Mindfulness, Rumination, and Stress Recovery: Investigation of the Effects of Mindfulness on Rumination and Cortisol Responses following a Social-Evaluative Stressor

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This thesis titled
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Abstract

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Mindfulness, Rumination, and Stress Recovery: Investigation of the Effects of Mindfulness on Rumination and Cortisol Responses following a Social-Evaluative Stressor

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Biological models of mindfulness suggest that mindfulness is able to affect a variety of health outcomes by reducing physiological stress reactivity (i.e., an increase or change from resting states). Although some support exists for this view, the stress literature suggests that stress recovery (i.e., a return to resting states) is a better or at least equivalent predictor of long-term health outcomes compared to stress reactivity. Further, mindfulness tends to be negatively associated with coping strategies like rumination which have been shown to inhibit stress recovery. Thus, the purpose of the present study is to test for the direct and indirect (via a reduction in state stress-related rumination) effects of mindfulness on cortisol reactivity and recovery. Cortisol is a stress hormone of the hypothalamic-pituitary-adrenal (HPA) axis, which is critical to many health processes. Participants in the study were subjected to a stressful speech task, and subsequently asked to report the extent to which they ruminated over the speech task. Salivary cortisol was measured at various time points during the study to capture baseline, peak levels, and expected return to baseline. Contrary to hypotheses, high trait mindfulness predicted increased cortisol reactivity and was unrelated to state stress-related rumination. The relationship between state stress-related rumination and cortisol
recovery was mixed. In conclusion, the present study was not able to replicate previous findings suggesting that trait mindfulness reduces cortisol reactivity. Furthermore trait mindfulness (as assessed with the Mindful Attention Awareness Scale) does not appear to improve health by reducing cortisol recovery directly or indirectly (i.e., via reduction in state stress-related rumination). Implications for current theories and suggestions for future research are discussed.
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Introduction

Mindfulness, which is the practice of observing and appraising inner experience in a non-judgmental way, is becoming an increasingly popular subject of research (e.g., Kabat-Zinn, 2003; Mars & Abbey, 2010). A driving force behind mindfulness’ scientific popularity lies in its association with numerous positive health outcomes. For example, Mindfulness Based Stress Reduction (MBSR) programs and Mindfulness Based Cognitive Therapy (MBCT) have been found to be effective treatments for alcohol and drug users (Alterman, Koppenhaver, Mulholland, Ladden, & Baime, 2004), patients suffering from fibromyalgia (Astin et al., 2003), cancer (Monti et al., 2006; Shapiro, Bootzin, Figueredo, Lopez, & Schwartz, 2003), multiple sclerosis (Mills & Allen, 2000), and heart disease (Robert McComb, Tacon, Randolph, & Caldera, 2004; Weissbecker et al., 2002). Creswell and Lindsay (2014) suggest that mindfulness leads to positive health outcomes by buffering against stress. They propose that mindfulness reduces the extent to which individuals appraise events as stressful and physiologically react to stressors.

Although the mindfulness stress buffering account has received initial support from controlled laboratory experiments (Brown, Weinstein, & Creswell, 2012; Nykliček, C, Van Beugen, Ramakers, & Van Boxtel, 2013), the account does not include factors (e.g., rumination) that can prolong stress recovery (i.e., a return to a resting state, or baseline levels). Yet some suggest that recovery from stressors is a better or at least equivalent predictor of long term health outcome than stress reactivity (i.e., a change or increase from baseline levels; Radstaak, Geurts, Brosschot, Cillessen, & Kompier, 2011). Rumination, which is defined as a mental rehearsal of past stressful events (Zoccola &
Dickerson, 2012), has been shown to prolong stress recovery to acute stressors in controlled laboratory experiments (Zoccola, Figueroa, Rabideau, Woody, & Benencia, 2014). Furthermore, measures of repetitive thoughts (including rumination) are generally negatively related to trait mindfulness (Deyo, Wilson, Ong, & Koopman, 2009; Evans & Segerstrom, 2011; Feldman, Greeson, & Senville, 2010). Thus, the present study investigated if mindfulness leads to positive health outcomes by reducing not only stress reactivity, but also improving stress recovery via a reduction in state stress-related rumination. The purpose of the present project was to investigate this claim by examining the relationship between trait mindfulness, state stress-related rumination, and the stress hormone cortisol in a controlled laboratory setting.

**Mindfulness**

Mindfulness is “self-regulation of attention so that it is maintained on immediate experience, thereby allowing for increased recognition of mental events in the present moment” and “adopting a particular orientation toward one’s experience that is characterized by curiosity, openness, and acceptance (p. 232)” (Bishop et al., 2006). Mindfulness is considered to be a process; it is often compared to a skill that can be acquired and perfected (Bishop et al., 2006). Unfortunately, little to no consensus currently exists as to the best definition of mindfulness (Chiesa, 2012). Some mindfulness researchers (Gilpin, 2008; Rapgay & Bystrisky, 2009) have argued that a thorough understanding of mindfulness should be attained from a review of its Buddhist origins. In the Buddhist tradition, a series of practices and insights are thought to guide the development of mindfulness via meditation. Goleman (1977) suggests that two major
types of meditation exist: concentration and mindfulness meditation. Concentration meditation involves a complete focus of attention onto a very specific element of the present experience. The subject of focus is usually a monotone stimuli such as breathing, an abstract image, or a chant. Conversely, mindfulness meditation entails an open monitoring of the present experience. In other words, mindfulness meditation leads one to focus indiscriminately on present thoughts, sensations, and emotions. When practicing meditation, novice meditators are generally instructed to redirect their full attention onto the meditative target in the event that their mind has wandered off. They are also encouraged to hold an accepting and non-judgmental attitude towards their experience so as to avoid a feedback loop in which meditators become aware that their mind has wandered off and begin to pay attention to their difficulties with staying on task rather than the meditative target.

Although concentration and mindfulness meditation may appear contradictory in terms of attentional focus, their practice is thought to be complementary (Chambers, Gullone, & Allen, 2009). More specifically, concentration meditation often precedes mindfulness meditation because its mastery is less effortful and is thought to ease the transition into mindfulness meditation (Chiesa, 2012). Eventually, the target of one’s attentional focus should shift from a single focal point to all present moment to moment experiences (Lutz, Slagter, Dunne, & Davidson, 2008), thus marking the transition from concentration to mindfulness meditation. The hypothesized result of this development is to perceive experiences without their projective or associative meanings (Thera, 1973).
In light of the Buddhist viewpoint of mindfulness, it becomes clear that certain elements are necessary for its development (Bishop et al., 2006). First, one must hold an accepting attitude towards the present experience (including an accepting attitude towards one’s failures to self-regulate attention). Then, one must practice self-regulation of attention via concentration and/or mindfulness meditation. Eventually, a state of mindfulness generalizes from meditation to one’s day to day experience. Although there is no clear cutoff point at which one successfully applies meditative skills to everyday life, individuals are encouraged to apply meditative skills to everyday events while learning them, and mindfulness researchers often categorize individuals with over six month of experience in meditation as “experienced meditators” (Strick, van Noorden, Ritskes, de Ruiter, & Dijksterhuis, 2012). Supporting an eventual generalization of mindfulness skills, Bishop et al. (2006) suggest that the effects of mindfulness are not limited to the meditation timeframe; they state: “Although mindfulness-based interventions rely on meditation techniques to teach the necessary skills for evoking mindfulness, we hypothesize that this mode of awareness is not limited to meditation. Once the skills are learned, attention can be regulated to evoke mindfulness in many situations, thus allowing the student to respond skillfully to situations that provoke emotional reactions (p. 234-235).” Thus, mindfulness is a state that can develop into a trait-like quality for individuals, and the ability to transition into this state often develops through meditation. Once developed, mindfulness skills are thought to affect various aspects of daily life (e.g., day to day emotional reaction). One should note that even if a conceptual definition of mindfulness based on present moment awareness and acceptance
is accurate, mindfulness may remain difficult to measure. Although the Buddhist approach provides an elegant theoretical understanding of mindfulness, evidence based research aiming to investigate the construct of mindfulness still faces significant challenges in spite of decades of work.

Mindfulness is generally operationalized using self-report scales, behavioral measures, or intervention programs. Self-report scales can measure either state (i.e., the extent to which individuals experienced a state of mindfulness during a specific window of time) or dispositional mindfulness (i.e., the extent to which individuals experience mindful states across time and situations). Although meditation training is thought to affect trait levels of mindfulness, non-training related factors (e.g., genetic predisposition, socialization, and attention-specific training) also lead to natural variations in trait mindfulness (Brown, Creswell, & Ryan, 2015). Behaviorally, some suggest that the extent to which individuals experience mind wandering (i.e., task unrelated thoughts) is a behavioral indicator of lack of mindfulness (Christoff, Gordon, Smallwood, Smith, & Schooler, 2009). Nevertheless, given the subjective nature of mindfulness, it is unlikely that it may be reduced to any single behavioral assessment; such an approach would be inconsistent with most mindfulness definitions available. Finally, interventions like the Mindfulness Stress Reduction Program (MBSR) have also been used to operationalize the construct of mindfulness. MBSR entails that individuals meet once a week (over an 8-10 week period) to learn meditative practices, discuss the use of mindfulness techniques, and obtain daily 45 min. meditation/yoga homework assignments (Grossman, Niemann, Schmidt, & Walach, 2004). Individuals who undergo such interventions
generally display increased dispositional mindfulness, and various functional improvements (e.g., symptom reduction, improved mood, and stress reduction). Given that the present investigation is limited to self-report measures, the following section discusses evidence for the leading mindfulness factor structure and criticism of self-report measures.

A Conceptual Model of Mindfulness

Numerous attempts have been made to identify a factor structure for the construct of mindfulness. Bishop et al. (2006) proposed a two component model that mirrors the suggestions provided by the Buddhist conceptualization. The model entails: (1) self-regulation of attention, generally maintained on the present experience (sensations, cognitions, and emotions), and (2) an open, curious, and accepting attitude towards the present experience, including failures to regulate attention. Further, they suggest that the concept of mindfulness is more reflective of a state than a trait, though individuals vary in their ability to engage in mindfulness and the frequency to which they experience mindful states in daily life.

Recent research provides support for the attention regulation component of the Bishop et al., (2006) model using a variety of methods. For example, Hodgins & Adair (2010) found evidence that individuals who were more experienced in mindfulness tend to display more efficient and flexible visual perceptual processing relative to less experienced individuals. They found that experienced meditators outperformed non-meditators on a change blindness flickering task, a concentration task, a visual selective attention task, and perspective switching task. In addition, Greenberg, Reiner, & Meiran,
(2013) found that individuals who underwent mindfulness training exhibited improved backward inhibition—a capacity thought to play a significant role in preventing uncontrollable thoughts (Whitmer & Gotlib, 2013)—relative to a comparison group of individuals who did not receive mindfulness training. Additionally, some evidence suggests that mindfulness influences meta-cognition (i.e., awareness of one’s thoughts). Meta-cognition is defined as the conscious awareness of cognitive control processes (Fernandez-Duque, Baird, & Posner, 2000). For example, mindfulness training has been found to improve alerting and conflict monitoring on an attention network test (Cahn & Polich, 2006; Jha, Krompinger, & Baime, 2007). Altogether, these findings support the claim that attention regulation is a core component of mindfulness.

Fewer studies have examined the second component of the model—an accepting and open attitude towards the present experience. Using 613 undergraduate students inexperienced in meditation, Baer et al. (2006) found that self-report measures of mindfulness are positively associated with openness to experience (Costa & McCrae, 1992). Openness to experiences is thought to reflect attentiveness and receptivity to inner feelings and external stimuli (Baer, 2006). Thus, individuals who report greater openness to experience should be more “receptive to” or accepting of experiences. The positive relationship between openness to experiences and dispositional mindfulness found by Baer et al. (2006) was not dependent upon any one mindfulness scale, as it was reliably found using the Five Factor Mindfulness Inventory (Baer, 2006), the Mindful Attention Awareness Scale (Brown & Ryan, 2003), the Freiburg Mindfulness Inventory (Walach, Buchheld, Buttenmüller, Kleinknecht, & Schmidt, 2006), the Kentucky Inventory of
Mindfulness Skills (Baer, 2004), the Cognitive and Affective Mindfulness Scale (Feldman, Hayes, Kumar, Greeson, & Laurenceau, 2007), and the Mindfulness Questionnaire (Chadwick et al., 2008).

Thus, some empirical evidence exists for the claim that mindful awareness and acceptance are essential subcomponents of mindfulness. However, the interactive effect of mindful awareness and acceptance has only recently been addressed. Monitor and Acceptance Theory (MAT; Lindsay & Creswell, under review) suggests that although mindful awareness training alone may improve cognitive function, the combination of both mindful awareness and acceptance is necessary for the effect of mindfulness on stress, and physical health outcomes to be observed. More specifically, this theory posits that mindful awareness heightens positive and negative affective experiences, and thus attention regulation skills alone may not be sufficient to improve performance on tasks that require emotion regulation (e.g., stressor tasks). This account is new and primarily supported by indirect tests. For example, a longitudinal study of 145 college students found that self-reported mindful acceptance was inversely related to depressive symptoms throughout the semester, while the combination of high mindful awareness and low mindful acceptance was associated with higher depressive symptoms. In other words, mindful awareness without acceptance predicted worse mood outcomes. Therefore, there is some preliminary evidence suggesting that the effects of mindfulness on health outcomes involving efficient emotional regulation are dependent upon the presence of both of its subcomponents.
Although promising, the two component model of mindfulness is not widely accepted within the mindfulness literature. Single component (Brown & Ryan, 2003), three component (Shapiro, Carlson, Astin, & Freedman, 2006), and five component (Baer, 2006) models of mindfulness have also been proposed, and all models (including the Bishop et al., model) have faced significant challenges. Psychometric scales aiming to confirm a given factor structure by measuring self-report mindfulness before and after a mindfulness based intervention have not been able to clearly distinguish between core components of mindfulness and side-effects of interventions (Chiesa, 2012). That is, changes in self-report mindfulness observed after interventions cannot be attributed specifically to mindfulness as opposed to nonspecific factors (e.g., social interactions, relaxation). Nevertheless, the two factor model proposed by Bishop et al. (2006) was preferred in the present study due to its empirical support, and theoretical relevance to the primary outcome (i.e., emotional and physiological responses to acute stress).

**Health, Stress and Cortisol**

Despite its debated conceptualization, mindfulness has been studied in relation to a wide variety of health related issues. Among others, mindfulness appears to modulate the secretion of primary stress mediators like the stress hormone cortisol (Brown et al., 2012; Creswell & Lindsay, 2014; Tang et al., 2007). Cortisol is a hormone of the HPA axis that plays a significant and varied role in the stress response (King & Hegadoren, 2002). Cortisol is often used in health research because it can be sampled easily in saliva and accurately reflects prior HPA axis activation (Dickerson & Kemeny, 2004). Upon appraisal of a stressful stimulus, the hypothalamus secretes corticotrophin–releasing
hormone (CRH), which in turn reaches the anterior pituitary gland and stimulates the release of adrenocorticotropin hormone (ACTH). Subsequently, ACTH reaches the adrenal cortex via the blood stream and stimulates the secretion of cortisol (Sapolsky, Romero, & Munck, 2000). Cortisol exerts effects throughout the body. For example, cortisol increases blood pressure, blood sugar levels, analgesia, and suppresses the reproductive, immune, and digestive systems (Matousek, Dobkin, & Pruessner, 2010). Cortisol is therefore able to prepare the body to efficiently react to a stressor by promoting survival functions (e.g., supplying energy for physical activity necessary to address threats).

Some suggest that HPA axis activation is initiated in a nonspecific manner; that is, both psychological and physical stressors can activate the HPA axis (Slavich & Irwin, 2014). Others suggest that all psychological stressors are not equally potent activators of the HPA axis (Dickerson & Kemeny, 2004). Specifically, social-evaluative stressors (e.g., giving a speech in front of an evaluative panel) have been found to elicit greater cortisol responses relative to non-social evaluative stressors (e.g., giving a speech in isolation). Therefore, the types of stressors used to elicit and observe an acute HPA axis activation in a laboratory must be selected carefully.

Furthermore, the effects of cortisol can extend far beyond survival functions. An arguably “healthy” acute cortisol response is thought to be short; it occurs rapidly in the presence of the stressor and quickly ends in the absence of the stressor (Charmandari, Tsigos, & Chrousos, 2005). The benefits of cortisol responses can therefore be thought to depend upon the duration of that response. That is, when the response is short, the
adverse effects of cortisol (i.e., immunosuppression, anti-growth, anti-reproduction effects) are not sustained long enough to negatively affect physical health while the individual may still benefit from short term gains of cortisol secretion (i.e., increased energy). Dysregulated or persistent cortisol responses can damage the body, increase allostatic load (i.e., wear and tear of the body), and ultimately result in various negative health outcomes (McEwen, 1998). The areas affected by chronic cortisol exposure are abundant (e.g., physical growth/development, thyroid function, cortisol receptor affinity, reproduction, metabolism, gastrointestinal function, and immune function; McEwen, 2007). For example, overactivation of the HPA axis can increase susceptibility to infectious and autoimmune diseases (e.g., rheumatoid arthritis, Sjogren's syndrome) through the immunosuppressive effects of glucocorticoids (McEwen, 2007). Cortisol may also increase insulin resistance (i.e., lead to decreased treatment efficiency) in diabetic patients, via its effect on metabolism (Charmandari et al., 2005). In sum, hormones like cortisol, which serve an adaptive function in the short-term, can damage the body via various means and promote pathogenesis when dysregulated.

Relevant to the present study, mindfulness appears to influence HPA axis functioning. For example, following an eight-week MBSR intervention, breast and prostate cancer patients reported significantly lower stress symptoms (e.g., muscle tension, cognitive disorganization), and improved HPA axis function relative to baseline (Carlson, Speca, Patel, & Goodey, 2004). More specifically, the proportion of individuals who display elevated late afternoon diurnal cortisol levels—an arguably abnormal pattern of diurnal cortisol secretion (Touitou, Bogdan, Lévi, Benavides, &
Auzéby, 1996)—decreased from pre- to post-intervention. Unfortunately, without a comparison group, the observed effects of MBSR cannot be distinguished from those of time alone (i.e., participants may improve over time on their own). Nevertheless, it is possible that mindfulness interventions are able to impact various health outcomes by affecting biological stress response systems like the HPA axis and ultimately its products (e.g., the stress hormone cortisol). In contrast, other hormones like Dehydroepiandrosterone (DHEA), or melatonin, do not appear to be influenced by mindfulness training (Carlson et al., 2004). Cortisol was therefore an ideal dependent variable for the present study because preliminary results suggest that cortisol secretion is influenced by mindfulness, and cortisol widely impacts health.

**Stress Reactivity and Stress Recovery**

In the context of an acute stressor, stress responses such as HPA axis activation may be further broken down into two interdependent yet essentially different processes—reactivity and recovery. Reactivity refers to the increase of a given marker (e.g., cortisol, blood pressure, heart rate) from baseline/resting levels. Conversely, recovery is characterized by a return to baseline levels. For example, salivary cortisol levels are generally thought to peak 21-30 minutes post-stressor onset, and return to near baseline levels 51-60 minutes post-stressor onset (Dickerson & Kemeny, 2004). A recent meta-analysis by Panaite, Salomon, Jin, & Rottenberg (2015) suggests that both cardiovascular reactivity and recovery to acute stressors predict future cardiovascular morbidity and mortality. Thus both the size of a stress response and its duration must be considered in relation to health outcomes.
Although there is evidence that both reactivity and recovery from stressors predicts future disease states, the relative impact of stress recovery and reactivity in relation to health outcomes is debated (Lovallo, 2015). For example, poor cardiovascular recovery has been linked to serious health threats such as hypertension (Hocking Schuler & O’Brien, 1997). Yet a comparison of effect sizes associated with cardiovascular recovery and reactivity to psychological and physical acute stressors reveals that both processes have relatively equivalent predictive power with regards to cardiovascular outcomes (about 1% of the variance in cardiovascular disease outcomes is accounted for by either process; Lovallo, 2015). Thus, given that the stress literature suggests that recovery is at least as good of a predictor of long-term health outcome as reactivity, the present investigation took into account both stress reactivity and recovery.

**Evidence for the Mindfulness Stress Buffering Account**

Emerging research suggests that mindfulness may impact stress reactivity. The mindfulness stress buffering account was recently formally described by Creswell & Lindsay (2014). In their model, Creswell and Lindsay define mindfulness as “monitoring one’s present-moment experience with acceptance (p. 402).” They propose that mindfulness interventions are able to affect health outcomes by buffering against the effects of stress on health, and do so particularly in high stress populations. More specifically, they suggest that mindfulness alters stress reactivity via both an increase in the recruitment of prefrontal regulatory regions, which inhibit stress processing regions, and a reduction in the reactivity of central stress processing regions (e.g., amygdala) responsible for signaling peripheral stress-response cascades (e.g. the HPA axis).
Supporting an effect of mindfulness on stress processing regions, a study found that trait mindfulness is positively associated with neural activation of stress-regulatory regions (e.g. ventrolateral, ventromedial, and medial prefrontal cortex; Creswell, Way, Eisenberger, & Lieberman, 2007). In this experiment, 27 undergraduate students reported dispositional mindfulness and completed an affect labeling task (i.e., labeling faces as angry or scared). During affect labeling, mindful individuals showed increased widespread activation in the prefrontal cortex and decreased amygdala activation relative to less mindful individuals. In addition, other research (Taren et al., 2015) implies that mindfulness interventions may reduce the connectivity strength between brain networks responsible for stress reactivity (e.g., the amygdala to subgenual anterior cingulate cortex connection). In this experiment, unemployed adults underwent a 3-day mindfulness intervention or 3-day relaxation training (i.e., an active control condition). Following the interventions, participants in the meditation group showed decreased resting state functional connectivity of the amygdala relative to control. In sum, these findings provide the literature with a neural pathway via which mindfulness affects stress reactivity.

Additionally, the mindfulness stress buffering account posits that if mindfulness can alter stress processing pathways (i.e., prefrontal cortex and amygdala), then peripheral stress-response cascades like the sympathetic-adrenal-medullary (SAM) and HPA axes should also be affected. More specifically, greater mindfulness is thought to decrease stress induced HPA axis activation and lead to lower reactive secretion of glucocorticoids (e.g., cortisol). A recent experiment by Brown et al. (2012) partially
supported this hypothesis using an acute laboratory stressor. In this experiment, participants were randomly assigned to either give a speech in front of evaluators (high stress condition) or in front of a recording device (low stress condition). The speech task (i.e., the Trier Social Stress Test or TSST; Kirschbaum, Pirke, & Hellhammer, 1993) entails that participants give a 5-minute speech and complete a 5-minute mental arithmetic task in front of an emotionally unresponsive evaluative panel. The TSST has been shown in previous research to be a potent social-evaluative stress manipulation capable of activating the HPA axis (Dickerson & Kemeny, 2004). Brown et al., (2012) found that undergraduates who scored highly in trait mindfulness displayed lower stress-induced cortisol reactivity while completing a highly stressful task relative to participants who scored low in trait mindfulness. Consistent with the stress buffering account, the effects of dispositional mindfulness on cortisol responses were limited to participants assigned to the high stress condition. Additionally, individuals with high trait mindfulness who underwent the stressful speech task reported significantly less stressor-related anxiety and negative affect relative to low trait mindfulness participants. Again, these differences were not significant for participants assigned to the low stress condition. Thus, this research partially supports the mindfulness stress buffering account by demonstrating a direct effect of mindfulness on cortisol reactivity.

One should note that trait mindfulness was associated with a reduced, yet still present, cortisol response. Thus, trait mindfulness was not found to eliminate cortisol reactivity, but rather to limit hyper-reactivity. This distinction is important because little to no cortisol reactivity would limit short-term gains of this reaction (i.e., increased
survival function), and may promote negative health outcomes; cortisol secretion counter-regulates the production of inflammatory cytokine, which can lead to autoimmune disorders when overproduced (McEwen, 1998). In sum, the Mindfulness Stress Buffering Account predicts a reduction of peripheral stress responses like cortisol secretion, but does not predict a complete elimination of cortisol reactivity.

Relevant to the present investigation, Brown et al. (2012) were able to show that dispositional mindfulness (measured using the Mindful Attention Awareness Scale; MAAS) was related to cortisol reactivity following a psychological stressor. Thus, their findings suggest that self-report measures of mindfulness may be sufficient to observe the effect of mindfulness on HPA axis activation. Furthermore, Brown et al. (2012)’s use of the TSST suggests that it is a suitable stress manipulation for observing the effects of mindfulness on acute HPA axis activation. Nevertheless, Brown et al. (2012) did not explicitly examine the effect of mindfulness on cortisol recovery. As previously discussed, such effects are relevant predictors of health outcomes. As a result, the present investigation attempted to extend the Brown et al. (2012) findings using measures of cortisol recovery as well as reactivity.

**Rumination**

The mindfulness stress buffering account does not make specific predictions as to how mindfulness may interact with other psychological constructs to buffer against the deleterious effects of stress. Yet, the mindfulness stress buffering account may benefit from considering the relationship between mindfulness and other psychological factors. Evans & Segerstrom (2011) found that trait mindfulness was negatively associated with
repetitive thought measures, including rumination. Further, a review of the relationship between rumination and cortisol reveals that rumination modulates cortisol recovery (Zoccola & Dickerson, 2012). Thus, it is possible that mindfulness also affects cortisol recovery either directly or via its effect on rumination. As such, the present investigation also explored the potential effect of mindfulness on rumination.

Given the rich and divergent nature of the rumination literature, this construct is generally defined within the context of a specific theory, and therefore no uniform definition of rumination exists to date (Smith & Alloy, 2009). For example, rumination is defined as repetitive thinking about “causes, consequences, and symptoms of one’s negative affect (p.117)” if interpreted within the context of Response Style Theory (Smith & Alloy, 2009). This theory posits that rumination increases the availability of negative thoughts and thus maintains depressive symptoms. However, given the present investigation’s focus on reactivity to stressors, rumination is defined as: “repetitive thoughts about past stressful events (p. 1606)” (Zoccola et al., 2014). Thus, rumination is presently considered solely as a state characterized by repetitive thoughts emerging from the experience of a stressful event.

The hypothesized causes of rumination are diverse as well. For example, Martin, Tesser, & McIntosh (1993) propose that frustrated or blocked goals play an important role in prompting ruminative thoughts. Others suggest that stressful events initiate rumination (Robinson & Alloy, 2003). Yet, others posit that certain dispositional tendencies, like difficulties with inhibiting previously relevant information, contribute to the mechanism by which negative thoughts become repetitive (Whitmer & Gotlib, 2013).
It is likely that all of these factors cause rumination of some kind. For example, a stressor may block a goal to perform well on a difficult task and result in rumination. Additionally, it is possible that difficulty with inhibiting previously relevant information contributes to rumination regardless of its content, while a stressor specifically causes stress-related rumination. However, the degree to which a proposed cause for rumination is specific to a given type of rumination has yet to be systematically evaluated.

A growing body of literature suggests that rumination (broadly defined) is related to both psychological (Nolen-Hoeksema & Watkins, 2011) and physiological health (Denson, Spanovic, & Miller, 2009; Zoccola & Dickerson, 2012; Zoccola et al., 2014). Currently depressed and recovered individuals tend to report more positive attitudes towards rumination (e.g., believing that rumination is helpful) than never-depressed samples (Watkins & Moulds, 2005). Related, Nolen-Hoeksema and Watkins (2011) suggest that rumination is a trans-diagnostic risk factor involved in the development of numerous psychological disorders. For example, in depressed individuals, rumination is thought to make negative thoughts more readily available to consciousness and thus maintain depressed states. Additionally, rumination predicts self-reported physical health (Thomsen et al., 2004), cardiovascular function (Radstaak et al., 2011), immune function (Denson et al., 2009), pain perception (Gilliam et al., 2010), and sleep quality (Thomsen, Yung Mehlisen, Christensen, & Zachariae, 2003). Additionally, experimentally induced stress-related rumination has been shown to cause poor cortisol and C-reactive protein (an immune marker) recovery relative to distraction, following the TSST (Zoccola et al., 2014). Finally, both state and trait measures of rumination predict longer sleep onset
(number of minutes from time in bed to sleep onset; Zoccola, Dickerson, & Lam, 2009).

In conclusion, mounting evidence suggests that rumination affects one’s psychological and physiological health.

**Rumination and Stress Reactivity/Recovery**

Brosschot, Gerin, and Thayer (2006) proposed that perseverative cognitions (including rumination) may lead to prolonged activation of the HPA axis. They defined perseverative cognitions as “the repeated or chronic activation of the cognitive representation of one or more psychological stressors (Brosschot et al., 2006)” (p. 114). Therefore, perseverative cognitions include both worry (i.e., pre-stressor perseverative cognitions) and rumination (i.e., post-stressor perseverative cognitions). Based on this model, they argue that stress appraisal must be examined in both an acute and prolonged fashion. More specifically, they propose that if the mental representation of the stressor persists (e.g., in the form of worry or rumination), then a prolonged stress response will occur.

Although increasingly numerous studies support the perseverative cognition hypothesis, it remains important to consider that the relationship between rumination and stress recovery depends on how rumination is conceptualized. Zoccola and Dickerson (2012) conducted a review of the relationship between rumination and HPA axis activation. They found that state measures of rumination are more consistent predictors of HPA axis activation relative to trait measures, and that stress-related measures of rumination are better predictors of HPA axis activations relative to anger or depression-related measures (Zoccola & Dickerson, 2012). Although the relationship between
rumination and stress reactivity has for the most part been examined using correlational analyses, a recent experiment by Zoccola et al., (2014) demonstrated a causal link between state stress-related rumination and prolonged HPA axis activation. In this experiment, participants were randomly assigned to either a guided rumination or a distraction condition after completing the TSST. Salivary cortisol was collected pre-stressor, 8, 20, 34, 48, and 62 minutes after the stressor. Zoccola et al., (2014) found that cortisol concentrations at time 48 and 62 were significantly larger for participants in the rumination condition relative to participants in the distraction condition.

Although the causal link between dispositional mindfulness and state stress-related rumination has yet to be tested in a controlled laboratory setting, the relationship between mindfulness and repetitive thoughts has been investigated. For example, Evans & Segerstrom, (2011) found that trait mindfulness (assessed using the Five Facet Mindfulness Inventory Baer, 2006) was negatively associated with total repetitive thought. They measured total repetitive thought by summing up scores on various repetitive thought questionnaires. After subjecting these repetitive thought measures to multidimensional scaling (yielding a two dimensional model defined by purpose and valence), they found that dispositional mindfulness was negatively associated with negative types of repetitive thoughts. In other words, individuals with low trait mindfulness scores also reported more negative repetitive thought. In a separate line of research, Borders, Earleywine, and Jajodia (2010) found that dispositional mindfulness is negatively related to dispositional rumination (broadly defined), hostility, anger, and verbal aggression. Taken together, these results suggest that mindfulness may reduce
stress-related rumination because it is negatively related to broadly defined rumination and other types of repetitive thoughts. If true, then this relationship could contribute to the psychological factors underlying the mindfulness stress buffering account. Nevertheless, one should note that the relationship between dispositional mindfulness and state stress-related rumination has yet to be investigated. Establishing a link between mindfulness and state stress-related rumination is presently important because state stress-related measures of rumination generally predict cortisol recovery more consistently than other types of rumination measures (Zoccola & Dickerson, 2012).

**Research Goals**

The mindfulness stress buffering account implies that mindfulness leads to positive health outcomes by reducing the magnitude of psychological and physiological stress responses (e.g., acute HPA axis activation; Creswell & Lindsay, 2014). Quasi-experimental support for the model suggests that mindfulness directly reduces cortisol reactivity under conditions of high stress (Brown et al., 2012). Additionally, recent research implies that stress-related rumination following a social-evaluative stressor leads to prolonged activation of the HPA axis (Zoccola et al., 2014), and trait mindfulness is negatively associated with trait rumination (Borders et al., 2010) and repetitive thought measures (Evans & Segerstrom, 2011). Thus, I proposed that mindfulness may buffer against overactivation of the HPA axis by improving cortisol recovery via a reduction in stress-related rumination.

The present research thus aimed to: 1) replicate the effect of mindfulness on cortisol reactivity; 2) investigate the effect of mindfulness on cortisol recovery; 3) test the
effect of dispositional mindfulness on state stress-related rumination; 4) replicate the effect of state stress-related rumination on cortisol recovery; 5) examine if the effect of mindfulness on cortisol recovery is mediated by stress-related rumination; 6) test if the relationship between mindfulness and cortisol reactivity/recovery is independent of factors which are related to mindfulness and known to also affect HPA axis activation (e.g., depression).

**Primary Hypotheses**

The following hypotheses were tested in the present study: (1) Participants who score high in trait mindfulness would display lower cortisol reactivity to acute stress relative to participants who score low in trait mindfulness; (2) Participants who score high in trait mindfulness would display improved cortisol recovery relative to participants who score low in trait mindfulness; (3) Participants who score high in trait mindfulness would report lower post-stressor state rumination relative to participants who score low in trait mindfulness; (4) Participants who report high post-stressor state rumination would display poor cortisol recovery relative to participants who report low stressor-related rumination; (5) The effects of mindfulness on cortisol recovery would be statistically mediated by stress-related rumination.

**Secondary Research Questions**

Dispositional mindfulness has been shown to positively predict openness to experience in past research (Baer, 2006). Thus, a secondary aim of the present research was to replicate the past finding suggesting that dispositional mindfulness (measured...
using the MAAS; Brown & Ryan, 2003) is positively correlated with scores on the openness to experience subscale of the Big Five Inventory (BFI; Pervin & John, 1999).

**Integration of Cortisol Covariates and Sensitivity Measures**

Given that cortisol is affected by factors other than mindfulness and rumination, it was important for the present investigation to demonstrate that the hypothesized effects of mindfulness on HPA axis activation occur independently of other factors known to influence cortisol secretion. In addition, it is important to test whether any associations between mindfulness and the various cortisol outcomes, are not better accounted for by other psychological constructs that are related to mindfulness. For this reason, significant covariates (e.g., gender, wake time, body mass index), and all sensitivity measures (i.e., self-reported depression, anxiety, neuroticism, and perceived stress over the last month) were included in final analyses predicting cortisol reactivity/recovery.
Methods

Participants

Undergraduate students were recruited in the study using online advertisement on a university website and flyers posted on campus locations at the University of California, Irvine. Participants were excluded from the study if they reported a chronic or serious health condition, use of tobacco, or medication (e.g., hormonal contraceptives). Additionally, participants were excluded if they indicated that they generally wake up after 10:00 AM on weekdays. These exclusion criteria were used to control for individual variations in diurnal cortisol (Adam & Kumari, 2009). In total, the study enrolled 124 participants. However, 4 participants were excluded from analyses due to eligibility and protocol issues (one participant did not meet the eligibility criterion, one participant ended the study during the speech performance, one participant did not finish the study due to a fire alarm, and one participant experienced altered protocol timing). Thus, the final sample size was 120. Participants were 67 females (55.8%) and 53 males (44.2%) with ages ranging from 18 to 36 years (M = 19.54 SD = 2.07). The racial/ethnic background of the sample was: 71 (59.2%) Asian, 40 (33.3%) White (27.5% of whom were Hispanic or Latino), 3 (2.5%) Black or African American, 1 (0.8%) Native Hawaiian or Other Pacific Islander, 2 (1.7%) American Indian or Alaska Native, and 3 (2.5%) Other. The Institutional Review Board of University of California, Irvine, approved all procedures in advance.
Primary Measures

**Salivary cortisol.** Saliva samples were collected using a Salivette sampling device (Sarstedt, Inc., Newton, N. C.) immediately prior to exposure to the stressor, and then 15, 25, 40, and 55 minutes after stressor onset. Participants were instructed to place the cotton roll into their mouth for up to three minutes, saturate it with saliva, and replace it in the tube. Samples were stored at -20°C until full completion of data collection. All saliva samples were centrifuged and assayed at the University General Clinical Research Center using standard enzyme-linked immunoassay procedures (Diagnostic Systems Laboratories, Inc., Webster, TX). Each sample was assayed in duplicate and averaged. The sensitivity of the assay is < 0.012 μg/dL; inter-assay and intra-assay coefficients of variance are less than 8%.

**Mindfulness.** Trait mindfulness was assessed using the Mindful Attention Awareness Scale (MAAS; Brown & Ryan, 2003). The MAAS is not prone to mindfulness approach bias because it assesses mindfulness indirectly by asking participants to report inattentive behaviors. This scale is comprised of 15 reverse-scored items, which ask participants to rate the degree to which they are attentive to/aware of the present experience on a 6 point scale (1 = almost never; 6 = almost always). For example, participants were asked to rate the following statement: “I find it difficult to stay focused on what’s happening in the present.” The scores on each item were reverse coded and averaged to obtain a total trait mindfulness score ($M = 3.99$, $SD = 0.79$, $\alpha = .88$). Thus, higher scores on this scale reflect higher levels of trait mindfulness; scores can range from 1 to 6. The MAAS is generally positively related to measures of
awareness ($r = .23$) and openness to experience ($r = .18$); it is also generally negatively related to measures of rumination ($r = -.39$), anxiety ($r = -.36$), and negative affect ($r = - .37$; Brown & Ryan, 2003).

Although, the MAAS has been successfully used to discriminate between mindfully experienced and inexperienced samples (Brown & Ryan, 2003), an approach solely focused on the frequency of mindful states is unable to capture mindful state quality. Yet, measuring the quality of mindfulness states in a non-practitioner sample may be difficult because some meditation experience may be necessary for individuals to distinguish between high and low quality mindful states. Thus, the factors which contribute to mindfulness, one’s ability to reach a state of mindfulness, or the quality of mindful states were not measured. Rather, the self-report frequency of mindful states in daily life was used to infer a dispositional tendency for mindfulness.

**State stress-related rumination.** State stress-related rumination was measured using the Thought Questionnaire (TQ; Edwards, Rapee, & Franklin, 2003). This questionnaire is comprised of 24 items (8 positive, 14 negative, and 2 neutral), which measure the frequency of speech related thoughts since it ended on a 5 point scale (0 = never, 4 = very often). Participants are given the following instructions: “Please rate each statement as to how often you thought about that aspect in the time since you gave your speech.” Example items include: “how well I handled it” and “how bad my speech was”. Rumination was therefore derived from average scores of the negative items ($M = 1.36$, $SD = 0.94$, $\alpha = .93$). Scores can range from 0 to 4, with higher scores indicating greater
speech related rumination. The TQ is generally positively related to measures of fear of evaluation \( r = .57 \), and social avoidance \( r = .69 \); Edwards et al., 2003).

**Secondary Measures**

**Demographics questionnaire.** Participants were instructed to indicate sociodemographic information, including the following: age, (self-identified) gender, and racial/ethnic background.

**Wake time.** Time since awakening was measured by asking participants to indicate at what time they had awoken on the day of the experiment. Wake time was recoded as time in minutes since midnight. Thus, greater scores on wake time indicate that participants awoke later in the day. Wake time influences naturally occurring changes in diurnal cortisol (e.g., the cortisol awakening responses; Adam & Kumari, 2009). As such, wake time (on the day of the experiment) was considered as a potential covariate in analyses predicting cortisol responses.

**Body mass index.** Body Mass Index (BMI) was measured using self-reported height and weight. BMI was calculated using the following formula: \( \text{BMI} = \left(\frac{\text{weight in pounds} \times 703}{\text{height in inches}^2}\right) \). Body Mass Index (BMI) has been shown to affect diurnal cortisol secretion such that greater BMI correlates with lower awakening cortisol levels, a smaller increase during the first hour after awakening, and a greater decline immediately following the diurnal peak (Champaneri et al., 2013). As such, the present investigation considered BMI as a potential covariate in analyses predicting cortisol.

**Anxiety.** Trait anxiety was measured using the 20-item State-Trait Anxiety Inventory (STAI; Spielberger, Gorsuch, & Lushene, 1970). To measure trait anxiety,
participants were given the following instructions: “Listed below are statements that people sometimes use to describe themselves. Please read each statement and then circle the number that best describes the extent to which you GENERALLY FEEL. Do not spend too much time on any one statement”. Participants rated each statement on a 4 point scale (1 = “not at all”; 4 = “very”). Scores were averaged and thus ranged from 1 to 4 ($M = 2.09$, $SD = 0.50$, $\alpha = .90$). Higher scores are indicative of higher trait anxiety. The STAI-T strongly correlates with the Taylor manifest anxiety scale and the IPAT anxiety scale ($r = .80$ and $r = .75$ respectively; Spielberger, Gorsuch, & Lushene, 1970). Recent research suggests that clinically anxious individuals exhibit significantly lower levels of morning cortisol relative to non-clinically anxious individuals (O’Donovan et al., 2010). Additionally, trait mindfulness is negatively associated with trait anxiety measures ($r = -.36$; Brown & Ryan, 2003). Given its relationship to mindfulness and cortisol, trait anxiety was included as a sensitivity measure in analyses of cortisol responses.

**Neuroticism.** Neuroticism was measured with the 8-item subscale of the Big Five Inventory (BFI; Pervin & John, 1999). For this scale, participants were asked to indicate on a 5 point scale (1 = disagree strongly, 5 = agree strongly) the extent to which they identify with certain personality characteristics. Example items include: “I see myself as someone who can be tense”. Three out of the 8 items of the neuroticism subscale were reverse coded. Scores were averaged and thus can range from 1 to 5, with higher scores indicating greater neuroticism ($M = 2.75$, $SD = 0.80$, $\alpha = .84$). The neuroticism subscale of the Big Five Inventory is positively correlated with measures of
depression ($r = .53$) and negatively correlated with well-being ($r = -.29$; Gosling, Rentfrow, & Swann, 2003). Neuroticism is related to both awakening cortisol levels and cortisol responses to acute psychological stressors (Oswald et al., 2006; Portella, Harmer, Flint, Cowen, & Goodwin, 2014). Additionally, neuroticism is moderately negatively associated with trait mindfulness ($r = -.56$; Brown & Ryan, 2003). As a result, neuroticism was included as a sensitivity measure in analyses predicting cortisol reactivity/recovery.

**Depressed mood.** Depressed mood over the past week was assessed with the Center for Epidemiologic Studies Depression Scale (CES-D; Radloff, 1991). Participants are asked to indicate “the number for each statement which best describes how often you felt or behaved this way-DURING THE PAST WEEK” (e.g., during the past week, I was bothered by things that usually don't bother me) using the following scale: 1 = rarely or none of the time (less than 1 Day), 4 = most or all of the time (3-7 days). This scale consists of 20 items; scores were averaged and thus can range from 0 to 4 ($M = .67$, $SD = 0.33$, $\alpha = .82$). Greater scores on this scale indicate more depressed moods. The CES-D tends to be positively related to scales measuring symptoms of depression (e.g., negative affect; $r = .60$), and successfully discriminates between clinically depressed and healthy individuals (Radloff, 1977). Depression has also been shown to influence HPA axis activation. A study found that depressive symptoms were positively associated with greater cortisol awakening response in a sample of 40 men (Pruessner, Hellhammer, Pruessner, & Lupien, 2003). Furthermore, scores on the CES-D and the MAAS tend to
negatively correlate \( (r = -0.37; \text{Brown} \& \text{Ryan}, 2003) \). Thus, depression was used as a sensitivity measure in final analyses predicting cortisol responses.

**Perceived stress.** Perceived stress over the past month was assessed using the Perceived Stress Scale (PSS; Cohen, Kamarck, \& Mermelstein, 1983). This scale consists of 10 items (e.g., in the last month, how often have you been upset because of something that happened unexpectedly?) rated on a 5 point scale (0 = never, 4 = very often). Higher scores are indicative of greater perceived stress; scores were averaged and therefore can range from 0 to 4 \( (M = 1.77, SD = 0.62, \alpha = .86) \). The PSS positively relates to the occurrence of stressful life events \( (r = .20) \), depression \( (r = .76) \), and predicts negative health outcomes \( (r = .52) \) to a greater degree than stressful life event scales (Cohen, Kamarck, \& Mermelstein, 1983). Given that chronic stress has been found to dysregulate HPA axis functioning (McEwen, 2007), it was presently important to distinguish between the hypothesized short-term (i.e., reduced stress reactivity to an acute laboratory stressor) and long-term (i.e., improved HPA axis functioning due to reduced susceptibility to chronic stress) effects of mindfulness on HPA axis activation. As such, perceived stress over the last month was used as a sensitivity measure in the present analyses to assess the extent to which the effects of mindfulness on acute HPA axis activation occur independently of long-term perceptions of stress.

**Trait rumination.** Trait rumination was assessed using the Rehearsal subscale of the Emotional Control Questionnaire version 2 (ECQ2-R; Roger \& Najarian, 1989) This subscale consists of 14 items (e.g., “I remember things that upset me or make me angry for a long time afterwards”). Participants were asked to indicate if a given statement was
most like them by choosing if the statement is “1 = true” or “0 = false”. Scores on this scale were summed; higher scores indicate a greater dispositional tendency to ruminate over emotionally upsetting events (\(M = 5.71, SD = 3.29, \alpha = .90\)). The ECQ2-R tends to be positively related to neuroticism measures (\(r = .57\)), and trait anxiety (\(r = .24\)); it is also negatively related to measures of interpersonal control (\(r = -.37\); Roger & Najarian, 1989).

**Openness to experience.** Openness to experience was measured with the 10-item subscale of the Big Five Inventory (BFI; Pervin & John, 1999). For this scale, participants are asked to indicate on a 5 point scale (1 = disagree strongly, 5 = agree strongly) the extent to which they identify with certain personality characteristics. Example items include: “I see myself as someone who is curious about many different things”. Two out of the 10 items of the openness subscale are reverse coded. Scores were averaged and thus can range from 1 to 5 with higher scores indicating greater openness to experience (\(M = 3.6, SD = 0.53, \alpha = .72\)). The openness subscale of the Big Five Inventory generally positively correlates with measures of creativity (\(r = .26\)) and divergent thinking (\(r = .39\); McCrae, 1987).

**State negative affect.** Negative affect was measured using the negative subscale of the Positive Affect Negative Affect Scale (PANAS; Watson, Clark, & Tellegen, 1988). Subjects were asked to rate the extent to which each statement reflects the way they feel at the present moment using a 5-point scale (1 = very slightly or not at all; 5 = extremely). Negative affect scores were averaged and ranged from 1 to 5 (pre-stressor \(M\)
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\[ M = 1.33, SD = 0.39, \alpha = .75; \text{ post-stressor } M = 2.05, SD = 0.88, \alpha = .90 \]; higher scores reflect higher negative affect.

**Procedure**

All laboratory sessions were conducted in the afternoon to control for diurnal cortisol secretion (all experimental sessions began between 12:00PM and 5:30PM). Upon arrival in the laboratory, participants first provided consent, then completed a series of baseline questionnaires, followed by a rest period (45 minutes in total). Baseline questionnaires included: demographics questionnaires, health behavior/history questionnaires, trait depression, trait anxiety, perceived stress over the last month, and pre-stressor state negative affect scales. Subsequently, all participants completed the stressor task. Participants were given 5 minutes to prepare their speech and 5 minutes to deliver it. Next, participants were given the opportunity to rest (10 minutes in total). Thereafter, participants completed post task questionnaires and were given the opportunity to rest by reading emotionally neutral magazines (30 minutes in total). Post-task state measures were administered first. Post task questionnaires included: state stress-related rumination, post-stressor state negative affect, neuroticism, openness to experience, and trait mindfulness. Finally, participants were debriefed and compensated with $20 for their participation.

**Stressor Task**

All participants completed a modified version of the Trier Social Stress Test (TSST; Kirschbaum et al., 1993). In contrast to the original TSST, the present stress task included a speech task, but no mental arithmetic portion. Individuals were asked to
deliver a speech pertaining to a hypothetical job interview; they were given 5 minutes to prepare their speech and 5 minutes to deliver it. Thus, the stressor task lasted 10 minutes in its entirety. The speech was given in front of an emotionally neutral evaluative panel (1 male and 1 female wearing white lab coats who were trained to remain stoic and maintain eye contact during the speech). This task was used because it has been shown to elicit greater salivary cortisol reactivity and post-task rumination than similar non-social-evaluative tasks (Dickerson, Mycek, & Zaldivar, 2008; Zoccola, Dickerson, & Zaldivar, 2008).

Analytic Plan

**Overview.** The effects of mindfulness on cortisol reactivity and recovery (Hypotheses 1-2), as well as the effects of rumination on cortisol recovery (Hypothesis 4) were tested using multilevel modeling (MLM). This method of analysis allows one to examine change patterns in cortisol response trajectories over time (e.g., reactivity and recovery), within and between subject variability (e.g., individual differences in mindfulness), and their interaction (Singer & Willett, 2003). MLM also provides several advantages relative to other statistical tests (e.g., hierarchical linear regression or repeated measure analysis of variance). MLM is robust to missing data (i.e., no list-wise deletion of participants with partial missing data), and is able to fit unevenly spaced repeated measurements (Raudenbush & Bryk, 2002). MLM generates unbiased estimations of the relationship between baseline levels and subsequent change, and allows one to control for effects of baseline values on subsequent change (Chiolero, Paradis, Rich, & Hanley,
Finally, MLM does not assume independence of observation; an assumption which is likely to be violated with repeated salivary cortisol data.

The relationship between dispositional mindfulness and state stress-related rumination (Hypothesis 3) was tested using Pearson correlations. In the event that Hypothesis 3 is supported (i.e., mindfulness is negatively related to state stress-related rumination), the hypothesized indirect effects of mindfulness on cortisol recovery via state stress-related rumination (Hypothesis 5) would be tested using multilevel mediation analyses (Preacher & Hayes, 2008).

**Treatment of outliers.** All salivary cortisol measures underwent a natural log transformation prior to analyses to yield distributions of salivary cortisol scores which closely resemble a normal distribution, and are therefore fit to assess the presence of outliers. Participants with natural log transformed salivary cortisol exceeding 3 standard deviations from the mean of that sampling time period were considered outliers. Based on this criterion, two participants displayed outlying baseline cortisol values, and two participants displayed outlying cortisol values for samples taken 55 minutes since stressor onset. MLM assumes that the error terms at every level of the model are normally distributed (Singer & Willett, 2003). To comply with this assumption, these outliers were excluded from final analyses.

Self-report measures were also evaluated for the presence of outliers. Outlying values were again defined as those exceeding 3 standard deviations from the mean of that variable. One participant had outlying values on the BMI variable, 3 participants had outlying values on the pre-stressor negative affect scale, 1 participant had outlying values
on the time of wake variable and 2 participants had outlying values on the depression variable. All outlying values listed were greater than the mean. Removing these participants from analyses did not influence the present findings or violate test assumptions, thus these participants were retained in final analyses.

**Preliminary analyses.** To determine if the stressor task was successful in eliciting a physiological and psychological stress response, a paired sample t-test examined within-person changes in salivary cortisol and self-reported negative affect pre-to post-stressor. Additionally, so as to assess the extent to which all included measures related to one another in expected directions, correlations between the trait mindfulness, state stress-related rumination, gender, BMI, time of wake, trait rumination, perceived stress over the last month, trait anxiety, neuroticism, openness to experience, and depressed mood were calculated using Pearson correlations. These correlations included participants who had no missing data on any of the variables included in the analysis (n = 109), and may be found in Table 1.

**Multilevel modeling.** Final multi-level models are shown in Table 2 and were obtained using a sequential model building procedure available in the appendix section of this manuscript (see Appendix: Multi-level analysis model building procedure). A brief overview of this procedure is provided here. First, a random intercept model predicting salivary cortisol was fitted to test for between individual differences in mean cortisol levels across all time points (Model 1). Next, fixed linear and quadratic slopes relating time to salivary cortisol levels were added into Model 1 to test for a curvilinear relationship between salivary cortisol and time (Model 2). Random coefficients for the
linear and quadratic term of the slope relating time to cortisol levels were then added to
Model 2 to test for an effect of the law of initial values (i.e., baseline cortisol predicting
subsequent change in cortisol) and to test for between-subject variance in level 1 slopes
(Model 3). Subsequently, gender, BMI and time of wake were added to Model 3 as level
2 variables to identify significant cortisol covariates (Model 4). Next, the BMI and time
of wake variables were removed from Model 4 to assess if gender still predicted cortisol
responses in the absence of non-significant covariates (Model 5). Hypotheses 1 and 2
were tested by adding trait mindfulness to Model 5 as a level 2 predictor (Model 6). To
assess if the effects of mindfulness on temporal changes in cortisol occurred
independently of sensitivity measures, trait anxiety, neuroticism, depression, and
perceived stress over the last month were added into Model 6 as level 2 predictors
(Model 7). Hypothesis 4 was tested by adding state stress-related rumination to Model 5
as a level 2 predictor (Model 8). To assess if the effects of state stress-related rumination
on temporal changes in cortisol occurred independently of sensitivity measures, trait
anxiety, neuroticism, depression, and perceived stress over the last month were added
into Model 8 as level 2 predictors (Model 9).

All multilevel model analyses were conducted using the SAS 9.3 PROC MIXED
Participants with missing data on the gender, mindfulness, state stress-related rumination,
anxiety, neuroticism, depression, or perceived stress variables were excluded from final
analyses (N = 109). The use of this exclusion criterion allowed for sample size to be held
constant across models. All available cortisol time points (i.e., +0, +15, +25, +40, +55
minutes since stressor onset) were used and recoded as hours since stressor onset. The
time variable was centered at baseline (i.e., +0 minutes since stressor onset) unless noted
otherwise. All continuous variables entered into the model were mean centered prior to
analysis so as to avoid multicollinerarity issues present when testing nested interactions.
Finally, model parameters were estimated using maximum likelihood estimation, and an
unstructured covariance matrix. This method was used because an unstructured
covariance matrix allows the random intercept and random slopes to covary freely. Thus,
any effect of the law of initial value (Wilder, 1957) can be detected by assessing if the
covariances among random slopes and the random intercept are significantly different
from 0 (Chiolero et al., 2013). In the present data, random slopes (i.e., linear and
quadratic random slopes relating time to cortisol levels) and the random intercept did not
significantly covary in any of the multilevel models tested (all \( p > .13 \)). Thus, baseline
cortisol did not significantly predict subsequent cortisol reactivity.
Results

Preliminary Correlations

As shown in Table 1, dispositional mindfulness was negatively related to trait rumination, perceived stress over the last month, anxiety, neuroticism, and depression, and unrelated to gender, body mass index, time of wake, and openness to experience.

Stressor Manipulation Check

A paired sample t-test revealed a significant increase in salivary cortisol from samples taken pre-stressor ($M = 9.12 \text{ nmol/L}, SD = 5.53$) to samples taken 25 minutes post-stressor onset ($M = 13.12 \text{ nmol/L}, SD = 10.27$); $t(109) = 4.16, p < 0.001, d = 0.43$. The modified TSST was therefore successful in eliciting an acute cortisol response; the mean cortisol increase was 4.00 nmol/L, and the reported effect size is consistent with what is expected from acute stress protocols on average (Dickerson & Kemeny, 2004). Furthermore, the modified TSST successfully elicited an emotional reaction. A paired sample t-test revealed a significant increase in negative affect pre- ($M = 1.33, SD = .39$) to post- ($M = 2.10, SD = .91$) stressor; $t(113) = 9.82, p < 0.001, d = 0.92$.

Did Mindfulness Predict Cortisol Reactivity and Recovery? (Hypotheses 1 and 2)

Trait mindfulness was expected to predict lower cortisol reactivity and shorter cortisol recovery. To investigate the effect of dispositional mindfulness on temporal changes in cortisol, mean centered average scores on the MAAS were added as a level 2 variable into a model predicting salivary cortisol as a function of random linear and quadratic cortisol trajectories (i.e., slopes relating time to cortisol levels), and a fixed effect of gender.
As shown in Table 2 (Model 6), mindfulness did not significantly predict individual intercepts; thus mindfulness was unrelated to baseline cortisol values. However, the effect of mindfulness on the linear and quadratic terms for the slope relating sampling time to cortisol levels were significantly different from 0. Thus, after controlling for gender, the curvature of the cortisol response pattern differed as a function of trait mindfulness. A graphical representation of this interaction is shown in Figure 1; it illustrates cortisol response patterns for participants with high (top quartile) and low (bottom quartile) trait mindfulness scores. As shown in Figure 1, participants who reported high dispositional mindfulness showed a more peaked curvilinear relationship between time and salivary cortisol levels relative to participants who reported low dispositional mindfulness. The present data therefore is in direct contradiction with Hypothesis 1, which predicted lower cortisol reactivity for individuals with higher mindfulness.

To further probe this interaction, the analysis outlined in Model 6 was conducted again while centering the time variable on the +15, +25, +40, and +55 minute (since stressor onset) samples. Doing so allows one to test the effect of mindfulness on the intercept, and on the instantaneous rate of change at all available sample time points. The result of these analyses are shown in Table 3. As shown in Table 3, dispositional mindfulness had a marginally significant positive effects on the intercept for the +25 and +40 minute samples consistent with Figure 1. This indicates that trait mindfulness predicted higher cortisol levels during the expected peak (i.e., +25 minutes sample) and initial recovery (i.e., +40 minutes sample). Additionally, mindfulness showed a
significant positive effect on the instantaneous rates of change for the baseline, +15, and +25 minute time points; such that, as mindfulness increases, the linear slope relating time to cortisol levels becomes more positive (i.e., steeper rises in cortisol concentration). The marginal effect of mindfulness on the +40 minute post stressor onset intercept suggests that mindfulness was actually associated with higher cortisol during the early recovery period, in contrast with Hypothesis 2, which predicted that trait mindfulness would be associated with improved (i.e., lower) cortisol levels during the post-stressor recovery time points. Mindfulness also showed a significant negative effect on the instantaneous rates of change for the +55 minute time points; such that, as mindfulness increases, the linear slope relating time to cortisol levels becomes more negative (i.e., steeper decline). Although the present findings do not support Hypothesis 2, these analyses indicate that cortisol concentrations were dropping at a faster rate by the end of the visit for those with higher trait mindfulness scores. In isolation, these results may suggest that mindfulness improved late recovery (i.e., +55 minute samples). However, this effect was not independent of previous reactivity and thus may be a function of the high reactivity that preceded it.

**Inclusion of sensitivity measures.** A secondary goal of the present analysis was to test if the effects of mindfulness on cortisol responses to an acute stressor occur independently of other psychological constructs related to mindfulness and known to influence cortisol. As such, perceived stress over the last month, anxiety, neuroticism, and depression variables were added into Model 6 as level 2 predictors to produce Model 7. The resulting model did not lead to a significant improvement in model fit relative to
Model 6 (see Table 2, Model 7). Further, the cross-level interaction of trait mindfulness and the quadratic slope relating time to cortisol level remained significant after accounting for gender, anxiety, neuroticism, depression, and perceived stress over the last month (see Table 2, Model 7). Thus, the effect of mindfulness on cortisol responses presently occurred independently of selected sensitivity measures.

**Did Mindfulness Predict Post-task Rumination? (Hypothesis 3)**

Trait mindfulness is generally negatively related to repetitive thought (Evans & Segerstrom, 2011) and trait rumination measures (Brown & Ryan, 2003). As such, trait mindfulness was expected to negatively relate to state stress-related rumination. As shown in Table 1, the relationship between trait mindfulness and state stress-related rumination was negative, but non-significant. Therefore Hypothesis 3 was not supported; high dispositional mindfulness was not associated with lower state stress-related rumination.

**Did Rumination Predict Cortisol Recovery? (Hypothesis 4)**

To test for the effect of state stress related rumination on cortisol responses, mean-centered state stress-related rumination was added into Model 5 as a level 2 predictor of the level 1 intercept and slopes to produce Model 8. The addition of state stress-related rumination into Model 8 led to a marginally significant decrease in model deviance relative to Model 5 (see Table 2, Model 8), which indicates a slight improvement in model fit. Furthermore, interactions of state stress-related rumination with the quadratic or linear slopes relating time to cortisol levels were not significantly
different from 0, suggesting that rumination did not influence linear or curvilinear cortisol response patterns.

To investigate the effect of state stress-related rumination on cortisol recovery, the analysis outlined in Model 8 was conducted again while centering the time variable on the +15, +25, +40, and +55 minute (since stressor onset) samples. Although the effect of rumination on the linear and curvilinear growth curves were non-significant, reactivity sample time points (i.e., +15 and +25 minutes samples) were included to assess if rumination influenced cortisol in a non-linear/non-quadratic fashion. The result of these analyses are presented in Table 4, and a graphical representation of the effect of state stress-related rumination on cortisol trajectories is shown in Figure 2. As shown in Table 4, state stress-related rumination had no effect on the intercept for any cortisol time points available. However, state stress-related rumination showed a significant positive effect on the instantaneous rates of change for the +25 minute time point and a marginally positive effect on the instantaneous rate of change for the +40 minute time point; such that, as rumination increases, the linear slope relating time to cortisol levels also increases (i.e., becomes more positive). In other words, the post-stressor decline in cortisol concentrations was not as steep for those with greater stress-related rumination soon after the speech ended. In conclusion, there is mixed evidence in support of Hypothesis 4.

Inclusion of sensitivity measures. To test if the effects of state stress-related rumination on cortisol responses were independent of other psychological constructs known to influence cortisol, mean centered perceived stress over the last month, anxiety,
neuroticism, and depression variables were added into Model 8 as level 2 predictors to produce Model 9. The addition of trait anxiety, neuroticism, depression and perceived stress over the last month led a marginal decrease in model deviance relative to Model 8, which indicates (see Table 2) a slight improvement in model fit. The cross level interaction of perceived stress over the last month and the quadratic slope relating time to cortisol levels was marginally significant (see Table 2, Model 9), suggesting that as perceived stress of the last month decreased, cortisol slopes showed an increasingly peaked curvilinear shape.

The interaction of state stress-related rumination and the quadratic slope relating to cortisol remained non-significant (see Table 2, Model 9). Furthermore, the previously observed effects of state stress related rumination on the instantaneous rate of change for +25 and +40 minute samples were not influenced by the inclusion of sensitivity measures.

**Was the Effect of Mindfulness on Cortisol Recovery Mediated by Rumination? (Hypothesis 5)**

It was hypothesized that the effects of dispositional mindfulness on cortisol recovery would be mediated by state stress-related rumination (i.e., more mindfulness would improve cortisol recovery via a decrease in state stress-related rumination). However, given that Hypothesis 3 was not supported, one should conclude that Hypothesis 5 is not supported either; the effects of mindfulness on cortisol recovery are not mediated by state stress-related rumination because mindfulness was not significantly associated with state stress-related rumination.
**Did Mindfulness Predict Openness to Experience?**

Mindfulness theories (Bishop et al., 2006) and previous research (Baer, 2006) suggest that the mindfulness should positively correlate with openness to experience because this trait overlaps in content with mindful acceptance. However, as shown in Table 1, dispositional mindfulness was not significantly related to the openness to experience subscale of the Big Five Inventory (BFI; Pervin & John, 1999). Therefore, the present study did not replicate the findings of Baer (2006); trait mindfulness was unrelated to openness to experience.

Additionally, openness to experience did not significantly relate to cortisol changes over time. The association between openness to experience and the cortisol intercept, or the fixed linear and quadratic slopes relating time to cortisol levels were all non-significant (all $p$s > .52).
Discussion

The goal of the present study was to investigate the effects of trait mindfulness and state stress-related rumination on cortisol responses to acute stress. Cortisol is a primary stress mediator that widely impacts the body (McEwen, 1998), and has been hypothesized to play a role in how mindfulness buffers against negative health outcomes initiated or worsened by the presence of stress (Creswell & Lindsay, 2014). Based on prior research (e.g., Brown et al., 2012; Deyo et al., 2009; Tang et al., 2007), trait mindfulness was expected to predict lower cortisol reactivity and lower state stress-related rumination. Additionally, state stress-related rumination was expected to predict prolonged cortisol recovery, as it has in the past (e.g., Zoccola et al., 2008, 2014). Furthermore, trait mindfulness was expected to improve cortisol recovery following acute stress, and for this effect to be mediated by state stress-related rumination. Demonstrating an effect of mindfulness on cortisol recovery would have suggested a new pathway via which mindfulness buffers against the effects of stress on health; shorter recovery following acute stress would suggest lower cortisol exposure over time, and long-term health benefits (McEwen, 1998). The present study also attempted to replicate past findings (Baer, 2006), suggesting that mindfulness is positively correlated with openness to experience. Finally, the present study examined if the relationship between mindfulness, rumination, and cortisol reactivity/recovery were independent of other psychological factors related to mindfulness or HPA axis activation.
Mindfulness and Cortisol Reactivity

Contrary to hypotheses, the present study found that greater levels of trait mindfulness predicted a more peaked cortisol response to acute stress. The mindfulness stress buffering account suggests that mindfulness improves physical health by reducing the reactivity of stress-response systems including the HPA axis (Creswell & Lindsay, 2014). Additionally, prior work demonstrated that, under high stress load, participants who scored high in trait mindfulness had significantly lower cortisol reactivity relative to participants who scored low in trait mindfulness (Brown et al., 2012). Thus, the present study was not able to replicate the effect of mindfulness on cortisol reactivity observed by Brown et al., (2012). I propose that stressor intensity and sample characteristics may provide some insight into these discrepant findings.

In attempting to reconcile these apparently discrepant findings, it is important to note that Brown et al., (2012) observed a moderating effect of stressor intensity on the mindfulness-cortisol reactivity relationship. They manipulated stressor intensity by randomly assigning participants to give a speech in front of evaluators (high stress condition) or in front of a recording device (low stress condition), and showed that mindfulness predicted decreased cortisol reactivity only in the high stress condition. More specifically, participants in the high stress condition gave a 5 minute speech and completed a 5 minute mental arithmetic task in front of an evaluative panel (i.e., they completed the TSST; Kirschbaum et al., 1993). In contrast, the present study used a modified TSST involving a 5 minute speech but no mental arithmetic task. Thus, the present stress task was relatively more moderate than the full TSST because it did not
include a mental arithmetic portion and resulted in a smaller baseline to peak cortisol change (d = .43 in present study; d=92 in Brown et al., 2012). As a result, one may suggest that the present stressor was not strong enough to replicate Brown et al., (2012). Nevertheless, the direction of the present finding suggests that the moderating effect of stressor intensity on the mindfulness-cortisol reactivity relationship may be more complex than previously theorized. It is possible that mindfulness increases cortisol reactivity under moderate stress load, decreases reactivity under high stress load, and has no effect on cortisol reactivity under low stress load. Such a relationship would theoretically enable individuals to mobilize physical resources more easily while minimizing cortisol output (and associated negative health outcomes) across a variety of stressors—effectively normalizing acute cortisol responses across varying degrees of stressor intensities.

Such a normalizing effect of mindfulness on acute cortisol responses would be a new approach to understanding how mindfulness improves health by regulating stress responses. Nonetheless, “normalization” of cortisol responding would still be consistent with the Mindfulness Stress Buffering Account (Creswell & Lindsay, 2014), because both exaggerated and diminished cortisol responding to stress is thought to lead to allostatic load and poor health over time (McEwen, 2007). Other research suggests that mindfulness training may normalize diurnal cortisol secretions in cancer patients (Carlson et al., 2004). Carlson and colleagues found that, relative to pre-intervention, participants who underwent an MBSR intervention return to an arguably more typical pattern of diurnal secretion (i.e., they displayed lower evening cortisol levels at the end of the
study). However, a normalizing effect of mindfulness on acute stress responses has yet to be reported in the literature, and is not currently included in predictions of the mindfulness stress buffering account (Creswell & Lindsay, 2014). Nevertheless, the allostatic load model suggests that cortisol responses that are too high or too low can both lead to negative health outcomes (McEwen, 2007). For example, cortisol hyper-reactivity increases cortisol exposure, which can lead to poor regulation of the HPA axis (e.g., via down regulation of hippocampal and pituitary glucocorticoid receptors) and ultimately allostatic load, and disease (McEwen, 2007). Similarly, little to no cortisol responses during acute stress can result in increased levels of cytokines that are normally counter-regulated by glucocorticoids. For example, low levels of cortisol are associated with auto-immune and inflammatory diseases in the Lewis rat strain (Sternberg, 1997).

Thus, from a purely theoretical perspective, the present findings are consistent with the notion that mindfulness also improves health outcomes by “normalizing” cortisol reactivity under moderate to high stress load. Future studies should investigate the effect of mindfulness on cortisol reactivity using a control (no stress), moderate, and high stress condition. This type of methodology may be necessary to fully tease apart the moderating effect of stress intensity on the relationship between mindfulness and cortisol reactivity.

Beyond stressor intensity, protocol variations based on sample size, gender ratio, and ethnic composition were also considered. Brown et al., (2012) recruited 44 participants (82% female; 77% Caucasian) and randomly assigned half of the participants to the high and low stress condition, resulting in 22 participants per condition. In
contrast, the present study used 109 participants in final analyses (56% female; 59% Asian). The present experiment therefore used a more gender balanced design, more participants, and was comprised primarily of Asian participants. Variations in sample size suggest that the present finding may have achieved greater statistical precision (i.e., lower standard errors) than Brown et al., (2012). Additionally, differences with regards to gender ratio may suggest that the effect of mindfulness on cortisol reactivity is influenced by gender. Previous research (Saucier, 2011) making use of 29 participants (15 females) found that, for males, trait mindfulness positively predicted increased cortisol reactivity to the TSST, and was unrelated to cortisol reactivity for females. Nevertheless, Brown et al. (2012) controlled for gender in their analyses, and in the present study, gender did not interact with trait mindfulness to predict cortisol reactivity. Finally, variations in ethnic composition may also influence results. Asian and other collectivistic cultures may be more susceptible to shame-related HPA axis activation (Sorge & Hofstede, 1983; Triandis, Bontempo, Villareal, Asai, & Lucca, 1988). Some suggest that individuals from collectivistic cultures are more likely to make shame-related appraisals, which are linked to greater cortisol responses (Dickerson et al., 2008; Tracy & Robins, 2007). As such, the majority of the present sample may be more sensitive to social-evaluative stress, and could limit the generalizability of findings to non-Asian or non-collectivistic populations. It is possible that mindfulness influences cortisol responses differently for collectivistic relative to non-collectivistic cultures, though race did not moderate the relationship between trait mindfulness and cortisol in
the present data. In sum, sample size and ethnic composition may have contributed to the present replication failure, while gender most likely did not.

In terms of the broader mindfulness literature, the present study is not the first to report discrepant results regarding the relationship between mindfulness and cortisol reactivity. For example, Tang et al., (2007) found that 5 days of meditation training decreased cortisol reactivity to a mental arithmetic task relative to relaxation training. Additionally, Creswell, Pacilio, Lindsay, & Brown, (2014) found that a brief 3-day mindfulness training increased reactivity cortisol secretion to the TSST relative to a cognitive training condition; with individuals who scored low in dispositional mindfulness showing the greatest increase. Thus again, the emerging literature on mindfulness and cortisol reactivity to acute stress lacks consistency even when using more involved mindfulness manipulations. As such, it may be best for future studies investigating the relationship between mindfulness and cortisol responses to make use of standard 8-week interventions like the Mindfulness Based Stress Reduction (MBSR) program. The present state of the literature suggests that mindfulness operationalizations based on self-report or short interventions may not provide a sufficient basis for reliable conclusions to be drawn.

In sum, the presently observed relationship between trait mindfulness and cortisol reactivity add to a new and somewhat inconsistent literature. As noted, protocol deviations in terms of stressor intensity and sample characteristics may possibly account for the present findings, and should be investigated in future studies, as they may inform current theories. More broadly, the current state of this literature calls for more
established mindfulness manipulations (e.g., 6-8 week MBSR training) and more replication attempts such that conclusions based on aggregated studies (i.e., meta-analyses) can be drawn regarding the effect of mindfulness on cortisol reactivity.

**Mindfulness and Cortisol Recovery**

The present study is the first to investigate the relationship between trait mindfulness and cortisol recovery following acute stress. Demonstrating a relationship between mindfulness and cortisol recovery may reveal another pathway via which mindfulness buffers against the negative effects of stress on health. Contrary to proposed hypotheses, dispositional mindfulness was marginally associated with higher cortisol levels 40 minutes post stressor onset. Yet, this effect did not hold for the 55 minute post stressor onset sample, which suggests that the effects of mindfulness may be limited to initial recovery. Further, mindfulness was negatively related to the linear cortisol slope 55 minutes post stressor onset (i.e., higher mindfulness predicted steeper cortisol decline). Thus, mindfulness may potentially improve recovery beyond 55 minutes, although the present data do not allow one to draw this conclusion without extrapolation. In isolation, these results may imply that mindfulness predicted poor initial recovery (i.e., 40 minutes since stress onset) and potentially improved late recovery (i.e., beyond +55 minutes since stress onset). However, the effect of mindfulness on cortisol recovery was not independent of previous reactivity and thus may be a function of the high reactivity that preceded it. Therefore, evidence in support of Hypothesis 2 (i.e., mindfulness predicts improved cortisol recovery) is mixed at best. Future studies could collect
cortisol data for a longer duration (e.g., beyond +55 minutes since stressor onset) to investigate if mindfulness improves late cortisol recovery.

The use of the MAAS to operationalize mindfulness may have contributed to the present findings because the MAAS may not reliably capture aspects of mindfulness that relate to cortisol recovery. The MAAS is designed to measure trait mindfulness by assessing the frequency of inattentive states in daily life (Brown & Ryan, 2003), and, as a result, has been criticized for not measuring mindful acceptance (Chiesa, 2012). Assessing the extent to which the MAAS was unable to measure mindfulness acceptance is difficult, and beyond the scope of the present project. The only available measure conceptually overlapping with mindful acceptance was openness to experience, and the MAAS was presently non-significantly (but positively) associated with openness to experience ($r = .12$). In contrast, previous studies (Baer, 2006; Brown & Ryan, 2003) found the MAAS to positively (albeit weakly) correlate with openness to experience (e.g., $r = .18$; Brown et al., 2012). The overall weak relationship between the MAAS and openness to experience may provide some slight support for the claim that the MAAS does not reliably capture mindful acceptance. Additionally, some have proposed that equanimity (i.e., a construct resembling mindful acceptance characterized by a mental attitude of openness, even-mindedness, and acceptance that results from meditation training) improves health by shortening the time course of emotional and physiological responses to stress (Desbordes et al., 2014). One should note that Desbordes et al. (2014) define mindfulness strictly in terms of attention towards the present moment, while equanimity is defined as an attitude of non-resistance and non-judgment, which allows
mindful awareness to remain even and unbiased. Thus, equanimity mirrors what other theorist define as mindful acceptance. Although untested, it is possible that aspects of mindfulness like acceptance, which are not always captured by the MAAS, may still predict shorter cortisol recovery. To test this hypothesis, future studies could use a scale that more specifically assesses mindful awareness and acceptance (e.g., the Philadelphia Mindfulness Scale; Cardaciotto, Herbert, Forman, Moitra, & Farrow, 2008) or manipulate levels of mindful awareness and acceptance, and evaluate if high levels of both are necessary for mindfulness to reduce cortisol recovery.

**Mindfulness and State Stress-Related Rumination**

Based on previous research (Brown & Ryan, 2003; Evans & Segerstrom, 2011), trait mindfulness was expected to predict lower state stress-related rumination following the speech task. Illustrating that mindfulness reduces state stress-related rumination was presently important because previous work suggests that state and stress-related measures of rumination are more consistent predictors of prolonged HPA axis activation relative to trait or anger related rumination measures (Zoccola & Dickerson, 2012). Contrary to hypothesis 3, trait mindfulness was not significantly related to state stress-related rumination. Yet, consistent with prior work, trait mindfulness was negatively related to trait rumination measures. Given that mindfulness predicted trait but not state rumination, it is possible that the present use of a trait measure of mindfulness to predict state rumination was inadequate. Although, a trait should remain constant across time and settings, the use of a state measure of mindfulness may be necessary to capture the relationship between mindfulness and state stress-related rumination. Additionally, the
relationship between trait mindfulness and state stress-related rumination was small \( (r = -0.09) \), and thus could therefore require a potent mindfulness manipulation or greater statistical power to reach significance. Thus, future studies could use state measures of mindfulness, a larger sample size, or a potent mindfulness manipulation to further investigate the effects of mindfulness on state stress-related rumination.

**Rumination and Cortisol Recovery**

The perseverative cognition hypothesis suggests that the mental rehearsal of a stressor in the form of rumination can extend the duration of stress responses (Brosschot et al., 2006). Thus, it was hypothesized that more negative thoughts pertaining to the preceding stressor task (i.e., state stress-related rumination) would predict prolonged cortisol recovery. Contrary to hypotheses, state stress related rumination did not predict greater cortisol levels 40 or 55 minutes post stressor onset. Nevertheless, state stress-related rumination showed a significant positive effect on the linear cortisol slope for the +25 minute time point and a marginally positive effect on the linear cortisol slope for the +40 minute time point. Thus, state stress-related rumination predicted a more positive linear slope relating time to cortisol levels during and shortly following the expected peak. Therefore, support for Hypothesis 4 was mixed. In sum, although weak, the reported effect of state stress-related rumination on cortisol recovery is generally consistent with correlational, quasi-experimental, and experimental studies linking rumination to elevated cortisol concentrations during stress recovery (Zoccola & Dickerson, 2012; Zoccola et al., 2014).
Mindfulness, Rumination and Cortisol Recovery

Contrary to hypotheses, the effect of mindfulness on cortisol recovery was not mediated by state stress related rumination. Given that broadly defined rumination is negatively related to mindfulness, and state stress-related rumination has been shown to prolong cortisol recovery relative to distraction (Zoccola et al., 2014), I expected the effect of mindfulness on cortisol recovery to be mediated by state stress-related rumination. Demonstrating such an effect may outline yet another pathway via which mindfulness influences health outcomes. However, although trait mindfulness was negatively related to trait rumination, it was not significantly related to state stress-related rumination. As previously mentioned, the use of a trait mindfulness measure, and the presently weak relationship between trait mindfulness and state stress-related rumination may provide some explanation for the present lack of finding.

Role of Sensitivity Measures

The present study also attempted to evaluate if the effects of mindfulness on cortisol response were independent of other psychological factors known to influence cortisol or related to mindfulness. Mindfulness is negatively related to perceived stress, depression, anxiety, and neuroticism (Atanes et al., 2015; Brown & Ryan, 2003). Additionally, neuroticism, anxiety, depression, and perceive stress over the last month have been shown to predict HPA axis function (Burke, Davis, Otte, & Mohr, 2005; O’Donovan et al., 2010; Oswald et al., 2006; Portella et al., 2014; M. Pruessner et al., 2003). Thus, it was presently important to illustrate that the observed effects of trait mindfulness on cortisol responses were not due to shared variance with sensitivity
measures. Trait anxiety, neuroticism, depression, and perceived stress over the last month did not significantly influence the relationship between trait mindfulness and cortisol reactivity or recovery in the present data. Nevertheless, consistent with previous research (Pruessner, Hellhammer, & Kirschbaum, 1999), perceived stress over the last month was marginally positively related to cortisol reactivity. Thus, the present research was generally successful in differentiating between the effect of trait mindfulness and other psychological factors on cortisol responses.

**Strengths, Limitations and Future Directions**

The present study attempted to extend previous work examining the relationship between mindfulness and cortisol responses using mixed linear models resulting in a nuanced examination of cortisol response trajectories (i.e., both reactivity and recovery were examined). Additionally, relative to prior work, the present study made use of a large sample size, and a balanced gender ratio.

Nevertheless, the present findings relating trait mindfulness to cortisol responses involve several limitations. First, operationalizing trait mindfulness using self-report questionnaires does not allow one to infer causality. Additionally, trait mindfulness questionnaires were completed after the stressor task. This is important because although a trait should remain relatively constant across times and situations, it is possible that performance on the stressor task influenced subsequent self-reports of trait mindfulness. Moreover, although the MAAS is well suited to measure trait mindfulness in a non-practitioner sample, this scale may be unable to capture aspects of the mindfulness construct (e.g., mindful acceptance), which are essential for its effect on cortisol
responses to be observed. Furthermore, the amount of time measured for cortisol recovery may not have been sufficient for some participants’ cortisol levels to return to baseline. Although, on average, participants are expected to return to near baseline levels of cortisol by 50-60 minutes post stressor onset (Dickerson & Kemeny, 2004b), collecting cortisol data over a longer duration may be necessary to understand how long the effects of mindfulness and rumination on cortisol found in the current study persist. Further, while trait mindfulness was used as a predictor, it is unclear to what degree the current findings are a result of state mindfulness. The present analyses did not find that trait mindfulness affected cortisol recovery via a decrease in state stress-related rumination, so it is unclear what state level mechanism led to the observed effect of trait mindfulness on cortisol recovery. Finally, the majority of the present sample was Asian which may limit generalizability. Thus, future research would benefit from revisiting the relationship between mindfulness and cortisol reactivity/recovery using: 1) well established mindfulness operationalizations (e.g., MBSR intervention), 2) mindfulness scales that clearly tap into both of its subcomponents (i.e., mindful awareness and mindful acceptance), 3) self-report measures that are completed prior to stress induction, 4) trait and state measures of mindfulness, 5) longer periods of testing such that all participants may return to baseline levels of cortisol, and 6) a sample composition that allows for greater generalizability.

The present study attempted to investigate the effect of mindfulness on two pathways via which stress is hypothesized to affect health. As outlined by the Allostatic load model (McEwen, 1998), reducing cortisol reactivity and shortening cortisol recovery
should limit cortisol exposure, and ultimately protect individuals from negative health outcomes associated with poorly regulated cortisol secretions. Nevertheless, other pathways may be considered. For example, poor habituation to repeated acute stress, and no response to acute stress are associated with poor health. The present findings and those of Saucier (2011) may suggest that mindfulness buffers against a lack of cortisol response during acute stress. Additionally, mindfulness may also influence health by improving stress habituation (i.e., decreasing reactivity to stress during repeated stressor exposure). Theoretical reviews of mindfulness have proposed that learning processes like habituation may be implicated in mindfulness (Kabat-Zinn, 1982; Kabat-Zinn et al., 1992). Further, mindfulness based interventions are successful in alleviating Post Traumatic Stress Disorder (PTSD) symptoms (Kearney, McDermott, Malte, Martinez, & Simpson, 2012), and failure of habituation to trauma-related stimuli is hypothesized to contribute to the development and maintenance of PTSD (Liberzon & Martis, 2006). Thus, an effect of mindfulness on stress habituation is generally consistent with mindfulness theories and may account for the effects of mindfulness interventions on PTSD symptoms. While most studies only administer a single stressor to test for the effect of mindfulness on cortisol responses, future studies may benefit from incorporating repeated acute stress protocols (i.e., multiple TSSTs). In conclusion, future research could benefit from considering the effects of mindfulness on multiple pathways via which stress is thought to influence health.
Conclusions and Implications

Mindfulness is linked to improvements in a variety of health outcomes, and has become an increasingly popular subject of research. However, the mechanism driving the positive health effects of mindfulness on health remain elusive. The present study investigated both psychological and physiological pathways via which mindfulness may improve health. More specifically, the relationship between trait mindfulness, cortisol reactivity, cortisol recovery, and state stress-related rumination was tested. The present study found that trait mindfulness was associated with increased cortisol reactivity following a relatively moderate stressor task. Additionally, trait mindfulness may be associated with prolonged initial cortisol recovery, and improved late recovery; yet, the effects of mindfulness on cortisol recovery were not clearly distinguishable from the effects of mindfulness on preceding reactivity. Thus, evidence linking mindfulness to cortisol recovery was mixed. Consistent with previous work, state stress-related rumination was related to prolonged cortisol recovery. Finally, trait mindfulness did not predict lower state stress-related rumination. As a result, state stress-related rumination did not appear to mediate the relationship between trait mindfulness and cortisol recovery. In conclusion, future research may benefit from investigating potential moderators of the relationship between mindfulness and stress responses, considering other means to operationalize mindfulness, and testing for effects of mindfulness on other pathways via which stress influences health.
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Table 1. Zero Order Correlations for Questionnaire, Sensitivity and Covariate Measures (N=109).

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<td>1. Mindfulness</td>
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<td>2. SS-R Rumination(^a)</td>
<td>-.097</td>
<td>-</td>
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<td>3. Gender(^b)</td>
<td>-.082</td>
<td>-.153</td>
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<td>4. Body Mass Index</td>
<td>-.017</td>
<td>-.014</td>
<td>.201*</td>
<td>-</td>
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<td>5. Wake Time</td>
<td>.078</td>
<td>-.210*</td>
<td>.256*</td>
<td>.067</td>
<td>-</td>
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<td>6. Trait Rumination</td>
<td>-.235*</td>
<td>.397**</td>
<td>-.082</td>
<td>-.041</td>
<td>.043</td>
<td>-</td>
<td></td>
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<td>7. Perceived Stress</td>
<td>-.282**</td>
<td>.446**</td>
<td>-.299*</td>
<td>-.120</td>
<td>-.155</td>
<td>.514**</td>
<td>-</td>
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<tr>
<td>8. Trait Anxiety</td>
<td>-.246*</td>
<td>.347**</td>
<td>-.190*</td>
<td>-.125</td>
<td>-.210*</td>
<td>.501**</td>
<td>.770**</td>
<td>-</td>
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<td>9. Neuroticism</td>
<td>-.271**</td>
<td>.540**</td>
<td>-.233*</td>
<td>-.088</td>
<td>-.157</td>
<td>.604**</td>
<td>.718**</td>
<td>.685**</td>
<td>-</td>
<td></td>
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<tr>
<td>10. Openness</td>
<td>.123</td>
<td>-.216*</td>
<td>.053</td>
<td>.165*</td>
<td>.166†</td>
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<td>-.250**</td>
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<td>-.063</td>
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<td>.681**</td>
<td>.531**</td>
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</table>

\(^†\) Correlation is at the 0.10 level (2-tailed).
\(^*\) Correlation is significant at the 0.05 level (2-tailed).
\(^**\) Correlation is significant at the 0.01 level (2-tailed).

\(^a\) SS-R Rumination refers to State Stress-Related Rumination.
\(^b\) Gender was coded as 1 = male, 0 = female.
Table 2. Parameter Estimates for the Eight Models Examining the Relationship between Time, Gender, Mindfulness, Rumination, Anxiety, Neuroticism, Depression, Perceived Stress and Cortisol (N=109).

<table>
<thead>
<tr>
<th>Model</th>
<th>Fixed Effects</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
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<td>1.99**</td>
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<td>1.90**</td>
<td>1.90**</td>
<td>1.90**</td>
<td>1.90**</td>
<td>1.89**</td>
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<td>.20†</td>
<td>.22†</td>
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<td>Perceived Stress*Time^2</td>
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Table 2: continued

<table>
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<tr>
<th>SS-R Ruminationde</th>
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<th>-.10</th>
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</tr>
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<td>SS-R Ruminati*Time²</td>
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<td>.06</td>
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</table>

Random Effects

| Residual          | .21**| .20**| .15**| .15**| .15**| .15**| .15**| .15**|
| Intercept         | .30**| .30**| .19**| .17**| .17**| .17**| .17**| .17**|
| Time              | 2.90**| 2.32*| 2.43*| 2.03*| 1.67†| 2.39*| 1.97*|
| Time²             | 2.94**| 2.26*| 2.37*| 2.02*| 1.65†| 2.33*| 1.93*|

Estimation: ml

| -2 Log Likelihood | 908.7 | 895.3 | 872.9 | 843.7 | 849.0 | 839.8 | 823.3 | 842.3 | 822.4 |
| Parameters        | 3     | 5     | 10    | 19    | 13    | 16    | 28    | 16    | 28    |

Model Comparisons

| Δ-2 Log Likelihoodf | 13.4  | 22.4  | 29.2  | 23.9g | 9.2   | 16.5  | 6.7h  | 19.9  |
| p-value            | .001  | <.001 | <.001 | <.001 | .026  | .169  | .082  | .069  |

- p < .10 * p < .05 ** p < .01
- Time (in hours) was centered on the +0 minutes post stressor onset (i.e., baseline) sample.
- Gender was coded as: male = 1, female = 0.
- Wake time was coded as hours since midnight.
- SS-R Ruminati refers to State Stress-Related Ruminati.
- ml refers to maximum likelihood estimation.
- Δ-2 Log Likelihood corresponds to the change in -2 Log Likelihood from the previous model unless noted otherwise.
- Δ-2 Log Likelihood among Model 3 and 5
- Δ-2 Log Likelihood among Model 5 and 7
Table 3. *Parameter Estimates of the Multilevel Model Examining the Relationship between Mindfulness, Time, Gender and Cortisol Levels (N=109).*

<table>
<thead>
<tr>
<th>Time Centering</th>
<th>0 min</th>
<th>+15 min</th>
<th>+25 min</th>
<th>+40 min</th>
<th>+55 min</th>
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<tbody>
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<td>SE</td>
<td>Estimate</td>
<td>SE</td>
<td>Estimate</td>
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<td><strong>Fixed Effects</strong></td>
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<tr>
<td>Intercept</td>
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<td>.073</td>
<td>1.93**</td>
<td>.077</td>
<td>1.95**</td>
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<tr>
<td>Time(a)</td>
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<td>.09</td>
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<tr>
<td>Time(2)</td>
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<td>.318</td>
<td>-.01</td>
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<td>-.01</td>
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<tr>
<td>Gender(b)</td>
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<td>.47**</td>
<td>.117</td>
<td>.53**</td>
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<td>Gender*Time(1)</td>
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<td>.467</td>
<td>.66**</td>
<td>.248</td>
<td>.14</td>
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<td>-1.56**</td>
<td>.476</td>
<td>-1.56**</td>
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<td>Mindfulness</td>
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<td>.09</td>
<td>.073</td>
<td>.14†</td>
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<td>Mindfulness*Time(1)</td>
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<td>-1.84**</td>
<td>.300</td>
<td>-1.84**</td>
</tr>
</tbody>
</table>

\(†p < .10\) *\(p < .05\) **\(p < .01\)

\(a\) Time was coded as hours since the baseline sample.

\(b\) Gender was coded as 1 = male, 0 = female.
Table 4. Parameter Estimates of the Multilevel Model Examining the Relationship between Rumination, Time, Gender and Cortisol Levels (N=109).

<table>
<thead>
<tr>
<th>Time Centering</th>
<th>0 min</th>
<th>+15 min</th>
<th>+25 min</th>
<th>+40 min</th>
<th>+55 min</th>
</tr>
</thead>
<tbody>
<tr>
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<td>Estimate</td>
<td>SE</td>
<td>Estimate</td>
<td>SE</td>
<td>Estimate</td>
</tr>
<tr>
<td>Fixed Effects</td>
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</tr>
<tr>
<td>Intercept</td>
<td>1.90**</td>
<td>.073</td>
<td>1.94**</td>
<td>.078</td>
<td>1.96**</td>
</tr>
<tr>
<td>Time(^a)</td>
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<td>.170</td>
<td>.09</td>
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<tr>
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<td>.326</td>
<td>-.11</td>
<td>.326</td>
<td>-.11</td>
</tr>
<tr>
<td>Gender(^b)</td>
<td>.20†</td>
<td>.110</td>
<td>.44**</td>
<td>.118</td>
<td>.51**</td>
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<td>.61**</td>
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<td>.491</td>
<td>-1.39**</td>
<td>.491</td>
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<td>SS-R Rumination(^c)</td>
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</tr>
<tr>
<td>SS-R Rumination*Time(^2)</td>
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<td>.263</td>
<td>.13</td>
<td>.263</td>
<td>.13</td>
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</tbody>
</table>

\(^†\) p < .10  \(^*\) p < .05  \(^**\) p < .01
\(^a\) Time was coded as hours since the baseline sample.
\(^b\) Gender was coded as 1 = male, 0 = female.
\(^c\) SS-R Rumination refers to State Stress-Related Rumination.
Figure 1. Effect of dispositional mindfulness on salivary cortisol concentrations.

Data shown are the untransformed estimated mean cortisol levels at each sample time point for high (top quartile) and low (bottom quartile) mindfulness scores. Estimated means were adjusted for gender. Error bars represent standard errors for the estimates at each time point.
Figure 2. Effect of state stress-related rumination on salivary cortisol concentrations.

Data shown are the untransformed estimated mean cortisol levels at each sample time point for high (top quartile) and low (bottom quartile) state stress-related rumination scores. Estimated means were adjusted for gender. Error bars represent standard errors for the estimates at each time point.
Endnotes

1 The relationship between positive (positive items on the thought questionnaire), total (i.e., positive and negative items on the thought questionnaire) state stressor-related thought and cortisol responses was also tested. This procedure mirrored that used to test the effects of (negative) state stress-related rumination in Model 8, and yielded no significant results.
Appendix: Multi-Level Analysis Model Building Procedure

So as to build a multilevel model predicting temporal changes in cortisol levels (level 1) nested within participants (level 2), the following null model was first tested:

Model 1:

Level 1: \( \text{Cortisol}_{ij} = \beta_{0j} + r_{ij} \) \hspace{1cm} 1a

Level 2: \( \beta_{0j} = \gamma_{00} + U_{0j} \) \hspace{1cm} 1b

Resulting Mixed Model:

\( \text{Cortisol}_{ij} = \gamma_{00} + U_{0j} + r_{ij} \) \hspace{1cm} 1c

Where \( \beta_{0j} \) is the estimate of the intercept; the average cortisol levels across all i samples for subject j. \( \gamma_{00} \) is the cortisol grand mean; the average cortisol level across all j subject and all i samples. \( U_{0j} \) is the difference between the average cortisol for subject j across all i sampling time points and the cortisol grand mean.

As shown on Table 2, the random component of the intercept (\( U_{0j} \)) was significantly different from 0; subjects differed from each other in terms of salivary cortisol levels recorded across all i samples. Further, the addition of the random effect led to a significant decrease in likelihood ratio from Model 1 to 2 (see Table 2). Comparing the deviance of model (i.e., likelihood ratio) allows one to evaluate if a random effect is significantly different from 0 without assuming that the sampling distribution of the variance is normal (Hayes, 2006). In conclusion, the random effect of the intercept was retained in subsequent models given that it accounted for a significant amount of variance in cortisol levels.
Previous research (e.g., Dickerson & Kemeny, 2004) has found that cortisol secretions in response to acute stress show a curvilinear relationship with time such that cortisol levels tend to immediately increase following the stressor, then level off and decrease as time increase. As such, the linear and quadratic (fixed) effects of time (coded as hours since the first sample) were added into Model 1 to create Model 2:

Model 2:

Level 1: \[ \text{Cortisol}_{ij} = \beta_{0j} + \beta_{1j} (\text{time}_{ij}) + \beta_{2j} (\text{time}^2_{ij}) + r_{ij} \]  

Level 2: \[ \beta_{0j} = \gamma_{00} + U_{0j} \]  
\[ \beta_{1j} = \gamma_{10} \]  
\[ \beta_{2j} = \gamma_{20} \]

Resulting Mixed Model:

\[ \text{Cortisol}_{ij} = \gamma_{00} + (\gamma_{10} \times \text{time}_{ij}) + (\gamma_{20} \times \text{time}^2_{ij}) + U_{0j} + r_{ij} \]

Where \( \text{time}_{ij} \) is the time elapsed since the first cortisol sample (i.e., baseline) for sample i and subject j. Given that the time variable was centered at baseline, \( \beta_{0j} \) is now the baseline cortisol level for subject j; \( \gamma_{00} \) is now the average baseline cortisol for all j subjects, and \( U_{0j} \) is now the difference between the baseline cortisol value for subject j and the average baseline cortisol for all j subjects. \( \beta_{1j} \) and \( \gamma_{10} \) are both the linear term for the slope relating sampling time to cortisol levels or the average linear effect of time elapsed since baseline on cortisol levels across all j subjects. \( \beta_{2j} \) and \( \gamma_{20} \) are both the quadratic term for slope relating sampling time to cortisol levels or the average quadratic effect of time elapsed since baseline on cortisol levels across all j subjects.
As shown on Table 2, the linear and quadratic terms for the effect of time on cortisol levels were significantly different from 0. As expected, reactive cortisol secretion to the TSST showed a curvilinear relationship with time elapsed since baseline; that is the positive relationship between cortisol levels and time became increasingly smaller and eventually negative as time increased. Further, the addition of the fixed effects of time led to a significant decrease in likelihood ratio from Model 1 to 2 (see Table 2) suggesting an improvement in model fit. As such, the fixed effects of time were retained in subsequent models.

So as to test for individual differences in slope relating sampling time to cortisol levels, random components of the linear and quadratic term for the effects of time on cortisol were added to Model 2 to create Model 3.

Model 3:

Level 1: \[ \text{Cortisol}_{ij} = \beta_{0j} + \beta_{1j} (\text{time}_{ij}) + \beta_{2j} (\text{time}_{ij}^2) + r_{ij} \]  

Level 2: 
\[ \beta_{0j} = \gamma_{00} + U_{0j} \]  
\[ \beta_{1j} = \gamma_{10} + U_{1j} \]  
\[ \beta_{2j} = \gamma_{20} + U_{2j} \]

Resulting Mixed Model:

\[ \text{Cortisol}_{ij} = \gamma_{00} + ((\gamma_{10} + U_{1j}) \times (\text{time}_{ij})) + ((\gamma_{20} + U_{2j}) \times (\text{time}_{ij}^2)) + U_{0j} + r_{ij} \]  

Where \( U_{1j} \) is the difference between the linear term for the slope (relating time elapsed baseline and cortisol levels) of subject \( j \) and the average linear term for slope across all \( j \) subjects (i.e., \( \gamma_{10} \)). \( U_{2j} \) is the difference between the quadratic term for the
slope (relating time elapsed since baseline and cortisol levels) of subject j and the average quadratic term for the slope across all j subjects. Notice that whereas $\beta_{1j}$ was representative of an average linear rate of change in Model 3, this level 1 parameter now represents an individual rate of change (i.e., subject j’s rate of change in cortisol for every hour since baseline). Similarly $\beta_{2j}$ now represents an individual rate of acceleration/deceleration.

As shown on Table 2, the variances of the random effects for the linear and quadratic slope relating time to cortisol levels were significantly different from 0. Further, the addition of these random effects led to a significant decrease in model deviance (see Table 2), suggesting improved model fit. Thus, subjects differed from one another in the extent to which their cortisol levels changed as a linear and quadratic function of time. The present use of an unstructured covariance matrix allowed for the random intercept and random slopes (linear and quadratic) to covary freely. The covariance between the random intercept and linear random slope for time or the covariance between the random intercept and quadratic random slope for time were not significantly different from 0 (all $p$s > .13). Thus one can conclude that baseline cortisol levels did not presently predict subsequent changes in cortisol levels. Furthermore, allowing these parameters to freely covary ensure that the effects of baseline values on slopes relating change over time are accounted for. For these reasons, subsequent models retained random parameters for the linear or quadratic terms of the slope relating time to cortisol levels.
The purpose of Model 4 is to test for the effect of proposed covariates on cortisol responses. Prior evidence (Kirschbaum et al., 1999) suggests that, males display a greater cortisol reactivity to the TSST (i.e., a greater initial increase followed by a steeper decline) relative to females. Furthermore, both BMI and wake time have been found to influence diurnal cortisol patterns (Champaneri et al., 2013; Clow et al., 2010) and thus may affect acute cortisol responses. So as to investigate the effect of gender, BMI and time of wake on cortisol responses as a function of time, the gender, BMI, and wake time variable was added into Model 3 at the subject level to produce Model 4:

Model 4:

Level 1:  \[ \text{Cortisol}_{ij} = \beta_0j + \beta_1j (\text{time}_{ij}) + \beta_2j (\text{time}^2_{ij}) + r_{ij} \quad 4a \]

Level 2:  
\[ \beta_0j = \gamma_{00} + \gamma_{01}*(\text{Gender}_j) + \gamma_{02}*(\text{BMI}_j) + \gamma_{03}*(\text{Wake Time}_j) + U_{0j} \quad 4b \]
\[ \beta_1j = \gamma_{10} + \gamma_{11}*(\text{Gender}_j) + \gamma_{12}*(\text{BMI}_j) + \gamma_{13}*(\text{Wake Time}_j) + U_{1j} \quad 4c \]
\[ \beta_2j = \gamma_{20} + \gamma_{21}*(\text{Gender}_j) + \gamma_{22}*(\text{BMI}_j) + \gamma_{23}*(\text{Wake Time}_j) + U_{2j} \quad 4d \]

Resulting Mixed Model:

\[ \text{Cortisol}_{ij} = \gamma_{00} + \gamma_{01}*(\text{Gender}_j) + \gamma_{02}*(\text{BMI}_j) + \gamma_{03}*(\text{Wake Time}_j) \]
\[ + ((\gamma_{10} + \gamma_{11}*(\text{Gender}_j) + \gamma_{12}*(\text{BMI}_j) + \gamma_{13}*(\text{Wake Time}_j) + U_{1j})*(\text{time}_{ij})) \]
\[ + ((\gamma_{20} + \gamma_{21}*(\text{Gender}_j) + \gamma_{22}*(\text{BMI}_j) + \gamma_{23}*(\text{Wake Time}_j) + U_{2j})*(\text{time}^2_{ij})) \]
\[ + U_{0j} + r_{ij} \quad 4e \]

Where Gender\(_j\) is the value on the gender variable for subject \(j\); males were coded as 1, and females were coded as 0. BMI\(_j\) is the BMI scores for subject \(j\). Wake Time\(_j\) is the time of wake in minutes since midnight for subject \(j\). \(\beta_0j\) remains the baseline cortisol level for subject \(j\). However \(\gamma_{00}\) is now the average baseline cortisol level for females
with mean BMI and mean time of wake scores. $\gamma_{01}$ is the average effect of gender on the intercept; it quantifies the average difference between males and females for baseline cortisol levels (i.e., average male baseline cortisol = $\gamma_{00} + \gamma_{01}$; average female baseline cortisol = $\gamma_{00}$). $\gamma_{02}$ is the effect of BMI on the intercept. $\gamma_{13}$ is the effect of time of wake on the intercept. Similarly, $\beta_{1j}$ remains the linear term of the slope relating time to cortisol levels for subject j. $\gamma_{10}$ is now the average linear term for the slope relating time to cortisol levels for females with mean BMI and mean time of wake scores. $\gamma_{11}$ is the difference in the linear term of the slope relating time to cortisol level between male and female. $\gamma_{12}$ is the effect of BMI on the linear term of the slope relating time to cortisol levels. $\gamma_{13}$ is the effect of time of wake on the linear term of the slope relating time to cortisol levels. $\beta_{2j}$ is the quadratic term of the slope relating time to cortisol levels for subject j. $\gamma_{10}$ is the average quadratic term of the slope relating time to cortisol levels for females with mean BMI and mean time of wake scores. $\gamma_{21}$ is the difference in the quadratic term of the slope relating time to cortisol level between male and female. $\gamma_{22}$ is the effect of BMI on the quadratic term of the slope relating time to cortisol levels. $\gamma_{23}$ is the effect of time of wake on the quadratic term of the slope relating time to cortisol levels.

As shown on Table 2, the effect of gender on the linear and quadratic terms of the slope relating sampling time to cortisol levels were significantly different from 0. Consistent with prior research (Kirschbaum et al., 1999), males showed a greater cortisol reactivity to the TSST (i.e., a greater initial increase followed by a steeper decline) than females. However, BMI and time of wake did not significantly predict baseline cortisol
or interact with level 1 slopes (see Table 2). As such, only gender was retained as a covariate in subsequent models.

Next the effect of gender on cortisol responses was tested in the absence of other covariates in. This model served to confirm that gender was a significant predictor of cortisol responses in the absence of the BMI and time of wake variable, and to provide subsequent model with a valid reference for model comparison (i.e., a model with fewer parameters).

Model 5:

Level 1: \[ \text{Cortisol}_{ij} = \beta_{0j} + \beta_{1j} (\text{time}_{ij}) + \beta_{2j} (\text{time}_{ij}^2) + r_{ij} \]  

Level 2: \[ \beta_{0j} = \gamma_{00} + \gamma_{01} \ast (\text{Gender}_j) + U_{0j} \]  
\[ \beta_{1j} = \gamma_{10} + \gamma_{11} \ast (\text{Gender}_j) + U_{1j} \]  
\[ \beta_{2j} = \gamma_{20} + \gamma_{21} \ast (\text{Gender}_j) + U_{2j} \]

Resulting Mixed Model:

\[ \text{Cortisol}_{ij} = \gamma_{00} + \gamma_{01} \ast (\text{Gender}_j) + ((\gamma_{10} + \gamma_{11} \ast \text{Gender}_j + U_{1j}) \ast (\text{time}_{ij})) 
+ ((\gamma_{20} + \gamma_{21} \ast \text{Gender}_j + U_{2j}) \ast (\text{time}_{ij}^2)) + U_{0j} + r_{ij} \]

Where \( \text{Gender}_j \) is the value on the gender variable for subject \( j \); males were coded as 1, and females were coded as 0. \( \beta_{0j} \) remains the baseline cortisol level for subject \( j \).

However \( \gamma_{00} \) is now the average baseline cortisol level for females. \( \gamma_{01} \) is the average effect of gender on the intercept; it quantifies the average difference between males and females for baseline cortisol levels (i.e., average male baseline cortisol = \( \gamma_{00} + \gamma_{01} \); average female baseline cortisol = \( \gamma_{00} \)).
Similarly, $\beta_{1j}$ remains the linear term of the slope relating time to cortisol levels for subject $j$. $\gamma_{10}$ is now the average linear term for the slope relating time to cortisol levels for females. $\gamma_{11}$ is the difference in the linear term of the slope relating time to cortisol level between male and female. 

$\beta_{2j}$ is the quadratic term of the slope relating time to cortisol levels for subject $j$. $\gamma_{20}$ is the average quadratic term of the slope relating time to cortisol levels for females. $\gamma_{21}$ is the difference in the quadratic term of the slope relating time to cortisol level between male and female. 

As shown on Table 2, the effect of gender on the linear and quadratic terms of the slope relating sampling time to cortisol levels remained significant in the absence of the BMI and time of wake variable. 

Previous research suggest that dispositional mindfulness modulates reactive cortisol secretions such that individual with high levels of mindfulness will display lower cortisol reactivity (Brown et al., 2012). So as to investigate the effect of dispositional mindfulness on cortisol responses as a function of time, mean centered average scores on the MAAS were added into Model 5 at the subject level to produce Model 6. 

**Model 6:**

**Level 1:**

$$\text{Cortisol}_{ij} = \beta_{0j} + \beta_{1j} (\text{time}_{ij}) + \beta_{2j} (\text{time}^2_{ij}) + r_{ij} \quad \text{6a}$$

**Level 2:**

$$\beta_{0j} = \gamma_{00} + \gamma_{01} (\text{Gender}_j) + \gamma_{02} (\text{Mindfulness}_j) + U_{0j} \quad \text{6b}$$

$$\beta_{1j} = \gamma_{10} + \gamma_{11} (\text{Gender}_j) + \gamma_{12} (\text{Mindfulness}_j) + U_{1j} \quad \text{6c}$$

$$\beta_{2j} = \gamma_{20} + \gamma_{21} (\text{Gender}_j) + \gamma_{22} (\text{Mindfulness}_j) + U_{2j} \quad \text{6d}$$
Resulting Mixed Model:

\[
\text{Cortisol}_{ij} = (\gamma_{00} + \gamma_{01}\text{*(Gender}_j) + \gamma_{02}\text{*(Mindfulness}_j)) \\
+ (\gamma_{10} + \gamma_{11}\text{*(Gender}_j + \gamma_{12}\text{*(Mindfulness}_j + U_{1j})*\text{(time}_{ij}) \\
+ (\gamma_{20} + \gamma_{21}\text{*(Gender}_j + \gamma_{22}\text{*(Mindfulness}_j + U_{2j})*\text{(time}^2_{ij}) \\
+ U_{0j} + r_{ij}
\]

Where time \_ij is the time elapsed (in hours) since the first cortisol sample (i.e., baseline) for sample i and subject j. Mindfulness \_j is the dispositional mindfulness score for subject j. Gender \_j is the value on the gender variable for subject j; males were coded as 1, and females were coded as 0. \( \beta_{0j} \) is the level of baseline cortisol for subject j. \( \gamma_{00} \) is the average level of baseline cortisol for females with mean scores on dispositional mindfulness. \( \gamma_{01} \) is the average effect of gender on the intercept; it quantifies the average difference between males and females for baseline cortisol levels. \( \gamma_{02} \) is the average effect of mindfulness on baseline cortisol; it quantifies the slope relating dispositional mindfulness to baseline cortisol level. \( \beta_{1j} \) is the linear term of the slope relating time to cortisol levels for subject j. \( \gamma_{10} \) is the average linear term of the slope relating time to cortisol level for females with average scores on dispositional mindfulness. \( \gamma_{11} \) is the average effect of gender on the linear term of the slope relating time to cortisol levels. \( \gamma_{12} \) is the average effect of mindfulness on the linear term of the slope relating time to cortisol levels; it quantifies the relationship between dispositional mindfulness and the linear term of the slope relating time to cortisol levels. \( \gamma_{20} \) is the average quadratic term of the slope relating time to cortisol level for females with average scores on dispositional mindfulness. \( \gamma_{21} \) is the average effect of gender on the quadratic term of the slope
relating time to cortisol levels. \( \gamma_{22} \) is the average effect of mindfulness on the quadratic term of the slope relating time to cortisol levels; it quantifies the relationship between dispositional mindfulness and the quadratic term of the slope relating time to cortisol levels. \( U_{0j} \) is the residual variance in baseline cortisol levels (or the difference between average baseline cortisol and subject j’s baseline cortisol level) controlling for gender and dispositional mindfulness. \( U_{1j} \) is the residual variance in the linear term of the slope relating time to cortisol levels (or the difference between the average linear term of the slope relating time to cortisol levels and subject j’s linear term of the slope relating time to cortisol levels) controlling for gender and dispositional mindfulness. \( U_{2j} \) is the residual variance of the quadratic term of the slope relating time to cortisol levels (or the difference between the average quadratic term of the slope relating time to cortisol levels and subject j’s quadratic term of the slope relating time to cortisol levels) controlling for gender and dispositional mindfulness. \( r_{ij} \) is the level-1 residual variance across all i cortisol samples for individual j; it summarizes the net (vertical) scatter of the observed cortisol levels around subject j’s hypothesized change trajectory.

As shown on Table 2 (Model 6), mindfulness did not significantly predict individual intercepts; thus mindfulness was unrelated to baseline cortisol values. However, the effect of mindfulness on the linear and quadratic terms for the slope relating sampling time to cortisol levels were significantly different from 0. Thus dispositional mindfulness moderated the relationship between time and cortisol levels, controlling for gender. A graphical representation of this interaction is shown in Figure 1 for participants with high (top quartile) and low (bottom quartile) mindfulness scores. As
shown on Figure 1, this interaction was driven by the observation that participants who reported high dispositional mindfulness showed a more peaked curvilinear relationship between time and salivary cortisol levels relative to participants who reported low dispositional mindfulness. The present data therefore is in direct contradiction with Hypothesis 1 which predicted lower cortisol reactivity for individuals with higher mindfulness.

So as to further probe this interaction, the analysis outlined in Model 6 was conducted again while centering the time variable on the +15, +25, +40, +55 minutes (since stressor onset) samples. Doing so allows one to test the effect of mindfulness on the intercept and on the instantaneous rate of change at all available sample time points. The result of these analyses are shown in Table 3. As shown in Table 3, dispositional mindfulness had marginally significant positive effects on the intercept for the +25 and +40 minutes samples consistent with Figure 1. Additionally, mindfulness showed a significant positive effect on the instantaneous rates of change for the baseline, +15, and +25 minutes time points; such that, as mindfulness increases, the linear slope relating time to cortisol levels becomes more positive (i.e., steeper reactivity). Mindfulness also showed a significant negative effect on the instantaneous rates of change for the +55 minutes time points; such that, as mindfulness increases, the linear slope relating time to cortisol levels becomes more negative (i.e., steeper decline). The present findings therefore do not support Hypothesis 2; trait mindfulness did not predict lower cortisol levels at the +40 or +55 recovery time points. The marginal effect of mindfulness on the
+40 minutes post stressor onset intercept suggests that mindfulness was actually associated with prolonged cortisol recovery.

A secondary goal of the present analysis was to test if the effects of mindfulness on cortisol responses to an acute stressor occur independently of other psychological constructs known to influence cortisol. As such, mean centered anxiety, neuroticism, depression, and perceived stress over the last month variables were added into Model 6 as level 2 predictors to create Model 7.

Model 7:

Level 1: \[ \text{Cortisol}_{ij} = \beta_{0j} + \beta_{1j} (\text{time}_{ij}) + \beta_{2j} (\text{time}^2_{ij}) + r_{ij} \quad 7a \]

Level 2: \[ \beta_{0j} = \gamma_{00} + \gamma_{01} (\text{Gender}_j) + \gamma_{02} (\text{Mindfulness}_j) + \gamma_{03} (\text{Anxiety}_j) \]
\[ + \gamma_{04} (\text{Neuroticism}_j) + \gamma_{05} (\text{Depression}_j) + \gamma_{06} (\text{Perceived Stress}_j) \]
\[ + U_{0j} \quad 7b \]

\[ \beta_{1j} = \gamma_{10} + \gamma_{11} (\text{Gender}_j) + \gamma_{12} (\text{Mindfulness}_j) + \gamma_{13} (\text{Anxiety}_j) \]
\[ + \gamma_{14} (\text{Neuroticism}_j) + \gamma_{15} (\text{Depression}_j) + \gamma_{16} (\text{Perceived Stress}_j) \]
\[ + U_{1j} \quad 7c \]

\[ \beta_{2j} = \gamma_{20} + \gamma_{21} (\text{Gender}_j) + \gamma_{22} (\text{Mindfulness}_j) + \gamma_{23} (\text{Anxiety}_j) \]
\[ + \gamma_{24} (\text{Neuroticism}_j) + \gamma_{25} (\text{Depression}_j) + \gamma_{26} (\text{Perceived Stress}_j) \]
\[ + U_{2j} \quad 7d \]

Resulting Mixed Model:

\[ \text{Cortisol}_{ij} = (\gamma_{00} + \gamma_{01} * (\text{Gender}_j) + \gamma_{02} * (\text{Mindfulness}_j) + \gamma_{03} (\text{Anxiety}_j) \]
\[ + \gamma_{04} (\text{Neuroticism}_j) + \gamma_{05} (\text{Depression}_j) + \gamma_{06} (\text{Perceived Stress}_j) ) \]
\[ + (\gamma_{10} + \gamma_{11} * (\text{Gender}_j) + \gamma_{12} * (\text{Mindfulness}_j) + \gamma_{13} * (\text{Anxiety}_j) ) \]
\[ + \gamma_{14} \cdot (\text{Neuroticism}_j) + \gamma_{15} \cdot (\text{Depression}_j) + \gamma_{16} \cdot (\text{Perceived Stress}_j) \\
+ U_{1j} \cdot (\text{time}_{ij}) + (\gamma_{20} + \gamma_{21} \cdot (\text{Gender}_j) + \gamma_{22} \cdot (\text{Mindfulness}_j) \\
+ \gamma_{23} \cdot (\text{Anxiety}_j) + \gamma_{24} \cdot (\text{Neuroticism}_j) + \gamma_{25} \cdot (\text{Depression}_j) \\
+ \gamma_{26} \cdot (\text{Perceived Stress}_j) + U_{2j} \cdot (\text{time}^2_{ij}) + U_{0j} + r_{ij} \]

Where \( \text{Anxiety}_j \) is the dispositional anxiety score for subject \( j \). \( \text{Neuroticism}_j \) is the dispositional neuroticism score for subject \( j \). \( \text{Depression}_j \) is the dispositional depression score for subject \( j \). \( \text{Perceived Stress}_j \) is the perceived stress over the last month score for subject \( j \). \( \gamma_{00} \) is now the average level of baseline cortisol for females with mean scores on dispositional mindfulness, anxiety, neuroticism, depression, and perceived stress over the last month. \( \gamma_{03} \) is the average effect of anxiety on baseline cortisol. \( \gamma_{04} \) is the average effect of neuroticism on baseline cortisol. \( \gamma_{05} \) is the average effect of depression on baseline cortisol. \( \gamma_{06} \) is the average effect of perceived stress over the last month on baseline cortisol. \( \gamma_{10} \) is now the average linear slope relating to cortisol levels for females with mean scores on dispositional mindfulness, anxiety, neuroticism, depression, and perceived stress over the last month. \( \gamma_{13} \) the average effect of anxiety on the linear slope relating time to cortisol levels. \( \gamma_{14} \) the average effect of neuroticism on the linear slope relating time to cortisol levels. \( \gamma_{15} \) the average effect of depression on the linear slope relating time to cortisol levels. \( \gamma_{16} \) the average effect of perceived stress on the linear slope relating time to cortisol levels. \( \gamma_{20} \) is now the average quadratic slope relating to cortisol levels for females with mean scores on dispositional mindfulness, anxiety, neuroticism, depression, and perceived stress over the last month. \( \gamma_{23} \) the average effect of anxiety on the quadratic slope relating time to cortisol levels. \( \gamma_{24} \) the average effect of
neuroticism on the quadratic slope relating time to cortisol levels. \( \gamma_{25} \) the average effect of depression on the quadratic slope relating time to cortisol levels. \( \gamma_{26} \) the average effect of perceived stress on the quadratic slope relating time to cortisol levels.

The resulting model did not lead to a significant improvement in model fit relative to Model 6 (see Table 2). Further, the cross-level interaction of trait mindfulness and the quadratic slope relating time to cortisol level remained significant after accounting for gender, anxiety, neuroticism, depression, and perceived stress over the last month (see Table 2). Thus the effect of mindfulness on cortisol responses presently occurs independently of selected sensitivity measures.

So as to test for the effect of state stress related rumination on cortisol responses, mean centered state stress-related rumination was added into Model 5 as a level 2 predictor to produce Model 8.

Model 8:

\[
\text{Level 1: } \text{Cortisol}_{ij} = \beta_{0j} + \beta_{1j} (\text{time}_{ij}) + \beta_{2j} (\text{time}^2_{ij}) + r_{ij} \quad 8a
\]

\[
\text{Level 2: } \begin{align*}
\beta_{0j} &= \gamma_{00} + \gamma_{01} (\text{Gender}_j) + \gamma_{02} (\text{Rumination}_j) + U_{0j} \\
\beta_{1j} &= \gamma_{10} + \gamma_{11} (\text{Gender}_j) + \gamma_{12} (\text{Rumination}_j) + U_{1j} \\
\beta_{2j} &= \gamma_{20} + \gamma_{21} (\text{Gender}_j) + \gamma_{22} (\text{Rumination}_j) + U_{2j}
\end{align*} \quad 8b, 8c, 8d
\]

Resulting Mixed Model:

\[
\text{Cortisol}_{ij} = (\gamma_{00} + \gamma_{01} (\text{Gender}_j) + \gamma_{02} (\text{Rumination}_j)) \\
+ (\gamma_{10} + \gamma_{11} (\text{Gender}_j) + \gamma_{12} (\text{Rumination}_j) + U_{1j}) (\text{time}_{ij}) \\
+ (\gamma_{20} + \gamma_{21} (\text{Gender}_j) + \gamma_{22} (\text{Rumination}_j) + U_{2j}) (\text{time}^2_{ij}) \\
+ U_{0j} + r_{ij} \quad 8e
\]
Where $t_{ij}$ is the time elapsed (in hours) since the first cortisol sample (i.e., baseline) for sample $i$ and subject $j$. Rumination$_j$ is the state stress-related rumination score for subject $j$. Gender$_j$ is the value on the gender variable for subject $j$; males were coded as 1, and females were coded as 0. $\beta_{0j}$ is the level of baseline cortisol for subject $j$. $\gamma_{00}$ is the average level of baseline cortisol for females with mean scores on state stress-related rumination. $\gamma_{01}$ is the average effect of gender on the intercept; it quantifies the average difference between males and females for baseline cortisol levels. $\gamma_{02}$ is the average effect of rumination on baseline cortisol; it quantifies the slope relating state stress-related rumination to baseline cortisol level. $\beta_{1j}$ is the linear term of the slope relating time to cortisol levels for subject $j$. $\gamma_{10}$ is the average linear term of the slope relating time to cortisol level for females with average scores on state stress-related rumination. $\gamma_{11}$ is the average effect of gender on the linear term of the slope relating time to cortisol levels. $\gamma_{12}$ is the average effect of rumination on the linear term of the slope relating time to cortisol levels; it quantifies the relationship between state stress-related rumination and the linear term of the slope relating time to cortisol levels. $\gamma_{20}$ is the average quadratic term of the slope relating time to cortisol level for females with average scores on state stress-related rumination. $\gamma_{21}$ is the average effect of gender on the quadratic term of the slope relating time to cortisol levels. $\gamma_{22}$ is the average effect of rumination on the quadratic term of the slope relating time to cortisol levels; it quantifies the relationship between state stress-related rumination and the quadratic term of the slope relating time to cortisol levels. $U_{0j}$ is the residual variance in baseline cortisol levels (or the difference between average baseline cortisol and subject $j$’s baseline
cortisol level) controlling for gender and state stress-related rumination. \( U_{1j} \) is the residual variance in the linear term of the slope relating time to cortisol levels (or the difference between the average linear term of the slope relating time to cortisol levels and subject j’s linear term of the slope relating time to cortisol levels) controlling for gender and state stress-related rumination. \( U_{2j} \) is the residual variance of the quadratic term of the slope relating time to cortisol levels (or the difference between the average quadratic term of the slope relating time to cortisol levels and subject j’s quadratic term of the slope relating time to cortisol levels) controlling for gender and state stress-related rumination. \( r_{ij} \) is the level-1 residual variance across all i cortisol samples for individual j; it summarizes the net (vertical) scatter of the observed cortisol levels around subject j’s hypothesized change trajectory.

The addition of state stress-related rumination into Model 5 led to a marginal significant decrease in model deviance (see Table 2). However, the interaction of state stress-related rumination with the quadratic slope relating time to cortisol levels was not significantly different from 0 suggesting that rumination did not influence cortisol reactivity.

So as to investigate the effect of state stress-related rumination on cortisol recovery, the analysis outlined in Model 8 was conducted again while centering the time variable on the +15, +25, +40, +55 minutes (since stressor onset) samples. The result of these analyses are presented on Table 4. As shown on Table 4, state stress-related rumination had no effect on the intercept for any cortisol time point available. However, state stress-related rumination showed a significant positive effect on the instantaneous
rates of change for the +25 minutes time point and a marginally positive effect on the instantaneous rate of change for the +40 minutes time point; such that, as rumination increases, the linear slope relating time to cortisol levels becomes more positive. In conclusion, Hypothesis 4 was supported; state stress-related rumination presently marginally predicted prolonged cortisol secretion following the TSST.

So as to test if the effects of state stress-related rumination on cortisol responses to an acute stressor occur independently of other psychological constructs known to influence cortisol, mean centered anxiety, neuroticism, depression, and perceived stress over the last month variables were added into Model 8 as level 2 predictors to create Model 9.

Model 9:

Level 1: \[ \text{Cortisol}_{ij} = \beta_{0j} + \beta_{1j}(\text{time}_{ij}) + \beta_{2j}(\text{time}_{ij}^2) + r_{ij} \]  \hspace{1cm} 9a

Level 2: \[ \beta_{0j} = \gamma_{00} + \gamma_{01}(\text{Gender}_j) + \gamma_{02}(\text{Rumination}_j) + \gamma_{03}(\text{Anxiety}_j) \]
\[ + \gamma_{04}(\text{Neuroticism}_j) + \gamma_{05}(\text{Depression}_j) + \gamma_{06}(\text{Perceived Stress}_j) \]
\[ + U_{0j} \]  \hspace{1cm} 9b

\[ \beta_{1j} = \gamma_{10} + \gamma_{11}(\text{Gender}_j) + \gamma_{12}(\text{Rumination}_j) + \gamma_{13}(\text{Anxiety}_j) \]
\[ + \gamma_{14}(\text{Neuroticism}_j) + \gamma_{15}(\text{Depression}_j) + \gamma_{16}(\text{Perceived Stress}_j) \]
\[ + U_{1j} \]  \hspace{1cm} 9c

\[ \beta_{2j} = \gamma_{20} + \gamma_{21}(\text{Gender}_j) + \gamma_{22}(\text{Rumination}_j) + \gamma_{23}(\text{Anxiety}_j) \]
\[ + \gamma_{24}(\text{Neuroticism}_j) + \gamma_{25}(\text{Depression}_j) + \gamma_{26}(\text{Perceived Stress}_j) \]
\[ + U_{2j} \]  \hspace{1cm} 9d
Resulting Mixed Model:

\[
\text{Cortisol}_{ij} = (\gamma_{00} + \gamma_{01}(\text{Gender}_j) + \gamma_{02}(\text{Rumination}_j) + \gamma_{03}(\text{Anxiety}_j)
+ \gamma_{04}(\text{Neuroticism}_j) + \gamma_{05}(\text{Depression}_j) + \gamma_{06}(\text{Perceived Stress}_j))
+ (\gamma_{10} + \gamma_{11}(\text{Gender}_j) + \gamma_{12}(\text{Rumination}_j) + \gamma_{13}(\text{Anxiety}_j)
+ \gamma_{14}(\text{Neuroticism}_j) + \gamma_{15}(\text{Depression}_j) + \gamma_{16}(\text{Perceived Stress}_j)
+ U_{1j})(\text{time}_ij) + (\gamma_{20} + \gamma_{21}(\text{Gender}_j) + \gamma_{22}(\text{Rumination}_j)
+ \gamma_{23}(\text{Anxiety}_j) + \gamma_{24}(\text{Neuroticism}_j) + \gamma_{25}(\text{Depression}_j)
+ \gamma_{26}(\text{Perceived Stress}_j) + U_{2j})(\text{time}^2_{ij}) + U_{0j} + \epsilon_{ij})
\]

Where \(\gamma_{00}\) is now the average level of baseline cortisol for females with mean scores on state stress-related rumination, anxiety, neuroticism, depression, and perceived stress over the last month. \(\gamma_{03}\) is the average effect of anxiety on baseline cortisol. \(\gamma_{04}\) is the average effect of neuroticism on baseline cortisol. \(\gamma_{05}\) is the average effect of depression on baseline cortisol. \(\gamma_{06}\) is the average effect of perceived stress over the last month on baseline cortisol. \(\gamma_{10}\) is now the average linear slope relating to cortisol levels for females with mean scores on state stress-related rumination, anxiety, neuroticism, depression, and perceived stress over the last month. \(\gamma_{13}\) the average effect of anxiety on the linear slope relating time to cortisol levels. \(\gamma_{14}\) the average effect of neuroticism on the linear slope relating time to cortisol levels. \(\gamma_{15}\) the average effect of depression on the linear slope relating time to cortisol levels. \(\gamma_{16}\) the average effect of perceived stress on the linear slope relating time to cortisol levels. \(\gamma_{20}\) is now the average quadratic slope relating to cortisol levels for females with mean scores on state stress-related rumination, anxiety, neuroticism, depression, and perceived stress over the last month. \(\gamma_{23}\) the
average effect of anxiety on the quadratic slope relating time to cortisol levels. $\gamma_{24}$ the average effect of neuroticism on the quadratic slope relating time to cortisol levels. $\gamma_{25}$ the average effect of depression on the quadratic slope relating time to cortisol levels. $\gamma_{26}$ the average effect of perceived stress on the quadratic slope relating time to cortisol levels.

The addition of trait anxiety, neuroticism, depression and perceived stress over the last month led a marginal decrease in model deviance (see Table 2). The cross level interaction of perceived stress over the last month and the quadratic slope relating time to cortisol levels was marginally significant (see Table 2), suggesting that as perceived stress of the last month decreased, cortisol slopes showed an increasingly curvilinear shape.

The interaction of state stress-related rumination and the quadratic slope relating to cortisol remained non-significant (see Table 2). Furthermore, the previously observed effect of state stress related rumination on the instantaneous rate of change for +25 and +40 minute samples were not influenced by the inclusion of sensitivity measures.