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Brief mindfulness meditation training alters psychological and neuroendocrine responses to social evaluative stress

J. David Creswell [a,*], Laura E. Pacilio [a], Emily K. Lindsay [a], Kirk Warren Brown [b]

[a] Carnegie Mellon University, 5000 Forbes Avenue, Pittsburgh, PA 15213, USA
[b] Virginia Commonwealth University, 806 West Franklin Street, Richmond, VA 23284-2018, USA

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KEYWORDS
Mindfulness;
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Summary
Objective: To test whether a brief mindfulness meditation training intervention buffers self-reported psychological and neuroendocrine responses to the Trier Social Stress Test (TSST) in young adult volunteers. A second objective evaluates whether pre-existing levels of dispositional mindfulness moderate the effects of brief mindfulness meditation training on stress reactivity.
Methods: Sixty-six ($N = 66$) participants were randomly assigned to either a brief 3-day (25-min per day) mindfulness meditation training or an analytic cognitive training control program. All participants completed a standardized laboratory social-evaluative stress challenge task (the TSST) following the third mindfulness meditation or cognitive training session. Measures of psychological (stress perceptions) and biological (salivary cortisol, blood pressure) stress reactivity were collected during the social evaluative stress-challenge session.
Results: Brief mindfulness meditation training reduced self-reported psychological stress reactivity but increased salivary cortisol reactivity to the TSST, relative to the cognitive training comparison program. Participants who were low in pre-existing levels of dispositional mindfulness and then received mindfulness meditation training had the greatest cortisol reactivity to the TSST. No significant main or interactive effects were observed for systolic or diastolic blood pressure reactivity to the TSST.

Abbreviations: SBP, systolic blood pressure; DBP, diastolic blood pressure; TSST, Trier Social Stress Test; MLM, mixed effect linear model; ANOVA, analysis of variance; AUC_I, area under the curve with respect to increase; RCT, randomized controlled trial; HIV, human immunodeficiency virus; MAAS, Mindful Attention Awareness Scale; MBSR, Mindfulness-Based Stress Reduction; HPA, hypothalamic—pituitary—adrenal; SMA, sympathetic—adrenal—medullary.

* Corresponding author. Tel.: +1 412 268 9182; fax: +1 412 268 2798.
E-mail address: creswell@cmu.edu (J.D. Creswell).

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Conclusions: The present study provides an initial indication that brief mindfulness meditation training buffers self-reported psychological stress reactivity, but also increases cortisol reactivity to social evaluative stress. This pattern may indicate that initially brief mindfulness meditation training fosters greater active coping efforts, resulting in reduced psychological stress appraisals and greater cortisol reactivity during social evaluative stressors.

Over the last fifteen years, there has been a dramatic increase in research and public interest in mindfulness meditation training. This interest has largely focused on using mindfulness meditation training to foster well-being and improve mental and physical health outcomes (Brown et al., 2007; Ludwig and Kabat-Zinn, 2008). For example, randomized controlled trials (RCTs) show that mindfulness meditation training buffers HIV-pathogenesis in HIV-positive adults (Creswell et al., 2009; SeyedAlinaghi et al., 2012), accelerates skin clearing rates in psoriasis patients (Bernhard et al., 1988; Kabat-Zinn et al., 1998), reduces risk for depression relapse in at-risk patient populations (Ma and Teasdale, 2004; Teasdale et al., 2000), decreases pain symptomatology (Kabat-Zinn, 1982; Zeidan et al., 2011), and reduces markers of inflammatory disease risk (e.g., C Reactive Protein) (Creswell et al., 2012; Malarkey et al., 2013). This emerging research base indicates that mindfulness meditation training may have beneficial effects across a spectrum of health conditions, but the mechanisms linking mindfulness meditation training with health are unknown. The stress buffering hypothesis, initially described in the social support literature (e.g., Cohen and Wills, 1985), is described as a potential pathway linking mindfulness meditation training with health (Brown et al., 2012; Creswell, 2014). Specifically, this stress buffering hypothesis posits that mindfulness meditation training effects on health may, in part, be explained by the capacity of mindfulness meditation training to foster resilience to stress (Creswell, 2014). The present study describes the first well-controlled experimental test of mindfulness meditation training and changes in self-reported psychological and neuroendocrine stress reactivity to the Trier Social Stress Test (TSST).

It is well known that repeated, excessive, or prolonged stress reactivity can increase one's health risks (Cohen et al., 2002, 2007; McEwen, 1998). One striking feature of the mindfulness training literature to-date is that mindfulness training effects on disease outcomes have been observed in diseases where stress is known to trigger the onset or exacerbation of disease symptoms and pathogenesis (e.g., HIV, psoriasis, depression, pain, chronic inflammation) (Cohen et al., 2007). One possibility, then, is that mindfulness meditation training may facilitate reduced stress reactivity and resilience in at-risk stressed patient populations, and that this stress resilience may buffer or reverse stress-related disease outcomes. Although the stress buffering account of mindfulness meditation training has been offered in several theoretical accounts and reviews of the mindfulness literature (Creswell, 2014; Ludwig and Kabat-Zinn, 2008), very little experimental work has directly tested whether mindfulness training reduces psychological and biological stress reactivity under controlled conditions. In support of the stress buffering account, two recent correlational studies show that greater self-reported dispositional mindfulness is associated with reduced self-reported psychological responses and biological stress reactivity to physical (Arch and Craske, 2010) and social (Brown et al., 2012) (cf. Barnes et al., 2007; Skinner et al., 2008) laboratory stressors. For example, Brown and colleagues found that dispositional mindfulness (measured by the Mindful Attention and Awareness Scale (MAAS), which measures sustained, receptive attentiveness to daily life experiences) was associated with reduced negative affect and salivary cortisol responses to the TSST, but was not associated with these stress markers under a low stress TSST control task (Brown et al., 2012). More recently, two RCTs of Mindfulness-Based Stress Reduction (MBSR) training provide initial evidence that eight weeks of mindfulness training can reduce blood pressure reactivity to the TSST in high stress community adults (Nyklíček et al., 2013) and self-reported stress perceptions to the TSST in patients with generalized anxiety (Hoge et al., 2013), but notably two recent studies also showed no effects of MBSR training on buffering cortisol reactivity to the TSST (Nyklíček et al., 2013; Rosenkranz et al., 2013).

Although recent studies provide an initial indication that dispositional mindfulness and mindfulness meditation training may reduce stress reactivity, there are several important unknowns that the present study will address. First, it is unclear whether mindfulness meditation training reduces stress reactivity compared to other active cognitive training programs. An active control program is important because it is currently unclear whether it is the specific capacity for developing a non-evaluative attention and awareness to present experience in mindfulness meditation training that fosters stress resilience, as opposed to general attention training and cognitive skill learning, which can buffer stress reactivity (Gaab et al., 2003). To test this, the present study compares mindfulness meditation training to an analytic cognitive training control program, and includes assessments of whether this active comparator is well-matched on attentiveness and positive treatment expectancies.

Second, it is unclear whether small doses of mindfulness meditation training are sufficient for increasing stress resilience. Previous RCT studies have described how an intensive 8-week MBSR program may reduce stress reactivity (Hoge et al., 2013; Nyklíček et al., 2013), but several studies show that just three or four days of 20-min mindfulness meditation training can increase analgesia to stimulated pain (Zeidan et al., 2011, 2010). Moreover, these (and other) initial studies indicate that pre-recorded audio mindfulness interventions can be efficacious (e.g., Cavanagh et al., 2013; Morledge et al., 2013; Zautra et al., 2012). The present study tests whether three consecutive days of 25-min audio-guided mindfulness meditation (vs. control) training in meditation naïve participants reduces stress reactivity to the TSST.

Finally, no studies have tested whether there are interactive effects of pre-existing dispositional mindfulness and mindfulness meditation training on stress reactivity. One recent study suggests that more dispositionally mindful participants are more responsive to training, showing greater increases in subjective well-being and decreases in stress symptoms after eight weeks of mindfulness training (Shapiro et al., 2011). The present study is the first to test for interactive effects of dispositional mindfulness and brief mindfulness training on stress reactivity to the TSST. This investigation of moderation has practical value: it can determine whether certain individuals respond to mindfulness training to a greater or lesser degree than others.

We tested two primary predictions in the present study. First, it was hypothesized that three days of mindfulness meditation training (compared to an active cognitive comparison training) would reduce self-reported psychological and neuroendocrine stress reactivity to the TSST. Second, it was hypothesized that dispositional mindfulness would moderate these effects of mindfulness training, such that participants higher in dispositional mindfulness who received three days of mindfulness meditation training would have lower stress reactivity to the TSST.

1. Methods

1.1. Participants

We recruited 73 healthy male and female students from the Carnegie Mellon University and University of Pittsburgh campus communities. Inclusion criteria for study participation were being between the ages of 18 and 30 years, being mentally and physically healthy (i.e., no medical diagnosis of any ongoing disease), and not currently taking any form of oral contraceptive (i.e., birth control). We excluded one participant who was administered the wrong study training on day two and three participants who elected to discontinue study participation before the day three experimental session. Also, three outlier participants with extreme dispositional mindfulness scores (±2 SDs from the sample mean) were excluded. Study analyses are reported on 66 participants (31 participants in mindfulness training group, 35 in attention control training).

The average age of participants was 21.70 years (SD = 2.91) and 59% were male. The ethnic breakdown of participants was 33.3% Caucasian, 31.8% Asian American, 9.1% Latino, 4.5% African American, and 21.2% other. All study procedures were approved by the Carnegie Mellon Institutional Review Board. All study data was collected between August 2012 and April 2013.

1.2. Procedure

1.2.1. Overview

Fig. 1 provides an overview of the study procedures. Participants were recruited for a three-day study testing how attention training impacts performance. To minimize potential expectancy and other biases, there was no mention of 'meditation training' in study advertisements or screening/informed consent. The experimental sessions

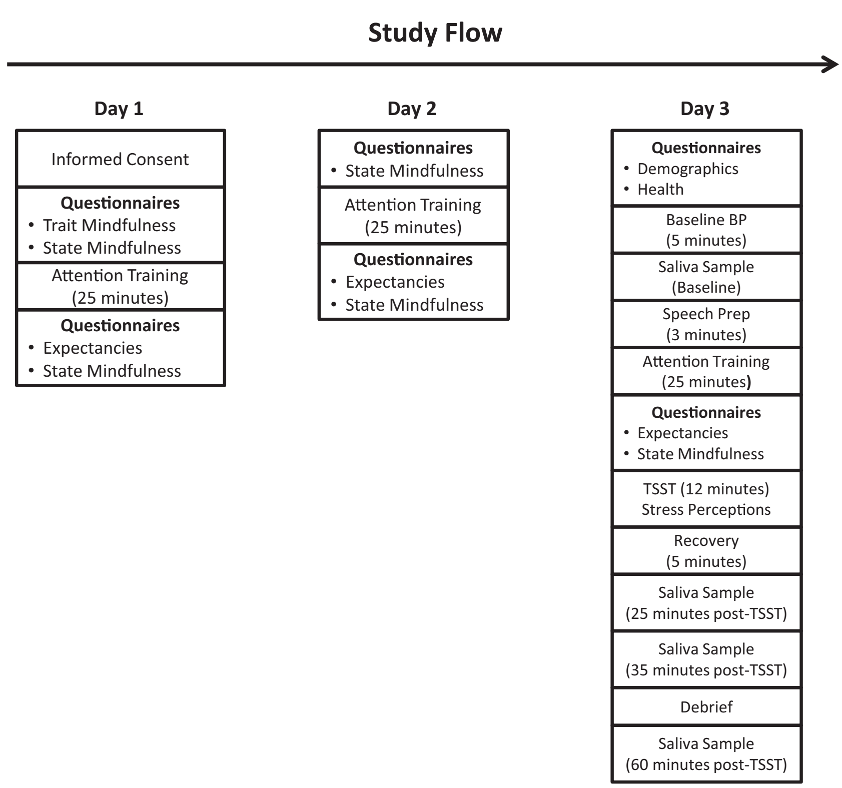

Figure 1 An overview of study procedures. Participants completed three consecutive days of attention training, then completed the TSST after their attention training on day three.

were conducted on three consecutive days. Participants arrived for study sessions one at a time, and were randomly assigned on day one to either a three-day mindfulness meditation training group or a matched three day cognitive training control group, which consisted of developing critical thinking skills by analyzing poetry passages. After completing their training on day three, all participants completed the TSST.

1.2.2. Day one and two procedure

Upon arrival on day one, participants provided written informed consent and completed individual difference measures, which included a measure assessing prior experience with meditation or mind-body practices and a 15-item unidimensional measure of dispositional mindfulness (see Section 1.4) (Brown and Ryan, 2003). Participants were then instructed and guided through their assigned training program (delivered using prerecorded audio files via PC computer and headphones) (see Section 1.3). During each day's training exercise, participants were probed on how attentive they were to task instructions (see Section 1.4). To enable experimenter blinding to study condition, the experimenter launched audio files labeled as "1" or "2" followed by the session number on a PC computer. Participants completed their training in a laboratory room. The experimenter monitored participants from an adjacent room during the training to ensure that participants were engaged (e.g., not sleeping) during the trainings. If participants appeared to be off-task, the experimenter re-entered the room to remind participants to actively participate in the training. Each audio training session was 25 min, after which participants completed a brief questionnaire assessing their reactions to the training exercise (see Section 1.4). This training protocol was repeated on day two.

1.2.3. Day three procedure

To control for diurnal variation in cortisol, all participants completed their third study session between 1400 h and 1900 h. Upon arriving, participants completed demographic and health questionnaires. A blood pressure cuff was applied to measure cardiovascular responses to the study tasks, and the experimenter took a 5-min baseline blood pressure reading. Participants provided a saliva sample for baseline cortisol 35 min after arriving for the experimental session. Participants then heard pre-recorded instructions explaining the upcoming speech performance activity and were given 3 min to mentally prepare. Next, participants completed a third session of attention training.

Then, following general guidelines for conducting the TSST (Kirschbaum et al., 1993), participants were seated in front of two evaluators trained to be cold and non-accepting. They first gave a 5-min speech addressing why they would be a good administrative assistant for a hypothetical job in the department, and then completed 5 min of difficult mental arithmetic (specifically, counting backwards from 2083 by 17's). The evaluators interrupted participants during the speech task to ask critical questions and during the arithmetic task to point out mistakes and instruct participants to restart counting from 2083. The evaluators also instructed participants on several occasions to sit as still as possible in the chair and to maintain eye contact throughout the speech and arithmetic tasks. We (and others) have used these procedures for reliably eliciting group-level increases in sympathetic—adrenal—medullary (SAM) and hypothalamic—pituitary—adrenal (HPA) axis activation (Creswell et al., 2013, 2005; Dickerson and Kemeny, 2004). To assess psychological stress perceptions during the math and speech tasks, participants were asked to complete self-report visual analog scale items immediately after the speech task and again after the math task (see Section 1.4) (Hellhammer and Schubert, 2012).

To measure peak cortisol responses to the TSST, saliva samples were acquired at 25 and 35 min after the start of the task (Dickerson and Kemeny, 2004). Participants were then probed for suspicion of the evaluators using a funnel debriefing, and informed of the primary study aim (to explore how attention training impacts stress responding). To reduce potential distress, participants were given performance feedback that the tasks were designed to be stressful and that their performance was normative. A final saliva sample was taken at the conclusion of the study (60 min after the start of the performance task).

1.3. Training interventions

Training consisted of three 25-min audio-guided exercises. The training sessions were designed to be well-matched on attention training demand and instructor contact (the same female voice narrated all study audio training). Word count and timing of instructions and silent rest periods were matched between the two three-day training programs.

1.3.1. Mindfulness training

The mindfulness training scripts were adapted from 3 to 4 days mindfulness training interventions used previously in studies of mindfulness training and pain (Zeidan et al., 2011, 2010). Participants were told that they would participate in training designed to foster attention and awareness to present-moment experience. Instructions in the first session focused around breath awareness: labeling inhales and exhales, noting the sensations and subtleties of the full breath cycle, and noticing mental distractions and mind-wandering away from the breath. The second session reviewed breath awareness and progressed to full body awareness, guiding participants through a body scan. In the final session, participants again practiced breath and body awareness, and concluded with open awareness of emotions and thoughts in conjunction with breath and body awareness.

1.3.2. Analytic cognitive control training

Participants in the analytic cognitive control training condition were told that they would be receiving training that would teach them how to develop an analytical focus for effective problem-solving. Each session consisted of a series of poems that the narrator first read and then instructed the participant on how to analyze quietly (these silent periods were included as a match for the periods of silent meditation in the experimental sessions, and at three time points in each session, all participants were probed for attentiveness). To mirror the progression of meditation exercises in the mindfulness trainings, the sessions progressed in analytical complexity from noticing the structure of the poems (day one), to structure and imagery (day two), to analyzing their symbolism and deeper meanings (day three).

1.4. Measures

1.4.1. Task engagement

To test whether attention to task instructions was equivalent between the mindfulness and control conditions, participants were asked to rate their lack of attentiveness three times during each attention training session, following procedures for assessing probe-caught mind wandering described in Mrazek et al. (2012). At the sound of a chime, participants were asked to rate how inattentive they were to the task instructions from 1 (completely on task) to 5 (completely focused on task-unrelated concerns), where higher ratings indicated less attentiveness to task instructions. The three chimes were pre-recorded so that all participants rated their attentiveness at the same time in a particular training session. The three ratings were summed to produce a total inattentiveness score for each day of training.

1.4.2. Training expectancy

Directly after each training session, participants were given a four-item questionnaire assessing their beliefs about the efficacy and relevancy of the training on a scale from 1 (Not at All) to 9 (Very Much). Two thinking and two feeling items were adapted from the Credibility/Expectancy Questionnaire (Devilly and Borkovec, 2000) for the present study. They were: "At this point, how logical does the attention training offered to you seem?"; "How confident would you be in recommending this attention training program to a friend who wants to improve their attentional focus?"; "At this point, how much do you feel that attention training will help your cognitive performance at the end of the study?"; "How much do you feel that the techniques you learn in this program will be worth your time and effort?". Higher scores refer to greater positive expectancies about the perceived benefits of their training for performance. The four questions were summed to produce a composite training expectancy score for each day of the training: day one Cronbach's $\alpha = .88$, day two $\alpha = .92$, day three $\alpha = .93$.

1.4.3. Dispositional mindfulness

On day one prior to training, participants completed the 15-item Mindful Attention Awareness Scale (Brown and Ryan, 2003) which asks participants to rate the degree to which they are attentive to and aware of present moment experience, e.g., "I find it difficult to stay focused on what's happening in the present," on a scale from 1 (Almost Never) to 6 (Almost Always). We made one change to scale administration to facilitate ease of completing questionnaire items: we anchored the scale such that higher raw scores indicated lower levels of mindfulness, and we then reverse-scored all items so that in all reported analyses, higher scores indicate greater levels of dispositional mindfulness. Individual items were averaged to create a composite dispositional mindfulness score (Cronbach's $\alpha = .76$).

1.4.4. Stress perceptions

Participants were asked to indicate their stress perceptions immediately following the 5-min speech (and before commencing the math task), and again immediately following the 5-min math task using visual analog scales (following procedures described in Hellhammer and Schubert, 2012). Participants placed a slash mark on a bipolar, 140 mm line to indicate how stressed, anxious, and insecure they felt from 0 (Not at All) to 140 (Highly). We used the distance of the slash marks (in centimeters) from the beginning of the line to create numerical values, where a greater number of centimeters indicated higher levels of stress perceptions during the speech and math tasks. Ratings from both the speech and counting task were summed to create a composite measure of overall stress perceptions during the TSST (Cronbach's $\alpha = .89$).

1.4.5. Cortisol and cardiovascular measures

Salivary cortisol was collected using a Salivette (Rommelsdorf, Germany). All Salivettes were frozen at −20 °C in a locked and secure laboratory freezer. Participants kept the Salivette under their tongue for 2 min during each collection period and did not touch the sample with their hands. At the conclusion of the experiment, the samples were shipped on dry ice to a professional laboratory in Dresden, Germany specializing in cortisol measurement. At this laboratory, cortisol was measured using a chemoluminescence-immuno-assay with high sensitivity (IBL International, Hamburg, Germany). Intra- and inter-assay coefficients of variation from this laboratory are typically below 10%.

A measure of oscillometric blood pressure was collected using an automatic sphygmomanometer (Dinamap Carescape V100, General Electric Company, GE, Finland). Systolic (SBP) and diastolic (DBP) blood pressure were recorded with this device at 2-min intervals. Averages of these 2-min readings were calculated during the 5-min baseline epoch, the 3-min speech preparation epoch, the 25-min attention training epoch, the 12-min performance epoch during the stress task, and a 5-min recovery epoch directly after the stress task. Participants remained seated during the collection of all cortisol and cardiovascular measures.

1.5. Statistical data analysis

All analyses were conducted with the SPSS 20.0 software package (IBM, Armonk, New York). The training condition variable was dummy-coded as 1 = mindfulness training; 0 = control training. Preliminary analyses evaluated success of randomization (using chi-square and independent-samples t-tests), tested for baseline to peak stress increases in the total sample (using paired-sample t-tests), and tested for associations between treatment expectancies, psychological stress perceptions, and biological stress reactivity (using Pearson's correlations). Preliminary analyses also evaluated whether the control training program was effective at controlling for attention and expectancies across the three training days, using mixed effect linear models (MLMs) and independent samples t-tests. MLMs, which are robust to missing data (relative to listwise deletion of subjects in repeated measures ANOVAs), were used for study analyses that included a within-subjects variable (i.e., time). Participants who had partial missing data over time were still included in MLM analyses, following intent-to-treat principles. In all MLMs, variables of interest were modeled as fixed effects using maximum likelihood estimation. All MLMs modeled the repeated measures variable (time) with a compound symmetry covariance structure, and the baseline (pre-stress) value was included as the first time point testing for linear time interactions with predictor variables of interest (e.g., condition, dispositional mindfulness).

Primary stress reactivity analyses were implemented in two steps. First, multiple regression analyses were conducted to test for condition differences and dispositional mindfulness moderated condition effects on psychological stress reactivity, and area-under-the-curve with respect to increase (AUC-I) cortisol stress reactivity to the TSST. The AUC-I cortisol measure was calculated using Pruessner's trapezoid formula (Pruessner et al., 2003), using the following equation: AUC_I = ((Cortisol time 1 + Cortisol time 2)/2 $\times$ 70 + (Cortisol time 2 + Cortisol time 3)/2 $\times$ 10 + (Cortisol (Cortisol time 3 + Cortisol time 4)/2 $\times$ 25) $-$ (Cortisol time 1 $\times$ (70 + 10 + 25)). Note that the AUC-I result subtracts out the baseline (or ground) cortisol level; thus AUC-I measures cortisol reactivity to the TSST. In cases where a participant was missing a cortisol time point value (1.5% of the total number of salivary cortisol samples were missing in this study), mean replacement (i.e., the series mean) was used in order to calculate a total AUC-I for each participant. Second, we conducted a follow-up MLM analysis of the AUC-I cortisol reactivity effect, permitting us to examine the cortisol reactivity effect over time. Due to a computer malfunction, we were unable to collect one subject's dispositional mindfulness data. This subject is included in our final sample but excluded from analyses that include the dispositional mindfulness moderator variable.

2. Results

2.1. Preliminary analyses

Randomization was successful in equalizing the mindfulness and cognitive training control groups at baseline; they did not differ significantly on age ($t(64) = -.05$, $p = .96$), gender ($\chi^2(1) = 1.81$, $p = .18$), ethnicity ($\chi^2(4) = 5.89$, $p = .21$), prior exposure to meditation or mind-body practices ($\chi^2(1) = .33$, $p = .57$), or day one dispositional mindfulness ($t(63) = -1.36$, $p = .18$). Likewise, on the day three TSST session, there were no group differences in time of day of first cortisol sample ($t(64) = -.43$, $p = .67$).

Did the TSST procedure effectively produce a stress response? Paired-samples t-tests confirmed that there was a significant increase in cortisol from baseline to peak reactivity (25 min post-stress task onset) ($t(65) = -4.06$, $p = <.001$) in the total sample. Similarly, there were significant increases from baseline to the stress task in systolic blood pressure ($t(60) = -18.97$, $p = <.001$) and in diastolic blood pressure ($t(60) = -22.03$, $p = <.001$). *Was there a significant association between treatment expectancies and stress?* There was no association between treatment expectancies and measures of self-reported psychological stress reactivity ($r(64)) = -.07$, $p = .56$) or AUC-I salivary cortisol reactivity to the TSST ($r(64) = -.07$, $p = .56$). *Did psychological stress reactivity co-vary with cortisol reactivity?* There was also no association between AUC-I cortisol reactivity and self-reported psychological stress perceptions to the TSST ($r(64) = -.15$, $p = .22$).

Did the analytic control training effectively control for task engagement compared to mindfulness meditation training? Participants in both groups indicated similar levels of task engagement during the training tasks. Specifically, an MLM showed no main effect of study condition ($F(1,66) = .47$, $p = .50$); participants in the mindfulness group (M[SE] = 2.36[.12]) were similarly attentive to participants in the control group (M[SE] = 2.47[.12]). This analysis also showed no condition $\times$ time interaction ($F(2,132) = 1.84$, $p = .16$) indicating that participants in both conditions were also similarly task engaged across all three training days.

Did the analytic control training effectively control for positive treatment expectancies compared to the mindfulness meditation training after the three days of training? An independent samples t-test indicated that mindfulness meditation training group had significantly higher positive treatment expectancies upon completion of training (on day three) compared to the analytic control training program group ($t(64) = 2.89$, $p = .005$ (mindfulness training group $M = 6.10$[.31], control training group: $M = 4.95$[.25])). Given this significant difference, day three training expectancies were included as a covariate in all psychological and salivary cortisol stress reactivity analyses.

2.2. Psychological stress perceptions

We tested two predictions: first, that brief mindfulness meditation training reduces stress reactivity, and second, that this main effect of mindfulness meditation training would be moderated by dispositional mindfulness. To test these predictions, we conducted a multiple regression analysis that tested for main and interactive effects of three day training and dispositional mindfulness on self-reported psychological stress perceptions to the TSST performance tasks (controlling for day three expectancies). We observed a significant main effect for three day mindfulness training ($\beta = -1.98$, $t(4) = -2.13$, $p = .038$), a significant main effect for dispositional mindfulness ($\beta = -.40$, $t(4) = -2.54$, $p = .01$), and a significant training condition $\times$ dispositional mindfulness interaction ($\beta = 1.89$, $t(4) = 2.02$, $p = .048$) on stress perceptions. As shown in Fig. 2, (1) participants in the mindfulness training group had significantly lower stress perceptions compared to the control group, (2) participants higher in dispositional mindfulness had lower stress perceptions, and (3) these main effects were qualified by their interaction: participants in the control training program who were low in dispositional mindfulness had the greatest psychological stress perceptions to the TSST. Specifically, receiving mindfulness training or reporting higher dispositional mindfulness (or having both mindfulness training and high dispositional mindfulness) buffered self-reported psychological stress responses to the TSST.

2.3. Physiological stress reactivity

2.3.1. Cortisol reactivity

A multiple regression analysis tested whether mindfulness (vs. control) training, dispositional mindfulness, and their interaction predict AUC-I salivary cortisol reactivity to the TSST (controlling for day three expectancies). We observed a significant main effect for the three-day mindfulness training

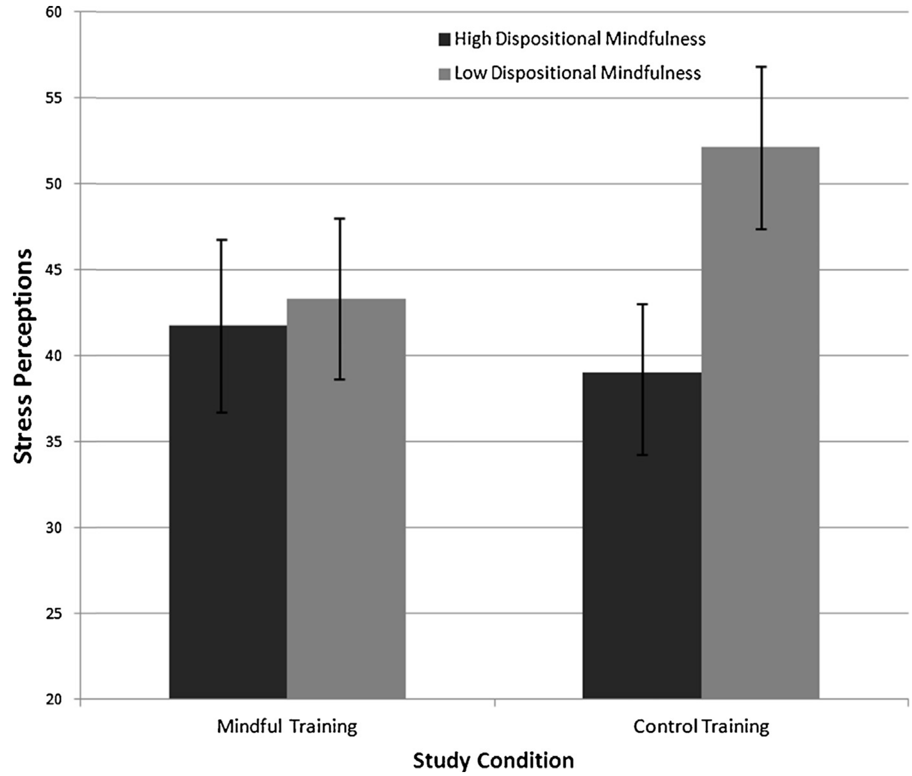

Figure 2 Psychological stress perceptions during the TSST math and speech tasks as a function of dispositional mindfulness and mindfulness meditation (vs. control) training. To graphically depict the interaction pattern, low and high dispositional mindfulness groups were defined by a median split. Error bars reflect ±1 standard error.

(vs. control training) (β = 1.98, $t(4)$ = 2.10, p = .04), such that the mindfulness training group showed significantly *greater* AUC-I cortisol reactivity to the TSST compared to the control training group. No significant main effect of dispositional mindfulness was observed (β = .15, $t(4)$ = .941, p = .35), but there was a significant training condition × dispositional mindfulness interaction on AUC-I cortisol reactivity to the TSST (β = −1.85, $t(4)$ = −1.97, p = .05).

To probe this interaction and examine how these cortisol reactivity effects occur over time, a follow-up MLM tested the interactive effects of training condition, dispositional mindfulness, and time on salivary cortisol response to the TSST. Like the two-way interaction effect on AUC-I cortisol reactivity, we observed a significant three-way dispositional mindfulness × training condition × time interaction in the MLM (controlling for day three expectancies) ($F(3,191)$ = 4.58, p = .004). As shown in Fig. 3, this interaction was driven by the observation that participants lower in dispositional mindfulness, who then received the mindfulness training, had the greatest salivary cortisol reactivity responses to the TSST. The main effect and two-way interaction results from this MLM are provided in Table 1a.

2.3.2. Cardiovascular reactivity

We conducted the same follow-up MLM analyses on systolic and diastolic blood pressure responses to the TSST. We did not observe any significant main or interactive effects in these analyses. All results are provided in Table 1b, and the MLMs of systolic and diastolic blood pressure are visually depicted in Figs. 4 and 5.

3. Discussion

The present study is the first to demonstrate that a small dose of mindfulness meditation training (75 min over three days) reduces self-reported psychological stress reactivity to the TSST. Notably, this same psychological stress buffering effect was observed for participants who had high levels of dispositional mindfulness upon study entry. These results are consistent with previous studies indicating that eight weeks of mindfulness training or high levels of dispositional mindfulness are associated with reduced stress perceptions to controlled laboratory stressors (Arch and Craske, 2010; Brown et al., 2012; Hoge et al., 2013). Moreover, this study provides novel evidence for interactive effects of brief mindfulness meditation training and dispositional mindfulness on stress responses to the TSST: these main effects for mindfulness meditation training and dispositional mindfulness were qualified by their interaction. We found that participants low in mindfulness (either not receiving mindfulness meditation training or participants who are low in dispositional mindfulness) had the greatest psychological stress reactivity to the TSST. Although there has been recent interest in understanding whether individuals lower or higher in dispositional mindfulness are more likely to benefit from mindfulness

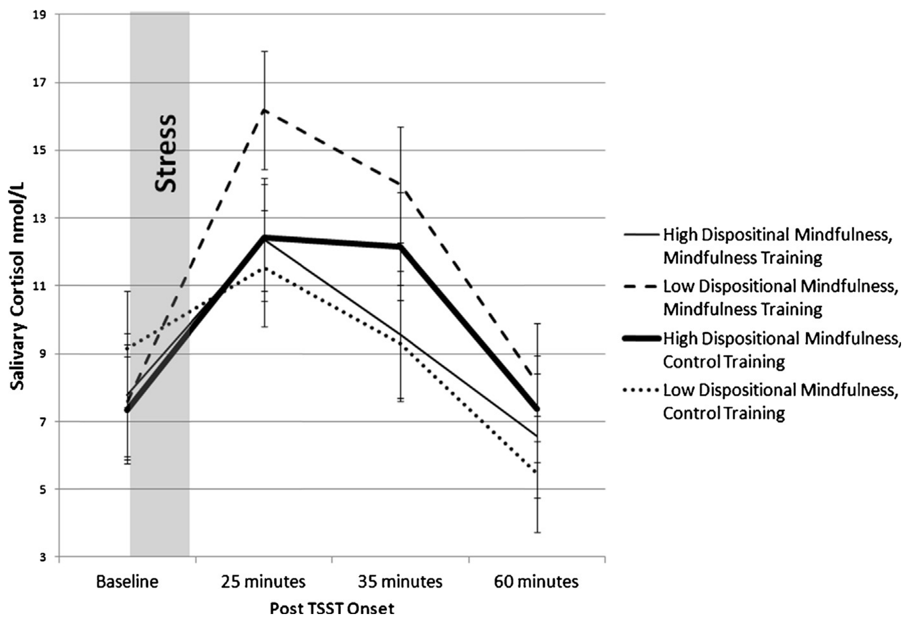

Figure 3 Salivary cortisol responses during the laboratory session as a function of dispositional mindfulness and mindfulness meditation (vs. control) training. To graphically depict the interaction pattern, low and high dispositional mindfulness groups were defined by a median split. Error bars reflect ±1 standard error.

meditation training, only one published study (to our knowledge) has tested for interactive effects of dispositional mindfulness and mindfulness meditation training (Shapiro et al., 2011). The present findings offer a novel perspective for their interaction, namely that either form of mindfulness (dispositional or trained) can foster psychological stress resilience.

We did not observe a significant association between self-reported psychological stress perceptions and salivary cortisol responses to the TSST, and the mindfulness effects on salivary cortisol reactivity to the TSST showed a different pattern from the psychological stress reactivity effects (for a review discussing this commonly observed dissociation between psychological and biological stress responses to acute stress-challenge tasks, see Campbell and Ehlert, 2012). Contrary to predictions, brief three-day mindfulness meditation training increased salivary cortisol responses to the TSST relative to the analytic cognitive training comparison group. Moreover, this main effect of brief mindfulness meditation training was moderated by dispositional mindfulness, such that it was the participants lower in dispositional mindfulness who showed the greatest cortisol reactivity to the TSST after mindfulness meditation training (a significant mindfulness training by dispositional mindfulness interaction).

Table 1a Mixed effect linear model analysis results for salivary cortisol reactivity to the TSST.

Effect	*F*-value	*p*-Value
Time	$F(3,191) = 2.54$	.058
Study condition	$F(1,65) = 4.60$	.036
Trait mindfulness	$F(1,65) = 2.30$	.13
Study condition × time	$F(3,191) = 4.80$	.003
Study condition × trait mindfulness	$F(1,65) = 4.38$	.040
Trait mindfulness × time	$F(3,191) = 1.16$	.33

One important question, then, is how brief mindfulness meditation training buffers psychological stress perceptions but increases cortisol reactivity to the TSST. A potential explanation for these results, to be tested in future research, is that mindfulness training fostered more engagement and active coping during the TSST tasks—the deployment of more active coping buffered psychological stress perceptions, but the increased coping efforts resulted in more cortisol reactivity (Akinola and Mendes, 2012; Lam et al., 2009). Indeed, it may be that participants who were lower in dispositional mindfulness may have had to deliberately make extra coping efforts, resulting in the greatest cortisol reactivity to the TSST (Brown et al., 2012). Like the effects observed here, a recent study shows that participants high in dispositional emotion regulation capacity have reduced anxiety but greater cortisol reactivity to a social-evaluative speech task (Lam et al., 2009); thus it may be that mindfulness meditation training facilitates active emotion-focused coping (e.g., cognitive reappraisal) during the TSST. Consistent with this active emotion-focused coping account, previous studies indicate that mindfulness training increases emotion regulation skills and fosters positive reappraisals for stressful events (Chambers et al., 2009; Garland et al., 2011; Weinstein et al., 2009). One testable hypothesis is that these active coping efforts may be particularly deliberate and effortful after brief mindfulness meditation training, but then become more automatic after longer periods of training (resulting in lower neuroendocrine stress reactivity over time) (Baer et al., 2012).

We speculate that an alternative explanation can be offered for the present findings. Specifically, initially mindfulness meditation training increases stress reactivity by depleting cognitive resources and that the decrease in self-reported psychological stress reactivity is merely a

Table 1b Mixed effect linear model analysis results for systolic and diastolic blood pressure reactivity to the TSST.

	F-value	*p*-Value
Systolic blood pressure		
Time	$F(4,254) = 6.91$	<.001
Study condition	$F(1,65) = 2.50$	.12
Trait mindfulness	$F(1,65) = .588$	.45
Study condition × time	$F(4,254) = .949$	.44
Study condition × trait mindfulness	$F(1,65) = 1.99$	.16
Trait mindfulness × time	$F(4,254) = .756$	.56
Study condition × trait mindfulness × time	$F(4,254) = 1.04$	.39
Diastolic blood pressure		
Time	$F(4,254) = 4.98$	.001
Study condition	$F(1,65) = .264$	.61
Trait mindfulness	$F(1,65) = .000$	>.99
Study condition × time	$F(4,254) = .677$	.61
Study condition × trait mindfulness	$F(1,65) = .116$	.73
Trait mindfulness × time	$F(4,254) = .477$	.75
Study condition × trait mindfulness × time	$F(4,254) = .621$	.65

demand characteristic associated with receiving a challenging body-awareness attention training program (cf. Baer et al., 2012). This 'resource depletion' explanation is consistent with some research, which shows that mindfulness meditation training, during the initial stages of meditation skill acquisition, can be cognitively demanding (Brefczynski-Lewis et al., 2007; Evans et al., 2014; Wadlinger and Isaacowitz, 2011), and this may be particularly pronounced for those with lower dispositional mindfulness. Thus, initial mindfulness meditation training (such as that found in our brief three-day training) increases positive views and treatment expectancies, but depletes cognitive resources, resulting in an overall greater cortisol reactivity response to the TSST (Bohnen et al., 1990). Although future studies are needed to test this resource depletion account of brief mindfulness meditation training, we suspect that it is unlikely to completely explain the present effects, given that previous brief mindfulness training studies suggest enhanced self-regulatory resources (Jain et al., 2007; Moore et al., 2012; Tang et al., 2007; Zeidan et al., 2010). Moreover, cognitive depletion has been linked with increased negative affect and fatigue (Hagger et al., 2010), whereas we did not find evidence consistent with this psychological profile in the mindfulness trained group. Rather, mindfulness meditation training in the present study lowered psychological stress perceptions of threat to the TSST even after controlling for group differences in positive treatment expectancies. It will be important for future studies to carefully test these mechanistic accounts of whether mindfulness meditation increases active emotion-focused coping (or is resource depleting), and how this may drive changes in psychological and neuroendocrine stress reactivity to acute stressors.

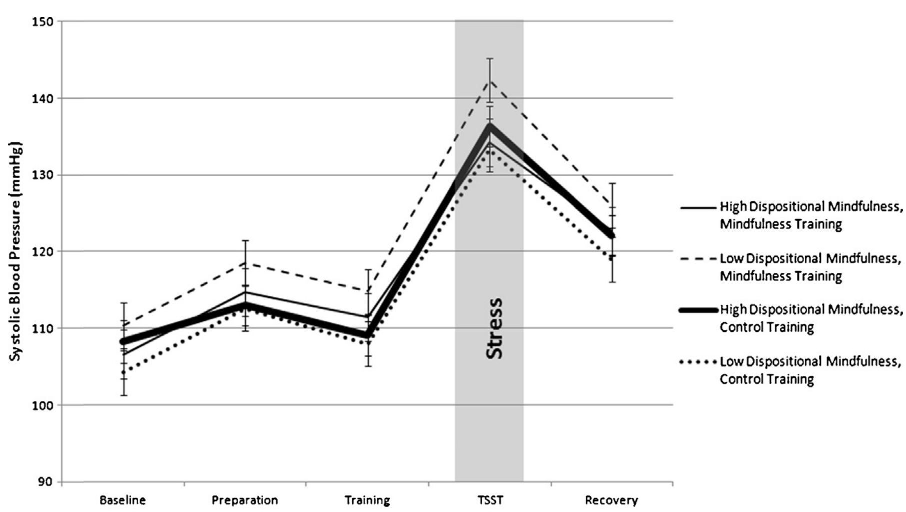

Figure 4 Systolic blood pressure responses during the laboratory session as a function of dispositional mindfulness and mindfulness meditation (vs. control) training. To graphically depict the interaction pattern, low and high dispositional mindfulness groups were defined by a median split. Error bars reflect ±1 standard error.

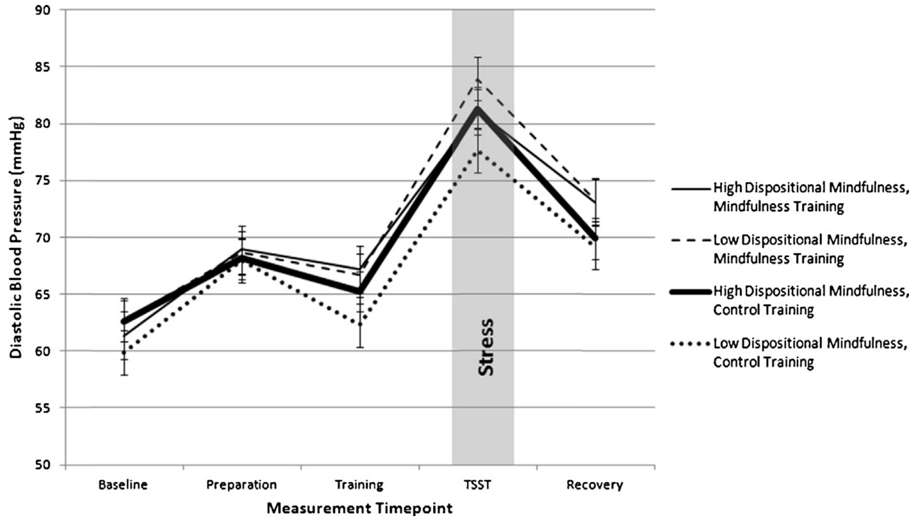

Figure 5 Diastolic blood pressure responses during the laboratory session as a function of dispositional mindfulness and mindfulness meditation (vs. control) training. To graphically depict the interaction pattern, low and high dispositional mindfulness groups were defined by a median split. Error bars reflect ±1 standard error.

The present study compared mindfulness meditation training to an active cognitive training. Variants of this type of reading/listening training control program are increasingly used in the mindfulness training literature as active comparison treatments (Allen et al., 2012; Koole et al., 2009), and previous studies indicate that mindfulness and cognitive-analytic modes of attention can be reliably distinguished (Farb et al., 2010, 2007). A careful assessment of attentiveness during the 25-min training periods (using probes) indicated that this active analytic training program was effective at controlling for attention and task engagement—there were no differences in attentiveness between the mindfulness meditation and cognitive training groups during the 25-min training periods. The present study is also the first to assess differential treatment expectancies in a mindfulness meditation training active treatment controlled trial, and we found that the mindfulness meditation training group had higher treatment expectancies for positive performance compared to the control training group. We note that this difference was controlled in all study analyses in the present report, thus it is not the case that underlying differences in positive treatment expectancies explain the present stress reactivity effects we observed. We believe our assessment of (and control for) participant expectancies is a strength of this study, and addresses recent calls for more rigorous evaluation of differential expectancies generated by behavioral interventions (Boot et al., 2013). Our findings highlight the need for future active treatment controlled trials of mindfulness meditation training to rigorously assess treatment expectancies.

This research has several limitations. Measures of baseline perceived stress and a pre-training TSST were not administered, thus it is unclear how mindfulness training changed stress reactivity from pre to post-training. We note that there are significant habituation effects in stress reactivity with repeated TSST administrations in healthy volunteers (for a review, see Kudielka et al., 2007), which may obscure (or change the nature of) mindfulness stress buffering effects to the TSST. This study did not include a validated state measure of mindfulness to evaluate whether mindfulness training altered reported mindfulness after each training session, another limitation. The blood pressure reactivity effects (see Figs. 4 and 5) in the present study followed similar patterns to cortisol reactivity (Fig. 3), such that participants low in dispositional mindfulness who received mindfulness meditation training had higher blood pressure reactivity to the TSST—although these effects were not statistically significant. Our periodic 2-min sampling of blood pressure during the TSST may have failed to reliably measure blood pressure reactivity, a study limitation. Finally, the use of an audio-guided mindfulness training program is both strength and limitation of this study. While this approach is more portable and replicable in different settings (a strength), the absence of a trained mindfulness instructor for guidance and feedback may diminish the efficacy of the training (a limitation).

4. Conclusions

The present study offers new insights into how brief mindfulness meditation training and dispositional mindfulness can impact stress reactivity to an acute stress challenge. Compared to an active cognitive analytic control training, we provide initial evidence that a brief mindfulness meditation training program (75 min) buffers self-reported psychological stress reactivity and increases cortisol reactivity to the TSST. We postulate that this pattern reflects greater engagement and active coping in the mindfulness meditation trained group. We also provide initial evidence for interactive effects of mindfulness meditation training and pre-existing dispositional mindfulness, showing that either mindfulness training or dispositional mindfulness can be used as a stress-protective psychological resource. This study is the first well-controlled test of the mindfulness training stress buffering hypothesis, and expands our understanding of how mindfulness training interventions impact stress reactivity. It will be important to test whether these mindfulness-stress pathways affect susceptibility to stress-related disease outcomes. Given that brief mindfulness meditation training increased cortisol reactivity, one possibility is that these increases in cortisol may blunt stress-related increases in inflammation via HPA-axis negative feedback (Barnes et al., 1993; Steptoe et al., 2007), but we note that longer-term mindfulness meditation training may be needed for clinically meaningful health benefits in at-risk stressed patient populations.

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Conflicts of interest

The authors report no conflicts of interest.

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