Further, sex is typically measured by sex assigned at birth which captures not only biological differences but the way an individual will be socialized throughout their life. Thus, gender and sex are largely conflated. This study is a secondary analysis of a previously collected dataset that only has traditional binary options for gender and a ‘refused’ category. Therefore, sex and gender are conflated as currently measured.

Admittingly, this approach is not granular enough to capture nuances in sex such as differences in hormone levels or subcomponents of the gendered experience such as felt gender-identity (Hyde et al., 2019). Thus, the proposed study is limited to examining binary gender identities and not informative to any nuanced differences between various gender identities and their interaction with sex characteristics which future studies should examine. In describing studies, I will use the term 'gender' to remain consistent with the proposed study unless details are provided to what they mean, in which case I will change the language accordingly for precision. Although I am unsure the degree to which gender, sex, and their interactions play in prior and proposed studies of these differences, it is almost certain that gender in the proposed study is indeed capturing a myriad of socialization processes and biological differences.

There is no obvious pattern of gender differences in basal DCS, with men and women displaying similar DCS profiles (e.g., Pössel et al., 2014; Hsiao et al., 2010); however, one study found that men were more likely than women to have a flatter DCS within the small minority of the sample who had flatter DCS (Dmitrieva et al., 2013). It is also unclear whether the men and women who ruminate have similar or different DCS profiles. Many factors including stress entrain or modulate circadian rhythms (Archer & Oster, 2015). Indeed, chronic stress is related to flatter DCS (Miller et al. 2007). In parallel, adolescent girls who self-reported a higher tendency to ruminate about peer-related stressors over a 3-month period was associated with flatter DCS (Hilt et al., 2017). Thus, the dance of ruminative thought may affect the cadence of diurnal rhythms, particularly DCS.

Although no studies to my knowledge have unveiled gender moderating the relation between diurnal cortisol and rumination, there is growing evidence from the laboratory of differences in cortisol responding between gendered individuals higher in trait rumination (Zoccola & Dickerson, 2015; Shull et al., 2016). In turn, these differences from the laboratory suggest gender differences in the relation between diurnal cortisol and rumination, which this study seeks to examine. Clarifying the role of gender and rumination in predicting DCS is crucial to understanding the manner in which rumination leads to pernicious outcomes (e.g., Aldao et al., 2010). In the subsequent sections, I will first review laboratory findings of cortisol recovery differences between those who tend to ruminate, which reveal gender differences. Afterward, I review naturalistic studies that have tested the associations between trait rumination and various diurnal cortisol markers in daily life that may imply gender differences when considered in light of laboratory findings of gender differences between rumination and cortisol recovery.

Laboratory Cortisol and Rumination

One of the most widely used laboratory stressor tasks used to examine acute cortisol stress response patterns is the Trier Social Stress Test (TSST; Kirschbaum et al., 1993). The TSST is a psychosocial stressor that consists of a panel of judges evaluating participants giving a five-minute speech about why they are an ideal job candidate followed by a five-minute challenging mental arithmetic task. The social-evaluative component and the uncontrollable aspect of this stressor elicit robust cortisol responses in most participants (Dickerson & Kemeny, 2004). This task also elicits rumination, which persisted for 3-5 days after the lab session (Zoccola, Dickerson, & Lam, 2012) and up to 2-weeks later in

women higher in stressor-related trait rumination (Zoccola et al., 2010). In parallel to social stressors eliciting cortisol effluxes, the perseverative cognition hypothesis (Brosschot et al., 2006) predicts that ruminative thought by sustaining a mental representation of the stressor will maintain cortisol secretion after a stressor, in turn leading to poorer recovery. Given the TSST reliably elicits cortisol responses (Dickerson & Kemeny, 2004) and rumination (Zoccola, Dickerson, & Lam, 2012), it is reasonable to deduce rumination about the TSST will also continually activate cortisol release. This reasoning is supported by Zoccola & Dickerson's (2015) findings.

On the same day of completing the TSST, participants were instructed to take cortisol samples into the evening and night. Consistent with the perseverative cognition hypothesis (Brosschot et al., 2006), higher stressor-related trait rumination scores predicted less cortisol decline throughout the day following the stressor up to bedtime (Zoccola & Dickerson, 2015). Importantly, further analyses revealed this was driven by gender differences: In women, but not men, higher stressor-related trait rumination scores predicted less cortisol decline throughout the evening with subsequent higher levels of cortisol at bedtime (Zoccola & Dickerson, 2015). The absence of the expected decline in cortisol concentrations following a social-evaluative stressor implies that ruminating on SET stressors may impede the typical diurnal cortisol decline - at least for women. In parallel to this finding, a study that utilized an anger-recall ruminative task alongside physiological parameters led women, but not men, to greater difficulties in subduing ruminative thought indexed by greater parasympathetic withdrawal and greater sympathetic dominance (Ottaviani et al., 2009). In other words, women had more difficulty

in recovering from a ruminative task, perhaps indicating less cognitive flexibility. Although not tested, if women struggled to inhibit thoughts related to the TSST more so than men, this could help explain the findings. A marked feature of the Zoccola & Dickerson's (2015) study is its extension beyond the laboratory context. One study indicated that trait rumination was associated with state rumination after the TSST but not cortisol responses (Gianferante et al., 2014), which highlights the necessity of examining cortisol measures over extended time to detect cortisol responding from trait rumination or the lack thereof.

Depressive rumination also seems to affect cortisol responses in a laboratory context, presumably through activating state rumination thereby altering cortisol recovery. In one study measuring depressive rumination scores, participants performed a TSST followed by a 10-minute distraction or state rumination task (Shull et al., 2016). In the rumination condition, participants were instructed to answer questions related to symptoms from the TSST (e.g., "think about your physical stress symptoms…") as well as potential consequences (e.g., "what does doing poorly on this task say about your abilities as a student…"). This was designed as a state rumination proxy of the RRS. The distraction condition prompted participants to focus on more neutral facts of the experience (e.g., describe the room) to inhibit any rumination from occurring. There was no main effect of condition on cortisol recovery, however an interaction revealed that the rumination condition led to prolonged activation of the HPA axis compared to the distraction condition in those who scored 1 standard deviation above the mean RRS score (those high in rumination), as evidenced by higher peak cortisol values when controlling for baseline levels of and rate of activation (reactivity) of cortisol (Shull et al., 2016).

Moreover, further analyses revealed that the prolonged activation in the rumination condition was found only in women, not men, high in depressive rumination (Shull et al., 2016). This may suggest women higher in trait rumination do not recover as swiftly and are thereby overexposed to cortisol. For men, there was no such association between trait rumination and cortisol. In addition, there was no difference in recovery rates between the men and women higher in trait rumination in the rumination condition despite the higher peaks among women higher in trait rumination. Typically, higher cortisol reactivity or peaks is often followed by more intense down-regulation (Lopez-Duran et al., 2014). However, Shull et al. found women high in trait rumination who were prompted to ruminate did not have this expected down-regulation, suggesting atypical recovery. It is important to note that each recovery slope was also person-centered in relation to the peak, whereas other studies typically have a consistent time period marker (e.g., 40-minutes posttask) to measure recovery values. This nuanced approach may have captured important distinctions that may have been missed in prior literature. In summary, this study's findings may indicate atypical cortisol recovery in response to ruminative episodes in women who have a tendency for depressive rumination.

Another study examined adolescents with or without depression and found those with depression who also scored higher on the child version of the RSQ, the earlier depressive rumination measure of the RRS, showed a smaller change in post-stressor cortisol levels in response to the TSST (Stewart et al., 2013). That is, individuals with higher depression who were also higher in trait rumination displayed altered cortisol recovery after a psychosocial stressor. Those without depression had much lower

depressive rumination scores which possibly accounts for the absence of an association between rumination and cortisol responses in this group. There was no evidence of gender differences in cortisol recovery in the pooled sample; however further analyses examining gender differences in cortisol recovery within the group higher in depression and trait rumination (depression sub-sample) were not reported. As in other studies that have revealed prolonged cortisol recovery in those higher in trait rumination (Zoccola & Dickerson, 2015; Shull et al., 2016), Stewart & colleagues (2013) found prolonged recovery among those with depression and higher trait rumination; however, future work examining higher-order interactions with gender is needed to replicate and extend prior studies suggesting prolonged recovery among those higher in trait rumination is driven by gender differences, specifically by women.

To recapitulate, the laboratory studies examined thus far suggest a general tendency for those higher in trait rumination to have prolonged cortisol recovery in response to a psychosocial stressor (Zoccola & Dickerson, 2015; Stewart et al., 2013) or a depressive rumination induction (Shull et al., 2016). Interestingly, this effect seems to be driven by women (Zoccola & Dickerson, 2015; Shull et al., 2016), suggesting women higher in trait rumination have prolonged physiological recovery evidenced by prolonged cortisol activation following some stressor, whereas men may not. However, this pattern has been underexplored in examining DCS, which is well suited to indicate prolonged activation (e.g., Miller et al., 2007). Given prolonged stress hormone exposure is predicted from rumination (Brosschot et al., 2006), this may be reflected in DCS thus providing an

opportunity to examine gender differences between cortisol exposure and tendencies to ruminate.

Diurnal Cortisol and Rumination in a Naturalistic Setting

The literature examining diurnal cortisol and trait rumination has used various parameters of the diurnal rhythm such as morning levels (Roger & Najarian, 1998; Rydstedt et al., 2011), evening levels (Rydstedt et al., 2009), CAR (Rnic et al., 2022), total cortisol output (Huffziger et al., 2013), and DCS (Hilt et al., 2017; Rnic et al., 2022). DCS can be calculated by taking the difference between evening or night cortisol values from wake values divided by the time elapsed between these values. Therefore, blunted morning values and/or higher evening values can contribute to flatter DCS (Adam et al., 2006; Miller et al., 2007). Extending investigations from the laboratory to daily life is crucial in understanding how repeated ruminative episodes relate to diurnal cortisol and ultimately health outcomes (Adam et al., 2017). Thus, I will examine the literature linking trait rumination to diurnal cortisol parameters and propose both stressor and brooding rumination will be related to flatter DCS, particularly among women.

Stressor-Related Rumination and Diurnal Cortisol

Higher stressor-related rumination may continually activate the HPA axis resulting in altered diurnal cortisol parameters. In support of this, one study found higher ECQ-R scores predicted greater morning urinary cortisol levels on the day of an exam in predominantly female student nurses (Roger & Najarian, 1998). Thus, greater tendencies to ruminate about upsetting or stressful events was related to altered diurnal cortisol. However, evening values were not captured which could have revealed how rumination

unfolds throughout the day of a stressor and subsequently influences DCS. For instance, if rumination in regards to the exam continued throughout the day, higher urinary cortisol levels in the evening from persistent activation may contribute to flatter slopes. A similar stressor-related trait rumination measure (Inhibition-Rumination Scale; Roger et al., 2000) was positively related to greater evening cortisol in both men and women four years after trait rumination measurement (Rydstedt et al., 2009); however, rumination was only related to elevated morning cortisol in conjunction with job-role ambiguity in a follow-up report using a stepwise linear regression (Rydstedt et al., 2011). Therefore, job-role ambiguity may provide ruminative content for those higher in rumination, leading to altered diurnal cortisol levels. However, there are important limitations to note.

One limitation is that trait rumination levels were sampled four years prior to the cortisol measurement. Although depressive rumination displays reasonable stability (Bagby et al., 2004), it is unclear how stable this specific measure is over time, which the authors assumed (Rydstedt et al., 2011). Additionally, this scale also assesses the tendency to inhibit emotional information, which is a different factor than rumination (Roger & Najarian, 1989). Therefore, it is unclear whether emotional inhibition or rumination is driving the association between altered cortisol levels. In summary, stressor-related information may alter morning cortisol (Roger & Najarian, 1998; Rydstedt et al., 2011), yet further work is needed using stressor-related rumination scales such as the ECQ-R (Roger & Najarian, 1989), that are not confounded with other constructs and are measured with concurrent self-reported levels of rumination.

Interpersonal stressors are especially frequent and burdensome in day-to-day life (Almeida, 2005). Indeed, ruminating about an interpersonal transgression over the past two weeks measured at multiple lab visits was related to higher afternoon cortisol levels sampled once each lab visit (McCullough et al., 2007). In line with the perseverative cognition hypothesis (Brosschot et al., 2006), this repeated increase in neuroendocrine activation from rumination may lead to prolonged activation reflected in DCS. In support of this prediction, trait rumination about peer-related stressors was related to flatter DCS measured over 3-days in adolescent girls (Hilt et al., 2017). SET is a key component found in laboratory studies that leads to increases in rumination, prolonged or altered recovery, and greater cortisol responses (Zoccola et al., 2008). Therefore, to the degree interpersonal stressors contain SET, cortisol responses are expected to be more robust. Indeed, peer-related stressors included being 'left out' or 'rejected' (Hilt et al., 2017) and transgressions that led to 'fear of the transgressor' appeared to mediate the rumination-cortisol association (McCullough et al., 2007). However, gender as a moderator was not able to be tested in examining DCS given only girls were included in this study (Hilt et al., 2017). The proposed study will expand upon this work by including both men and women.

Although it is beyond the purview of the current study to examine specific stressors such as peer-related (Hilt et al., 2017), examinations (Roger & Najarian, 1998), interpersonal transgressions (McCullough et al., 2007), or job-role ambiguity (Rydstedt et al., 2011), I will examine DCS over multiple days in those with a tendency for stressor-related rumination. In multiple contexts, stressor-related variables are related to altered diurnal cortisol. However, limited research has been done in regard to DCS and stressor-

related rumination (Hilt et al., 2017). Given Zoccola & Dickerson (2015) found higher evening levels in those higher in stressor-related rumination on the same day of a psychosocial stressor, and higher evening cortisol can contribute to flatter slopes (Adam et al., 2006), flatter DCS in those higher in stressor-related rumination may be expected when examining diurnal cortisol.

Further, given women drove the relation between higher evening cortisol and stressor-related rumination (Zoccola & Dickerson, 2015), this study will examine whether women who are higher in stressor-related rumination have flatter DCS than men higher in stressor-related rumination. A similar line of reasoning follows for depressive rumination.

Depressive Rumination and Diurnal Cortisol

Likewise, depressive rumination has been examined in multiple contexts with different cortisol parameters. In parallel with stressor-related rumination prolonging cortisol exposure through repetitive thinking about stressors, depressive rumination may prolong cortisol exposure to the degree one ruminates or repetitively thinks on sad or depressive mood throughout the day. Indeed, a recent meta-analysis revealed there was a significant positive association between momentary negative emotions and cortisol, with many studies including depressive (i.e., sad, unhappy, down) emotions (Joseph et al., 2021). Consistent with the perseverative cognition hypothesis (Brosschot et al., 2006), the degree to which these feelings are focused on ruminatively may lead to an overexposure of cortisol. If this persists throughout the day or occurs in the evening when rumination tends to be higher (Moberly & Watkins, 2008), flatter DCS may follow.

As already discussed, the RRS scale can be divided into the brooding and pondering subscales which specifically looks at how individuals cope in response to a sad, blue, or depressed mood (Nolen-Hoeksema & Morrow, 1991). A sparsity of studies have examined brooding or pondering with diurnal cortisol. For instance, a two day ecological momentary assessment (EMA) study only examining cortisol output with remitted depressed participants and participants without a history of depression showed neither trait brooding nor pondering was associated with cortisol over the day (Huffziger et al., 2013), with no gender differences in cortisol output in the sample. However, the 2-item state rumination measure which included "...I am thinking about my feelings" was related to higher cortisol output in both groups, although gender was not further analyzed to reveal nuances. Although this state rumination measure is not a proxy of the RRS, the increased HPA axis activity from momentary self-focus follows predictions from the perseverative cognition hypothesis (Brosschot et al., 2006), which theoretically isn't specific to any type of rumination. Thus, brooding may not have been related to HPA activity because trait and state measures do not always correspond, especially over short time periods. Although DCS and state rumination were not analyzed (Huffziger et al., 2013), higher cortisol output reflects increased activation throughout the day which in turn may resist natural decline, leading to flatter DCS. Thus, those with a tendency to ruminate may persistently have prolonged HPA activation and flatter DCS, which this study seeks to examine.

On the other hand, a recent two day EMA study of young adolescents during the COVID-19 lockdown found greater pondering scores were associated with lower cortisol at waking (Rnic et al., 2022), while brooding was associated with higher cortisol at waking.

Higher cortisol waking levels are associated with greater perceived stress (Sladek et al., 2019; Roger & Najarian, 1998), suggesting brooding is related to maladaptive diurnal cortisol. Conversely, adaptive coping strategies may be related to lower cortisol output throughout the day (O'Donnell et al., 2008), suggesting the lower waking levels among those higher in pondering may be more adaptive (Rnic et al., 2022).

Neither pondering nor brooding were significantly related to DCS (Rnic et al., 2022), although brooding was trending towards significance. However, this study only utilized two days of cortisol collection which may be inadequate to capture between-subject differences in DCS (Segerstrom et al., 2014) and did not examine gender as a higher order interaction term to distill any differences. Supporting this latter point, another study by Shull & colleagues (2016) showed depressive rumination scores interacted with gender in predicting cortisol responses in the laboratory, such that prolonged recovery in the rumination induction occurred only in women higher in trait rumination, not men higher in trait rumination. Thus, the degree to which similar processes occur in daily life may subsequently lead to prolonged activation of the diurnal rhythm, leading to flatter DCS over the day.

Further, greater brooding was also associated with a blunted cortisol awakening response (CAR) whereas pondering was unrelated to the CAR (Rnic et al., 2022). A blunted CAR is related to maladaptive outcomes such as depression (e.g., Dedovic & Ngiam, 2015), further supporting the unique link of brooding to altered diurnal cortisol. The degree to which brooding is uniquely related to different diurnal cortisol parameters is unknown and the current findings (Rnic et al., 2022) may have implications for other diurnal cortisol

parameters such as a flatter DCS if more days or gender differences are analyzed. However, the CAR is governed by distinct mechanisms than the rest of the cortisol rhythm (Clow et al., 2014), therefore any findings involving the CAR need to be interpreted cautiously in regards to its implications for DCS.

Taken together, the brooding subtype of depressive rumination is related to maladaptive diurnal cortisol profiles (Rnic et al., 2022), whereas the pondering subtype may not be. Additionally, the only study to examine DCS and brooding only utilized two days to investigate diurnal cortisol (Rnic et al., 2022); it may be that to capture between-subject DCS activity more days of assessment are warranted (Segerstrom et al., 2014). Further, laboratory findings of gender differences between depressive rumination and cortisol recovery (Shull et al., 2016) may extrapolate to DCS. To extend and address the limitations of prior studies examining depressive rumination and diurnal cortisol, this study will investigate five days of cortisol collection occurring in a naturalistic context to better capture between-person differences in diurnal cortisol while examining gender as a moderator between DCS and brooding.

Summary

To recapitulate, there are different operationalizations of the tendency for repetitive, intrusive, and negative thought aimed ultimately at goal-resolution (Nolen-Hoeksema et al., 1991; Roger & Najarian, 1989; Watkins, 2008). Stressor-related rumination, or rumination about upsetting events, involves repetitive focus on past and current stressors with difficulty removing thoughts from the mind (Roger & Najarian, 1989). Depressive rumination, or rumination about depressive symptoms, involves

repetitive focus on the causes, consequences, and feelings of depressive symptoms (Nolen-Hoeksema et al., 1991). Specifically, the brooding subscale of depressive rumination is overly self-critical whereas the pondering subscale is more contemplative or reflective (Treynor et al., 2003). Common to both measures of rumination is growing evidence from the laboratory and beyond of prolonged stress recovery in women who have such propensities.

For instance, these studies include less cortisol recovery into the evening and night in women higher in trait rumination following a laboratory stressor (Zoccola & Dickerson, 2015; Shull et al., 2016). Although there is an unclear pattern of results from an ecological context of the relation between diurnal cortisol slope and trait rumination in general, trait rumination tends to be related to alterations diurnal measures of cortisol (e.g., Hilt et al., 2017; Rnic et al., 2022; Rydstedt et al., 2011). If the laboratory findings extrapolate to diurnal cortisol, this would have two important implications: First, this would be reflected by flatter DCS through prolonged activation of the HPA axis; Second, this would also imply gender is crucial in detecting differences in diurnal cortisol, which may account for the null findings of brooding being related to diurnal cortisol (Rnic et al., 2022; Huffziger et al., 2013).

In addition, studies have largely neglected to examine higher-order gender and rumination interactions on cortisol in an experimental setting, let alone an ecological setting. Also, examining subcomponents of the RRS (brooding and pondering) when examining cortisol outcomes is important, given their differential relations to criterion variables in various contexts (e.g., Treynor et al., 2003; Moberly & Watkins, 2008),

including diurnal cortisol (Rnic et al., 2022). Brooding seems to be particularly deleterious (Treynor et al., 2003; Moberly & Watkins, 2008; Shull et al., 2016; Rnic et al., 2022; Olatunji et al., 2013), therefore brooding will be the focus in this study for depressive rumination. Further, many studies have failed to take into account multiple days when examining diurnal cortisol, and if they have, it only has been two days (Huffziger et al., 2013; Rnic et al., 2022) with one exception (Hilt et al., 2017), which is not the ideal for examining individual differences between diurnal cortisol and psychological traits (Segerstrom et al., 2014).

Current Study

This study addressed the aforementioned limitations by using five days of cortisol collection with multiple trait rumination measures while examining gender as a moderator in the relation between trait rumination and diurnal cortisol. I proposed altered cortisol trajectories in those higher in trait rumination would be reflected through flatter DCS over a five day EMA period, especially pronounced in women higher in trait rumination. My inquiry into the nature of rumination, gender, and neuroendocrine responding lead to the following hypotheses:

Hypothesis 1a: Those higher in stressor-related rumination measured by the Rehearsal subscale of the Revised Emotion Control Questionnaire (ECQ-R; Roger & Najarian, 1989) would have flatter DCS over five days.

Hypothesis 1b: Gender would moderate the stressor-related rumination-cortisol association. Specifically, women higher in stressor-related rumination measured by the Rehearsal subscale of the Revised Emotion Control Questionnaire (ECQ-R; Roger &

Najarian, 1989) would have flatter DCS over five days than men higher in stressor-related rumination.

Hypothesis 2a: Those higher in depressive-rumination measured by the brooding subscale of the ruminative response scale (RRS; Nolen-Hoeksema et al., 1991) would have flatter DCS over five days.

Hypothesis 2b: Gender would moderate the brooding rumination-cortisol association. Specifically, women higher in depressive-rumination measured by the brooding subscale of the ruminative response scale (RRS; Nolen-Hoeksema et al., 1991) would have flatter DCS than men higher in depressive-rumination.

Exploratory Research Questions: Pondering may not be as deleterious as brooding (Olatunji et al., 2013; Treynor et al., 2003; Moberly & Watkins, 2008; Shull et al., 2016; Rnic et al., 2022). Therefore, brooding was the focus in this study in driving altered diurnal cortisol. However, I further explored whether higher pondering was related to flatter DCS and whether this effect was exacerbated in women. Further, given the ECQ-R and RRS share some variance, (e.g., Siegle et al., 2004), I analyzed the RRS and ECQ-R entered together in the sample analysis with both their lower and higher order interaction terms entered as previously described (gender x rumination).

Methods

Participants

One hundred and twenty four (n = 124) undergraduate students participated in this laboratory and five-day ecological momentary assessment (EMA) study between January and November in 2007. Eligibility criteria required the participant be 18 years of age or older, without chronic medical or psychiatric disorders, a non-smoker, not pregnant, not taking hormonal contraceptives, able to speak English, and a typical wake time before 10 A.M. on weekdays. The Institutional Review Board of University California, Irvine, approved all procedures in advance.

Study Overview

Participants initially came to the lab to complete a TSST, saliva samples, and various questionnaires (see **Lab Portion** and **Appendix A**). Next, participants completed a take-home portion which lasted five-days, described below (**Diary Setting**). The study focused on rumination questionnaires measured from the lab portion, and cortisol samples from the take-home portion.

Diary Setting

For five-days, on three weekdays and two weekend days, participants were instructed six times per day and prompted via a personal digital assistant (PDA) five times per day to collect saliva samples and complete questionnaires related to affect, cognitions, stressors, interpersonal interactions, and health behaviors since the previous 'beep.' Specifically, participants were instructed to complete samples at wake, 12:00 P.M., 2:00 P.M., 4:00 P.M., 6:00 P.M., and 8:00 P.M., and were prompted via the PDA at 12:00 P.M.,

2:00 P.M., 4:00 P.M., 6:00 P.M., and 8:00 P.M. The PDA stamped the time upon questionnaire completion at all times (including wake), and provided a unique three-digit identifier to place on the Salivette collection device (Sarstedt, Inc., Newton, N.C.). A Salivette is a pre-packaged, sterile saliva collection kit consisting of a cotton roll in a plastic tube. Efforts to monitor compliance are necessary for data integrity, and this approach emphasizes accurate time reporting of saliva collection, despite any time deviation between scheduled and actual sampling time (Adam & Kumari, 2009). Participants were instructed to store samples in their freezer to prevent biodegradation, until they returned the samples to the laboratory. Samples were stored in the lab at -20°C until full completion of data collection. To increase compliance with at-home procedures, individuals who completed 90% of at-home assessments were entered into a raffle to win an Apple iPod.

Lab Portion

Participants initially came into the lab to complete a modified version of the Trier Social Stress Test (TSST), provide cortisol samples, and various questionnaires (see **Appendix A**). These included demographic characteristics, the Rehearsal subscale of the Revised Emotion Control Questionnaire (ECQ-R; Roger & Najarian, 1989), the Ruminative Response Scale of the Response Styles Questionnaire (Nolen-Hoeksema et al., 1991), the Center for Epidemiologic Studies Depression Scales (CES-D; Radloff, 1977), and body mass index (BMI).

Primary Measures

All participants completed the following measures (see **Appendix A** for all of the lab and EMA measures).

Demographics and Participant Characteristics

Participants were instructed to answer the following: Gender, education, ethnicity/cultural background, and age. As mentioned earlier, gender was measured as 'male,' 'female,' or 'refused.' Gender was dummy-coded such that female was coded as '0' and male was coded as '1.' Depressive symptoms were assessed with the Center for Epidemiologic Studies Depression Scales (CES-D; Radloff, 1977).

Rumination

Trait rumination was measured using two scales: the Rehearsal subscale of the Revised Emotion Control Questionnaire (ECQ-R; Roger & Najarian, 1989); and the Brooding and Pondering subscales (Treynor et al., 2003) of the Ruminative Responses Scale of the Response Styles Questionnaire (RRS; Nolen-Hoeksema & Morrow, 1991).

The ECQ-R is a 14-item true/false scale containing items such as "I find it hard to get thoughts about things that have upset me out of my mind." True ratings are coded '1' and false ratings '0.' Hence, higher scores reflect a higher propensity to ruminate over stressors. This scale has high internal consistency (Cronbach's alpha = .86) and test-retest reliability was r =.8 (Roger & Najarian, 1989) over 7 weeks; Cronbach's alpha in the current study was .78. This scale is positively related to neuroticism scores, trait anxiety, and Beck Depression Inventory scores (Roger & Najarian, 1989; Siegle et al., 2004).

The RRS is a 22-item scale developed to measure the tendency to ruminate when feeling 'sad' or 'blue' (Nolen-Hoeksema et al., 1991). The 5-item brooding subscale of the RRS (Treynor et al., 2003) will be used to assess brooding rumination. Items include responses to "when feeling 'sad' or 'blue'" such as "What am I doing to deserve this?" or

"Why do I always react this way?" Cronbach's alpha was .77 and the test-retest correlation was r = .62 (Treynor et al., 2003) over 1 year; Cronbach's alpha in the current study was also .77. Participants were asked whether they never, sometimes, often, or always think or do each item when feeling down, sad, or depressed. Higher scores indicate a greater propensity to depressively ruminate. Brooding is positively related to attentional biases and major depression (Joorman et al., 2006; Treynor et al., 2003). Lastly, the pondering subscale also consists of 5-items such as "Analyze your personality to understand why you are depressed" or "Write down what you are feeling and analyze it." The test-retest correlation was r = .62 and Cronbach's alpha was .72 (Treynor et al., 2003) over 1 year; Cronbach's alpha in the current study was .758.

Salivary Cortisol

Salivary cortisol was collected six times per day (upon waking, 12:00 P.M., 2:00 P.M., 4:00 P.M., 6:00 P.M., and 8:00 P.M.) using a Salivette collection device (Sarstedt, Inc., Newton, N.C.). Participants were instructed to place the cotton roll in their mouth to absorb saliva for up to three minutes until saturated then place it back into the tube. Samples were stored in personal freezers until they were returned to the lab, where they were stored at -20°C. All saliva samples were assayed in duplicate and averaged at the University General Clinical Research Center using standard enzyme-linked immunoassay procedures (Diagnostic Systems Laboratories, Inc., Webster, TX). The sensitivity of the assay is < 0.012 μg/dL; inter- and intra-assay coefficients of variance are both less than 8%.

To determine diurnal cortisol slope (DCS) values, I entered time as a within-subject predictor of cortisol at level-1 of the multilevel model (MLM). This linear term

reflects the difference between the natural log-transformed cortisol wake and evening values over time elapsed between wake and evening (see equation 1 below). Thus, larger values indicate a steeper slope and smaller values indicate a flatter slope.

Equation 1. DCS formula: (Wake value nmol/L - evening value nmol/L) / (Wake time hr - evening time hr) = DCS nmol/L/hr.

Covariates

Body Mass Index. Body Mass Index (BMI) was calculated using self-reported height and weight using the following formula: BMI = ((weight in pounds) x 703) / (height in inches)^2. Higher BMI is related to flatter DCS (Adam et al., 2017) and negatively related to waking cortisol levels (Champaneri et al., 2013). Thus, to avoid confounding flatter DCS with BMI, BMI was included as a covariate in the analyses.

Time of Wake. Participants self-reported their time of wake in a paper booklet. Diurnal cortisol patterns are based on the sleep-wake cycle rather than absolute time (Wilhem et al., 2007). Since the diurnal cortisol rhythm is not purely linear (Adam et al., 2009; Badrick et al., 2008) and cortisol slope values were calculated from participant's wake values and fixed evening values, I adjusted for *time of wake* as a between-subject predictor at level-2 of the MLM. Time of wake influences when cortisol levels peak (Kudielka & Kirschbaum, 2003), which may affect the course of natural decline throughout the day leading to the last sample collected in the evening. For instance, given late-wakers peak later in the morning (Kudielka & Kirschbaum, 2003), their respective cortisol decline rate can be different relative to another individual at the fixed evening time.

Any day in which participants took the wake sample more than 10 minutes after self-reported wake time were excluded (n = 14), as the cortisol awakening response is well underway by then (Kudielka & Kirschbaum, 2003). In addition, participants who wake after 10:00 A.M. were considered ineligible for the study, which should further limit the variability due to irregular sleep-wake cycles. Cortisol *cases* for which corresponding waking saliva collection times were after the time of the second scheduled (12 P.M.) saliva collection time were excluded (n = 6).

Data Analytic Plan

Multilevel Modeling and Hypotheses

I used a 2-level multilevel model to account for the nesting of occasions (samples) within persons, and treated the day level as a level-2 fixed effect to facilitate model convergence. Time was measured as hours since midnight and was grand-mean centered at wake for all subsequent analyses. Also, all other predictors were grand-mean centered. First, an unconditional growth model was fitted to the data to determine the appropriate covariance structure and whether there was substantial variance to be explained (Model 1). Next, lower-order fixed and random effects were added to level-2 to assess between-person variance in the level-1 intercept and slope relating time to cortisol values and allow individual variation in the intercept and slope (Model 2). Lastly, higher-order fixed effects were added to assess the interaction between gender and rumination on the level-1 intercept and slope parameters (Model 3). Thus, to test whether higher scores on the ECQ-R are related to flatter slopes (hypothesis **1a**), ECQ-R was examined in the presence of covariates (BMI, time of wake) and the lower-order gender term. To test whether women higher in

stressor-related rumination have flatter DCS (hypothesis **1b**), the higher-order interaction term (time x gender x ECQ-R) was examined (see **Equation 2** below). Similarly, to test whether higher brooding scores are related to flatter slopes (hypothesis **2a**), brooding was examined in the presence of covariates (BMI, time of wake) and the lower-order gender term. Further, to test whether women higher in brooding rumination have flatter DCS (hypothesis **2b**), the higher-order interaction term (time x gender x brooding) was examined (see **Equation 2** below). All lower-order effects are reported as well.

Equation 2. note. The term 'Rumination' is a placeholder for the different operationalizations of rumination.

Level 1:

$$Cortisol_{oi} = \beta_{0i} + \beta_{1i}Time_{oi} + U_{0oi}$$

Level 2:

$$\beta_{0i} = \gamma_{00} + \gamma_{01}MeanWakeTime_i + \gamma_{02}BMI_i + \gamma_{03}Rumination_i + \gamma_{04}Gender_i$$

$$\gamma_{05}Day_i + \gamma_{06}Gender\ x\ Rumination_i + U_{0i}$$

$$\beta_{1i} = \gamma_{10} + \gamma_{11}MeanWakeTime_i + \gamma_{12}BMI_i + \gamma_{13}Rumination_i + \gamma_{14}Gender_i + \gamma_{15}Day_i +$$

$$\gamma_{16}Gender\ x\ Rumination_i + U_{1i}$$

Final equation:

$$Cortisol_{oi} = \gamma_{00} + \gamma_{01}MeanWakeTime_i + \gamma_{02}BMI_i + \gamma_{03}Rumination_i + \gamma_{04}Gender_i + \gamma_{05}Day_i +$$

$$\gamma_{06}Gender\ x\ Rumination_i + U_{0oi} + \gamma_{10}*time_{oi} + \gamma_{11}MeanWakeTime_i*time_{oi} + \gamma_{12}BMI_i*time_{oi}$$

$$+ \gamma_{13}Gender_i*time_{oi} + \gamma_{14}Rumination_i*time_{oi} + \gamma_{15}Day_i*time_{oi} + \gamma_{16}Gender\ x\ Rumination_i*time_{oi} + U_{1i}*time_{oi} + r_{oi}$$

Exploratory Analysis

To test the exploratory aims: 1) Whether pondering scores are related to DCS, pondering was examined in the presence of covariates (BMI, time of wake) and the lower-order gender term. Further, to test whether women higher in pondering have flatter DCS, the higher-order interaction term (time x gender x pondering) was examined (see **Equation 2** above). All lower-order effects are reported; 2) To test the unique effects of each rumination measure, I analyzed the RRS and ECQ-R entered together in the analysis with both their lower and higher order interaction terms entered as previously described (e.g., gender x rumination).

An unstructured covariance matrix was utilized in all hypothesis-testing and exploratory analyses because deviance statistics indicated better model adequacy/fit for the unconditional growth model (Model 1), which is consistent with methodological choices often used in the cortisol literature (e.g., Stawski et al., 2013). Additionally, all hypothesis-testing and exploratory analyses use full maximum likelihood estimation.

Results

Data Reduction

Overall, there were a possible total of *n* = 1,240 cortisol values, with an observed *n* = 211 (17%) missing cortisol values throughout the dataset prior to data exclusion. All salivary cortisol measurements underwent a log transformation prior to further statistical analyses. This is done to establish normality and to detect outliers (e.g., Adam & Kumari, 2009). Each day, if someone's morning or evening saliva sample level exceeded 3 standard deviations from the mean of that sampling time, this person's sampling occasion was excluded (*n* = 14; 1.3%). Further, cortisol values with invalid wake-times (see **Time of wake** above) were excluded (*n* = 14; 1.3%). Additionally, those with cortisol values without evening sample times confirmed by the PDA were excluded (*n* = 131; 12.7%), as the time-of-sample was uncertain. Results remained similar with and without excluding these cases. Thus, to aid in analytic interpretability by remaining methodologically stringent, remaining consistent with the *a priori* analytic plan, and to better meet the random effect normality assumptions of multilevel modeling procedures by excluding outliers, all results reported reflect only valid cortisol values (*n* = 870) from participants (*n* = 116), which reflects 70% overall valid cortisol values from the entire participant sample.

After data reduction, there were 63 women (54.3%) and 53 men (45.7%), with a mean age of 19.6, SD = 2.2. Additionally, the racial/ethnic background of the sample was: 28 (24.1%) chinese, 17 (14.7%) white, 12 (10.3%) Middle Eastern and 12 (10.3%) East/Asian Indian, 10 (8.6%) Vietnamese, 9 (7.8%) Filipino, 7 (6%) Korean, 8 (6.9%)

Latino, 3 (2.6%) African American, 3 (2.6%) other, 3 (2.6%) Chicano, 2 (1.7%) Native American, 1 (.9%) Japanese and 1 (.9%) Islander/Eskimo.

Preliminary Correlations and Descriptives

As shown in Table 1, brooding (M = 10.28, SD = 3.19) was positively and moderately associated with the ECQ-R (M = 5.75, SD = 3.35), r = .503. Further, there were some gender differences among covariates: First, men (M = 23.36, SD = 4.29) had a higher BMI on average than women (M = 21.96, SD = 3.28, d = .37); second, men (M = 9.17, SD = .91) had later average wake-times than women (M = 8.70, SD = 1.07, d = .47). Interestingly, there were no gender differences in brooding rumination or stressor-related rumination in this sample. However, women (M = 10.06, SD = 3.36) had higher pondering values than men (M = 8.53, SD = 2.93, d = .49). Also, brooding was negatively associated with BMI (M = 22.60, SD = 3.82). Lastly, depression symptoms were relatively high, on average, (M = 13.69, SD = 6.94) in the current sample, as a score of 16 or greater indicates that a person is at risk for clinical depression (Weissman et al., 1977).

Table 1

Zero Order Correlations for Predictors and Covariates (n=113-116)

		1	2	3	4	5
1. Gender[a]		-				
	n	116				
2. SR[b]		-.077	-			
	n	115	115			
3. Brooding		-.092	.503**	-		
	n	115	115	115		
4. BMI		.184*	-.058	-.248**	-	
	n	114	113	113	114	
5. Wake-time[c]		.231*	.015	.040	.024	-
	n	115	114	114	113	115
6. Pondering		-.237**	.299**	.311**	-.181	.021
	n	115	115	113	11	114

*. Correlation is significant at the 0.05 level (2-tailed).
**. Correlation is significant at the .01 level (2-tailed).
[a]Gender was coded as 0 = women, 1 = men.
[b]Stressor-related rumination (SR)
[c]Wake-time was measured in hours since midnight

Did Rumination and Rumination x Gender Predict Diurnal Cortisol Slope? (Hypotheses 1 + 2)

ECQ-R (Hypotheses 1a, b)

As shown in Table 2, adding predictors to the unconditional growth curve model (Model 1) leads to a statistically better model fit, $p < .001$ (Model 2). Cortisol values were natural log transformed, thus applying the formula—$((e^b - 1) \times 100)$—yields coefficients interpreted as the percent change in cortisol (nmol/L) per unit difference in the predictor variable (Singer & Willett, 2003). Looking at the final model, the average wake value was 4.81 nmol/L, which decreased by 9.9% every hour from morning to evening, $p < .05$. On average, those who had later average wake times had higher morning cortisol values. Each hour someone woke up later was accompanied by a 11.6% increase in morning cortisol. Also, those with a higher BMI had lower or blunted morning cortisol values. Each 1-unit increase in BMI was related to a 2.76% decrease in waking cortisol, $p < .05$. All other predictor variables were non-significant.

Higher ECQR was not related to DCS, estimate = .003, *SE* = .003, $p = .301$. Thus, Hypothesis 1a that ECQR would be related to a flatter slope was not supported. Furthermore, the interaction between gender and rumination on DCS was in the expected direction, but was not statistically significant, estimate = -.006, *SE* = .004, $p = .072$. Thus, hypothesis 1b that women with higher ECQR scores would have flatter DCS than men with higher ECQR scores was not statistically supported.

Table 2

Parameter Estimates of the Multilevel Model Examining Stressor-Related Rumination and Diurnal Cortisol Slope (n = 870)

		Parameter	Model 1	Model 2	Model 3
Fixed Effects	Intercept	γ_{00}	2.60**	1.55**	1.57**
	Time	γ_{10}	-.079**	-.089†	-.104*
	Mean-Wake[a]	γ_{01}		.112*	.110*
	BMI[b]	γ_{02}		-.028*	-.028*
	SR[c]	γ_{03}		.007	.004
	Gender[d]	γ_{04}		.058	.062
	Day	γ_{05}		.006	.006
	Gender*SR	γ_{06}			.007
	Time*Mean-Wake	γ_{11}		.002	.004
	Time*BMI	γ_{12}		.001	.001
	Time*Gender	γ_{13}		.002	-.001

	Time*SR	γ_{14}		-.001	.003

Table 2: Continued

	Time*Day	γ_{15}		-.004	-.004
	Time*Gender*SR	γ_{16}			-.006[†]
Level 1	Within-person	U_{0oi}	.402**	.404**	.404**
Level 2	Morning Value	U_{0i}	.201**	.182**	.183**
	Time	U_{1i}	.002**	.001**	.001**
Model fit					
	Deviance		1918.92	1844.8	1841.1
	Parameters		6	16	18
	$\chi 2$ p-value			<.001	

[†]p <.10 * $p < .05$, ** $p < .01$ for the *T*-test parameters
[a]Wake-time was measured in hours
[b]Body Mass Index (BMI)
[c]Stressor-related rumination (SR)
[d]Gender was coded as 0 = women, 1 = men.

RRS (Hypotheses 2a,b)

Likewise, higher brooding rumination measured by the RRS was expected to be related to a flatter DCS across the study days. Further, gender was expected to moderate this association such that women higher in brooding rumination have flatter DCS than men higher in brooding rumination across the study days. The same procedures for formulating the multilevel model were done as noted above.

As shown in Table 3, all lower order interaction terms were non-significant. Further, higher brooding was not related to a flatter DCS, estimate = -.002, *SE* = .003, *p* = .552. Thus, Hypothesis 2a was not supported. Furthermore, the expected interaction between gender and brooding on DCS was not significant, estimate = .001, *SE* = .004, *p* = .863. Thus, hypothesis 2b was not supported. In sum, higher brooding rumination was not related to flatter DCS, and gender did not moderate the relationship between brooding rumination and DCS.

Table 3

Parameter Estimates of the Multilevel Model Examining Brooding Rumination and Diurnal Cortisol Slope (n = 870)

		Parameter	Model 1	Model 2	Model 3
Fixed Effects	Intercept	γ_{00}	2.60**	1.53**	1.37**
	Time	γ_{10}	-.079**	-.093†	-.09†
	Mean-Wake[a]	γ_{01}		.115**	.132**
	BMI[b]	γ_{02}		-.029*	-.028*
	Brooding	γ_{03}		-.005	.022
	Gender[c]	γ_{04}		.054	.033
	Day	γ_{05}		.006	.007
	Gender*Brooding	γ_{06}			-.054†
	Time*Mean-Wake	γ_{11}		.002	.002
	Time*BMI	γ_{12}		.000	.000
	Time*Gender	γ_{13}		.003	.003
	Time*Brooding	γ_{14}		-.002	-.002

	Time*Day	γ_{15}		-.004	-.004

Table 3: Continued

	Time*Gender*Brooding	γ_{16}			.001
Level 1	Within-person	U_{0oi}	.402**	.404**	.404**
Level 2	Morning Value	U_{0i}	.201**	.183**	.175**
	Time	U_{1i}	.002**	.001**	.001**
Model fit					
	Deviance		1918.9	1843.9	1840.6
	Parameters		6	16	18
	$\chi 2$ p-value			<.001	

[†]p <.10 * $p < .05$, ** $p < .01$ for the *T*-test parameters
[a]Wake-time was measured in hours
[b]Body Mass Index (BMI)
[c]Gender was coded as 0 = women, 1 = men

Exploratory Aims

The effects of pondering, measured by the RRS, and pondering by gender interaction on DCS was explored. As shown in Table 4, pondering (M = 9.36, SD = 3.25) was not significantly related to DCS, estimate = -.001, SE = .002, p = .803. Further, gender did not significantly moderate the relationship between pondering and DCS, estimate = .001, SE = .004, p = .83.

Table 4

Parameter Estimates of the Multilevel Model Examining Pondering Rumination and Diurnal Cortisol Slope (n = 870)

		Parameter	Model 1	Model 2	Model 3
Fixed Effects	Intercept	γ_{00}	2.60**	1.52**	1.52**
	Time	γ_{10}	-.079**	-.09†	-.09†
	Mean-Wake[a]	γ_{01}		.113*	.113**
	BMI[b]	γ_{02}		-.030*	-.031*
	Pondering	γ_{03}		.024	.025
	Gender[c]	γ_{04}		.045	.043
	Day	γ_{05}		.006	.006
	Gender*Pondering	γ_{06}			-.056†
	Time*Mean-Wake	γ_{11}		.002	.002
	Time*BMI	γ_{12}		.001	.001
	Time*Gender	γ_{13}		.002	.003

	Time*Pondering	γ_{14}		.000	-.001

Table 4: Continued

	Time*Day	γ_{15}		-.004	-.004
	Time*Gender*Pondering	γ_{16}			.001
Level 1	Within-person	U_{0oi}	.402**	.404**	.404**
Level 2	Morning Value	U_{0i}	.201**	.175**	.175**
	Time	U_{1i}	.002**	.001**	.001**
Model fit					
	Deviance		1918.9	1841.7	1840.7
	Parameters		6	16	18
	$\chi 2$ p-value			<.001	

[†]p <.10 * $p < .05$, ** $p < .01$ for the *T*-test parameters
[a]Wake-time was measured in hours
[b]Body Mass Index (BMI)
[c]Gender was coded as 0 = women, 1 = men.

Given brooding and stressor-related rumination shared substantial variance in this study (r = .526, p < .01) and others (e.g., Siegle et al., 2004), I formulated a multilevel model including both brooding rumination, stressor-related rumination, and their higher-order gender interaction terms to examine the unique predictive ability of each construct. As shown in Table 5, the expected interaction between gender and brooding rumination on DCS was non-significant, estimate = .005, *SE* = .004, p = .225. In contrast, the expected interaction between gender and stressor-related rumination on DCS was significant, estimate = -.009, *SE* = .004, p = .035. The follow interpretations are based on visual inspection: As shown in Figure 1, when controlling for brooding rumination, among women, those higher in stressor-related rumination had higher evening cortisol values than women lower in stressor-related rumination, and thus flatter DCS; among men, those higher in stressor-related rumination had lower evening and higher morning cortisol than those men lower in stressor-related rumination, and thus a steeper DCS with respect to diurnal cortisol decline, when controlling for brooding rumination (see Figure 2). Further, women higher in stressor-related rumination had flatter DCS than men higher in stressor-related rumination, when controlling for brooding rumination (see Figure 3).

Table 5

Parameter Estimates of the Multilevel Model Examining Stressor-Related Rumination, Brooding Rumination, and Diurnal Cortisol Slope (n = 870)

		Parameter	Model 1	Model 2	Model 3
Fixed Effects	Intercept	γ_{00}	2.60**	1.53**	1.40**
	Time	γ_{10}	-.079**	-.093†	-.097*
	Mean-Wake[a]	γ_{01}		.115*	.128*
	BMI[b]	γ_{02}		-.030*	-.032*
	SR[c]	γ_{03}		.012	-.009
	Brooding	γ_{04}		-.011	.026
	Gender[d]	γ_{05}		.057	.045
	Day	γ_{06}		.006	.007
	Gender*SR	γ_{07}			.044
	Gender*Brooding	γ_{08}			-.078*

	Time*Mean-Wake	γ_{11}		.002	.003

Table 5: Continued

	Time*BMI	γ_{12}		.000	.001
	Time*Gender	γ_{13}		.003	.001
	Time*SR	γ_{14}		.000	.004
	Time*Brooding	γ_{15}		-.001	-.004
	Time*Day	γ_{16}		-.004	-.004
	Time*Gender*SR	γ_{17}			-.009*
	Time*Gender*Brooding	γ_{18}			.005
Level 1	Within-person	U_{0oi}	.402**	.404**	.404**
Level 2	Morning Value	U_{0i}	.201**	.182**	.171**
	Time	U_{1i}	.002**	.001**	.001**
Model fit					
	Deviance		1918.9	1843.3	1835.4

Parameters	6	18	22

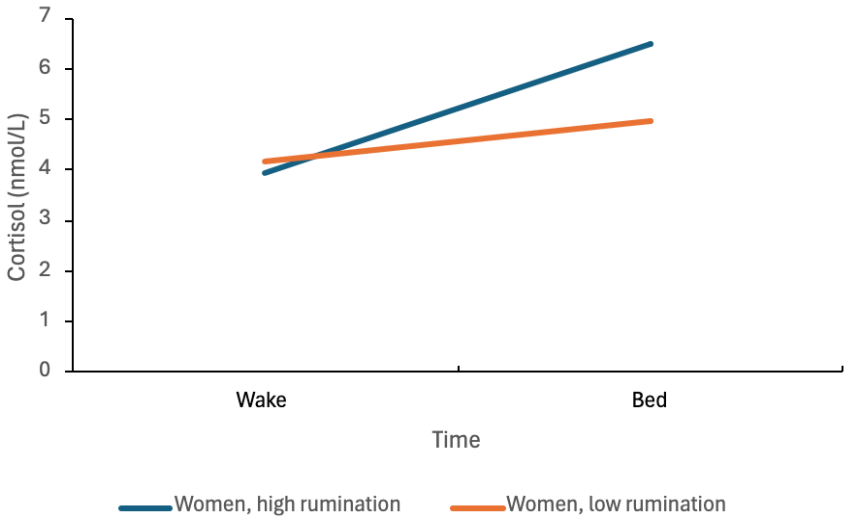
Table 5: Continued

$\chi 2$ p-value	<.001

[†]p <.10 * $p < .05$, ** $p < .01$ for the *T*-test parameters
[a]Wake-time was measured in hours
[b]Body Mass Index (BMI)
[c]Stressor-related rumination (SR)
[d]Gender was coded as 0 = women, 1 = men.

Figure 1

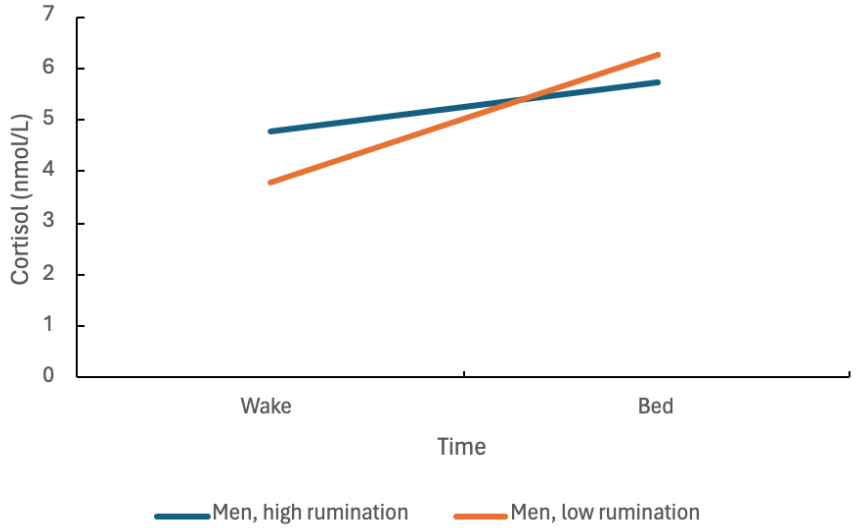
Stressor-Related Rumination and Diurnal Cortisol Slope for Women



Note. Estimated means were calculated using unstandardized coefficients for subjects scoring one standard deviation above and below the mean trait rumination score on day one while fixing brooding, wake time, and BMI at the grand-mean.

Figure 2

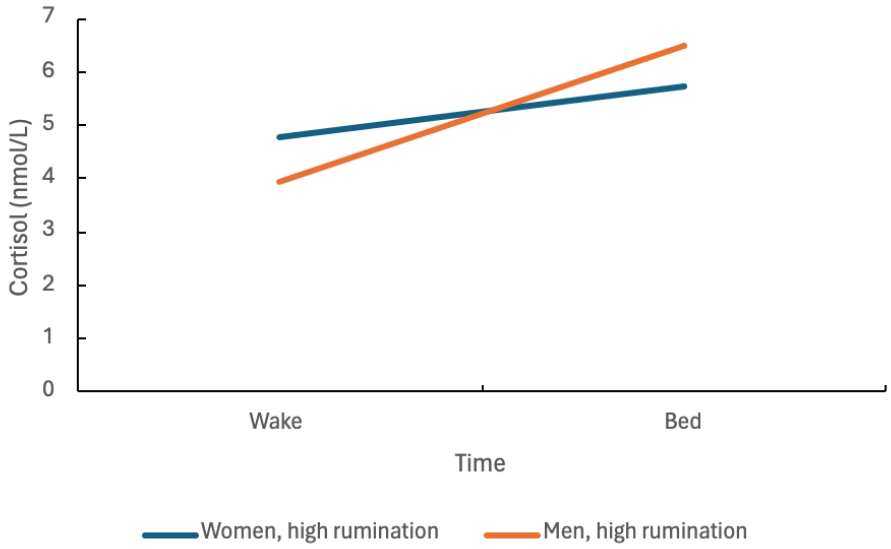
Stressor-Related Rumination and Diurnal Cortisol Slope for Men



Notes. Estimated means were calculated using unstandardized coefficients for subjects scoring one standard deviation above and below the mean trait rumination score on day one while fixing brooding, wake time, and BMI at the grand-mean.

Figure 3

Diurnal Cortisol Slope Between Men and Women High in Stressor-Related Rumination



Notes. Estimated means were calculated using unstandardized coefficients for subjects scoring one standard deviation above and below the mean trait rumination score on day one while fixing brooding, wake time, and BMI at the grand-mean.

Discussion

The goal of the present study was to investigate the effect of trait rumination on diurnal cortisol slope (DCS) across five days and to examine whether there are gender differences that qualify this relationship. This study analyzed two conceptualizations of rumination—stressor-related (Roger & Najarian, 1989) and brooding rumination (Nolen-Hoeksema et al., 1991)—which have both been linked to altered and maladaptive diurnal cortisol patterns (e.g., McCullough et al., 2007; Hilt et al., 2017; Rnic et al., 2022). However, there has been a lack of consensus as to which rumination measures correspond to different aspects of the diurnal rhythm (Rnic et al., 2022; Rydstedt et al., 2011). Taking evidence from the laboratory of prolonged HPA axis activation during rumination (Zoccola et al., 2008), I expected both types of rumination in a naturalistic setting would lead to flatter DCS via prolonged HPA axis activation. Further, consistent with growing evidence of gender differences between rumination and HPA axis activation (Zoccola & Dickerson, 2015; Shull et al., 2016), I predicted this effect would be exacerbated in women higher in rumination. I also explored whether pondering (Treynor et al., 2003) rumination was related to altered DCS and whether this was qualified by gender. Lastly, I explored whether both types of rumination predicted DCS in the presence of each other to examine their unique predictive ability.

Contrary to my hypotheses, both stressor-related and brooding-related rumination alone were not significantly related to DCS across five days. However, in line with hypothesizing, there was a non-significant trend for gender moderating stressor-related rumination effects on DCS, such that women higher in stressor-related rumination

exhibited a non-significant trend toward flatter DCS than women lower in stressor-related rumination. In contrast, and unexpectedly, men higher in rumination exhibited a non-significant trend toward steeper DCS than men lower in rumination. Additionally, women higher in stressor-related rumination exhibited a non-significant trend toward flatter DCS than men higher in stressor-related rumination. Thus, stressor-related rumination may be specifically related to flatter DCS, particularly in women. Indeed, the interaction between stressor-related rumination and gender became significant in the presence of brooding-rumination and its associated higher-order interaction term.

Stressor-Related Rumination, Gender, and DCS

The pattern suggesting that women higher in stressor-related rumination had flatter DCS than women lower in stressor-related rumination when controlling for brooding rumination is consistent with the perseverative cognition hypothesis (Brosschot et al., 2006), which postulates that rumination can prolong HPA-axis activation. This study adds further evidence to this theory and extends prior work (Zoccola & Dickerson, 2015) demonstrating that the tendency to ruminate on stressor-related themes in women may prolong HPA-axis activation in day-to-day life, in turn leading to flatter DCS across days. This study also shows nuance as this effect only occurred in women. Although men and women did not differ in trait rumination in this study, one possible explanation for the observed findings is that because historically girls ruminate on average more than boys (e.g., Rood et al., 2009) which continues into adulthood (Johnson & Whisman, 2013), women may be more practiced at this coping style. This is in line with studies only showing significant physiological responses from rumination in those high in trait rumination (e.g.,

Zoccola & Dickerson, 2015; Shull et al., 2016). Thus, the more practiced or natural the coping style is for an individual, perhaps the more physiological activation occurs. It will be important for future research to empirically evaluate this hypothesis.

A prior study found greater trait stressor-related rumination was related to greater state rumination over a 2-week period following a TSST among women, but trait and state rumination measures were not correlated among men (Zoccola et al., 2010). This finding suggests that perhaps trait rumination scores are more indicative of actual rumination in response to stress in women. Indeed, men consistently show less emotional awareness than women and report less articulate responses to simulated emotional scenarios even when controlling for intelligence (Barrett et al., 2000). Considering these studies alongside the current results, it is possible that men are less accurate in articulating their typical coping styles. This discrepancy may explain why flatter DCS was linked to stressor-related rumination in women only. This may further help explain the unexpected pattern suggesting that men higher in rumination had steeper DCS than men lower in rumination when controlling for brooding rumination, as DCS in men may not reflect ruminative processes to begin with. However, there are also other possible interpretations for the latter finding.

The pattern suggested men higher in stressor-related rumination had higher morning cortisol values than men lower and women higher in stressor-related rumination when controlling for brooding rumination. Results from one study employing EMA methodology showed rumination was highest in the morning and evenings (Moberly & Watkins, 2008) and other work has indicated elevated morning cortisol in those higher in

stressor-related rumination (Roger & Najarian, 1998) and greater perceived stress (Sladek et al., 2019). Thus, it is possible men may be more likely to ruminate in the morning and thus have typical or even steeper declines than men lower in rumination. Indeed, higher cortisol reactivity may be related to steeper or more intense down-regulation of cortisol during recovery (Lopez-Duran et al., 2014), which may be extrapolated to diurnal cortisol in the present context. Contrarily, women who were higher in rumination had higher evening cortisol levels than women lower in rumination in this study, in contrast with a prior study indicating higher waking cortisol in predominantly female nurses (Roger & Najarian, 1998). Thus, perhaps women higher in rumination are more likely to ruminate through the later hours of the day leading to the higher evening cortisol values observed in the current study and consequently, flatter DCS. Indeed, prior work has shown prolonged HPA activation from a psychosocial stressor up into the evening among women higher in stressor-related rumination (Zoccola & Dickerson, 2015).

Future work should examine momentary stressor-related rumination to examine if men and women tend to ruminate at different times of the day and the associated diurnal cortisol parameters. If men and women tend to ruminate at different times of the day, they likely respond differently in the face of stressors through appraisals or coping. For instance, gender stereotypes in women from an early age may instill a greater sense of dependence on those around them and subsequently less control over outcomes (Ruble et al., 1993) which may be related to greater co-rumination or rumination found in women (Johnson & Whisman, 2013; Dedovic et al., 2009). Further, a greater interpersonal orientation found in women in part mediated the gender difference in rumination (Nolen-Hoeksema & Jackson

2001). Given interpersonal stressors characterize the majority of day-to-day stressors and the ECQ-R (Roger & Najarian, 1989) contains many interpersonally oriented items, women may ruminate throughout the day in the face of interpersonal stressors more readily than men. Perhaps this occurs particularly in the latter parts of the day (Moberly & Watkins, 2008), whereas men may show more of an anticipatory ruminative response at the beginning of the day prior to facing stressors. Given no research to date has examined gender differences between trait rumination and diurnal cortisol, future research is warranted to investigate these possibilities.

Lack of Rumination Main Effects

Although inconsistent with my hypothesizing, the results revealed no main effect of trait rumination (either stressor-related or brooding rumination) on DCS, which is partially consistent with prior work examining diurnal cortisol and rumination (Rnic et al., 2022; Huffziger et al., 2013), however contrary to other work that found an effect of trait rumination on DCS (Hilt et al., 2017). The latter study utilized a trait rumination measure that assessed trait rumination regarding interpersonal stressors over the last 3-months in adolescent girls (Hilt et al., 2017), which is perhaps more specific than asking how you generally respond in response to a variety of items (see **Appendix)**. In further support of temporal proximity, higher cortisol output was related to state depressive rumination (Huffziger et al., 2013) and higher stressor-related rumination over the past two weeks was related to higher afternoon cortisol levels (McCullough et al., 2007). Thus, assessing state rumination over the course of the day or trait rumination measures that center around more proximal events is likely to be more consistently linked to diurnal cortisol parameters.

Further, to the extent prolonged HPA-axis activation only occurs in women when ruminating (Zoccola & Dickerson, 2015; Shull et al., 2016), main effects of rumination may become less likely unless the study is adequately powered. Although there were more women in this study, rumination scores tended to vary less in women than in men, which may have further limited statistical power needed to detect a main effect. Nonetheless, main effects of rumination on prolonged HPA-axis activation were found to be driven by women in other studies (Zoccola & Dickerson, 2015; Shull et al., 2016). Supporting these studies, as noted above, women higher in stressor-related rumination had flatter DCS than men higher in stressor-related rumination and women lower in stressor-related rumination when controlling for brooding rumination.

Depressive Rumination, Gender, and DCS

Unlike stressor-related rumination, the expected relationship between brooding rumination and DCS as well as the proposed gender difference was not found in this study. Momentary negative emotions are linked to higher cortisol reactivity (Joseph et al., 2021), and thus ruminating about these negative emotions was predicted to lead to prolonged cortisol activation reflected in DCS, particularly in women. However, there are some reasons why this may not have occurred. First, the sample was relatively high in depressive symptoms, with average scores approaching the cutoff for at-risk individuals for clinical depression (Weissman et al., 1977). Among clinically depressed samples or those scoring high on depressive inventories, blunted cortisol responses have been observed (Burke et al., 2005). In addition, laboratory studies inducing rumination or sadness have not found a main effect of rumination on cortisol reactivity (LeMoult & Joorman, 2014; Kuehner et al.,

2009); this is in contrast with a meta-analysis that found a positive association between negative mood and cortisol, although the majority of negative emotions were anxiety-related which may have driven the effects (Joseph et al., 2021). Thus, sad mood may not activate the HPA axis reliably and thus individuals in this study may not have experienced robust enough HPA activation to reflect altered DCS, consistent with the assumptions given by the perseverative cognition hypothesis of initial activation (Brosschot et al., 2006). Consequently, there may not be gender differences to detect in the relationship between depressive rumination and DCS.

Moreover, when both stressor-related and brooding rumination were simultaneously entered into one model, the interaction of gender and stressor-related rumination became significant whereas the same pattern of results was only trending with just stressor-related rumination in the model. Perhaps brooding rumination functioned as a suppressor variable, and thus including both variables removed shared variance to allow the unique effects of each to predict DCS. Given stressor-related and depressive-related rumination were moderately correlated in this sample along with the above reasoning about brooding rumination not being related to altered DCS, it is conceivable this noise obfuscated the relationship between gender and stressor-related rumination with DCS in the initial model.

Pondering, Gender, and DCS

Also, an exploratory analysis revealed that higher pondering was not related to an altered DCS which was subsequently not qualified by gender. This is in line with prior work showing pondering is either related to more adaptive diurnal cortisol parameters or

is not related (Rnic et al., 2022) and other work suggesting pondering is not as strongly related to negative affect (Olatunji et al., 2013; Moberly & Watkins, 2008; Treynor et al., 2003) as brooding. However, neither subtype of depressive rumination showed a maladaptive diurnal cortisol profile in this study. Thus, depressive rumination may not be related to altered DCS, although depression and depression symptoms are related to flatter DCS (Adam et al., 2017; Sjögren, Leanderson, & Kristenson, 2006).

Strengths and Limitations

There were notable strengths to this study. First, this study investigated five days of intensive longitudinal data collection to examine DCS. Prior studies investigating trait rumination and cortisol typically only examined up to 3 days at the most (Hilt et al., 2017), whereas more has been recommended to capture stable individual differences (Segerstrom et al., 2014). Second, this study analyzed gender as a moderator to distill otherwise obscured differences to further illustrate the relationship between rumination and DCS. However, given the valid cortisol cases accounted for approximately 70% of all potential cases, future studies should proactively increase data collection efforts to account for potential invalid and missing cases.

Also, no causal claims can be made about the relationship between gender, rumination, and DCS given the cross-sectional nature of capturing rumination once. Although I have interpreted the present findings to suggest that trait stressor-related rumination may lead to elevated morning cortisol for men and elevated evening cortisol for women, 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, Fabiansson, Creswell, & Pedersen, 2009; Zoccola et al., 2014). The results of these experiments make it difficult to attribute the present findings to spuriousness or reverse causation, but future work should continue to examine changes in rumination throughout the day that are temporally proximal to collected cortisol samples and control for reasonable confounds, covariates, and proximal mechanisms including stressor appraisals and emotional states to better make causal claims and elucidate underlying mechanisms.

Sample characteristics may have served as both a strength and a limitation in this investigation. The relatively large sample allowed the investigation of complex interactions among key variables which had often gone unexamined or undetected in prior work. The current sample was ethnically diverse and comprised undergraduate students, the former increasing generalizability and the latter being a strength because young adults may be particularly susceptible to rumination compared to older adults who typically demonstrate decreased rumination and enhanced emotion regulation (e.g., Nolen-Hoeksema & Aldao, 2011). It will be important for future research to examine the relationships tested here across the lifespan.

On the other hand, gender was only measured in a binary fashion and did not include any information on gender role attitudes, sex hormones, or the dissociation between gender identity and sex (Dedovic et al., 2009). Consequently, I am unable to examine the extent to which biological and psychosocial factors contribute to the present findings. For

instance, men may have larger cortisol responses to gender stereotyped achievement stressor tasks whereas women may have larger cortisol responses to social stressor tasks including rejection (Stroud et al., 2002). As priorly mentioned, given interpersonal stressors characterize the majority of day-to-day stressors (Almeida et al., 2005), perhaps women are more likely to experience daily prolonged cortisol output particularly in conjunction with rumination. Furthermore, estrogen fluctuations across the menstrual cycle interact with the HPA axis such that females display potentiated cortisol reactivity during the luteal phase in a manner similar to that observed in men (Kudielka & Kirschbaum, 2005), thus future work should also examine the rumination and cortisol associations across the menstrual cycle in females. In addition, measures of gender identity and gender role attitudes should be considered in future investigations.

Implications

Overall, the results of this study suggest women who tend to ruminate about stressors may have a greater physiological toll than men counterparts over and above depressive rumination reflected in flatter DCS. Flatter DCS are causally implicated or symptomatic of pathophysiology which are linked to mental health outcomes (Adam et al., 2017) such as depression symptoms (Sjögren, Leanderson, & Kristenson, 2006). Since the COVID-19 pandemic, depression and anxiety disorders have increased drastically, disproportionately afflicting women by over two-fold (Institute of Health Metrics and Evaluation, 2021). Thus, developments of rumination interventions need to be continually created and improved. Indeed, a recent intervention accessible as a smartphone app aimed to modify cognitive biases associated with rumination showed substantial promise in

reducing brooding rumination, anxiety, and the associated cognitive biases measured during the lockdown period of the COVID-19 pandemic (Blanco et al., 2023). Thus, the public health sector can aim to increase the accessibility and knowledge of this intervention and other brief psychological interventions (McCarrick et al., 2021). Future research should examine how these training programs can influence DCS, which may serve as an objective tool to further validate the efficacy of these interventions and track reductions in the gender health disparity that is driven in part by rumination (Nolen-Hoeksema, 2012). Perhaps other cortisol parameters than DCS can be examined in men higher in rumination to track intervention efficacy, which future work needs to uncover.

Conclusions

To conclude, women higher in stressor-related rumination may have flatter DCS than women lower and men higher in stressor-related rumination, above the effects of brooding rumination. On the other hand, depressive rumination—including both brooding and pondering—was not related to DCS or differential effects in men and women. Future work should examine more temporally proximal measures of rumination such as state rumination in an EMA setting to further delineate the relation of rumination in altering diurnal cortisol parameters in men, women, and other genders. Ultimately, further efforts by researchers, public health officials, and the government are needed to attenuate rumination and subsequently the gender health gap and promote health (Huber et al., 2016), in turn restoring proper flow that has been at the heart of psychosomatic medicine for millennia.

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Appendix A: Lab and Daily Diary Questionnaires

Lab Questionnaires

Positive and Negative Affect Schedule (PANAS; Watson, Clark, & Tellegan, 1988); Fear of Rejection Scale (FOR; Mehrabian, 1976); Hope for affiliation (Jackson, 1967); Ruminative Responses Scale (Nolen-Hoeksema & Morrow, 1991); Center for Epidemiologic Studies Depression Scales (CES-D; Radloff, 1977) ; Spielberger State-Trait Anxiety Scale (STAI; Spielberger, Gorsuch, Lushene, Vagg, & Jacobs, 1983); Rumination subscale of the Revised Emotion Control Questionnaire (ECQ-R; Roger & Najarian, 1989); Fear of Negative Evaluation Scale (FNE; Watson & Friend, 1969); Multi-Motives Grid (MMG; Schmalt, 1999); Reactions to Daily Events; Emotional Approach Coping (EAC; Stanton et al., 2000); Emotional Regulation (ERQ; Gross & John, 2003); Maslach Burnout Inventory (MBI-GS; Maslach et al., 1987); Pre/post-TSST appraisals/cognitions/emotions; Perceived Social Stress (PSS; Cohen et al., 1983); Recent stressful events appraisals; Positive and Negative Social Exchanges (PANSE; Newsom et al, 2005); Interpersonal Support Evaluation List–shortened version (ISEL-12; Cohen et al., 1985) Health history/behaviors; menstrual cycle; Pittsburgh Sleep Quality Index (PSQI; Buysee et al., 1989); Big Five Inventory (BFI; John & Srivastava, 1999); Mindful Attention Awareness Scale (MAAS; Brown & Ryan, 2003); Self-Compassion Scale (SCS; Neff, 2003).

TRAIT RUMINATION MEASURES

RRS

Ruminative Responses Scale (RRS; Nolen-Hoeksema & Morrow, 1991). Note: bold is the brooding subscale, asterisk is the pondering subscale.

People think and do many different things when they feel sad, blue, or depressed. Indicate below whether you never, sometimes, often, or always think or do each of the following when you feel down, sad, or depressed. Please indicate what you generally do, not what you think you should do.

1 (almost never) 2 (sometimes) 3 (often) 4 (almost always) REFUSED

1. Think about how alone you feel
2. Think "I won't be able to do my job if I don't snap out of this."
3. Think about your feelings of fatigue and achiness
4. Think about how hard it is to concentrate
5. **Think "What am I doing to deserve this?"**
6. Think about how passive and unmotivated you feel
7. Analyze recent events to try to understand why you are depressed*
8. Think about how you don't seem to feel anything anymore
9. Think "Why can't I get going?"
10. **Think "Why do I always react this way?"**
11. Go away by yourself and think about why you feel this way*

12. Write down what you are thinking and analyze it*
13. T**hink about a recent situation, wishing it had gone better**
14. Think “I won’t be able to concentrate if I keep feeling this way.”
15. **Think “Why do I have problems other people don’t have?”**
16. **Think “Why can’t I handle things better?”**
17. Think about how sad you feel
18. Think about all your shortcomings, failings, faults, and mistakes
19. Think about how you don’t feel up to doing anything
20. Analyze your personality to try to understand why you are depressed*
21. Go someplace alone to think about your feelings*
22. Think about how angry you are with yourself

ECQ-R

The Rehearsal or Rumination subscale of the Revised Emotion Control Questionnaire (ECQR; Roger & Najarian, 1989)

Please indicate how you feel about each item by checking either “TRUE” or “FALSE.” If you feel that an item is neither entirely true nor false, please choose the alternative that is most like you. If you haven't been in the situation described, please say how you feel you would behave in that situation.

True False Refused

1. I remember things that upset me or make me angry for a long time afterwards.
2. I generally don't bear a grudge - when something is over, it's over, and I don't think about it again. --Reverse coded

3. I get "worked up" just thinking about things that have upset me in the past.
4. I often find myself thinking over and over about things that have made me angry.
5. I can usually settle things quickly and be friendly again after an argument. --Reverse coded
6. If I see or hear about an accident, I find myself thinking about something similar happening to me or to people close to me.
7. I think about ways of getting back at people who have made me angry long after the event has happened.
8. I never forget people making me angry or upset, even about small things.
9. I find it hard to get thoughts about things that have upset me out of my mind.
10. I often daydream about situations where I'm getting back at people.
11. If I see something that frightens or upsets me, the image of it stays in my mind for a long time afterwards.
12. Thinking about upsetting things just seems to keep them going, so I try to put them out of my mind. --Reverse coded
13. If I lose out on something, I get over it quickly. --Reverse coded
14. If I have to confront someone, I try not to think too much about it beforehand. --Reverse coded

---

Daily Diary

Complete these questions right after getting out of bed. **[WAKE]**

[Paper booklet]

EMOTIONS

This scale consists of a number of words that describe different feelings and emotions. Read each item and then mark the appropriate answer in the space next to that word. Indicate to what extent you have felt this way RIGHT NOW. Use the following scale to record your answers.

1 (very slightly or not at all) 2 (a little) 3 (moderately) 4 (quite a bit) 5 (extremely)

_____ interested

_____ distressed

_____ excited

_____ upset

_____ strong

_____ guilty

_____ scared

_____ hostile

_____ enthusiastic

_____ proud

_____ irritable

_____ alert

_____ ashamed

_____ inspired

_____ nervous

_____ determined

_____ attentive

_____ jittery

_____ active

_____ afraid

_____ angry

_____ sad

_____ frightened

_____ joyful

_____ happy

_____ content

_____ calm

_____ rejected

_____ lonely

_____ accepted

_____ self-conscious

_____ embarrassed

ANTICIPATION

---

1. Over the next FEW HOURS, are you anticipating a negative event?

No Yes

If yes, how much does the event influence your emotions currently?

1 (very slightly or not at all) 2 (a little) 3 (moderately) 4 (quite a bit) 5 (extremely)

2. Over the next FEW HOURS, are you anticipating a positive event?

No Yes

If yes, how much does the event influence your emotions currently?

1 (very slightly or not at all) 2 (a little) 3 (moderately) 4 (quite a bit) 5 (extremely)

SLEEP

---

1. Bed time [the time that you were in bed and started to TRY to fall asleep—for example, if you watch tv in bed before sleep, only count from when you're actually trying to fall asleep (may or may not be the time that you get into bed)]

__:__

2. Wake up time [the time that you woke up—and no longer tried to sleep/accidentally fell back asleep. If you set an alarm and hit snooze—the "Wake" time would be the time that they finally got up]

___ : ___

3. Did you wake up with an alarm?

No Yes

4. Did you SNOOZE/FALL BACK ASLEEP after first waking up?

No Yes

5. Rate your overall sleep quality for last night:

_____1 – Very good

_____2 – Fairly good

_____3 – Fairly bad

_____4 – Very bad

6. Did you wake up throughout the night?

No Yes (if yes, how many times_____)

7. How long do you think it took you to fall asleep?

_____hr ____ min

8. Select the one option below which best describes how sleepy you RIGHT NOW:

_____1 – Feeling active and vital; alert; wide awake

_____2 – Functioning at a high level, but not at peak; able to concentrate

_____3 – Relaxed; awake; not at full alertness; responsive

_____4 – A little foggy; not a peak; let down

_____5 – Fogginess; beginning to lose interest in remaining awake; slowed down

_____6 – Sleepiness; prefer to be lying down; fighting sleep; woozy

_____7 – Almost in reverie (having dream-like thoughts); sleep onset soon; lost struggle to remain awake

Complete these questions throughout the day, after prompted by an electronic diary.

[Assessed at 12, 2, 4, 6 PM]

—----------

EMOTIONS (same as above)

SOCIAL ITEMS

---

1. Since the last beep, how often have you felt Accepted?

0 = Never 1 = Almost Never 2 = Sometimes 3 = Fairly Often 4 = Very Often

2. Since the last beep, how often have you felt Rejected?

0 = Never 1 = Almost Never 2 = Sometimes 3 = Fairly Often 4 = Very Often

3. Since the last beep, how often have you felt Criticized, Judged, or Evaluated?

0 = Never 1 = Almost Never 2 = Sometimes 3 = Fairly Often 4 = Very Often

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STRESS ITEMS

---

1. Since the last beep, how often have you felt Stressed?

0 = Never 1 = Almost Never 2 = Sometimes 3 = Fairly Often 4 = Very Often

2. Since the last beep, how often have you felt In Control?

0 = Never 1 = Almost Never 2 = Sometimes 3 = Fairly Often 4 = Very Often

3. Since the last beep, how often have you felt Resources to Cope?

0 = Never 1 = Almost Never 2 = Sometimes 3 = Fairly Often 4 = Very Often

—----------

ANTICIPATION (same as above)

—----------

EVENTS

---

1. Since the last beep, have you experienced a significant positive event?

No Yes (if yes, how many positive events_____)

If yes, think about the most significant positive event that you experienced since the last beep. Answer the following questions about this event.

a. How positive or pleasant was the event?

1 (very slightly or not at all) 2 (a little) 3 (moderately) 4 (quite a bit) 5 (extremely)

b. Were you alone during the event?

No Yes

c. Was the event due to your efforts (not chance)?

No Yes

2. Since the last beep, have you experienced a significant negative event?

No Yes (if yes, how many negative events_____)

If yes, think about the most significant negative event that you experienced since the last beep. Answer the following questions about this event.

a. How negative or unpleasant was the event?

1 (very slightly or not at all) 2 (a little) 3 (moderately) 4 (quite a bit) 5 (extremely)

b. Were you alone during the event?

No Yes

c. How threatening was the event?

1 (very slightly or not at all) 2 (a little) 3 (moderately) 4 (quite a bit) 5 (extremely)

d. How challenging was the event?

1 (very slightly or not at all) 2 (a little) 3 (moderately) 4 (quite a bit) 5 (extremely)

e. How in control of the event were you?

1 (very slightly or not at all) 2 (a little) 3 (moderately) 4 (quite a bit) 5 (extremely)

HEALTH BEHAVIORS

---

1. Since the last beep, have you had any cups of coffee (or 8-12 oz. servings of another caffeinated drink, i.e. cola)?

No Yes (if yes, how many cups of coffee or cola _____)

2. 1. Since the last beep, have you smoked any cigarettes?

No Yes (if yes, how many cigarettes _____)

3. Since the last beep, have you consumed any drinks containing alcohol (beer, wine, a mixed drink)?

No Yes (if yes, how many drinks containing alcohol _____)

4. Since the last beep, have you engaged in any physical exercise?

No Yes (if yes, how many minutes of exercise _____)

4. Since the last beep, have you taken any prescription or over-the-counter medication?

No Yes (if yes, please list _____)

Complete these questions throughout at the end of the day, after prompted by an electronic diary.

[Assessed at 8 PM]

EMOTIONS (see above)

Social Items (see above)

Stress Items (see above)

Events (see above)

Health Behaviors (see above)

END OF DAY SOCIAL ITEMS

Please rate your agreement with the following statements about today.

1. Today, I felt accepted by others and connected to them.

1 (very slightly or not at all) 2 (a little) 3 (moderately) 4 (quite a bit) 5 (extremely)

2. Today, I had enjoyable/fun times socializing with others.

1 (very slightly or not at all) 2 (a little) 3 (moderately) 4 (quite a bit) 5 (extremely)

3. Today, I had conflict/disagreements with others.

1 (very slightly or not at all) 2 (a little) 3 (moderately) 4 (quite a bit) 5 (extremely)

4. Today, I felt that others responded to my needs/wishes.

1 (very slightly or not at all) 2 (a little) 3 (moderately) 4 (quite a bit) 5 (extremely)

5. Today, I felt out of touch/disconnected from others.

1 (very slightly or not at all) 2 (a little) 3 (moderately) 4 (quite a bit) 5 (extremely)

RUMINATION/WORRY ITEMS (Only assessed at end of day)

---

1. Today, were there times when you tended to “ruminate” or dwell over negative things that happened to you or upset you ANY TIME IN THE PAST? (In other words, did you replay or rehash situations in your mind?)

No Yes

(If No, skip next two questions)

2. How hard was it to get these thoughts out of your mind?

Very Easy (1) --> Very Hard (7)

3. How upset or “worked up” did you get over these thoughts?

Not at all upset (1) --> Very upset (7)

4. Describe what these thoughts were about.

5. Today, were there times when you tended to worry or focus on negative things that may occur or happen to you in the future?

No Yes

(If No, skip next two questions)

6. How hard was it to get these thoughts out of your mind?

Very Easy (1) --> Very Hard (7)

7. How upset or "worked up" did you get over these thoughts?

Not at all upset (1) --> Very upset (7)

8. Describe what these thoughts were about.

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